POINT-OF-USE
WATER TREATMENT
CONTINUING EDUCATION
PROFESSIONAL DEVELOPMENT COURSE

Technical
Learning
College

Printing and Saving Instructions

It is recommended that you download this pdf document and assignment to your computer desktop and open it with Adobe Acrobat DC reader.

Adobe Acrobat DC reader is a free computer software program and you can find it at Adobe Acrobat's website.

You can complete the course by viewing the course on your computer or you can print it out. This course booklet does not have the assignment (the test). Please visit our website and download the assignment (the test).

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Hyperlink to Assignment…
http://www.abctlc.com/downloads/PDF/RO%20Assignment.pdf

State Approval Listing Link, check to see if your State accepts or has pre-approved this course. Not all States are listed. Not all courses are listed. Do not solely trust our list for it may be outdated. It is your sole responsibility to ensure this course is accepted for credit. No refunds.

State Approval Listing URL…
http://www.abctlc.com/downloads/PDF/CEU%20State%20Approvals.pdf

Hyperlink to the Appendix
http://www.abctlc.com/downloads/PDF/WTGlossary.pdf

You can obtain a printed version from TLC for an additional $189.95 plus shipping charges.

All downloads are electronically tracked and monitored for security purposes.

Some States and many employers require the final exam to be proctored.

Do not solely depend on TLC's Approval list for it may be outdated.

Most of our students prefer to do the assignment in Word and e-mail or fax the assignment back to us. We also teach this course in a conventional hands-on class. Call us and schedule a class today.

Responsibility

This course contains EPA's federal rule requirements. Please be aware that each state implements drinking water/wastewater/safety regulations that may be more stringent than EPA's or OSHA's regulations.

Check with your state environmental agency for more information. You are solely responsible in ensuring that you abide with your jurisdiction or agency's rules and regulations.

Copyright Notice

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Requests for acknowledgements or permission to make copies shall be made to the following address: TLC, P.O. Box 3060, Chino Valley, AZ 86323

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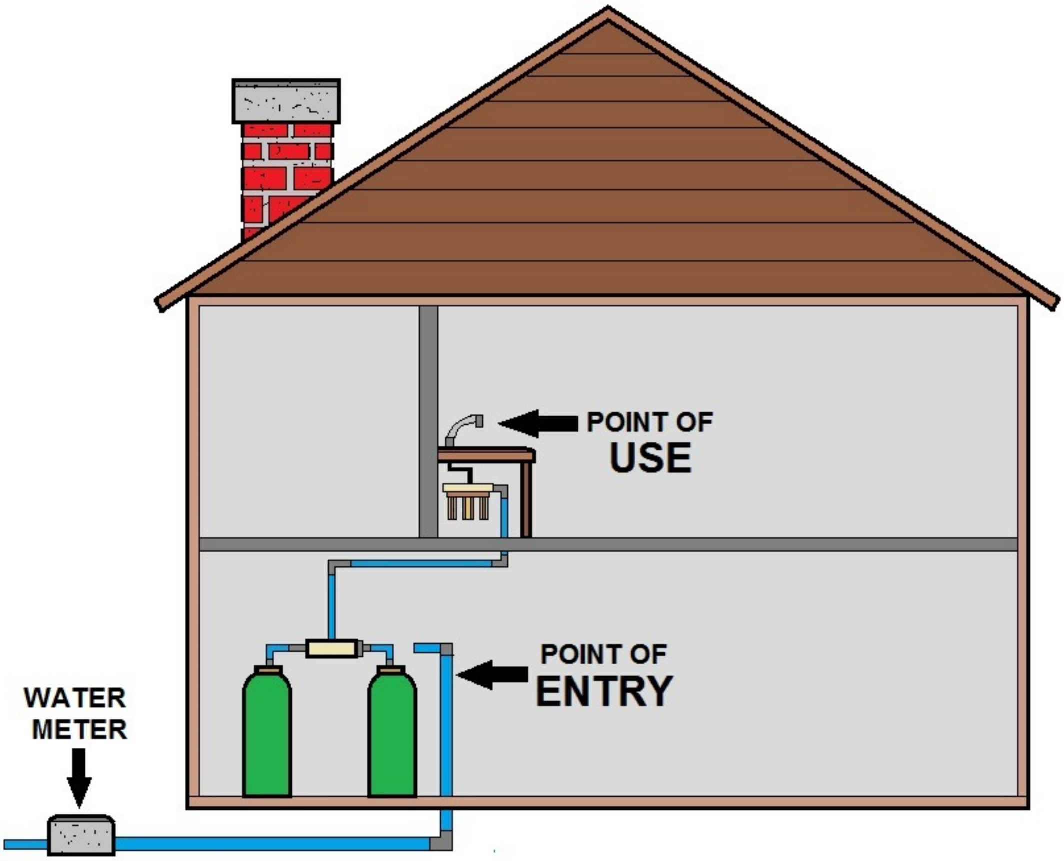

POINT-OF-USE vs. POINT-OF-ENTRY

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James Bevan, Water Quality Inspector S.M.E. Twenty years of experience in the environmental field dealing with all aspects of water regulations on the federal, state, and local levels. Teacher and Proctor in Charge for Backflow Certification Testing at the ASETT Center in Tucson for the past 15 years and possess an Arizona Community College, Special Teaching Certificate in Environmental Studies.

Dr. Pete Greer S.M.E., Retired biology instructor, chemistry and biological review.

Jack White, Environmental, Health, Safety expert, City of Phoenix. Art Credits.

Technical Learning College's Scope and Function

Welcome to the Program,

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds several different governmental agency approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. TLC's distance based or independent study courses are offered in a print - based distance educational format. We will beat any other training competitor's price for the same CEU material or classroom training.

Our courses are designed to be flexible and for you to finish the material at your convenience. Students can also receive course materials through the mail. The CEU course or e-manual will contain all your lessons, activities and instruction to obtain the assignments. All of TLC's CEU courses allow students to submit assignments using e-mail or fax, or by postal mail. (See the course description for more information.)

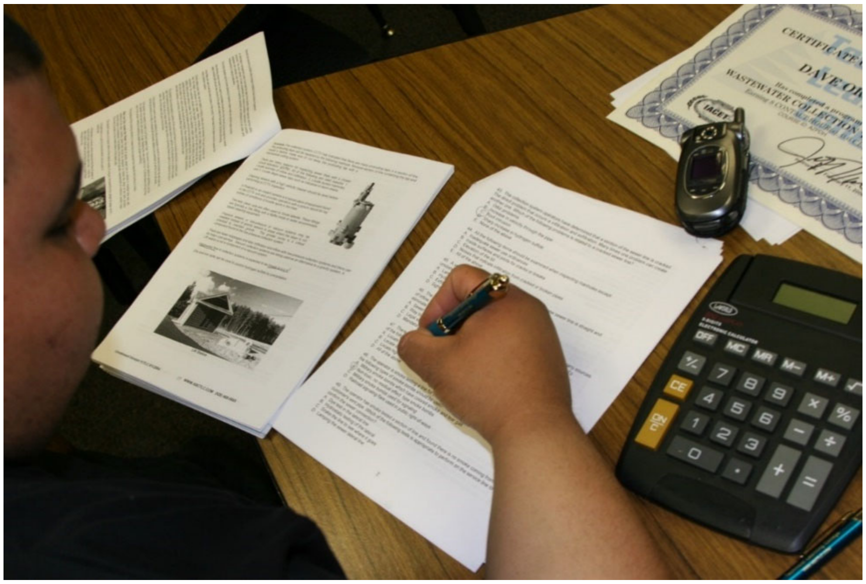
Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling; i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored closed-book exams, depending upon your state or employer requirements.

Flexible Learning
At TLC, there are no scheduled online sessions or passwords you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus based student. You will work at your own pace, completing assignments in time frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

Course Structure
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student-friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One
TLC offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members (S.M.E.) are assigned at the beginning of each course providing the academic support you need to successfully complete each course. Please call or email us for assistance.

Satisfaction Guaranteed
We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 20,000 students.



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail.

If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of $50.

Contact Numbers

Fax (928) 468-0675
Email Info@tlch2o.com
Telephone (866) 557-1746

Important Information about this Manual

This manual has been prepared to educate operators in the general awareness of dealing with the often-complex and various water treatment devices and methods.

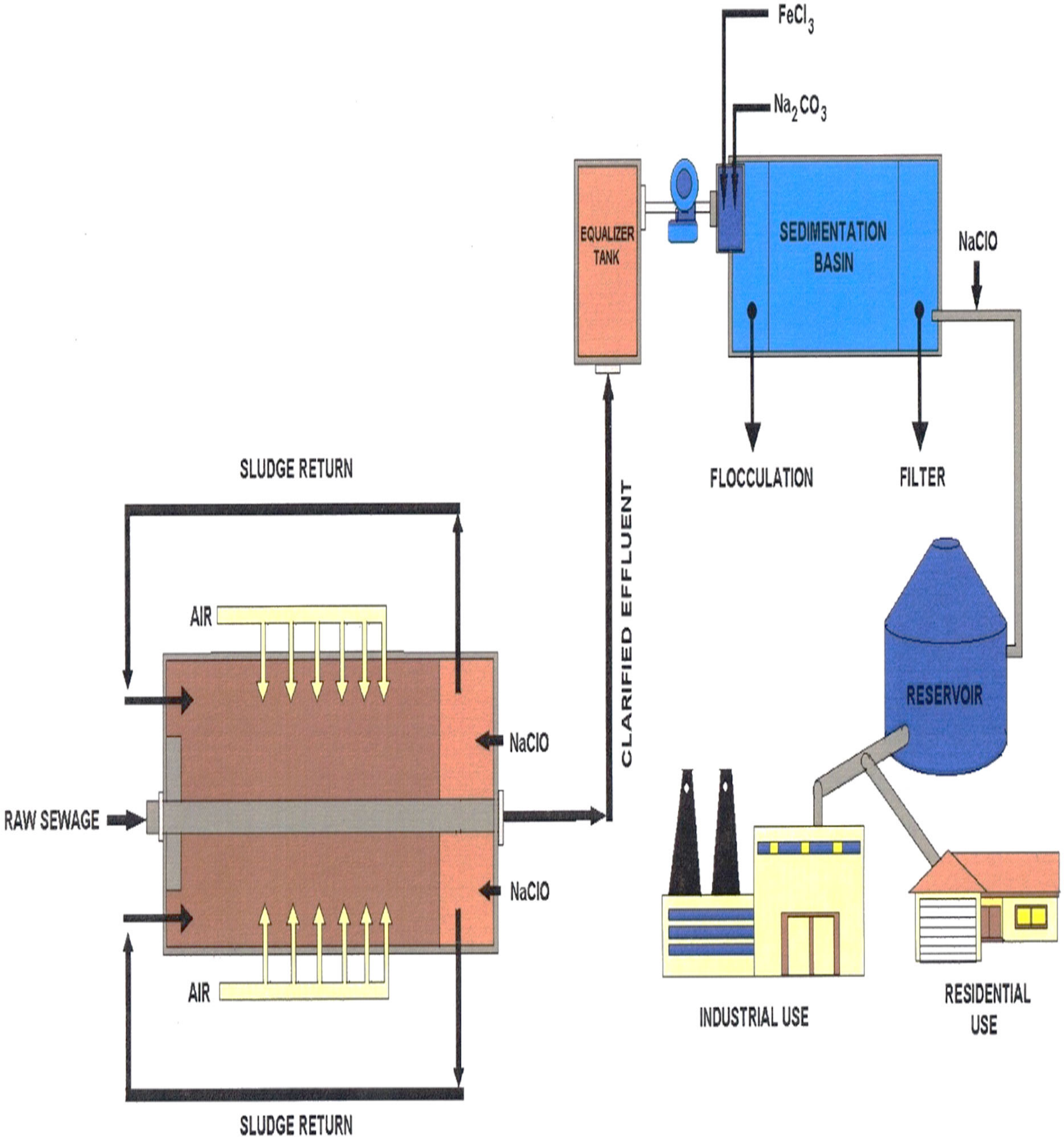
This manual will cover general laws, regulations, required procedures and accepted policies relating to point-of-use water treatment devices. It should be noted, however, that the regulation of water treatment and hazardous materials is an ongoing process and subject to change over time. For this reason, a list of resources is provided to assist in obtaining the most up-to-date information on various subjects.

This manual is a not a guidance document for operators who are involved with water treatment. It is not designed to meet the requirements of the United States Environmental Protection Agency or your local State environmental protection agency or health department.

This course manual will provide general Point-of-Use Water Treatment awareness and should not be used as a basis for water treatment methods/devices guidance. This document is not a detailed plumbing code or a source or remedy for water treatment or water quality improvement.

Technical Learning College or Technical Learning Consultants, Inc. make no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information. It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances.

This document should be used for educational purposes only and is not considered a legal document. Individuals who are responsible for water treatment, water quality and water distribution should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with the EPA and other appropriate federal, state and local agencies.



MICROBIOLOGICAL AND CHEMICAL PROCESS TO OBTAIN RE-USE WATER

CEU Course Description

Point-of-Use Water Treatment CEU Training Course

This course will review various point-of-use water treatment devices and methods including Ozone and Reverse Osmosis. This course will also cover water fundamentals/principles including chemistry and math. This course is general in nature and not state specific.

You will not need any other materials for this course. Task Analysis and Training Needs Assessments have been conducted to determine or set Needs-To-Know for this course. The following is a listing of some of the agencies who have conducted extensive validation studies from which TLC has based this program upon: the Environmental Protection Agency (EPA), the Arizona Department of Environmental Quality (ADEQ), the Texas Commission of Environmental Quality (TCEQ) and the American Boards of Certification (ABC).

Prerequisites: None

Course Procedures for Registration and Support:
All of Technical Learning College correspondence courses have complete registration and support services offered. Delivery of services will include, e-mail, web site, telephone, fax and mail support. TLC will attempt immediate and prompt service.

When a student registers for a distance or correspondence course, he/she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work.

If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request. All students will be tracked by a unique number assigned to the student.

Instructions for Written Assignments
The Point-Of-Use Water Treatment CEU training course uses a multiple choice style answer key.

You can write your answers in the assignment package. TLC would prefer that you type out and e-mail the final assignment to TLC.

Feedback Mechanism (examination procedures)
Each student will receive a feedback form as part of his or her study packet. You will be able to find this form in the front of the assignment.

Security and Integrity
All students are required to do their own work. Any fraud or deceit and the student will forfeit all fees and the appropriate agency will be notified.

Required Texts
The course will not require any other materials. This course comes complete. No other materials are needed.

Environmental Terms, Abbreviations, and Acronyms

TLC provides a glossary that defines in non-technical language commonly used environmental terms appearing in publications and materials. It also explains abbreviations and acronyms used throughout the EPA and other agencies. You can find the glossary this in the rear of the manual.

Feedback Mechanism (Examination Procedures)

Each student will receive a feedback form as part of their study packet. You will be able to find this form in the front section of the course assignment or lesson.

Security and Integrity

All students are required to do their own work. All lesson sheets and final exams are not returned to the student to discourage sharing of answers. Any fraud or deceit and the student will result in forfeiture of all fees and the appropriate agency will be notified.

Forfeiture of Certificate (Cheating)

If a student is found to have cheated on an examination, the penalty may include--but is not limited to--expulsion; foreclosure from future classes for a specified period; forfeiture of certificate for course/courses enrolled in at TLC; or all of the above in accordance with TLC's Student Manual.

A letter notifying the student's sponsoring organization (State Agency) of the individual's misconduct will be sent by the appropriate official at TLC. No refund will be given for paid courses. An investigation of all other students that have taken the same assignment within 60-day period of the discovery will be re-examined for fraud or cheating.

Grading Criteria

TLC will offer the student either pass/fail or a standard letter grading assignment. If TLC is not notified, you will only receive a pass/fail notice. For security purposes, please fax or e-mail a copy of your driver's license and always call us to confirm we've received your assignment and to confirm your identity. TLC offers students the option of either pass/fail or assignment of a standard letter grade. If a standard letter grade is not requested, a pass/fail notice will be issued.

Final course grades are based on the total number of possible points. The grading scale is administered equally to all students in the course. Do not expect to receive a grade higher than that merited by your total points. No point adjustments will be made for class participation or other subjective factors.

If TLC is not notified, you will only receive a pass/fail notice. In order to pass your final assignment, you are required to obtain a minimum score of 70% on your assignment.

Required Texts

The Point-of-Use Water Treatment CEU Training course will not require any other materials. This course comes complete. No other materials are needed.

Recordkeeping and Reporting Practices

TLC will keep all student records for a minimum of seven years. It is the student's responsibility to give the completion certificate to the appropriate agencies.

ADA Compliance

TLC will make reasonable accommodations for persons with documented disabilities. Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of this particular group.

You will have 90 days from receipt of this manual to complete it in order to receive your Continuing Education Units (CEUs) or Professional Development Hours (PDHs). A score of 70% or better is necessary to pass this course.

Educational Mission

The educational mission of TLC is:

To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,

To provide TLC students opportunities to apply and understand the theory and skills needed for operator certification,

To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

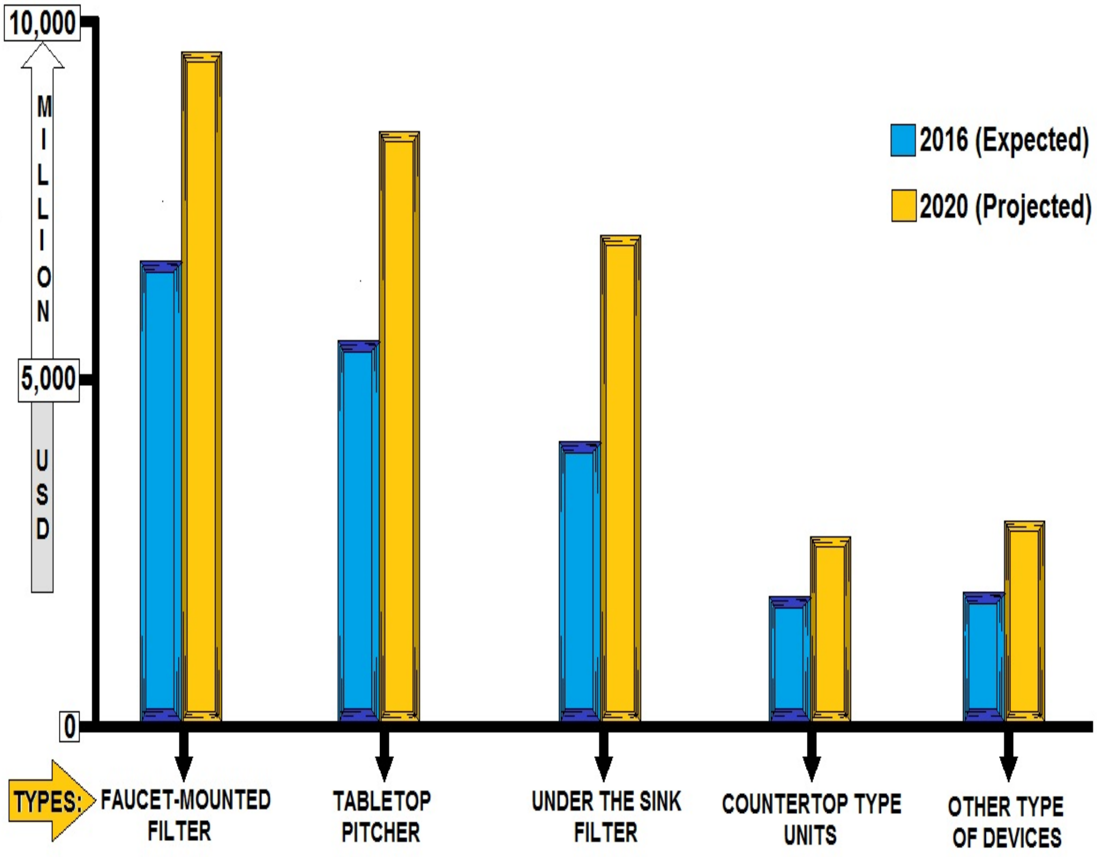
To provide a forum in which students can exchange experiences and ideas related to environmental education,

To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.

Course Objective: To provide education in effective and efficient Point-of-Use Water Treatment methods and related procedures.

Texas TCEQ Students Notice

Any course cannot be repeated for credit within the same renewal period. TCEQ students will also be given special assistance if you fail the examination. You will also have access to failed or wrong questions and/or the area or topic of the assignment to complete your learning experience. We will also report your credit using the electronic *Training Roster On-Line Submittal* (TROLS) procedure. Please give it two days for the credit to show before calling us.



POINT-OF-USE WATER TREATMENT SYSTEMS USED AND PROJECTED USE

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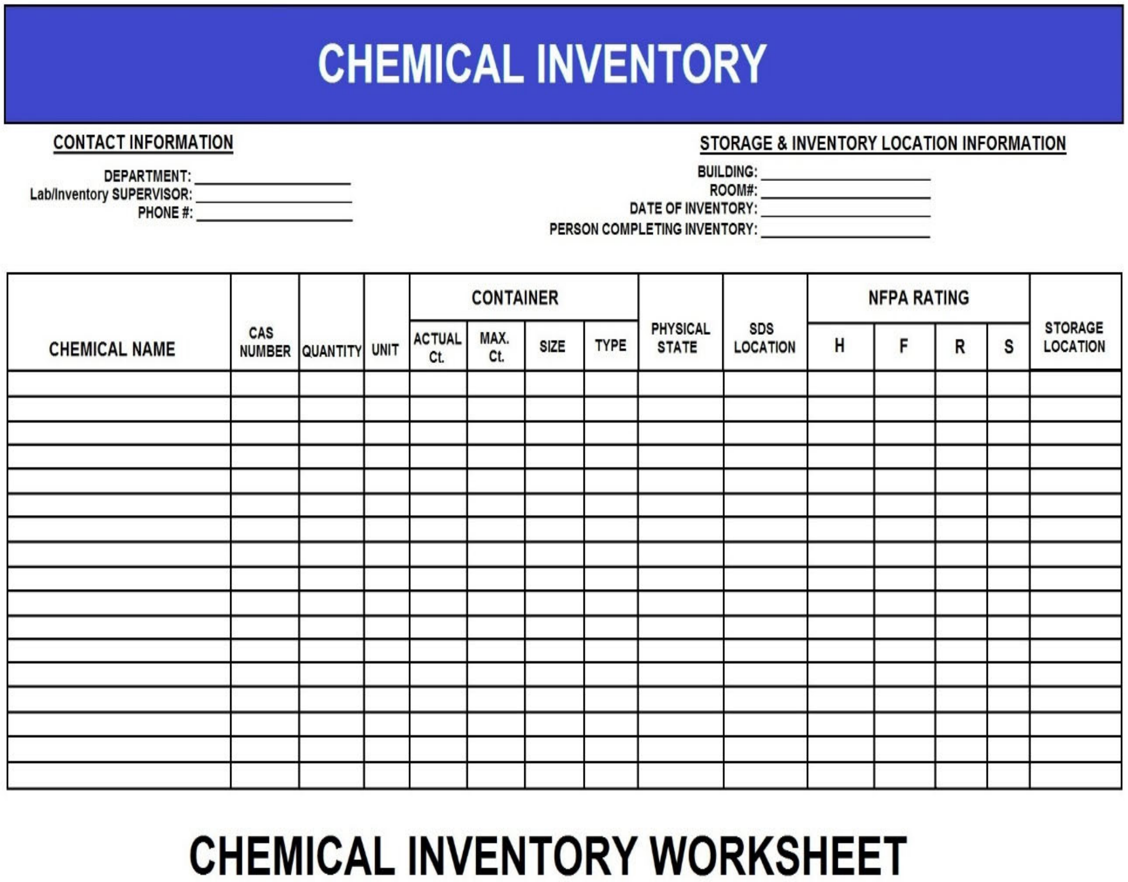


CHEMICAL INVENTORY

CONTACT INFORMATION

DEPARTMENT: ____________________
Lab/Inventory SUPERVISOR: ____________________
PHONE #: ____________________

STORAGE & INVENTORY LOCATION INFORMATION

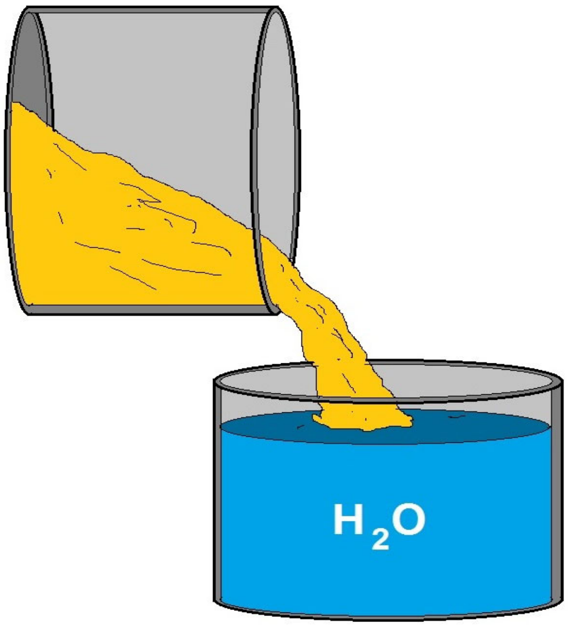
BUILDING: ____________________
ROOM#: ____________________
DATE OF INVENTORY: ____________________
PERSON COMPLETING INVENTORY: ____________________

CHEMICAL NAME	CAS NUMBER	QUANTITY	UNIT	CONTAINER				PHYSICAL STATE	SDS LOCATION	NFPA RATING				STORAGE LOCATION
				ACTUAL Ct.	MAX. Ct.	SIZE	TYPE			H	F	R	S	

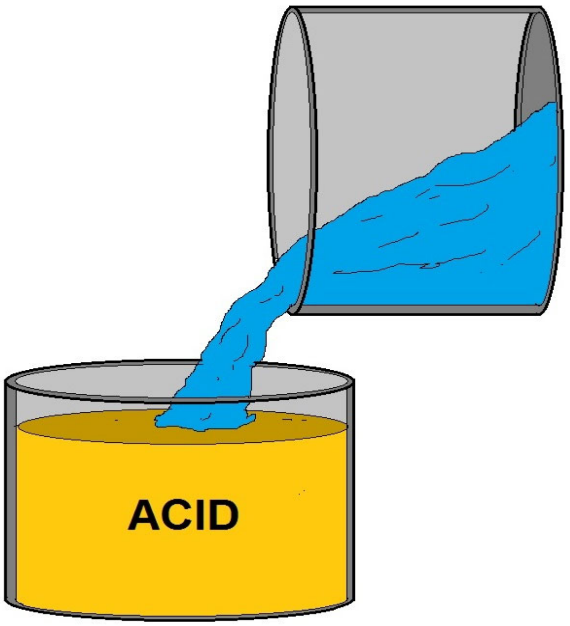
CHEMICAL INVENTORY WORKSHEET

In this section, the student will understand and explain basic water chemistry/ reactions terms and basic chemical uses.

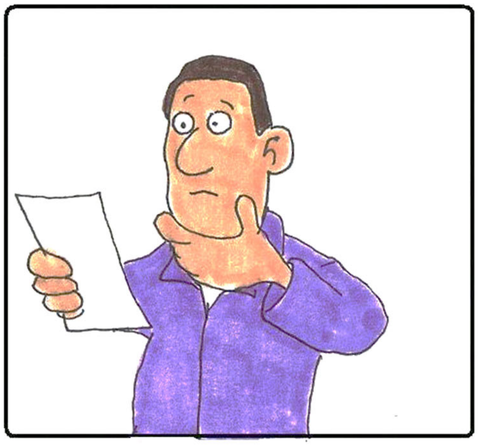
a. Water Treatment Acronyms
b. EPA Acronyms
c. Symbols and Characters
d. Water Chemistry Review
e. Modern Chemistry Principles
f. Understanding the Atom
g. Common Water Chemicals
h. Substances verses Mixtures
i. Understanding the Molecule
j. Phase
k. Bonding
l. Energy
m. Reactions



ADD ACID TO WATER



NEVER ADD WATER TO ACID



READ THE SAFETY DATA SHEET

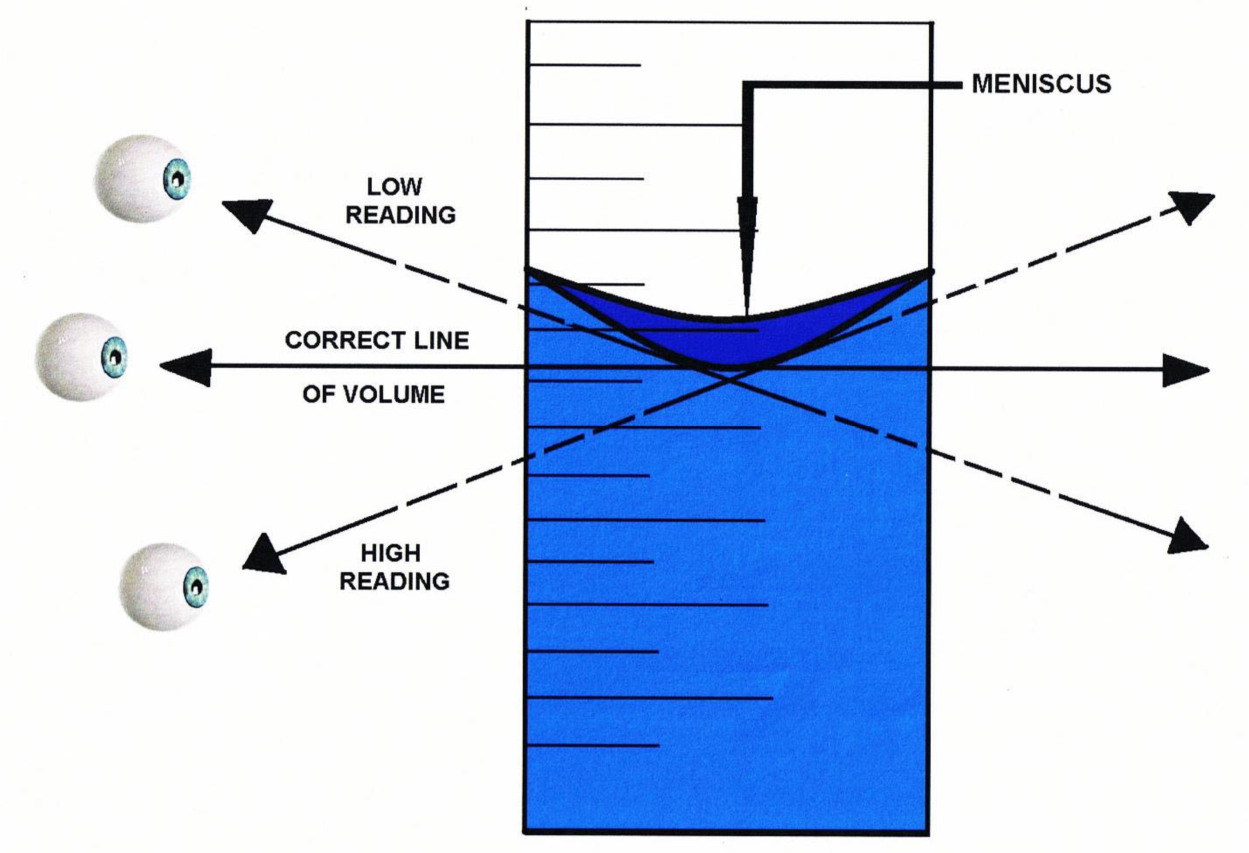
WEAR PROPER PPE

HANDLING CHEMICALS

Common Water Treatment Acronyms

AA - Activated alumina
AC - Activated carbon
ASR - Annual Status Report
As(III) - Trivalent arsenic, common inorganic form in water is arsenite, H_3AsO_3
As(V) - Pentavalent arsenic, common inorganic form in water is arsenate, H_2AsO_4
BDAT - Best demonstrated available technology
BTEX - Benzene, toluene, ethylbenzene, and xylene
CCA - Chromated copper arsenate
CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS 3 - CERCLA Information System
CLU-IN - EPA's CLeanUp INformation system
CRAO- Compliance and Regulatory Affairs Office
CWS - Community Water System
cy - Cubic yard
DDT - Dichloro-diphenyl-trichloroethane
DI - De-ionized
DOC - Dissolved organic carbon
DoD - Department of Defense
DOE - Department of Energy
EDTA - Ethylenediaminetetraacetic acid
EPA - U.S. Environmental Protection Agency
EPT - Extraction Procedure Toxicity Test
FRTR - Federal Remediation Technologies Roundtable
ft - feet
gpd - gallons per day
gpm - gallons per minute
HTMR - High temperature metals recovery
MCL - Maximum Contaminant Level (enforceable drinking water standard)
MF - Microfiltration
MHO - Metallurgie-Hoboken-Overpelt
mgd - million gallons per day
mg/kg - milligrams per kilogram
mg/L - milligrams per Liter
NF - Nanofiltration
NPL - National Priorities List
OCLC - Online Computer Library Center
ORD - EPA Office of Research and Development
OU - Operable Unit
PAH - Polycyclic aromatic hydrocarbons
PCB - Polychlorinated biphenyls
P.L. – Public Laws
POTW - Publicly owned treatment works
PRB - Permeable reactive barrier
RCRA - Resource Conservation and Recovery Act
Redox - Reduction/oxidation
RO - Reverse osmosis
ROD - Record of Decision
SDWA - Safe Drinking Water Act

SMZ - Surfactant modified zeolite
SNAP - Superfund NPL Assessment Program
S/S - Solidification/Stabilization
SVOC - Semi-volatile organic compounds
TCLP - Toxicity Characteristic Leaching Procedure
TNT - 2,3,6-trinitrotoluene
TWA - Total Waste Analysis
UF - Ultrafiltration
VOC - Volatile organic compounds
WET - Waste Extraction Test
ZVI - Zero valent iron



HOW TO READ A MENISCUS

The **meniscus** (plural: *menisci*, from the Greek for "crescent") is the curve in the upper surface of a liquid close to the surface of the container or another object, caused by surface tension. It can be either convex or concave.

A convex meniscus occurs when the molecules have a stronger attraction to each other (cohesion) than to the material of the container (adhesion). This may be seen between mercury and glass in barometers and thermometers. Conversely, a concave meniscus occurs when the molecules of the liquid attract those of the container's, causing the surface of the liquid to cave downwards. This can be seen in a glass of water.

EPA Acronyms

CCR	Consumer Confidence Report
CWS	Community Water System
DBP	Disinfection Byproduct
HPC	Heterotrophic Plate Count
IESWTR	Interim Enhanced Surface Water Treatment Rule
IOC	Inorganic Chemical
LCR	Lead and Copper Rule
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
NPDWR	National Primary Drinking Water Regulations
NTNCWS	Non-Transient Non-Community Water System
NTU	Nephelometric Turbidity Units
PN	Public Notification
PWS	Public Water Supply
SDWA	Safe Drinking Water Act
SMCL	Secondary Maximum Contaminant Level
SOC	Synthetic Organic Chemical
SWTR	Surface Water Treatment Rule
TCR	Total Coliform Rule
TT	Treatment Technique
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Chemical

Common Water Chemistry/Quality Definitions

Units of Measurement

mg/l = Milligrams per liter. One milligram per liter equals one packet of artificial sweetener sprinkled into 250 gallons of iced tea.

µg/l = Micrograms per liter. One microgram per liter is equal to one packet of artificial sweetener sprinkled into an Olympic-size swimming pool.

NTU = Nephelometric Turbidity Units. A measurement on the cloudiness of the water.

pCi/l = Picocuries per liter. A measure of radioactivity.

Acronyms

Maximum Contaminant Level (MCL) - The highest level of a contaminant that is allowed in drinking water.

Maximum Contaminant Level Goal (MCLG) - The level of a contaminant in drinking water below which there is no known or expected risk to health.

Treatment Technique (TT) - A required process intended to reduce the level of a contaminant in drinking water.

Action Level (AL) - The concentration of a contaminant that, if exceeded, triggers treatment or other requirements which a water system must follow.

Symbols and Characters

These symbols and characters are specific to water sampling methods but have been conformed to common usage as much as possible.

Units of weight and measure and their abbreviations
Symbols

°C degrees Celsius
µL microliter
< less than
> greater than
% percent

Alphabetical characters

ACUK - Acid chrome violet K
AECL - Alternate enhanced coagulant level
AOC - Assailable organic carbon
ASDWA - Association of State Drinking Water Administrators
AWWA - American Water Works Association
AWWARF - AWWA Research Foundation
BAC - Biologically active carbon
BAF - Biologically active filtration
BAT - Best Available Technology
BCAA - Bromochloroacetic acid
BDOC - Biodegradable organic carbon
BMP- Best management practice
BOM - Biodegradable Organic Matter (=BDOC + AOC)
Br- - Bromide ion
BrO^2- - Bromite ion
BrO^3- - Bromate ion
CI - Confidence interval
Cl^2 - Chlorine
ClO^2 - Chlorine Dioxide
cm - centimeter
CT - Concentration-Time
CWS - Community Water System
D/DBP - Disinfectants/disinfection byproducts
DBP - Disinfection byproduct
DBPFP - Disinfection byproduct formation potential
DBPP - Disinfection byproduct precursors
DBPR - Disinfectants/disinfection byproducts rule
DBPRAM - DBP Regulatory Assessment Model
DBPs - Disinfection byproducts
DOC- Dissolved organic carbon
DPD - N,N-diethyl-p-phenylendiamine
DWEL - Drinking Water Equivalent Level
EBCT - Empty bed contact time
EMSL - EPA Environmental Monitoring and Support Laboratory (Cincinnati)
EPA - United States Environmental Protection Agency
ESWTR - Enhanced Surface Water Treatment Rule
FBR - Filter Backwash Rule

FY - Fiscal year
G - acceleration due to gravity
g - gram
GAC - Granular activated carbon
GWR - Ground Water Rule
GWSS - Ground Water Supply Survey
H2O2 - Hydrogen Peroxide
HAA5 - Haloacetic acids (five)
HOBr - Hypobromous acid
HOCl - Hypochlorous acid
hr - hour
IC- Ion chromatography
ICR- Information Collection Rule
ID - inside diameter
IESWTR- Interim Enhanced Surface Water Treatment Rule
in. - inch
IOA- International Ozone Association
IOC - Inorganic chemical
KMnO4 - Potassium permanganate
L - liter
LOAEL - Lowest observed adverse effect level
LOQ - Limit of quantitation
LT1ESWTR - Long Term Stage 1 Enhanced Surface Water Treatment Rule
m - meter
MCL - Maximum Contaminant Level
MCLG - Maximum Contaminant Level Goal
M-DBP - Microbial and disinfection byproducts
MDL - Method Detection Limit
mg - milligram
mg/L - Milligrams per liter
mgd - Million gallons per day
MIB -Methylisoborneol
mL - milliliter
mm - millimeter
mM - millimolar
MRDL - Maximum Residual Disinfectant Level (as mg/l)
MRDLG - Maximum Residual Disinfectant Level Goal
MRL - Minimum Reporting Level
MX - 3-chloro-4-(dichloromethyl)-5-hydroxyl-2(5H)-furanone
N - normal; gram molecular weight of solute divided by hydrogen equivalent of solute, per liter of solution
NaCl - Sodium chloride
NCI - National Cancer Institute
ND - Not detected
NH^2Cl - Monochloramine
NIOSH - National Institute for Occupational Safety and Health
NIPDWR - National Interim Primary Drinking Water Regulation
NOAEL - No Observed Adverse Effect Level
NOM - Natural Organic Matter
NOMS - National Organic Monitoring Survey
NORS - National Organics Reconnaissance Survey for Halogenated Organics

NPDWR - National Primary Drinking Water Regulation
NTNCWS - Nontransient noncommunity water system
NTP - Normal Temperature and Pressure
O^2 - Oxygen
O^3 - Ozone
OBr- - Hypobromite ion
OCl- - Hypochlorite ion
PCE - Perchloroethylene
PE - Performance evaluation
POE - Point-of-Entry Technologies
POU- Point-of-Use Technologies
ppb - Parts per billion
ppm - Parts per million
PQL - Practical Quantitation Level
PTA - Packed Tower Aeration
PWS - Public water system
RIA - Regulatory Impact Analysis
RMCL - Recommended Maximum Contaminant Level
RNDB - Regulations Negotiation Data Base
RSC - Relative Source Contribution
RSD - relative standard deviation
SDWA - Safe Drinking Water Act, or the “Act,” as amended in 1996
SM - Standard Method
SMCL - Secondary Maximum Contaminant Level
SMR - Standardized mortality ratios
SOC - Synthetic Organic Chemical
s_r - standard deviation of recovery
SWTR- Surface Water Treatment Rule
TCE - Trichloroethylene
THM - Trihalomethane
THMFP - Trihalomethane formation potential
TMV - Tobacco mosaic virus
TOC - Total organic carbon
TTHM - Total trihalomethanes
TWG - Technologies Working Group
UV - Ultraviolet
VOC - Volatile Organic Chemical
WIDB - Water Industry Data Base
WS - Water supply
X - average percent recovery
XDBPs - Halogenated DBPs

Water Chemistry Review

All these principles are good for both water and wastewater and are necessary to understand the operation of microfiltration systems.

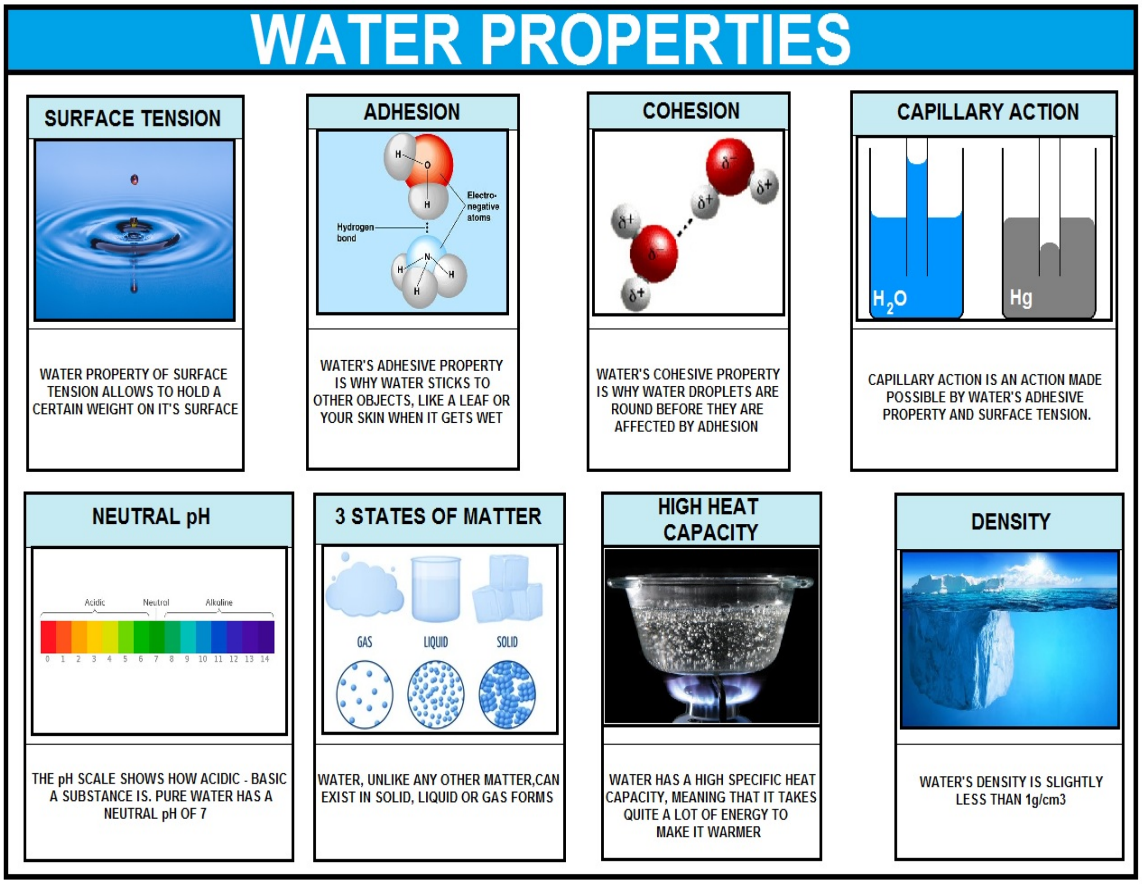
Commonly found Chemical Types

Many chemicals are commonly available in pure form. Others are available as reagents - inexpensive, convenient sources of chemicals with a bit of processing.

This is convenient for both amateur and professional chemistry work. Common reagents include:

- Metal oxides and carbonates (widely used in pottery)
- Organic acids (used for home brewing)
- Solvents and acids (used in cleaning materials and other hardware applications)
- Photographic chemicals, such as silver nitrate
- Single-chemical fertilizers, such as potassium nitrate (used in agricultural supply)
- Chlorinating agents, such as calcium hypochlorite (used in swimming pool and water purification)
- Mordants, such as potassium dichromate (used in arts and crafts)
- A *chemical substance* is a form of matter that has constant chemical composition and characteristic properties. It cannot be separated into components by physical separation methods, i.e. without breaking chemical bonds. Chemical substances can be chemical elements, chemical compounds, ions or alloys.
- Chemical substances are often called 'pure' to set them apart from mixtures. A common example of a chemical substance is pure water; it has the same properties and the same ratio of hydrogen to oxygen whether it is isolated from a river or made in a laboratory. Other chemical substances commonly encountered in pure form are diamond (carbon), gold, table salt (sodium chloride) and refined sugar (sucrose). However, in practice, no substance is entirely pure, and chemical purity is specified according to the intended use of the chemical.
- Chemical substances exist as solids, liquids, gases or plasma, and may change between these phases of matter with changes in temperature or pressure. Chemical reactions convert one chemical substance into another.
- Forms of energy, such as light and heat, are not considered to be matter, and thus they are not "substances" in this regard.
- Chemical substances (also called pure substances) may well be defined as "any material with a definite chemical composition" in an introductory general chemistry textbook. According to this definition a chemical substance can either be a pure chemical element or a pure chemical compound. But, there are exceptions to this definition; a pure substance can also be defined as a form of matter that has both definite composition and distinct properties. The chemical substance index published by CAS also includes several alloys of uncertain composition. Non-stoichiometric compounds are a special case (in inorganic chemistry) that violates the law of constant composition, and for them, it is sometimes difficult to draw the line between a mixture and a compound, as in the case of palladium hydride.
- In geology, substances of uniform composition are called minerals, while physical mixtures (aggregates) of several minerals (different substances) are defined as rocks.

- Many minerals, however, mutually dissolve into solid solutions, such that a single rock is a uniform substance despite being a mixture in stoichiometric terms. Feldspars are a common example: anorthoclase is an alkali aluminum silicate, where the alkali metal is interchangeably either sodium or potassium



WATER PROPERTIES

SURFACE TENSION

WATER PROPERTY OF SURFACE TENSION ALLOWS TO HOLD A CERTAIN WEIGHT ON IT'S SURFACE

ADHESION

WATER'S ADHESIVE PROPERTY IS WHY WATER STICKS TO OTHER OBJECTS, LIKE A LEAF OR YOUR SKIN WHEN IT GETS WET

COHESION

WATER'S COHESIVE PROPERTY IS WHY WATER DROPLETS ARE ROUND BEFORE THEY ARE AFFECTED BY ADHESION

CAPILLARY ACTION

CAPILLARY ACTION IS AN ACTION MADE POSSIBLE BY WATER'S ADHESIVE PROPERTY AND SURFACE TENSION.

NEUTRAL pH

THE pH SCALE SHOWS HOW ACIDIC - BASIC A SUBSTANCE IS. PURE WATER HAS A NEUTRAL pH OF 7

3 STATES OF MATTER

WATER, UNLIKE ANY OTHER MATTER,CAN EXIST IN SOLID, LIQUID OR GAS FORMS

HIGH HEAT CAPACITY

WATER HAS A HIGH SPECIFIC HEAT CAPACITY, MEANING THAT IT TAKES QUITE A LOT OF ENERGY TO MAKE IT WARMER

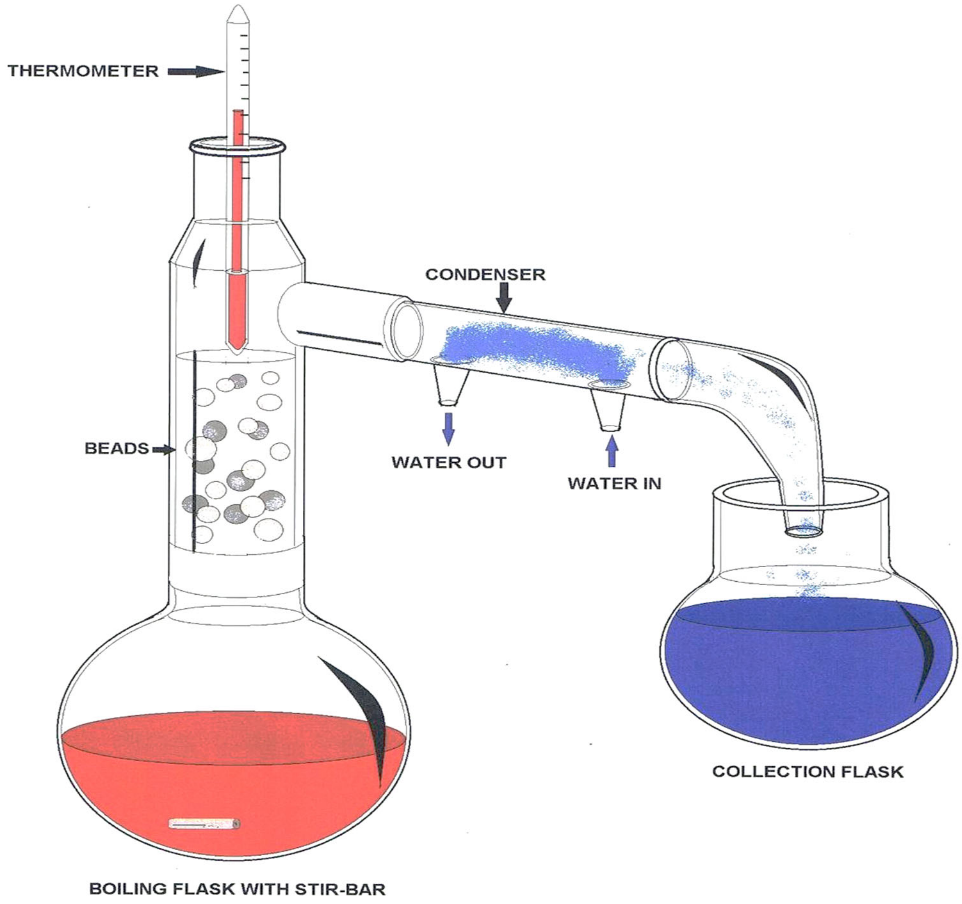
DENSITY

WATER'S DENSITY IS SLIGHTLY LESS THAN 1g/cm3

PROPERTIES OF WATER

Modern Chemistry Principles

The current model of atomic structure is the quantum mechanical model. Traditional chemistry starts with the study of elementary particles, atoms, molecules, substances, metals, crystals and other aggregates of matter. This matter can be studied in solid, liquid, or gas states, in isolation or in combination. The interactions, reactions and transformations that are studied in chemistry are usually the result of interactions between atoms, leading to rearrangements of the chemical bonds which hold atoms together. Such behaviors are studied in a chemistry laboratory.



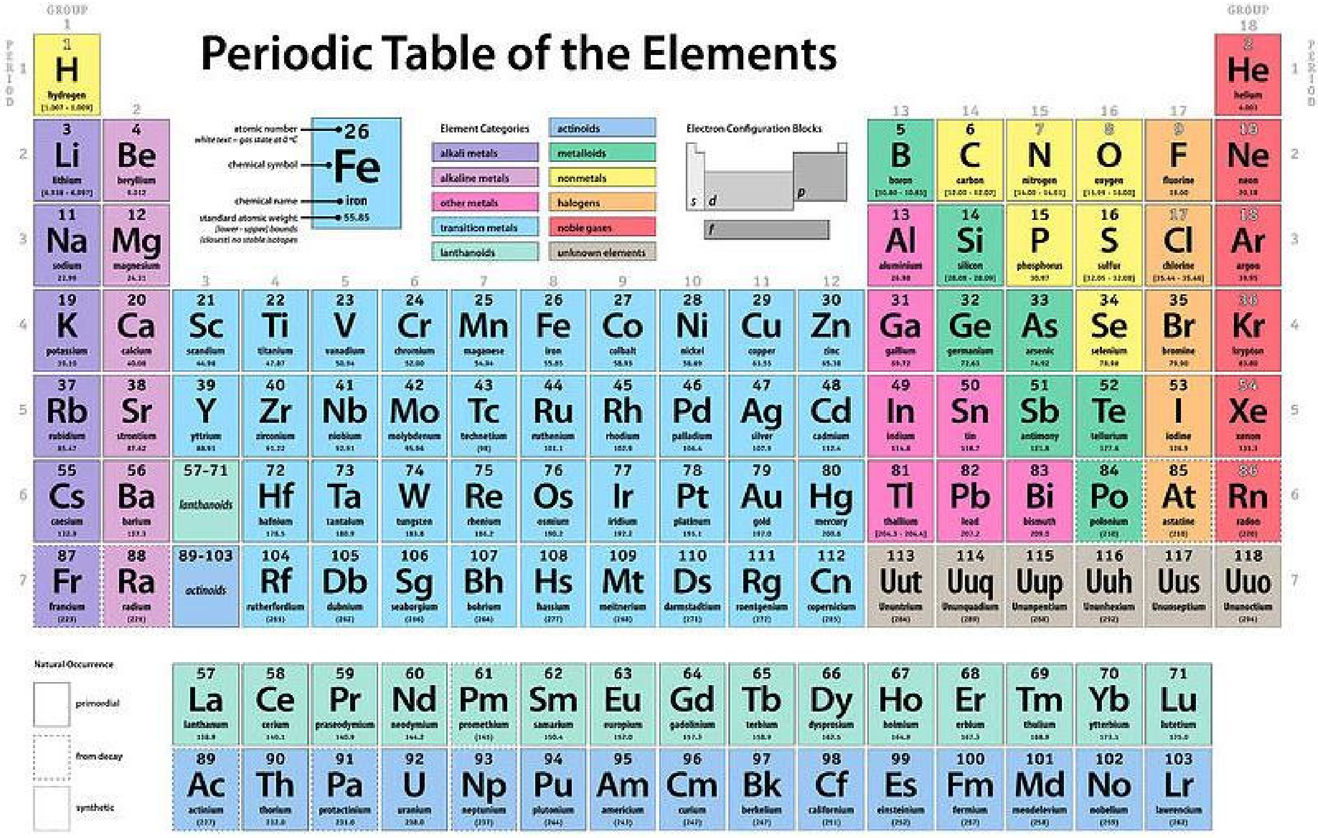
The chemistry laboratory stereotypically uses various forms of laboratory glassware. Glassware is not central to chemistry and a great deal of experimental (as well as applied/industrial) chemistry is done without it.

A chemical reaction is a transformation of some substances into one or more different substances. The basis of such a chemical transformation is the rearrangement of electrons in the chemical bonds between atoms. It can be symbolically depicted through a chemical equation, which usually involves atoms as subjects. The number of atoms on the left and the right in the equation for a chemical transformation is equal. (When the number of atoms on either side is unequal, the transformation is referred to as a nuclear reaction or radioactive decay.) The type of chemical reactions a substance may undergo and the energy changes that may accompany it are constrained by certain basic rules, known as chemical laws.

Energy and entropy considerations are invariably important in almost all chemical studies. Chemical substances are classified in terms of their structure, phase, as well as their chemical compositions. They can be analyzed using the tools of chemical analysis, e.g. spectroscopy and chromatography. Scientists engaged in chemical research are known as chemists. Most chemists specialize in one or more sub-disciplines.

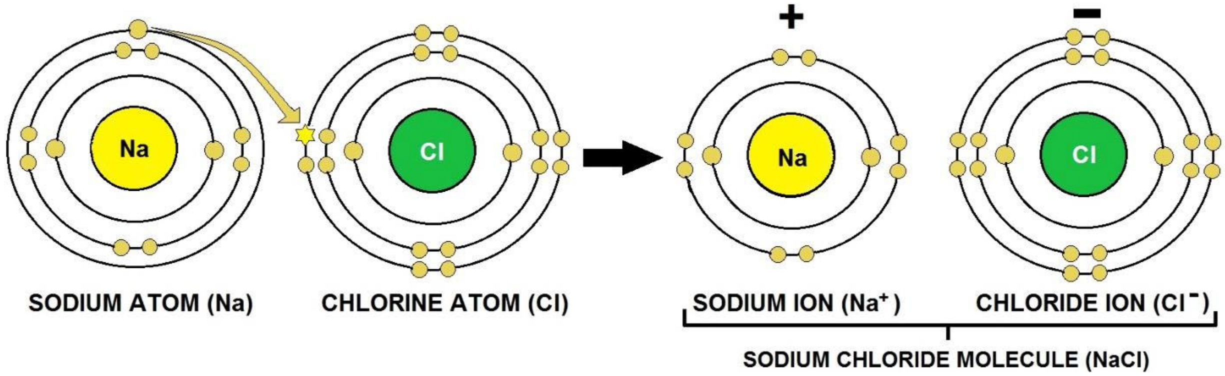
Matter

In chemistry, matter is defined as anything that has rest mass and volume (it takes up space) and is made up of particles. The particles that make up matter have rest mass as well - not all particles have rest mass, such as the photon. Matter can be a pure chemical substance or a mixture of substances.



Understanding the Atom

The atom is the basic unit of chemistry. It consists of a dense core called the atomic nucleus surrounded by a space called the electron cloud. The nucleus is made up of positively charged protons and uncharged neutrons (together called nucleons), while the electron cloud consists of negatively-charged electrons which orbit the nucleus. In a neutral atom, the negatively-charged electrons balance out the positive charge of the protons. The nucleus is dense; the mass of a nucleon is 1,836 times that of an electron, yet the radius of an atom is about 10,000 times that of its nucleus.



The atom is also the smallest entity that can be envisaged to retain the chemical properties of the element, such as electronegativity, ionization potential, preferred oxidation state(s), coordination number, and preferred types of bonds to form (e.g., metallic, ionic, covalent).

Element
Standard form of the periodic table of chemical elements. The colors represent different categories of elements.

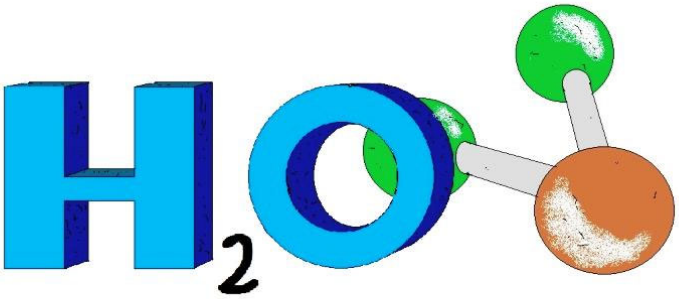
A chemical element is a pure substance which is composed of a single type of atom, characterized by its particular number of protons in the nuclei of its atoms, known as the atomic number and represented by the symbol *Z*. The mass number is the sum of the number of protons and neutrons in a nucleus.

Although all the nuclei of all atoms belonging to one element will have the same atomic number, they may not necessarily have the same mass number; atoms of an element which have different mass numbers are known as isotopes. For example, all atoms with 6 protons in their nuclei are atoms of the chemical element carbon, but atoms of carbon may have mass numbers of 12 or 13.

The standard presentation of the chemical elements is in the periodic table, which orders elements by atomic number. The periodic table is arranged in groups, or columns, and periods, or rows. The periodic table is useful in identifying periodic trends.

Compound
A *compound* is a pure chemical substance composed of more than one element. The properties of a compound bear little similarity to those of its elements. The standard nomenclature of compounds is set by the International Union of Pure and Applied Chemistry (IUPAC). Organic compounds are named according to the organic nomenclature system.

Inorganic compounds are named according to the inorganic nomenclature system. In addition, the Chemical Abstracts Service has devised a method to index chemical substances. In this scheme each chemical substance is identifiable by a number known as its CAS registry number.



Water (H_2O), an example of a chemical compound

Chemical Compounds

A pure chemical compound is a chemical substance that is composed of a particular set of molecules or ions. Two or more elements combined into one substance through a chemical reaction form a chemical compound. All compounds are substances, but not all substances are compounds.

A chemical compound can be either atoms bonded together in molecules or crystals in which atoms, molecules or ions form a crystalline lattice. Compounds based primarily on carbon and hydrogen atoms are called organic compounds, and all others are called inorganic compounds. Compounds containing bonds between carbon and a metal are called organometallic compounds.

Compounds in which components share electrons are known as covalent compounds. Compounds consisting of oppositely charged ions are known as ionic compounds, or salts.

In organic chemistry, there can be more than one chemical compound with the same composition and molecular weight. Generally, these are called isomers. Isomers usually have substantially different chemical properties, may be isolated and do not spontaneously convert to each other.

A common example is glucose vs. fructose. The former is an aldehyde; the latter is a ketone. Their interconversion requires either enzymatic or acid-base catalysis. However, there are also tautomers, where isomerization occurs spontaneously, such that a pure substance cannot be isolated into its tautomers.

A common example is glucose, which has open-chain and ring forms. One cannot manufacture pure open-chain glucose because glucose spontaneously cyclizes to the hemiacetal form. Materials may also comprise other entities such as polymers. These may be inorganic or organic and sometimes a combination of inorganic and organic.

Common Water Treatment Chemicals

Chemical Name	Common Name	Chemical Formula
Aluminum hydroxide		Al(OH)3
Aluminum sulfate	Alum, liquid	AL2(SO4)3 . 14(H2O)
Ammonia		NH3
Ammonium		NH4
Bentonitic clay	Bentonite	
Calcium bicarbonate		Ca(HCO3)2
Calcium carbonate	Limestone	CaCO3
Calcium chloride		CaCl2
Calcium Hypochlorite	HTH	Ca(OCl)2 . 4H2O
Calcium hydroxide	Slaked Lime	Ca(OH)2
Calcium oxide	Unslaked (Quicklime)	CaO
Calcium sulfate	Gypsum	CaSO4
Carbon	Activated Carbon	C
Carbon dioxide		CO2
Carbonic acid		H2CO3
Chlorine gas		Cl2
Chlorine Dioxide		ClO2
Copper sulfate	Blue vitriol	CuSO4 . 5H2O
Dichloramine		NHCl2
Ferric chloride	Iron chloride	FeCl3
Ferric hydroxide		Fe(OH)3
Ferric sulfate	Iron sulfate	Fe2(SO4)3
Ferrous bicarbonate		Fe(HCO3)2
Ferrous hydroxide		Fe(OH)3
Ferrous sulfate	Copperas	FeSO4.7H20
Hydrofluorsilicic acid		H2SiF6
Hydrochloric acid	Muriatic acid	HCl
Hydrogen sulfide		H2S
Hypochlorous acid		HOCL
Magnesium bicarbonate		Mg(HCO3)2
Magnesium carbonate		MgCO3
Magnesium chloride		MgCl2
Magnesium hydroxide		Mg(OH)2
Magnesium dioxide		MgO2
Manganous bicarbonate		Mn(HCO3)2
Manganous sulfate		MnSO4
Monochloramine		NH2Cl
Potassium bicarbonate		KHCO3

Chemical Name	Common Name	Chemical Formula
Sodium carbonate	Soda ash	Na2CO3
Sodium chloride	Salt	NaCl
Sodium chlorite		NaClO2
Sodium fluoride		NaF
Sodium fluorosilicate		Na2SiF6
Sodium hydroxide	Lye	NaOH
Sodium hypochlorite		NaOCl
Sodium Metaphosphate	Hexametaphosphate	NaPO3
Sodium phosphate	Disodium phosphate	Na3PO4
Sodium sulfate		Na2SO4
Sulfuric acid		H2SO4

Inside a water chemical lab with pH equipment.

Common Used Products	**Chemical Name**
acetone	dimethyl ketone
acid of sugar	oxalic acid
alcohol, grain	ethyl alcohol
alcohol, wood	methyl alcohol
alum	aluminum potassium sulfate
alumina	aluminum oxide
antichlor	sodium thiosulfate
aqua ammonia	aqueous solution of ammonium hydroxide
aqua regia	nitrohydrochloric acid
aqua fortis	nitric acid
aromatic spirit of ammonia	ammonia in alcohol
asbestos	magnesium silicate
aspirin	acetylsalicylic acid
baking soda	sodium bicarbonate
banana oil (artificial)	isoamyl acetate
benzol	benzene
bichloride of mercury	mercuric chloride
black copper oxide	cupric oxide
black lead	graphite (carbon)
bleaching powder	chlorinated lime
blue vitriol	copper sulfate
bluestone	copper sulfate
borax	sodium borate
brimstone	sulfur
brine	aqueous sodium chloride solution
butter of antimony	antimony trichloride
butter of tin	anhydrous stannic chloride
calomel	mercury chloride
carbolic acid	phenol
carbonic acid gas	carbon dioxide
caustic potash	potassium hydroxide
caustic soda	sodium hydroxide
chalk	calcium carbonate
Chile saltpeter	sodium nitrate
chrome, alum	chromic potassium sulfate
chrome, yellow	lead (VI) chromate
copperas	ferrous sulfate
cream of tartar	potassium bitartrate
crocus powder	ferric oxide
emery powder	impure aluminum oxide
Epsom salts	magnesium sulfate
ethanol	ethyl alcohol
fluorspar	natural calcium fluoride
formalin	aqueous formaldehyde solution
French chalk	natural magnesium silicate
galena	natural lead sulfide
Glauber's salt	sodium sulfate
gypsum	natural calcium sulfate

hydrocyanic acid	hydrogen cyanide
hypo (photography)	sodium thiosulfate solution
lime	calcium oxide
limewater	aqueous solution of calcium hydroxide
lunar caustic	silver nitrate
magnesia	magnesium oxide
mercury oxide, black	mercurous oxide
methanol	methyl alcohol
methylated spirits	methyl alcohol
muriatic acid	hydrochloric acid
oil of vitriol	sulfuric acid
oil of wintergreen (artificial)	methyl salicylate
Paris green	copper acetoarsenite
Paris white	powdered calcium carbonate
pear oil (artificial)	isoamyl acetate
pearl ash	potassium carbonate
plaster of Paris	calcium sulfate
plumbago	graphite
potash	potassium carbonate
potassa	potassium hydroxide
Prussic acid	hydrogen cyanide
pyro	tetrasodium pyrophosphate
quicklime	calcium oxide
quicksilver	mercury
red lead	lead tetraoxide
Rochelle salt	potassium sodium tartrate
rouge, jeweler's	ferric oxide
rubbing alcohol	isopropyl alcohol
sal ammoniac	ammonium chloride
sal soda	sodium carbonate
salt, table	sodium chloride
salt of lemon	potassium binoxalate
salt of tartar	potassium carbonate
saltpeter	potassium nitrate
silica	silicon dioxide
soda ash	sodium carbonate
soda lye	sodium hydroxide
soluble glass	sodium silicate
spirit of hartshorn	ammonium hydroxide solution
sugar, table	sucrose
talc or talcum	magnesium silicate
vinegar	impure dilute acetic acid
vitamin C	ascorbic acid
washing soda	sodium carbonate
water glass	sodium silicate

Substances Versus Mixtures

All matter consists of various elements and chemical compounds, but these are often intimately mixed together. Mixtures contain more than one chemical substance, and they do not have a fixed composition. In principle, they can be separated into the component substances by purely mechanical processes. Butter, soil and wood are common examples of mixtures.

Grey iron metal and yellow sulfur are both chemical elements, and they can be mixed together in any ratio to form a yellow-grey mixture. No chemical process occurs, and the material can be identified as a mixture by the fact that the sulfur and the iron can be separated by a mechanical process, such as using a magnet to attract the iron away from the sulfur.

In contrast, if iron and sulfur are heated together in a certain ratio (1 atom of iron for each atom of sulfur, or by weight, 56 grams (1 mol) of iron to 32 grams (1 mol) of sulfur), a chemical reaction takes place and a new substance is formed, the compound iron(II) sulfide, with chemical formula FeS. The resulting compound has all the properties of a chemical substance and is not a mixture. Iron(II) sulfide has its own distinct properties such as melting point and solubility, and the two elements cannot be separated using normal mechanical processes; a magnet will be unable to recover the iron, since there is no metallic iron present in the compound.

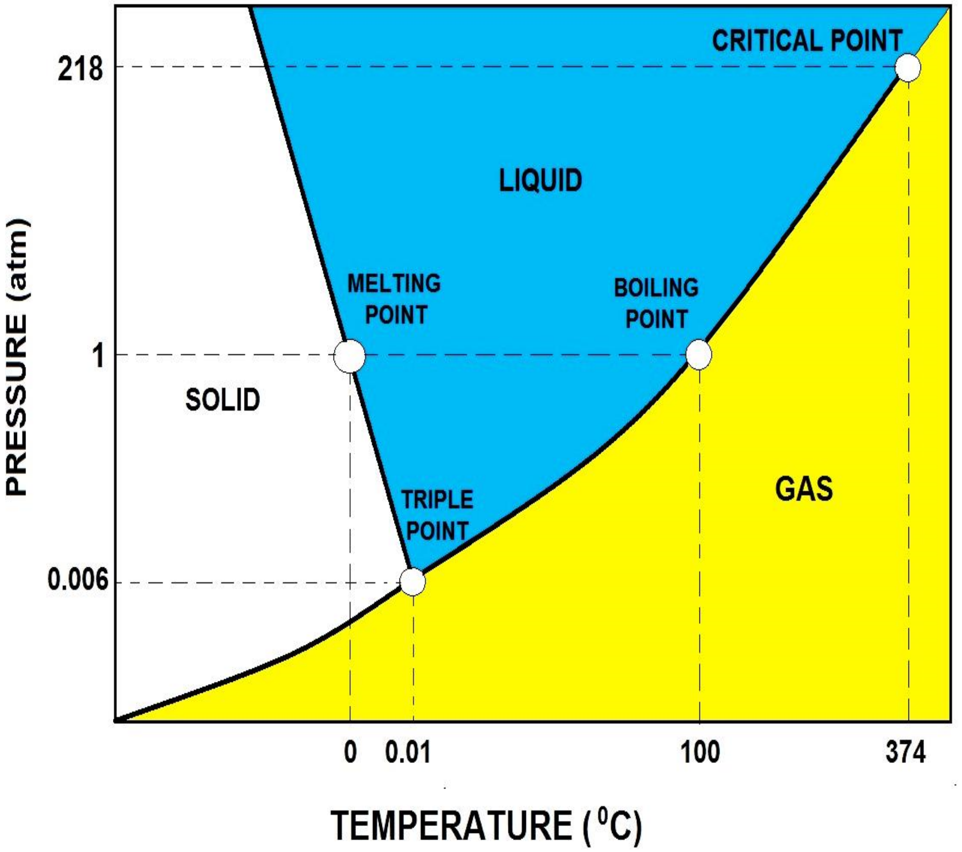
Chemicals Versus Chemical Substances

While the term *chemical substance* is a precise technical term that is synonymous with "chemical" for professional chemists, the meaning of the word *chemical* varies for non-chemists within the English speaking world or those using English. For industries, government and society in general in some countries, the word *chemical* includes a wider class of substances that contain many mixtures of such chemical substances, often finding application in many vocations. In countries that require a list of ingredients in products, the "chemicals" listed would be equated with "chemical substances".

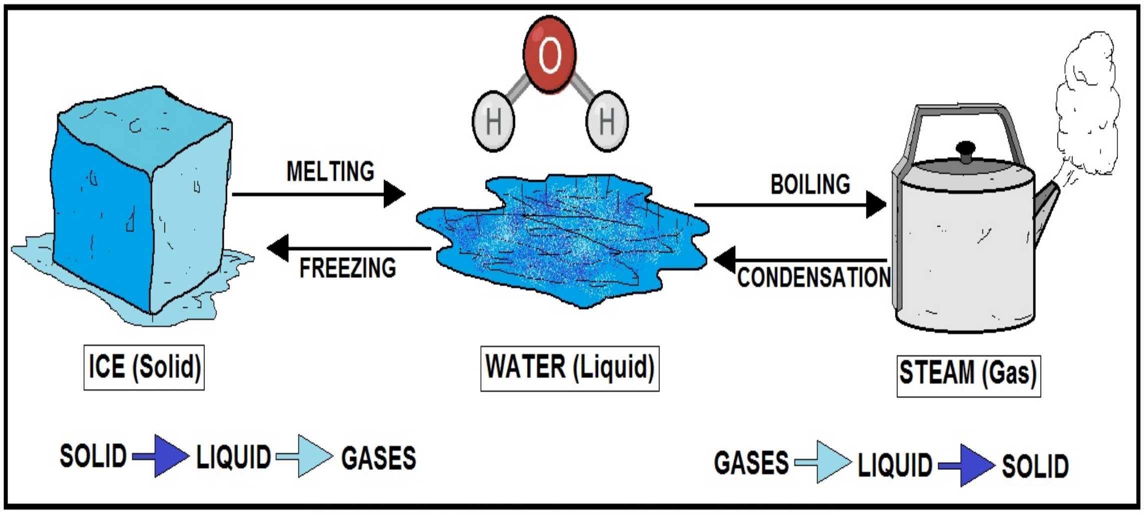
Within the chemical industry, manufactured "chemicals" are chemical substances, which can be classified by production volume into bulk chemicals, fine chemicals and chemicals found in research only:

- Bulk chemicals are produced in very large quantities, usually with highly optimized continuous processes and to a relatively low price.
- Fine chemicals are produced at a high cost in small quantities for special low-volume applications such as biocides, pharmaceuticals and specialty chemicals for technical applications.
- Research chemicals are produced individually for research, such as when searching for synthetic routes or screening substances for pharmaceutical activity. In effect, their price per gram is very high, although they are not sold.

The cause of the difference in production volume is the complexity of the molecular structure of the chemical. Bulk chemicals are usually much less complex.



WATER PHASE DIAGRAM

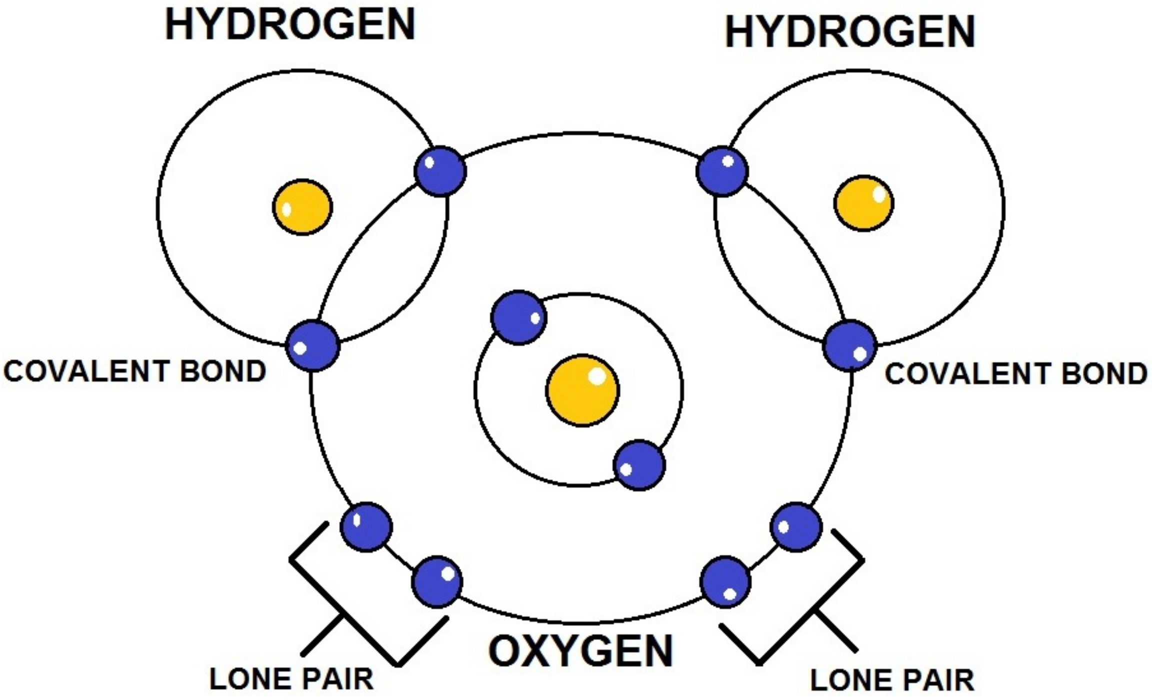


PHYSICAL CHARACTERISTICS OF WATER

Technical Learning College

Understanding the Molecule

A *molecule* is the smallest indivisible portion of a pure chemical substance that has its unique set of chemical properties, that is, its potential to undergo a certain set of chemical reactions with other substances. However, this definition only works well for substances that are composed of molecules, which is not true of many substances (see below). Molecules are typically a set of atoms bound together by covalent bonds, such that the structure is electrically neutral and all valence electrons are paired with other electrons either in bonds or in lone pairs.



WATER MOLECULE

Thus, molecules exist as electrically neutral units, unlike ions. When this rule is broken, giving the "molecule" a charge, the result is sometimes named a molecular ion or a polyatomic ion. However, the discrete and separate nature of the molecular concept usually requires that molecular ions be present only in well-separated form, such as a directed beam in a vacuum in a mass spectrometer. Charged polyatomic collections residing in solids (for example, common sulfate or nitrate ions) are generally not considered "molecules" in chemistry.

The "inert" or noble gas elements (helium, neon, argon, krypton, xenon and radon) are composed of lone atoms as their smallest discrete unit, but the other isolated chemical elements consist of either molecules or networks of atoms bonded to each other in some way.

Identifiable molecules compose familiar substances such as water, air, and many organic compounds like alcohol, sugar, gasoline, and the various pharmaceuticals.

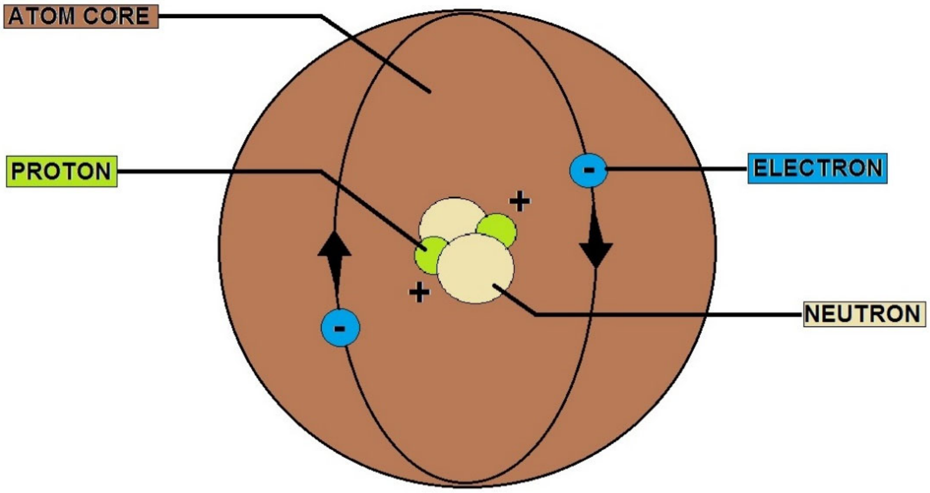
However, not all substances or chemical compounds consist of discrete molecules, and indeed most of the solid substances that make up the solid crust, mantle, and core of the

Earth are chemical compounds without molecules. These other types of substances, such as ionic compounds and network solids, are organized in such a way as to lack the existence of identifiable molecules *per se*. Instead, these substances are discussed in terms of formula units or unit cells as the smallest repeating structure within the substance.

Examples of such substances are mineral salts (such as table salt), solids like carbon and diamond, metals, and familiar silica and silicate minerals such as quartz and granite. One of the main characteristics of a molecule is its geometry often called its structure. While the structure of diatomic, triatomic or tetra atomic molecules may be trivial, (linear, angular pyramidal etc.) the structure of polyatomic molecules, that are constituted of more than six atoms (of several elements) can be crucial for its chemical nature.

Substance and Mixture
A chemical substance is a kind of matter with a definite composition and set of properties. A collection of substances is called a mixture. Examples of mixtures are air and alloys.

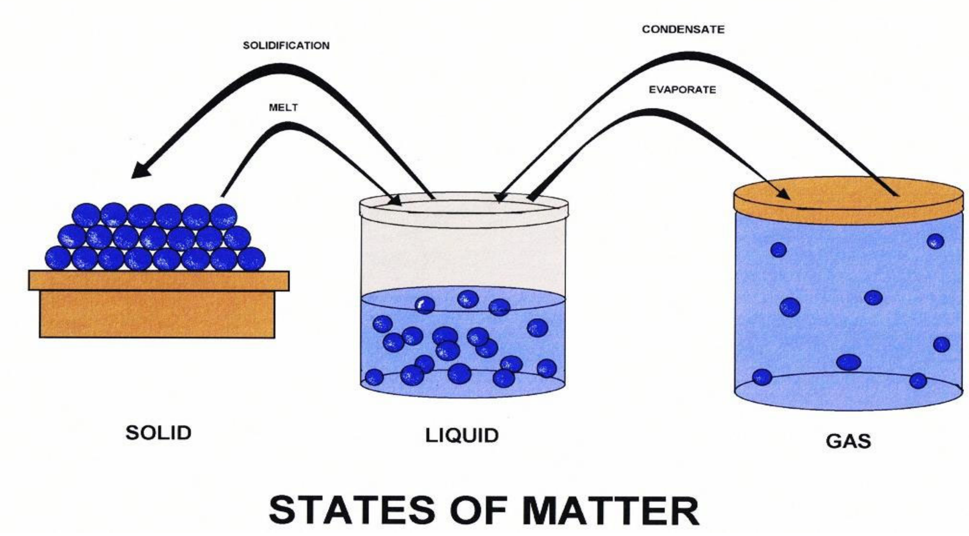
Mole and Amount of Substance
The mole is a unit of measurement that denotes an amount of substance (also called chemical amount). The mole is defined as the number of atoms found in exactly 0.012 kilogram (or 12 grams) of carbon-12, where the carbon-12 atoms are unbound, at rest and in their ground state. The number of entities per mole is known as the Avogadro constant, and is determined empirically to be approximately 6.022×10^{23} mol^{-1}. Molar concentration is the amount of a particular substance per volume of solution, and is commonly reported in $moldm^{-3}$.



BASICS OF AN ATOM

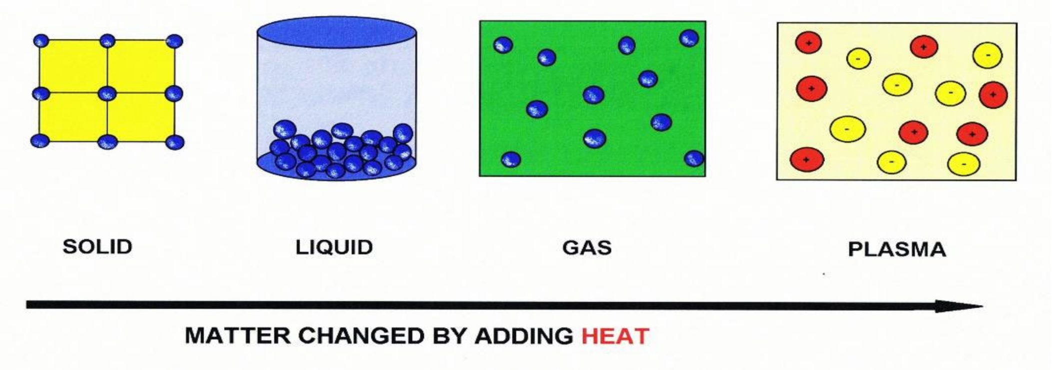
Phase

In addition to the specific chemical properties that distinguish different chemical classifications, chemicals can exist in several phases. For the most part, the chemical classifications are independent of these bulk phase classifications; however, some more exotic phases are incompatible with certain chemical properties. A *phase* is a set of states of a chemical system that have similar bulk structural properties, over a range of conditions, such as pressure or temperature.



Physical properties, such as density and refractive index tend to fall within values characteristic of the phase. The phase of matter is defined by the *phase transition*, which is when energy put into or taken out of the system goes into rearranging the structure of the system, instead of changing the bulk conditions.

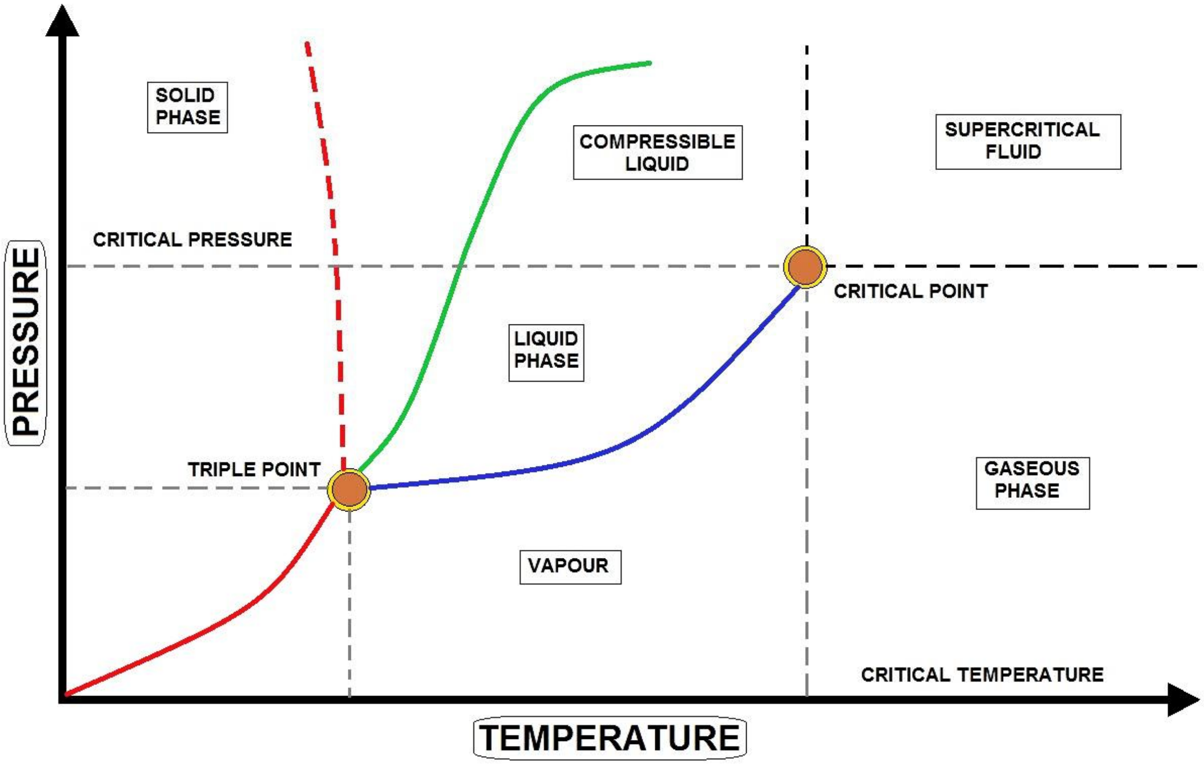
Sometimes the distinction between phases can be continuous instead of having a discrete boundary, in this case the matter is considered to be in a supercritical state. When three states meet based on the conditions, it is known as a triple point and since this is invariant, it is a convenient way to define a set of conditions.



The most familiar examples of phases are solids, liquids, and gases.

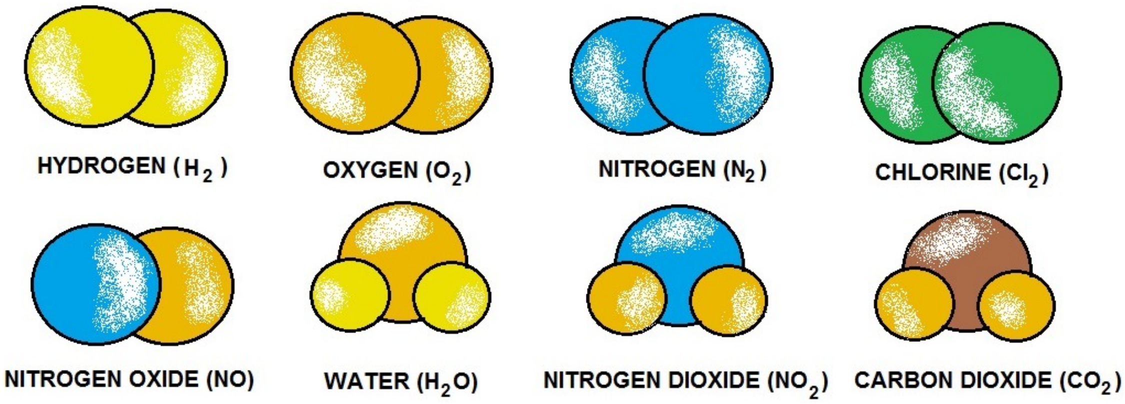
Many substances exhibit multiple solid phases. For example, there are three phases of solid iron (alpha, gamma, and delta) that vary based on temperature and pressure. A principal difference between solid phases is the crystal structure, or arrangement, of the atoms. Another phase commonly encountered in the study of chemistry is the *aqueous* phase, which is the state of substances dissolved in aqueous solution (that is, in water).

Less familiar phases include plasmas, Bose–Einstein condensates and fermionic condensates and the paramagnetic and ferromagnetic phases of magnetic materials. While most familiar phases deal with three-dimensional systems, it is also possible to define analogs in two-dimensional systems, which has received attention for its relevance to systems in biology.

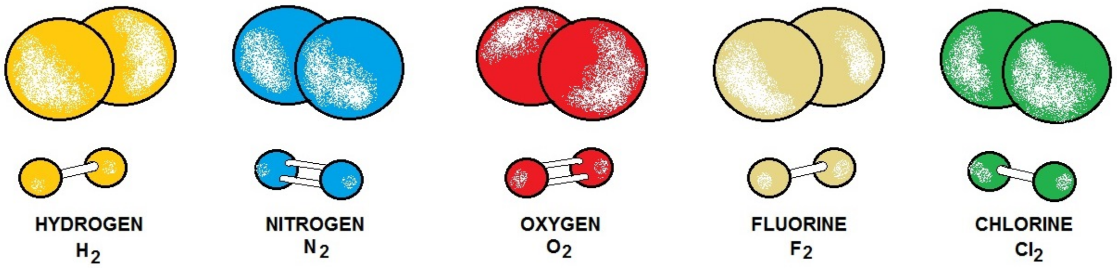


TRIPLE AND CRITICAL POINTS OF A SUBSTANCE

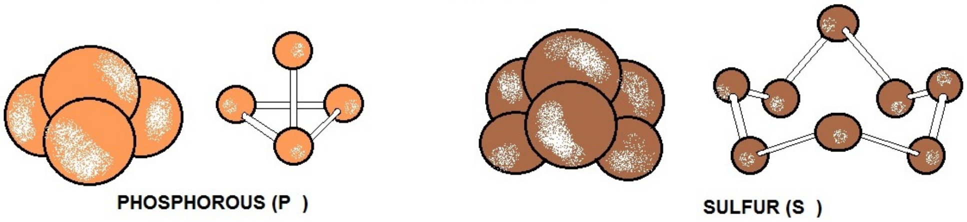
Bonding



Atoms sticking together in molecules or crystals are said to be bonded with one another. A chemical bond may be visualized as the multipole balance between the positive charges in the nuclei and the negative charges oscillating about them. More than simple attraction and repulsion, the energies and distributions characterize the availability of an electron to bond to another atom.



ELEMENTS THAT EXIST AS DIATOMIC MOLECULES

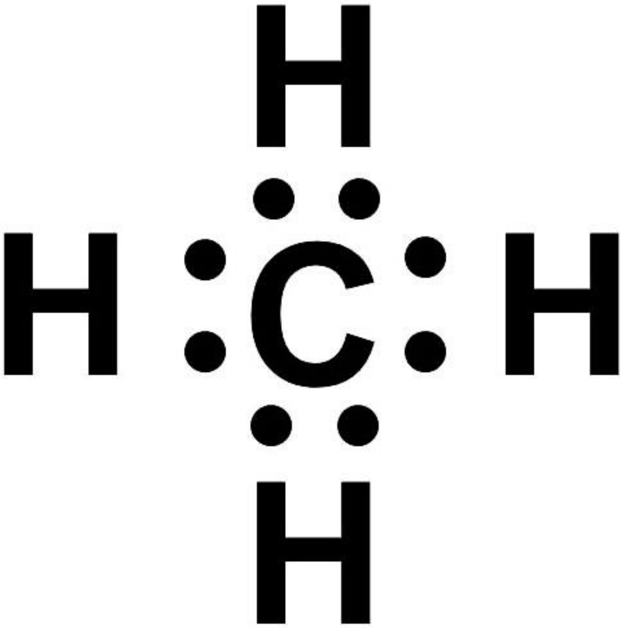


ELEMENTS THAT EXIST AS POLYATOMIC MOLECULES

A chemical bond can be a covalent bond, an ionic bond, a hydrogen bond or just because of Van der Waals force. Each of these kinds of bonds is ascribed to some potential. These potentials create the interactions which hold atoms together in molecules or crystals. In many simple compounds, valence bond theory, the Valence Shell Electron Pair Repulsion model (VSEPR), and the concept of oxidation number can be used to explain molecular structure and composition.

An ionic bond is formed when a metal loses one or more of its electrons, becoming a positively charged cation, and the electrons are then gained by the non-metal atom, becoming a negatively charged anion.

The two oppositely charged ions attract one another, and the ionic bond is the electrostatic force of attraction between them. For example, sodium (Na), a metal, loses one electron to become an Na^+ cation while chlorine (Cl), a non-metal, gains this electron to become Cl^-. The ions are held together due to electrostatic attraction, and that compound sodium chloride (NaCl), or common table salt, is formed.



Methane molecule (CH_4)

In the methane molecule (CH_4), the carbon atom shares a pair of valence electrons with each of the four hydrogen atoms. Thus, the octet rule is satisfied for C-atom (it has eight electrons in its valence shell) and the duet rule is satisfied for the H-atoms (they have two electrons in their valence shells).

In a covalent bond, one or more pairs of valence electrons are shared by two atoms: the resulting electrically neutral group of bonded atoms is termed a molecule. Atoms will share valence electrons in such a way as to create a noble gas electron configuration (eight electrons in their outermost shell) for each atom.

Atoms that tend to combine in such a way that they each have eight electrons in their valence shell are said to follow the octet rule. However, some elements like hydrogen and lithium need only two electrons in their outermost shell to attain this stable configuration; these atoms are said to follow the *duet rule*, and in this way they are reaching the electron configuration of the noble gas helium, which has two electrons in its outer shell.

Energy

In the context of chemistry, energy is an attribute of a substance as a consequence of its atomic, molecular or aggregate structure. Since a chemical transformation is accompanied by a change in one or more of these kinds of structures, it is invariably accompanied by an increase or decrease of energy of the substances involved. Some energy is transferred between the surroundings and the reactants of the reaction in the form of heat or light; thus the products of a reaction may have more or less energy than the reactants.

A reaction is said to be exergonic if the final state is lower on the energy scale than the initial state; in the case of endergonic reactions the situation is the reverse. A reaction is said to be exothermic if the reaction releases heat to the surroundings; in the case of endothermic reactions, the reaction absorbs heat from the surroundings.

Chemical reactions are invariably not possible unless the reactants surmount an energy barrier known as the activation energy. The *speed* of a chemical reaction (at given temperature T) is related to the activation energy E, by the Boltzmann's population factor - that is the probability of a molecule to have energy greater than or equal to E at the given temperature T.

$$e^{-E/kT}$$

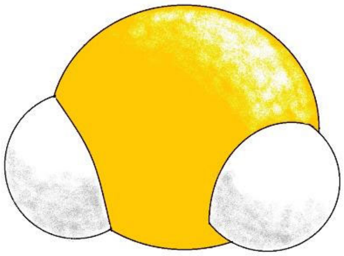
This exponential dependence of a reaction rate on temperature is known as the Arrhenius equation. The activation energy necessary for a chemical reaction to occur can be in the form of heat, light, electricity or mechanical force in the form of ultrasound.

A related concept free energy, which also incorporates entropy considerations, is a very useful means for predicting the feasibility of a reaction and determining the state of equilibrium of a chemical reaction, in chemical thermodynamics. A reaction is feasible only if the total change in the Gibbs free energy is negative, if it is equal to zero the chemical reaction is said to be at equilibrium.

$$\Delta G \leq 0$$

There exist only limited possible states of energy for electrons, atoms and molecules. These are determined by the rules of quantum mechanics, which require quantization of energy of a bound system. The atoms/molecules in a higher energy state are said to be excited. The molecules/atoms of substance in an excited energy state are often much more reactive; that is, more amenable to chemical reactions.

The phase of a substance is invariably determined by its energy and the energy of its surroundings. When the intermolecular forces of a substance are such that the energy of the surroundings is not sufficient to overcome them, it occurs in a more ordered phase like liquid or solid as is the case with water (H_2O); a liquid at room temperature because its molecules are bound by hydrogen bonds. Whereas hydrogen sulfide (H_2S) is a gas at room temperature and standard pressure, as its molecules are bound by weaker dipole-dipole interactions.

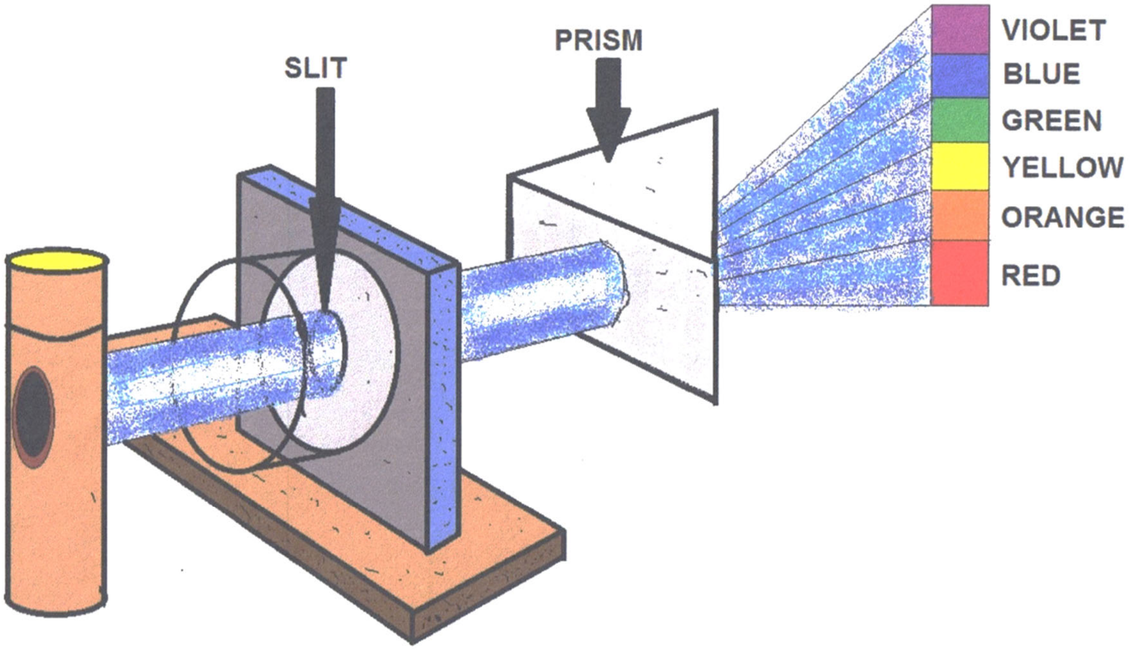


H_2S

The transfer of energy from one chemical substance to another depends on the *size* of energy quanta emitted from one substance.

However, heat energy is often transferred more easily from almost any substance to another because the phonons responsible for vibrational and rotational energy levels in a substance have much less energy than photons invoked for the electronic energy transfer.

Thus, because vibrational and rotational energy levels are more closely spaced than electronic energy levels, heat is more easily transferred between substances relative to light or other forms of electronic energy. For example, ultraviolet electromagnetic radiation is not transferred with as much efficacy from one substance to another as thermal or electrical energy.

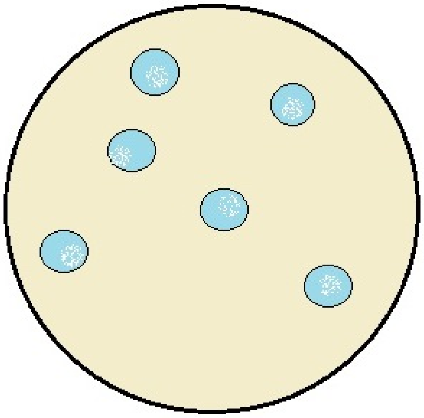


CONTINUOUS EMISSION SPETRUM

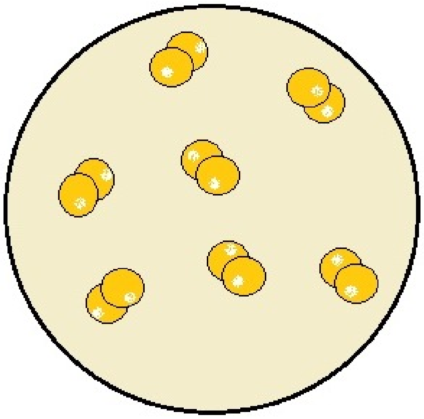
The existence of characteristic energy levels for different chemical substances is useful for their identification by the analysis of spectral lines. Different kinds of spectra are often used in chemical spectroscopy, e.g. IR, microwave, NMR, ESR, etc. Spectroscopy is also used to identify the composition of remote objects - like stars and distant galaxies - by analyzing their radiation spectra.

The term chemical energy is often used to indicate the potential of a chemical substance to undergo a transformation through a chemical reaction or to transform other chemical substances.

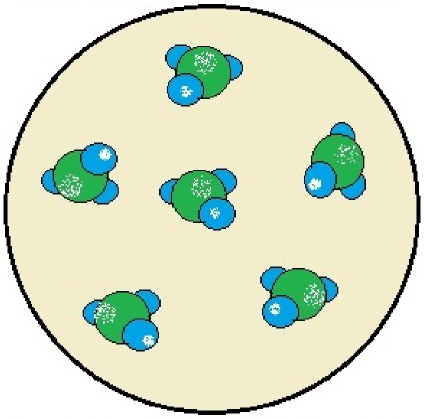
Reaction



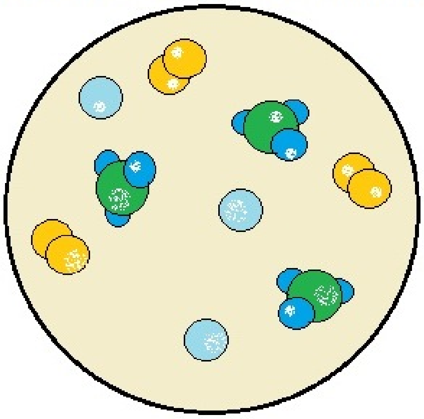
ATOMS OF AN ELEMENT



MOLECULES OF AN ELEMENT



MOLECULES OF A COMPOUND



MIXTURE OF TWO ELEMENTS
AND A COMPOUND

During chemical reactions, bonds between atoms break and form, resulting in different substances with different properties. In a blast furnace, iron oxide, a compound, reacts with carbon monoxide to form iron, one of the chemical elements, and carbon dioxide.

When a chemical substance is transformed as a result of its interaction with another substance or with energy, a chemical reaction is said to have occurred.

A *chemical reaction* is therefore a concept related to the "reaction" of a substance when it comes in close contact with another, whether as a mixture or a solution; exposure to some form of energy, or both. It results in some energy exchange between the constituents of the reaction as well as with the system environment, which may be designed vessels—often laboratory glassware.

Chemical reactions can result in the formation or dissociation of molecules, that is, molecules breaking apart to form two or smaller molecules, or rearrangement of atoms within or across molecules.

Chemical reactions usually involve the making or breaking of chemical bonds. Oxidation, reduction, dissociation, acid-base neutralization and molecular re-arrangement are some of the commonly used kinds of chemical reactions.

A chemical reaction can be symbolically depicted through a chemical equation. While in a non-nuclear chemical reaction the number and kind of atoms on both sides of the equation are equal, for a nuclear reaction this holds true only for the nuclear particles viz. protons and neutrons.

The sequence of steps in which the reorganization of chemical bonds may be taking place in the course of a chemical reaction is called its mechanism. A chemical reaction can be envisioned to take place in a number of steps, each of which may have a different speed. Many reaction intermediates with variable stability can thus be envisaged during the course of a reaction. Reaction mechanisms are proposed to explain the kinetics and the relative product mix of a reaction. Many physical chemists specialize in exploring and proposing the mechanisms of various chemical reactions. Several empirical rules, like the Woodward–Hoffmann rules often come in handy while proposing a mechanism for a chemical reaction.

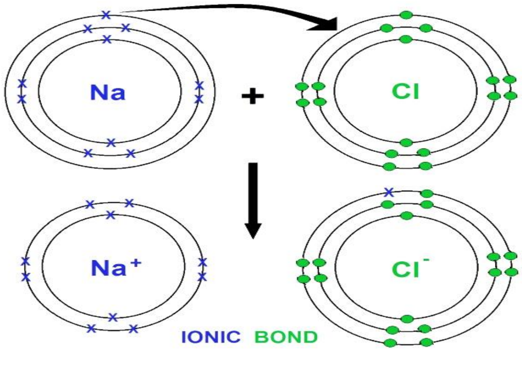
According to the IUPAC gold book, a chemical reaction is "a process that results in the interconversion of chemical species." Accordingly, a chemical reaction may be an elementary reaction or a stepwise reaction. An additional caveat is made, in that this definition includes cases where the interconversion of conformers is experimentally observable. Such detectable chemical reactions normally involve sets of molecular entities as indicated by this definition, but it is often conceptually convenient to use the term also for changes involving single molecular entities (i.e. 'microscopic chemical events').

Ions and Salts

An *ion* is a charged species, an atom or a molecule, that has lost or gained one or more electrons. When an atom loses an electron and thus has more protons than electrons, the atom is a positively-charged ion or cation. When an atom gains an electron and thus has more electrons than protons, the atom is a negatively-charged ion or anion. Cations and anions can form a crystalline lattice of neutral salts, such as the Na^+ and Cl^- ions forming sodium chloride, or NaCl.

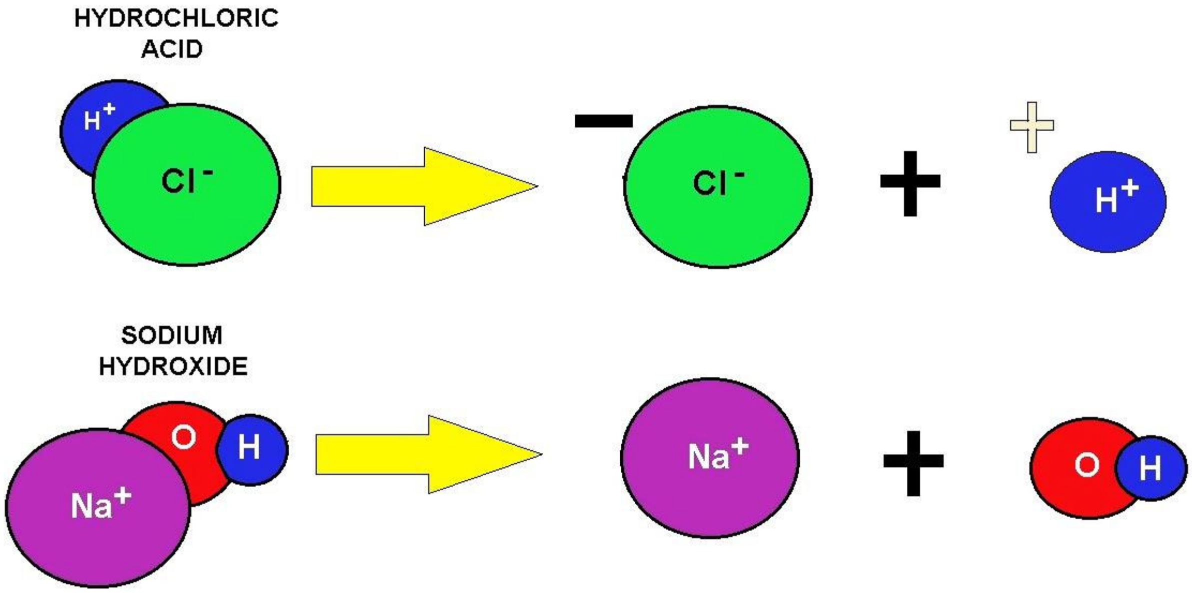
Examples of polyatomic ions that do not split up during acid-base reactions are hydroxide (OH^-) and phosphate (PO_4^{3-}).

Plasma is composed of gaseous matter that has been completely ionized, usually through high temperature.



SODIUM CHLORIDE

Acidity and Basicity



ACIDS VERSES BASES-COMPARISON

A substance can often be classified as an acid or a base. There are several different theories which explain acid-base behavior. The simplest is Arrhenius theory, which states than an acid is a substance that produces hydronium ions when it is dissolved in water, and a base is one that produces hydroxide ions when dissolved in water.

According to Brønsted–Lowry acid–base theory, acids are substances that donate a positive hydrogen ion to another substance in a chemical reaction; by extension, a base is the substance which receives that hydrogen ion.

A third common theory is Lewis acid-base theory, which is based on the formation of new chemical bonds. Lewis theory explains that an acid is a substance which is capable of accepting a pair of electrons from another substance during the process of bond formation, while a base is a substance which can provide a pair of electrons to form a new bond. According to this theory, the crucial things being exchanged are charges. There are several other ways in which a substance may be classified as an acid or a base, as is evident in the history of this concept.

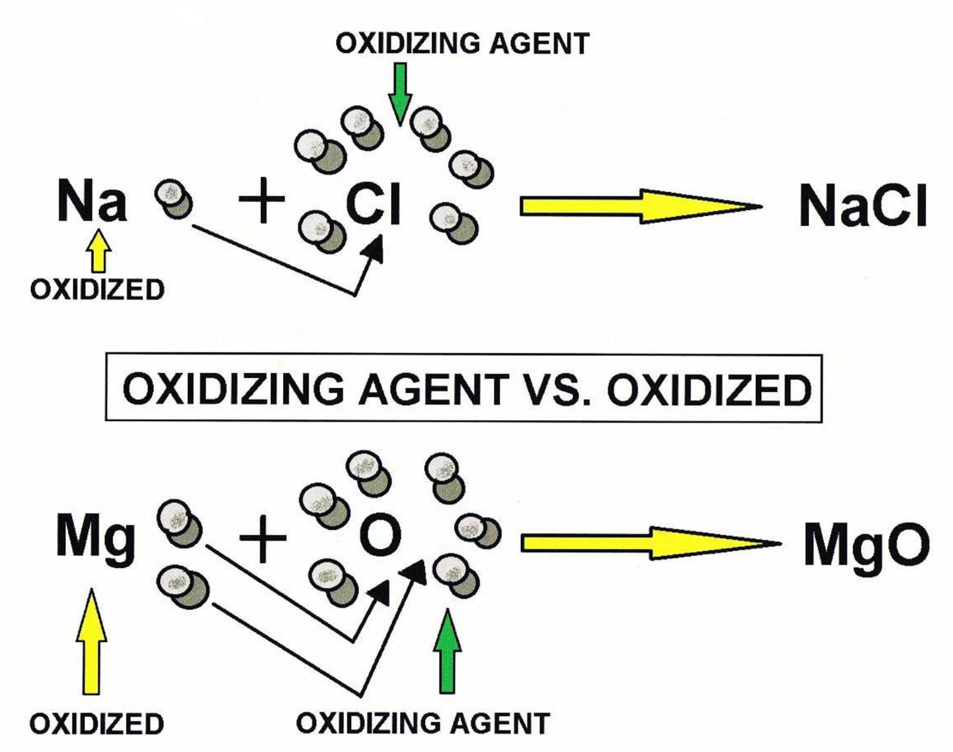
Acid strength is commonly measured by two methods:
One measurement, based on the Arrhenius definition of acidity, is pH, which is a measurement of the hydronium ion concentration in a solution, as expressed on a negative logarithmic scale. Thus, solutions that have a low pH have a high hydronium ion concentration, and can be said to be more acidic.

The other measurement, based on the Brønsted–Lowry definition, is the acid dissociation constant (K_a), which measures the relative ability of a substance to act as an acid under the Brønsted–Lowry definition of an acid. That is, substances with a higher K_a are more likely to donate hydrogen ions in chemical reactions than those with lower K_a values.

Redox

Redox (*red*uction-*ox*idation) reactions include all chemical reactions in which atoms have their oxidation state changed by either gaining electrons (reduction) or losing electrons (oxidation). Substances that have the ability to oxidize other substances are said to be oxidative and are known as oxidizing agents, oxidants or oxidizers.

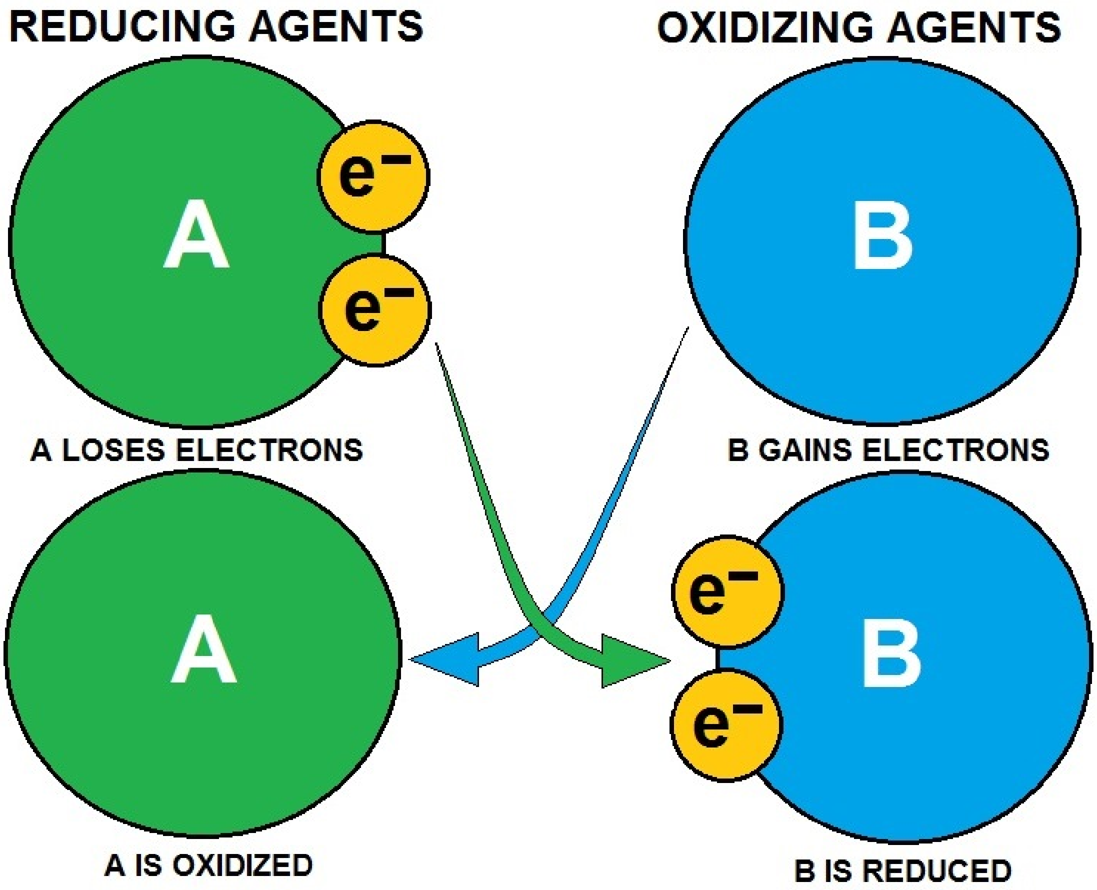
An oxidant removes electrons from another substance. Similarly, substances that have the ability to reduce other substances are said to be reductive and are known as reducing agents, reductants, or reducers.



A reductant transfers electrons to another substance, and is thus oxidized itself. And because it "donates" electrons it is also called an electron donor.

Oxidation and reduction properly refer to a change in oxidation number—the actual transfer of electrons may never occur. Thus, oxidation is better defined as an increase in oxidation number, and reduction as a decrease in oxidation number.

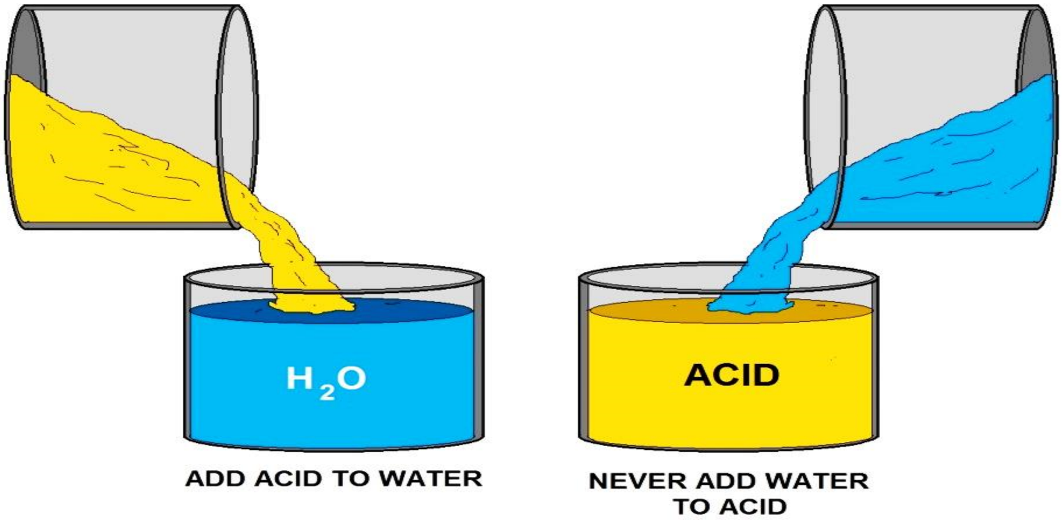
We will cover more on this subject in the next section.

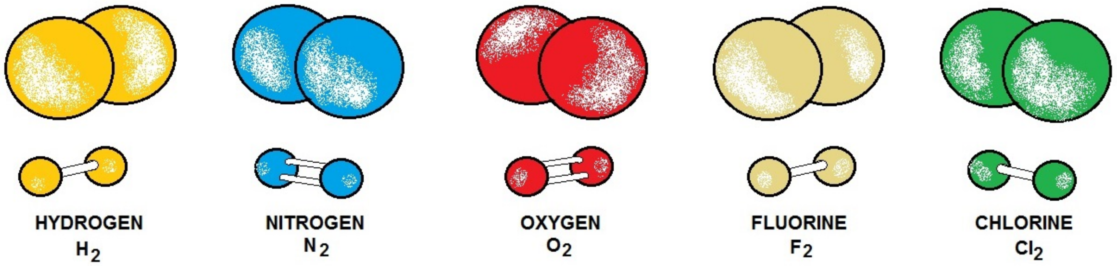


Equilibrium

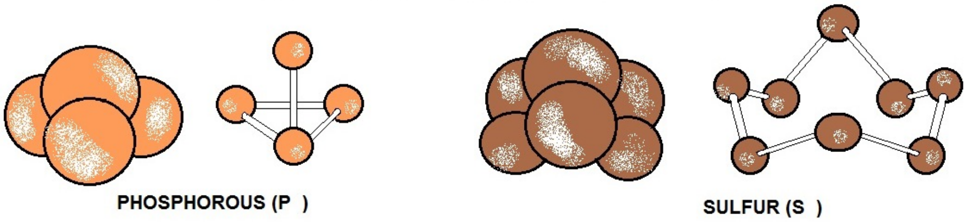
Although the concept of equilibrium is widely used across sciences, in the context of chemistry, it arises whenever a number of different states of the chemical composition are possible, as for example, in a mixture of several chemical compounds that can react with one another, or when a substance can be present in more than one kind of phase.

A system of chemical substances at equilibrium, even though having an unchanging composition, is most often not static; molecules of the substances continue to react with one another thus giving rise to a dynamic equilibrium. Thus the concept describes the state in which the parameters such as chemical composition remains unchanged over time.





ELEMENTS THAT EXIST AS DIATOMIC MOLECULES



ELEMENTS THAT EXIST AS POLYATOMIC MOLECULES

Water (H_2O) is the oxide of hydrogen and the most familiar oxygen compound. Its bulk properties partly result from the interaction of its component atoms, oxygen and hydrogen, with atoms of nearby water molecules. Hydrogen atoms are covalently bonded to oxygen in a water molecule but also have an additional attraction (about 23.3 $kJ \cdot mol^{-1}$ per hydrogen atom) to an adjacent oxygen atom in a separate molecule. These hydrogen bonds between water molecules hold them approximately 15% closer than what would be expected in a simple liquid with just Van der Waals forces.

Oxides, such as iron oxide or rust, Fe_2O_3, form when oxygen combines with other elements

Due to its electronegativity, oxygen forms chemical bonds with almost all other free elements at elevated temperatures to give corresponding oxides. However, some elements, such as iron which oxidizes to iron oxide, or rust, Fe_2O_3, readily oxidize at standard conditions for temperature and pressure (STP).

The surface of metals like aluminum and titanium are oxidized in the presence of air and become coated with a thin film of oxide that passivates the metal and slows further corrosion. So-called noble metals, such as gold and platinum, resist direct chemical combination with oxygen, and substances like gold(III) oxide (Au_2O_3) must be formed by an indirect route.

The alkali metals and alkali earth metals all react spontaneously with oxygen when exposed to dry air to form oxides, and form hydroxides in the presence of oxygen and water. As a result, none of these elements is found in nature as a free metal.

Caesium is so reactive with oxygen that it is used as a getter in vacuum tubes. Although solid magnesium reacts slowly with oxygen at STP, it is capable of burning in air, generating very high temperatures, and its metal powder may form explosive mixtures with air.

Oxygen is present as compounds in the atmosphere in trace quantities in the form of carbon dioxide (CO_2) and oxides of nitrogen (NO_x).

Water Chemistry Review Section 1 Post Quiz

Commonly found Chemical Types
1. Many chemicals are commonly available in_____________. Others are available as reagents - inexpensive, convenient sources of chemicals with a bit of processing.
A. Chemistry laboratory
B. Chemical substance(s)
C. Chemical(s)
D. Forms of energy
E. Pure form
F. None of the Above

2. __________ are often called 'pure' to set them apart from mixtures.
A. Chemical bond(s)
B. Chemical substance(s)
C. Chemical(s)
D. Forms of energy
E. Physical chemistry
F. None of the Above

3. Chemical substances exist as solids, liquids, gases or plasma, and may change between these phases of matter with changes in temperature or pressure. ___________ convert one chemical substance into another.
A. Chemistry laboratory
B. Chemical substance(s)
C. Chemical(s)
D. Chemical reactions
E. Physical chemistry
F. None of the Above

Principles of Modern Chemistry
4. The current model of atomic structure is the quantum mechanical model. _____________starts with the study of elementary particles, atoms, molecules, substances, metals, crystals and other aggregates of matter. This matter can be studied in solid, liquid, or gas states, in isolation or in combination.
A. Nuclear chemistry
B. Neurochemistry
C. Organic chemistry
D. Analytical chemistry
E. Traditional chemistry
F. None of the Above

5. _____________is a transformation of some substances into one or more different substances. The basis of such a chemical transformation is the rearrangement of electrons in the chemical bonds between atoms. It can be symbolically depicted through a chemical equation, which usually involves atoms as subjects.
A. Chemical element(s)
B. An electron
C. Atom
D. A chemical reaction
E. Energy and entropy
F. None of the Above

Matter
6. In chemistry, matter is defined as anything that has rest mass and volume (it takes up space) and is made up of particles. The particles that make up matter have rest mass as well - not all particles have rest mass, such as____________.
A. Chemical element(s)
B. An electron
C. Atom
D. The photon
E. Energy and entropy
F. None of the Above

(S) Means the answer can be plural or singular in nature

Atom

7. The atom is the basic unit of chemistry. It consists of a dense core called the atomic nucleus surrounded by a space called the_____________.

A. Chemical element(s)
B. An electron
C. Atom
D. Photon
E. Electron cloud
F. None of the Above

Element

8. The standard presentation of the ______________ is in the periodic table, which orders elements by atomic number. The periodic table is arranged in groups, or columns, and periods, or rows. The periodic table is useful in identifying periodic trends.

A. Chemical element(s)
B. An electron
C. Atom
D. Photon
E. Energy and entropy
F. None of the Above

Compound

9. A compound is a pure chemical substance composed of more than one element. The properties of a compound bear little similarity to those of its_______________.

A. Chemical bond(s)
B. Elements
C. Chemical(s)
D. Forms of energy
E. Physical chemistry
F. None of the Above

Chemical Compounds

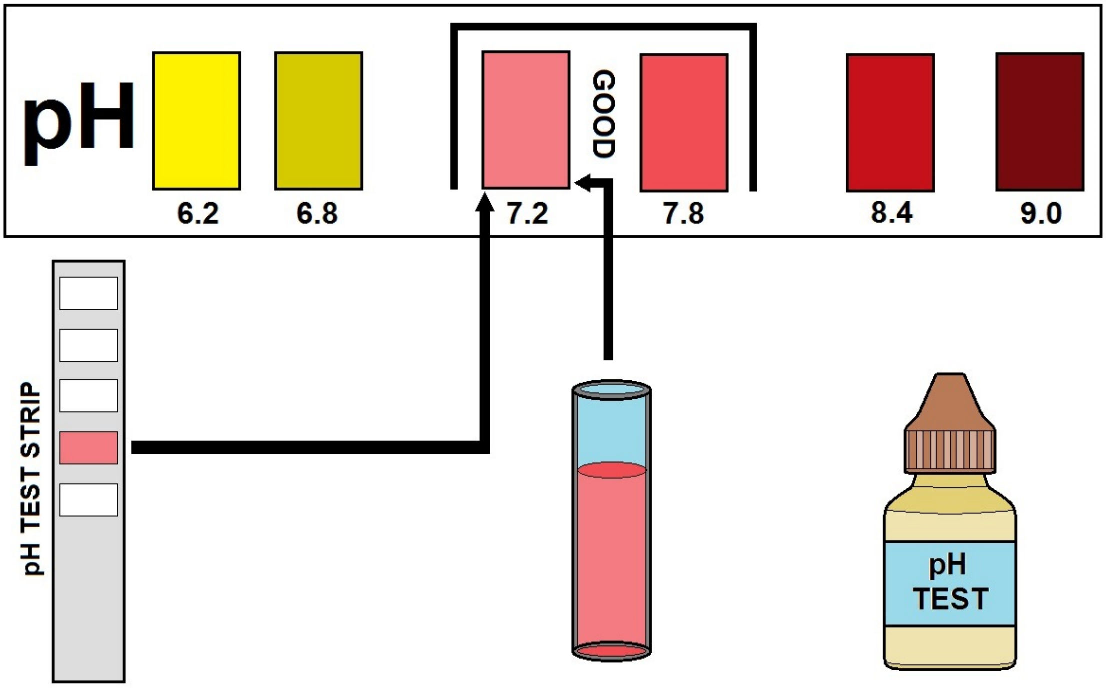
10. A pure chemical compound is a chemical substance that is composed of a particular set of molecules or ions. Two or more elements combined into one substance through a chemical reaction form a chemical compound. All ______________are substances, but not all substances are compounds.

A. Bulk chemical(s)
B. Chemical(s)
C. Mechanical processe(s)
D. Compound(s)
E. A pure chemical compound
F. None of the Above

(S) Means the answer can be plural or singular in nature

Answers are found in the rear before the References.

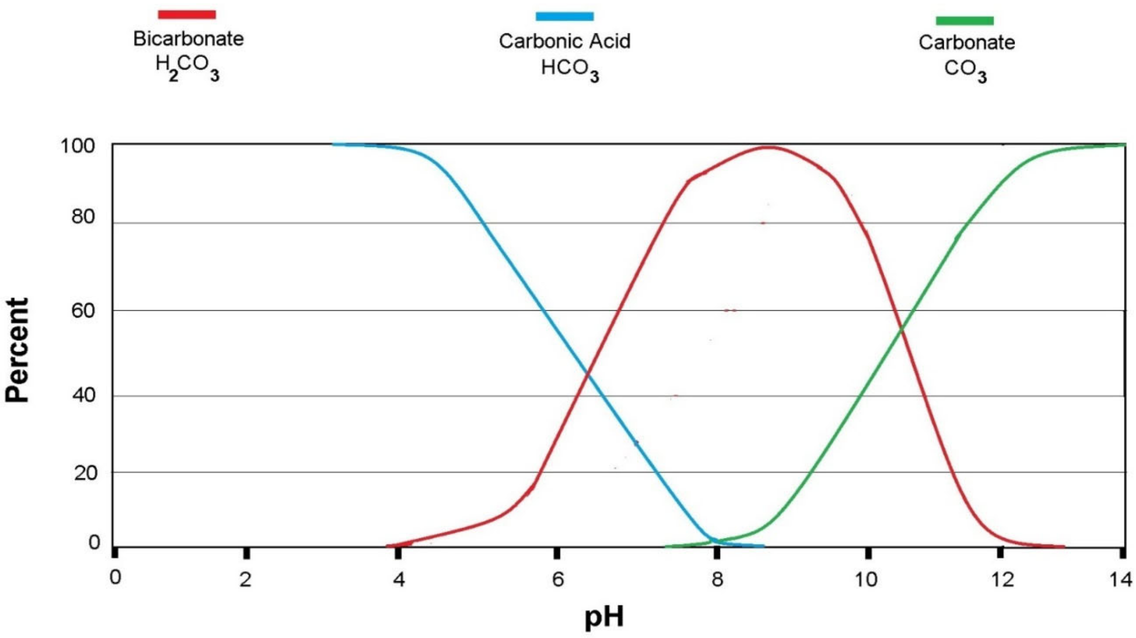
Physical Characteristics of Water -Section 2



TESTING THE pH OF WATER

In this section, the student will understand and explain simple Acidity and Basicity and understand pH and various pH related measurements and procedures.

a. Turbidity
b. Harness
c. TDS
d. Langelier Saturation Index
e. Tastes and Odors
f. Alkalinity
g. Reactions
h. Strong Acids and Bases
i. Total Alkalinity
j. Calculating pH
k. pH Measurement
l. Symbols and Characters

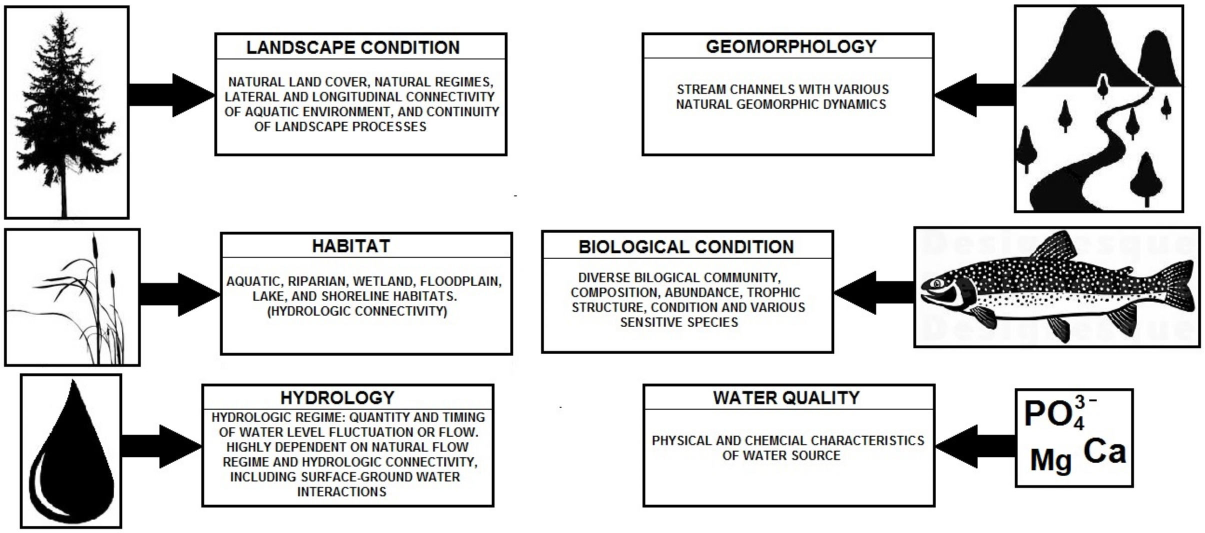


EFFECTS OF ALKALINITY FROM pH

Common pH measurement equipment and probe rinse agent in plastic bottle.

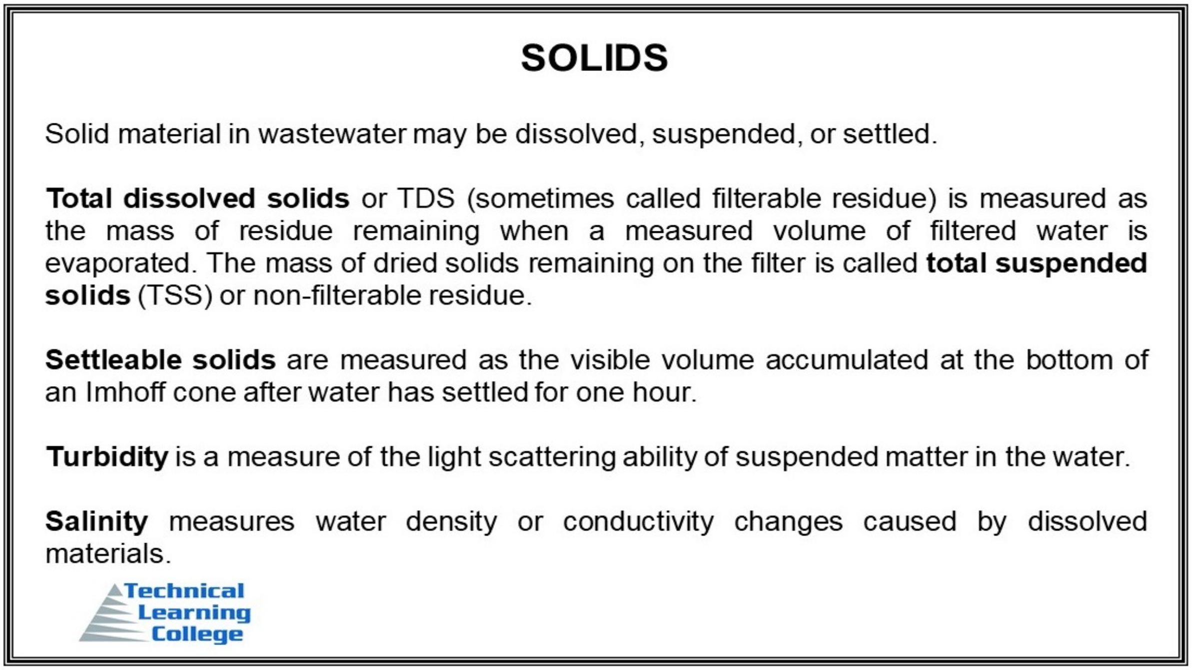
Physical Characteristics of Water

Physical characteristics such as taste, odor, temperature, pH, TDS, and turbidity; are mostly how the consumer judges how well the provider is treating the water.



ATTRIBUTES OF HEALTHY WATERSHED

Physical characteristics are the elements found that are considered alkali, metals, and non-metals such as carbonates, fluoride, sulfides or acids. The consumer relates it to scaling of faucets or staining. Particles and rust come from the distribution system, the gradual breakdown of the lining of concrete or iron water pipes (mains) or from sediment that has accumulated over the years and is disturbed in some way.



SOLIDS

Solid material in wastewater may be dissolved, suspended, or settled.

Total dissolved solids or TDS (sometimes called filterable residue) is measured as the mass of residue remaining when a measured volume of filtered water is evaporated. The mass of dried solids remaining on the filter is called **total suspended solids** (TSS) or non-filterable residue.

Settleable solids are measured as the visible volume accumulated at the bottom of an Imhoff cone after water has settled for one hour.

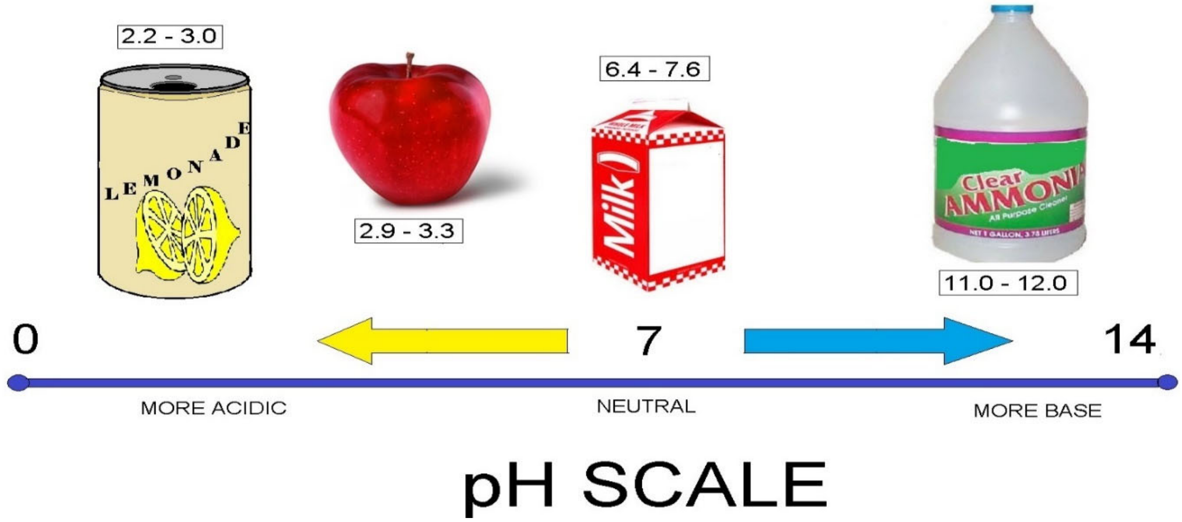
Turbidity is a measure of the light scattering ability of suspended matter in the water.

Salinity measures water density or conductivity changes caused by dissolved materials.

Total Dissolved Solids (TDS) is not a primary pollutant; it is an indicator of aesthetic water characteristics such as hardness and an indication of an assortment of chemical contaminants which might be present, such as Arsenic. We will cover this in a few more pages.

pH is the negative logarithm of the hydrogen ion concentration, [H^+], a measure of the degree to which a solution is acidic or alkaline. An acid is a substance that can give up a hydrogen ion (H^+); a base is a substance that can accept H^+.

The more acidic a solution the greater the hydrogen ion concentration and the lower the pH; a pH of 7.0 indicates neutrality, a pH of less than 7 indicates acidity, and a pH of more than 7 indicates alkalinity. We will cover this subject further in the Water Analysis/Laboratory Section.



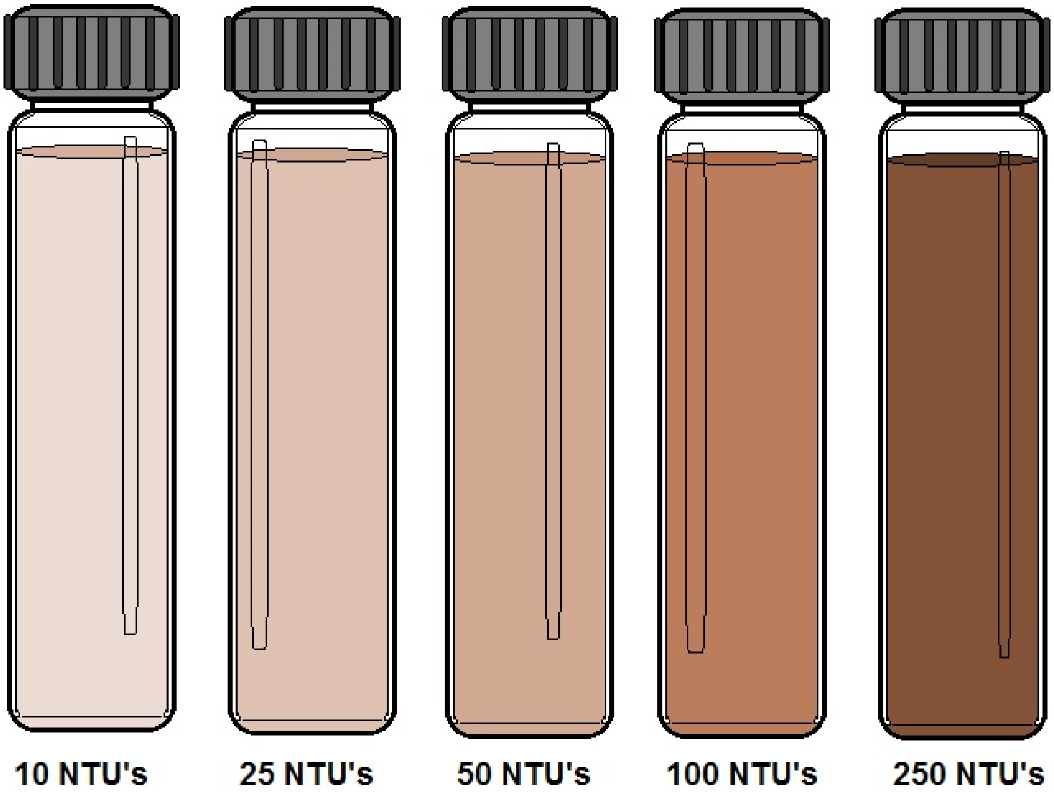
Alkalinity

Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. The measured value may vary significantly with the end-point pH used. Alkalinity is a measure of an aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known.

Alkalinity is significant in many uses and treatments of natural waters and wastewaters. Because the alkalinity of many surface waters is primarily a function of carbonate, bicarbonate, and hydroxide content, it is taken as an indication of the concentration of these constituents. The measured values also may include contributions from borates, phosphates, silicates or other bases if these are present.

Alkalinity Measurements

Alkalinity in excess of alkaline earth metal concentrations is significant in determining the suitability of water for irrigation. Alkalinity measurements are used in the interpretation and control of water and wastewater treatment processes



TURBIDITY SAMPLES IN NTU's (Neophelometric Turbidity Unit)

Turbidity Introduction

One physical characteristic of water is turbidity. A measure of the cloudiness of water caused by suspended particles. The cloudy appearance of water caused by the presence of tiny particles. High levels of turbidity may interfere with proper water treatment and monitoring. If high quality raw water is low in turbidity, there will be a reduction in water treatment costs. Turbidity is undesirable because it causes health hazards.

The turbidity in natural surface waters is composed of a large number of sizes of particles. The sizes of particles can be changing constantly, depending on precipitation and manmade factors.

When heavy rains occur, runoff into streams, rivers, and reservoirs occurs, causing turbidity levels to increase. In most cases, the particle sizes are relatively large and settle relatively quickly in both the water treatment plant and the source of supply. However, in some instances, fine, colloidal material may be present in the supply, which may cause some difficulty in the coagulation process.

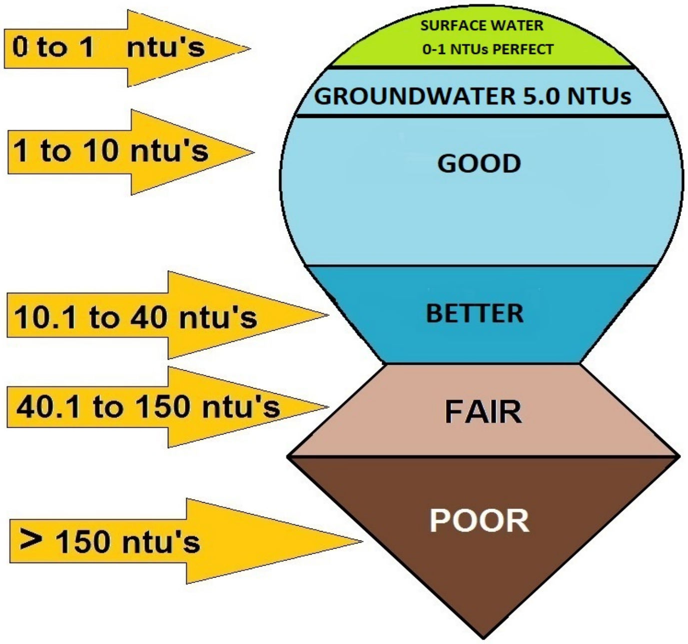
Generally, higher turbidity levels require higher coagulant dosages. However, seldom is the relationship between turbidity level and coagulant dosage linear. Usually, the additional coagulant required is relatively small when turbidities are much higher than normal due to higher collision probabilities of the colloids during high turbidities.

Conversely, low turbidity waters can be very difficult to coagulate due to the difficulty in inducing collision between the colloids.

In this instance, floc formation is poor, and much of the turbidity is carried directly to the filters. Organic colloids may be present in a water supply due to pollution, and these colloids can be difficult to remove in the coagulation process. In this situation, higher coagulant dosages are generally required.

Turbidity MCL

An MCL for turbidity established by the EPA because turbidity interferes with disinfection. This characteristic of water changes the most rapidly after a heavy rainfall. The following conditions may cause an inaccurate measure of turbidity; the temperature variation of a sample, a scratched or unclean sample tube in the nephelometer and selecting an incorrect wavelength of a light path.



TURBIDITY PARAMETERS (NTU) FOR WATER QUALITY

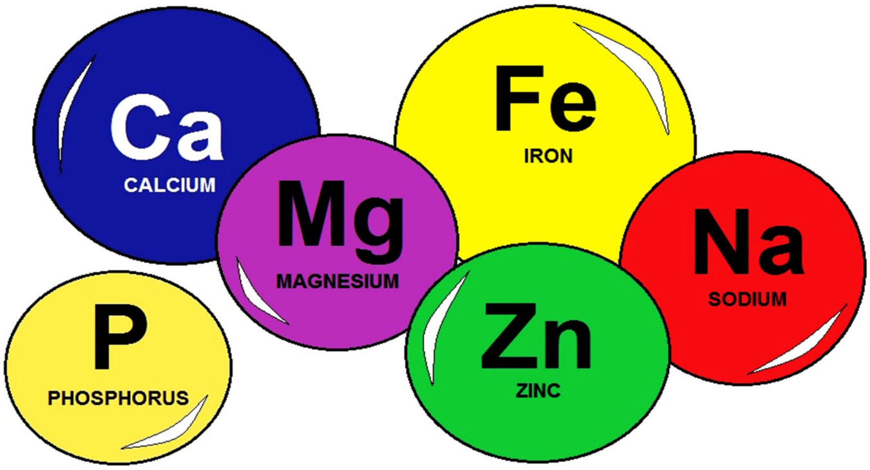
Surface Water System Compliance Information
(Depends on Systems and Rule)

- 0.34 NTU in 95% of samples, never to exceed 1.0 NTU spike
- Sample turbidity at each individual filter effluent
- Sample the combined filter turbidity at the clear well
- (Groundwater turbidity ≤ 5.0 NTU allowed)

Turbidity Key

- Turbidity can also be measured in ppm (parts per million) and its size is measured in microns. Turbidity can be particles in the water consisting of finely divided solids, larger than molecules, but not visible by the naked eye; ranging in size from .001 to .150mm (1 to 150 microns).

- 0.34 NTU in 95% of surface water samples, never to exceed 1.0 NTU spike



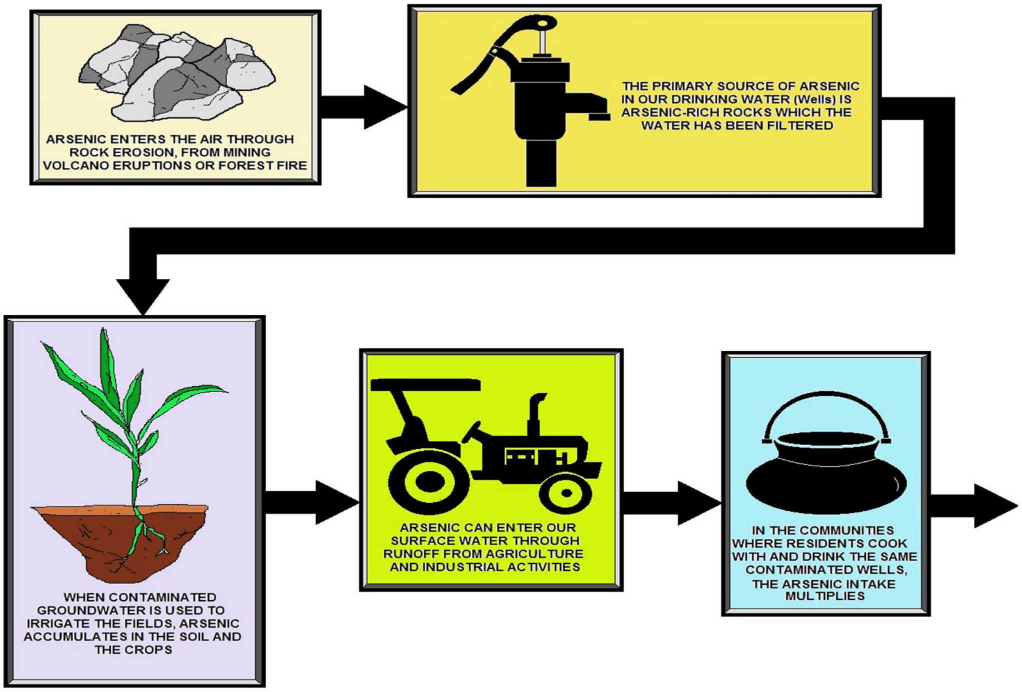
EXAMPLES OF TDS
(Total Dissolved Solids)
FOUND IN WATER SOURCES

CAN BE FROM AGRICULTURE OR URBAN RUNOFF, WHICH CARRY EXCESS MINERALS INTO THE WATER SOURCE

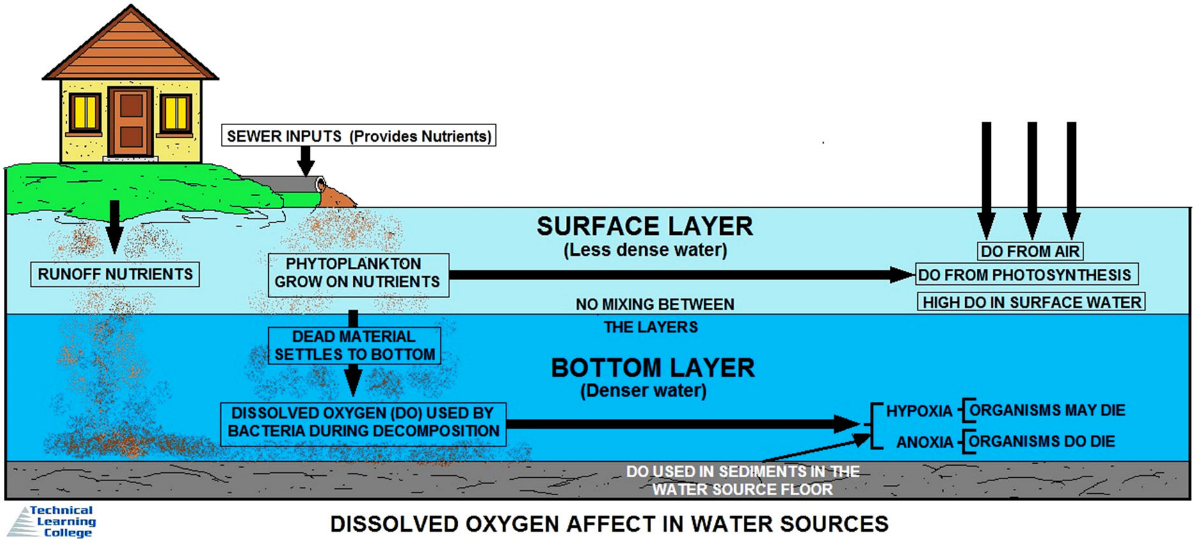
MINERAL SPRINGS CONTAIN HIGH LEVELS OF TDS BECAUSE THE ROCKS WHICH THE WATER SOURCE FLOWS THROUGH HAVE A HIGH SALT CONTENT

MINERALS THAT AFFECT THE QUALITY OF WATER SOURCE

Lead does not usually occur naturally in water supplies but is derived from lead distribution and domestic pipework and fittings. Water suppliers (distribution systems) have removed most of the original lead piping from the mains distribution system, however many older properties still have lead service pipes and internal lead pipework. The pipework (including the service pipe) within the boundary of the property is the responsibility of the owner of the property, not the water supplier.



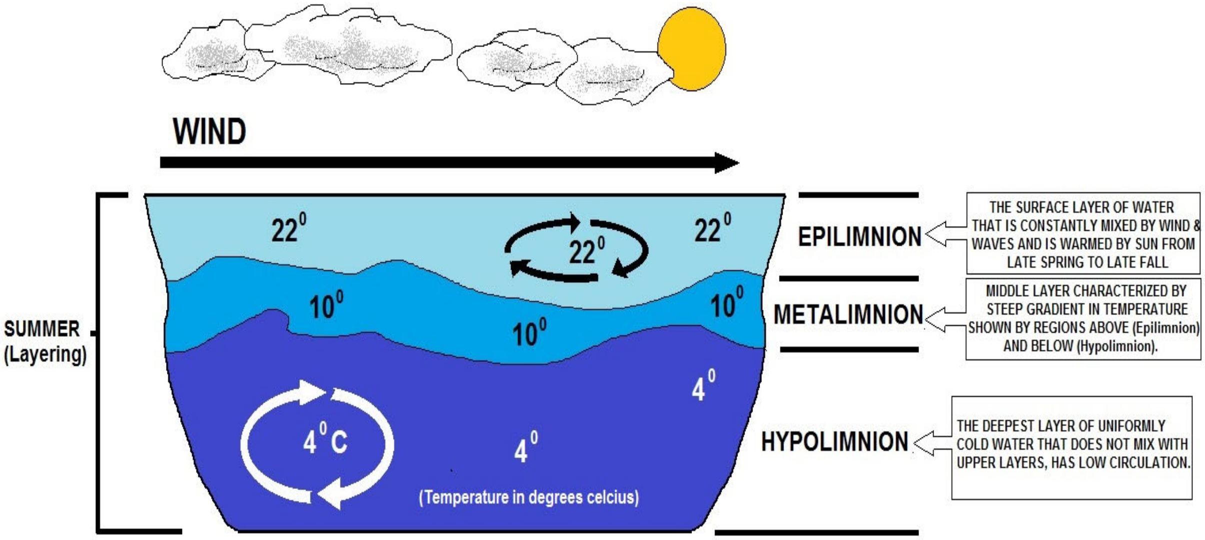
ARSENIC IN DRINKING WATER



DISSOLVED OXYGEN AFFECT IN WATER SOURCES

Dissolved Oxygen

The level of dissolved oxygen in natural waters is often a direct indication of quality, since aquatic plants produce oxygen, while microorganisms generally consume it as they feed on pollutants. At low temperatures the solubility of oxygen is increased, so that in winter, concentrations as high as 20 ppm may be found in natural waters; during summer, saturation levels can be as low as 4 or 5 ppm. Dissolved oxygen is essential for the support of fish and other aquatic life and aids in the natural decomposition of organic matter.



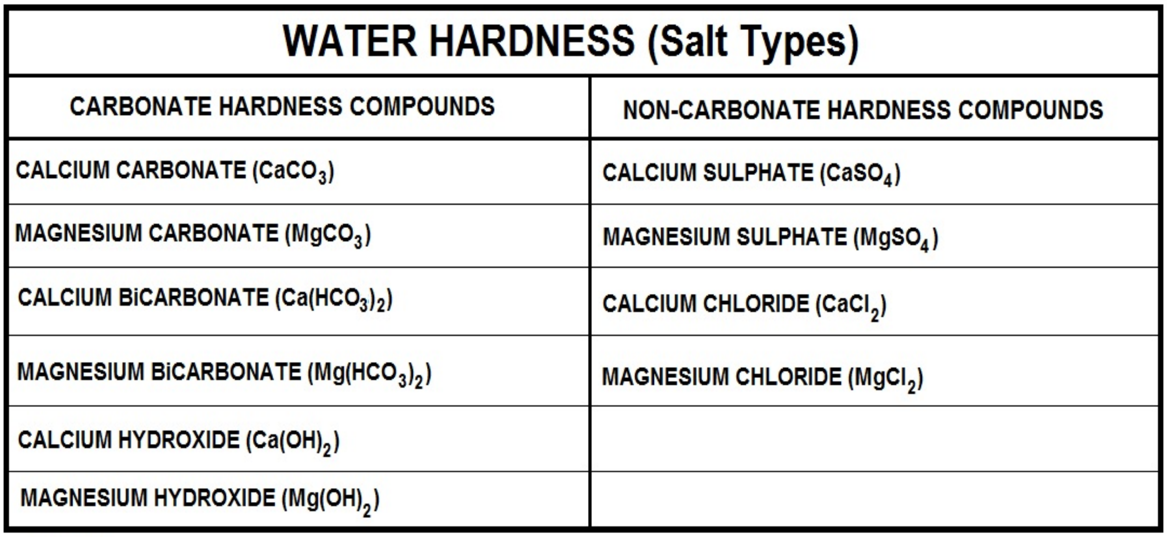
THERMAL STRATIFICATION (Temperature Transition Zones)

Thermal stratification is possible as **water becomes less dense when heated**, meaning water weighs less per unit volume. Therefore, warmer water will be lighter and colder water will be heavier. Due to this, there will always be a level of “self-induced” thermal stratification in a water storage.

Hardness Introduction

Temporary and Permanent

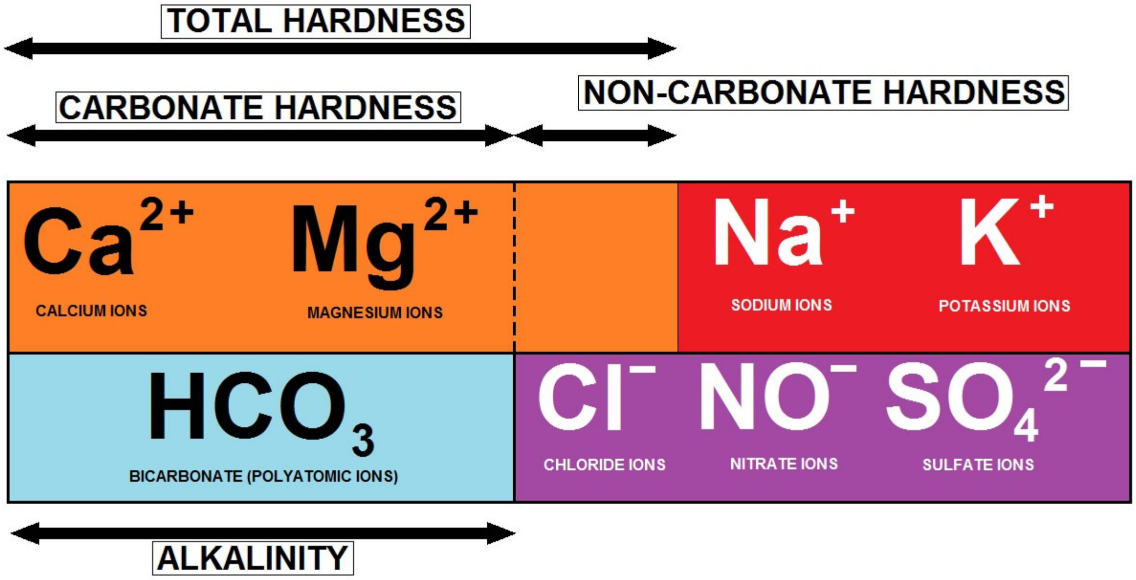
There are two types of hardness: temporary and permanent. Temporary hardness comes out of the water when it is heated and is deposited as scale and “fur” on kettles, coffee makers and taps and appears as a scum or film on tea and coffee. Permanent hardness is unaffected by heating. We will cover this in the advanced water treatment section



WATER HARDNESS (Salt Types)

CARBONATE HARDNESS COMPOUNDS	NON-CARBONATE HARDNESS COMPOUNDS
CALCIUM CARBONATE ($CaCO_3$)	CALCIUM SULPHATE ($CaSO_4$)
MAGNESIUM CARBONATE ($MgCO_3$)	MAGNESIUM SULPHATE ($MgSO_4$)
CALCIUM BiCARBONATE ($Ca(HCO_3)_2$)	CALCIUM CHLORIDE ($CaCl_2$)
MAGNESIUM BiCARBONATE ($Mg(HCO_3)_2$)	MAGNESIUM CHLORIDE ($MgCl_2$)
CALCIUM HYDROXIDE ($Ca(OH)_2$)	
MAGNESIUM HYDROXIDE ($Mg(OH)_2$)	

CAUSES OF HARDNESS THAT AFFECTS WATER QUALITY

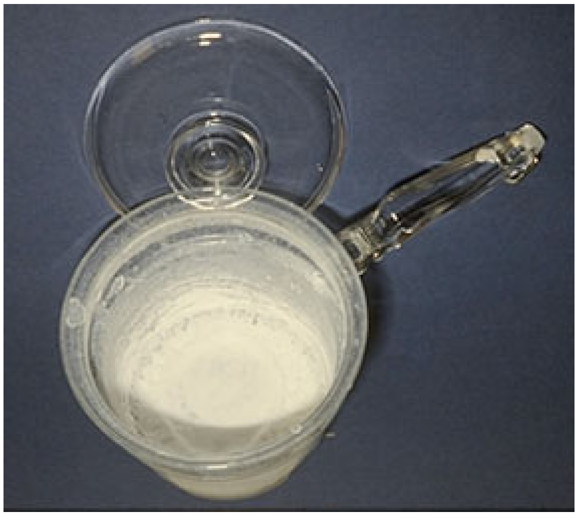


CARBONATE HARDNESS CHART

Objections to Hard Water

Scale Formation

Hard water forms scale, usually calcium carbonate, which causes a variety of problems. Left to dry on the surface of glassware and plumbing fixtures, including showers doors, faucets, and sink tops; hard water leaves unsightly white scale known as water spots. Scale that forms on the inside of water pipes will eventually reduce the flow capacity or possibly block it entirely. Scale that forms within appliances and water meters causes wear on moving parts.



When hard water is heated, scale forms much faster. In particular, when the magnesium hardness is more than about 40 mg/l (as $CaCO_3$), magnesium hydroxide scale will deposit in hot water heaters that are operated at normal temperatures of 140-150^{o}F (60-66^{o}C).

A coating of only 0.04 in. (1 mm) of scale on the heating surfaces of a hot water heater creates an insulation effect that will increase heating costs by about 10 percent.

Effect on Soap

The historical objection to hardness has been its effect on soap. Hardness ions form precipitates with soap, causing unsightly "**curd**," such as the familiar bathtub ring, as well as reduced efficiency in washing and laundering. To counteract these problems, synthetic detergents have been developed and are now used almost exclusively for washing clothes and dishes.

These detergents have additives known as sequestering agents that "**tie up**" the hardness ions so that they cannot form the troublesome precipitates. Although modern detergents counteract many of the problems of hard water, many customers prefer softer water. These customers can install individual softening units or use water from another source, such as a cistern, for washing.

Total Dissolved Solids (TDS)

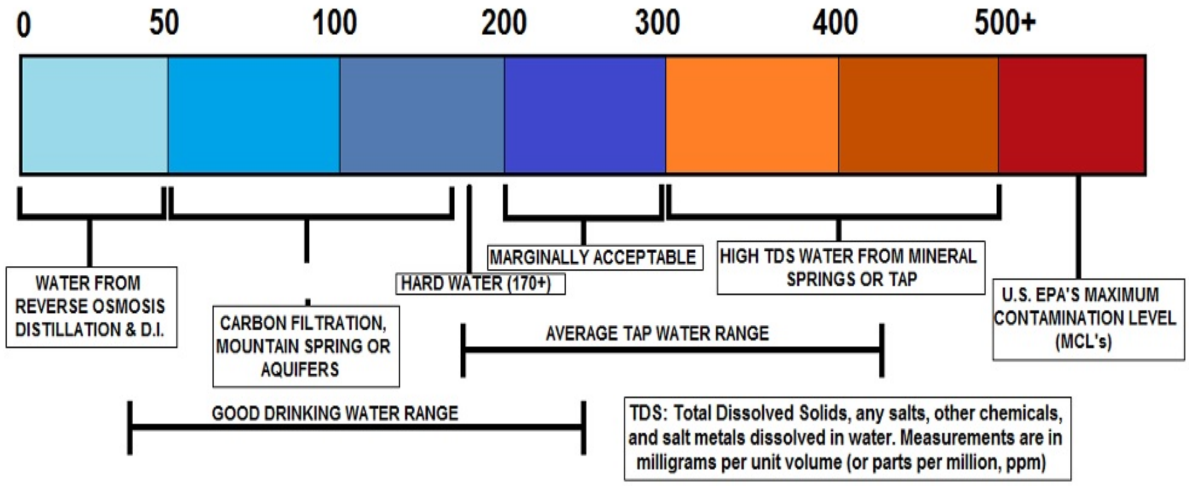
Total dissolved solids (TDS) represents the combined total of all organic and inorganic substances found in drinking water. The total dissolved solids present in water is one of the leading causes of particles and sediments in drinking water, which give water its color, odor, and flavor, and can be a general indicator of water quality.

Organic substances found in drinking water may include:

- Algae
- Bacteria
- Fungi
- Hair
- Pesticides
- Herbicides
- Fertilizers
- Disinfectants
- Pharmaceuticals

Inorganic substances found in drinking water may include:

- Arsenic
- Lead
- Mercury
- Chlorine
- Sodium
- Calcium
- Potassium
- Magnesium
- Fluoride



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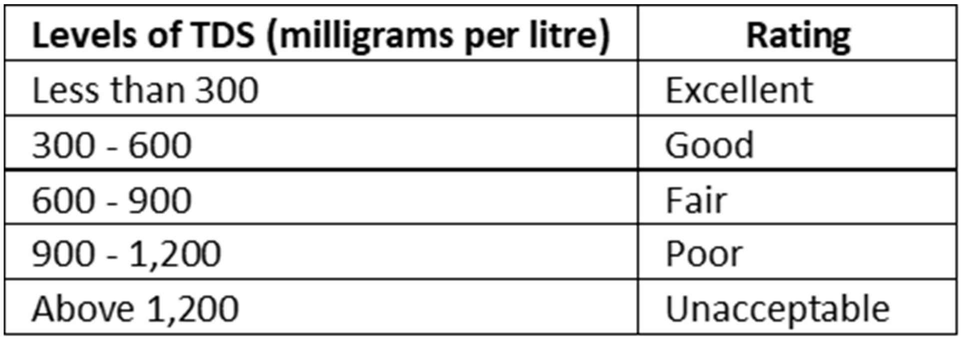
TDS (Total Dissolved Solids) Explained

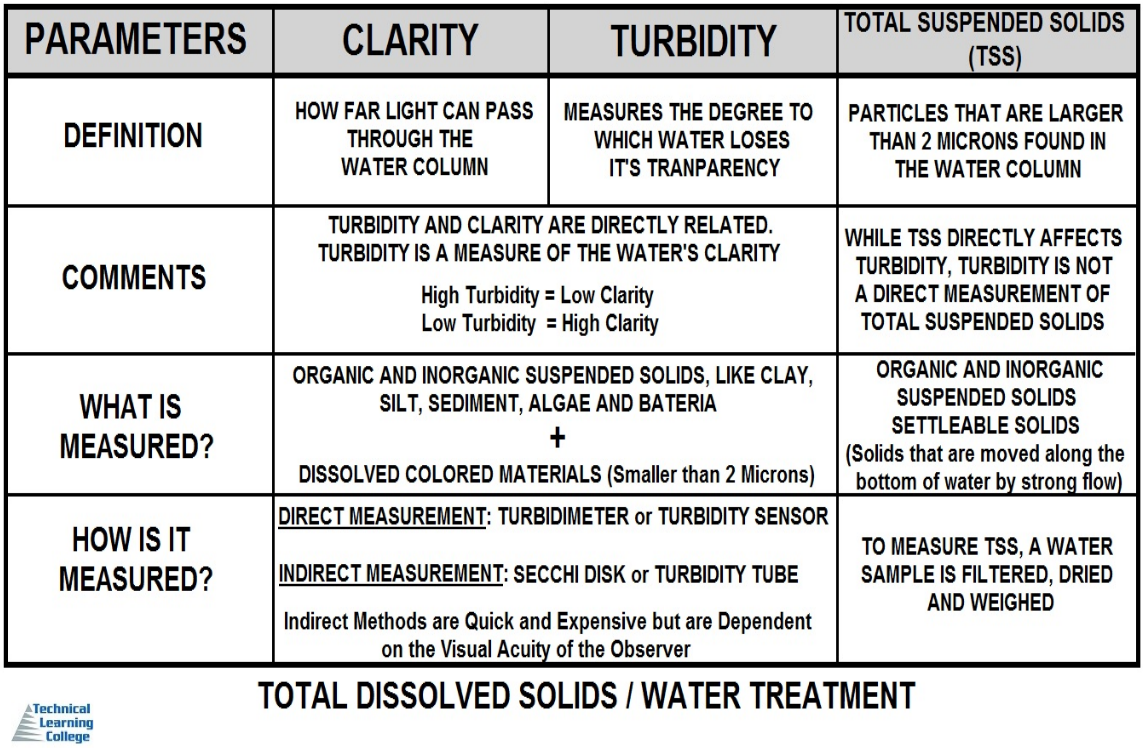
Secondary Standard

TDS is most often measured in parts per million (ppm) or milligrams per liter of water (mg/L). The normal TDS level ranges from 50 ppm to 1,000 ppm. The Environmental Protection Agency (EPA), which is responsible for drinking water regulations in the United States, has identified TDS as a secondary standard, meaning that it is a voluntary guideline. While the United States set legal standards for many harmful substances, TDS, along with other contaminants that cause aesthetic, cosmetic, and technical effects, has only a guideline.



Levels of TDS (milligrams per litre)	Rating
Less than 300	Excellent
300 - 600	Good
600 - 900	Fair
900 - 1,200	Poor
Above 1,200	Unacceptable

Increased concentrations of dissolved solids can also have technical effects. Dissolved solids can produce hard water, which leaves deposits and films on fixtures and can corrode the insides of hot water pipes and boilers.

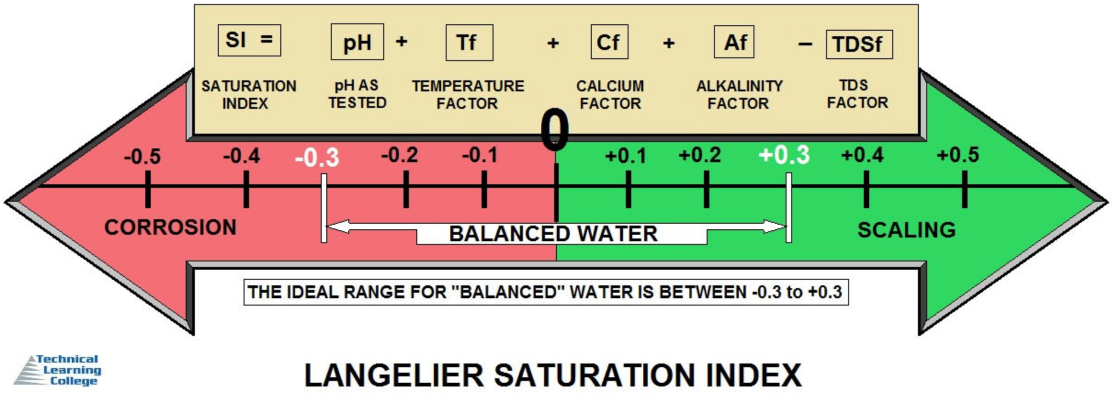


PARAMETERS	CLARITY	TURBIDITY	TOTAL SUSPENDED SOLIDS (TSS)
DEFINITION	HOW FAR LIGHT CAN PASS THROUGH THE WATER COLUMN	MEASURES THE DEGREE TO WHICH WATER LOSES IT'S TRANPARENCY	PARTICLES THAT ARE LARGER THAN 2 MICRONS FOUND IN THE WATER COLUMN
COMMENTS	TURBIDITY AND CLARITY ARE DIRECTLY RELATED. TURBIDITY IS A MEASURE OF THE WATER'S CLARITY High Turbidity = Low Clarity Low Turbidity = High Clarity		WHILE TSS DIRECTLY AFFECTS TURBIDITY, TURBIDITY IS NOT A DIRECT MEASUREMENT OF TOTAL SUSPENDED SOLIDS
WHAT IS MEASURED?	ORGANIC AND INORGANIC SUSPENDED SOLIDS, LIKE CLAY, SILT, SEDIMENT, ALGAE AND BATERIA + DISSOLVED COLORED MATERIALS (Smaller than 2 Microns)		ORGANIC AND INORGANIC SUSPENDED SOLIDS SETTLEABLE SOLIDS (Solids that are moved along the bottom of water by strong flow)
HOW IS IT MEASURED?	DIRECT MEASUREMENT: TURBIDIMETER or TURBIDITY SENSOR INDIRECT MEASUREMENT: SECCHI DISK or TURBIDITY TUBE Indirect Methods are Quick and Expensive but are Dependent on the Visual Acuity of the Observer		TO MEASURE TSS, A WATER SAMPLE IS FILTERED, DRIED AND WEIGHED

TOTAL DISSOLVED SOLIDS / WATER TREATMENT

Langelier Saturation Index

The Langelier Saturation index (LSI) is an equilibrium model derived from the theoretical concept of saturation and provides an indicator of the degree of saturation of water with respect to calcium carbonate. It can be shown that the Langelier saturation index (LSI) approximates the base 10 logarithm of the calcite saturation level. The Langelier saturation level approaches the concept of saturation using pH as a main variable. The LSI can be interpreted as the pH change required to bring water to equilibrium.



Water with a Langelier saturation index of 1.0 is one pH unit above saturation. Reducing the pH by 1 unit will bring the water into equilibrium. This occurs because the portion of total alkalinity present as CO_3^{2-} decreases as the pH decreases, according to the equilibria describing the dissociation of carbonic acid:

$$H_2CO_3 \rightleftarrows HCO_3^- + H^+$$

$$HCO_3^- \rightleftarrows CO_3^{2-} + H^+$$

- If LSI is negative: No potential to scale, the water will dissolve $CaCO_3$
- If LSI is positive: Scale can form and $CaCO_3$ precipitation may occur
- If LSI is close to zero: Borderline scale potential.
- Water quality or changes in temperature, or evaporation could change the index.

The LSI is probably the most widely used indicator of cooling water scale potential. It is purely an equilibrium index and deals only with the thermodynamic driving force for calcium carbonate scale formation and growth. It provides no indication of how much scale or calcium carbonate will actually precipitate to bring water to equilibrium.

It simply indicates the driving force for scale formation and growth in terms of pH as a master variable. In order to calculate the LSI, it is necessary to know the alkalinity (mg/l as $CaCO_3$), the calcium hardness (mg/l Ca^{2+} as $CaCO_3$), the total dissolved solids (mg/l TDS), the actual pH, and the temperature of the water (°C).

If TDS is unknown, but conductivity is, one can estimate mg/L TDS using a conversion table.

LSI is defined as:

$$\mathbf{LSI = pH - pH_s}$$

Where:

pH is the measured water pH

pH_s is the pH at saturation in calcite or calcium carbonate and is defined as:

$$\mathbf{pH_s = (9.3 + A + B) - (C + D)}$$

Where:

$A = (\text{Log}_{10}\ [\text{TDS}] - 1) / 10$

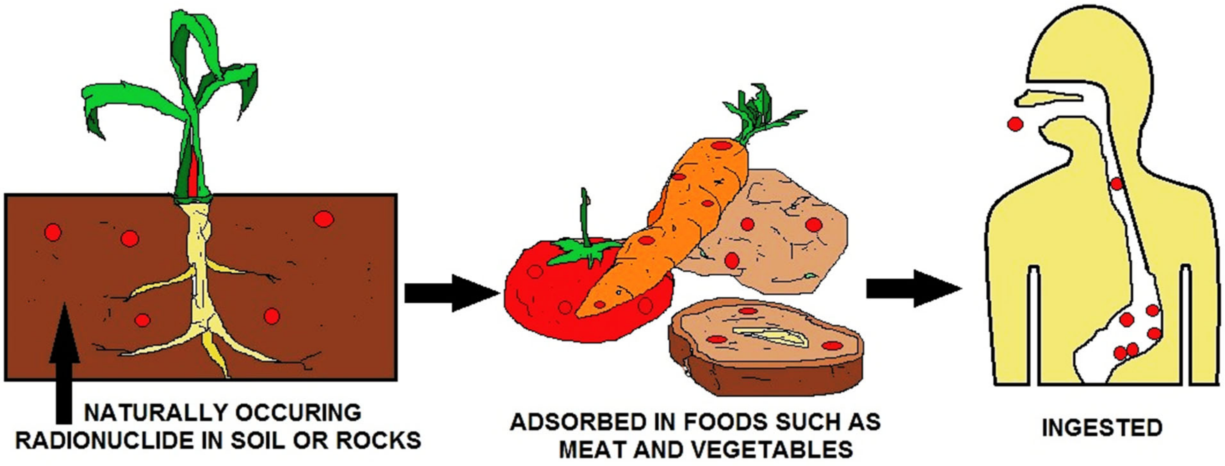
$B = -13.12 \times \text{Log}_{10}\ (^{o}C + 273) + 34.55$

$C = \text{Log}_{10}\ [Ca^{2+} \text{ as } CaCO_3] - 0.4$

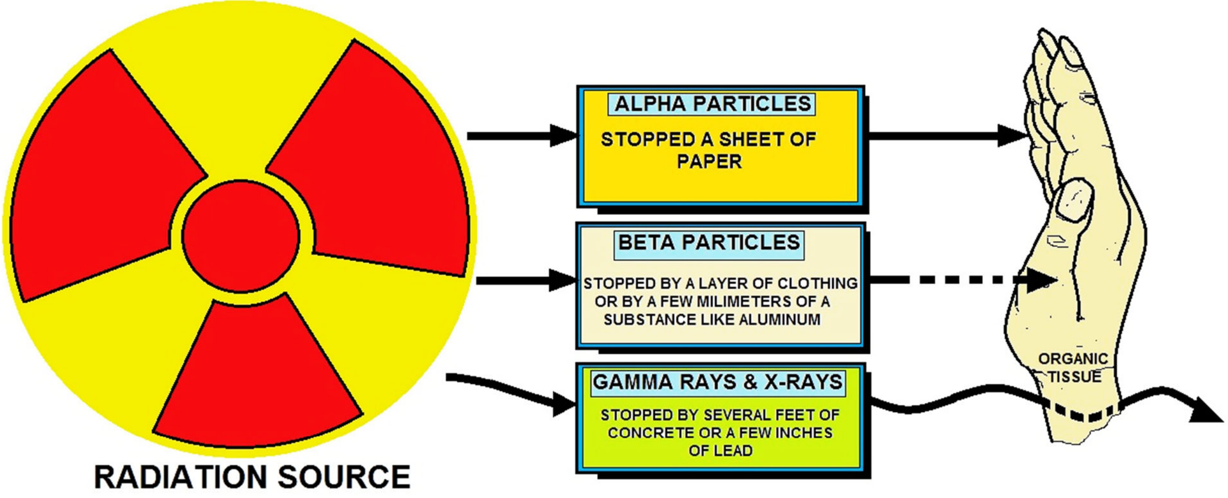
$D = \text{Log}_{10}\ [\text{alkalinity as } CaCO_3]$

Radiological Characteristics

Radiological characteristics are the result of water coming in contact with radioactive materials. This could be associated with atomic energy.

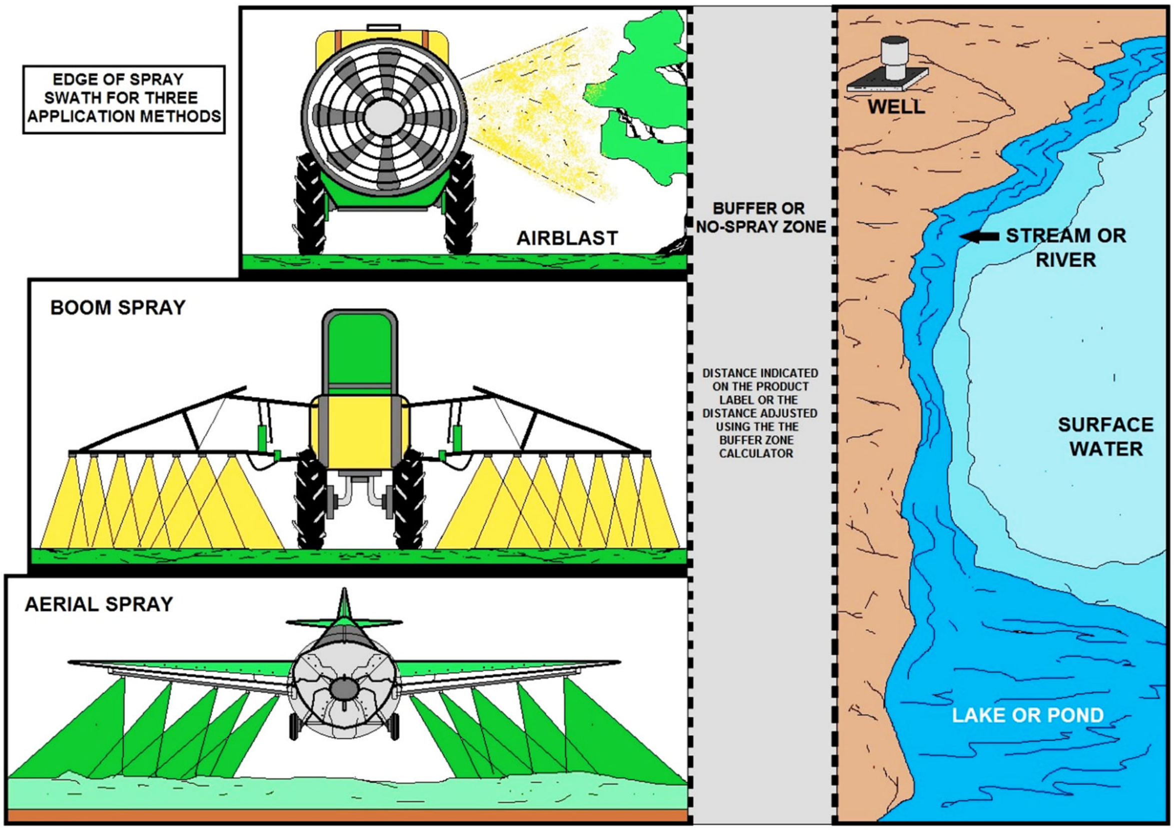


RADIONUCLIDES



PENETRATING POWER OF ALPHA / BETA PARTICLES AND GAMMA RAYS AND X-RAYS

Most of these substances are of natural origin and are picked up as water passes around the water cycle. Some are present due to the treatment processes that are used make the water suitable for drinking and cooking.



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ZONE USED TO AVOID CONTAMINATION OF WATER SOURCES FROM PESTICIDE APPLICATIONS

Insecticides and Herbicides

Insecticides and herbicides (sometimes referred to as pesticides) are widely used in agriculture, industry, leisure facilities and gardens to control weeds and insect pests and may enter the water cycle in many ways. Aluminum salts are usually added during water treatment to remove color and suspended solids and may reduce any residual insecticides in the water.

Biological Characteristics of Water

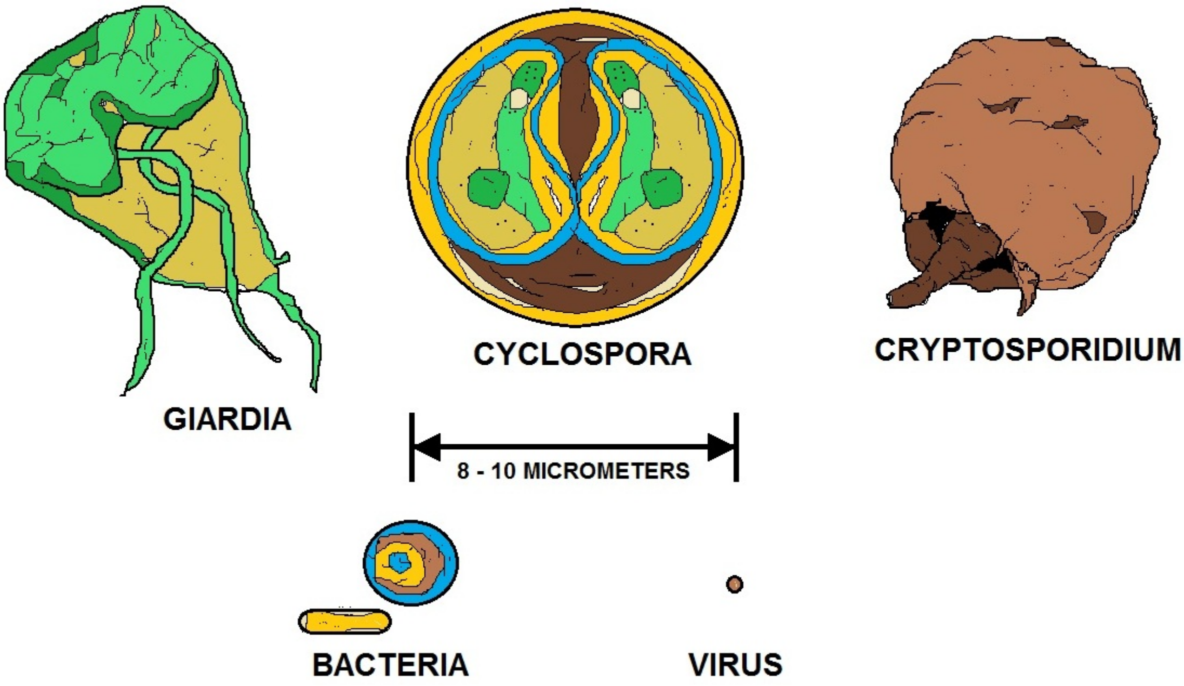
Biological characteristics are the presence of living or dead organisms. Biological characteristics will also interact with the chemical composition of the water. The consumer will become sick or complain about hydrogen sulfide odors, the rotten egg smell. We will cover the Total Coliform Rule in detail in the Water Monitoring Section - Microbiological section and again in the Appendix.

Pathogen Definition

A pathogen is an organism capable of causing disease. Pathogens include parasites, bacteria and viruses.

Biological Parameters

- Biological parameters are important factor that determine quality of drinking water. It is more important than physical and chemical parameters in term of direct effect on human health.
- Some important biological characteristics affecting quality of drinking water includes bacteria, protozoa, virus and algae.



COMPARATIVE SIZES OF PROTOZOAN PARASITES

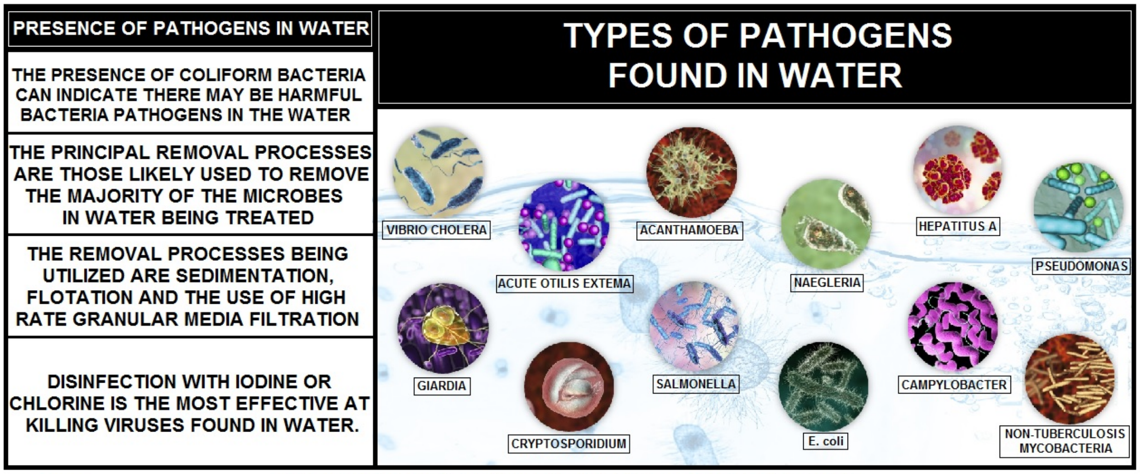
Bacteriological Aspects of Water Pollution

- Human beings and other animals discharge large number of intestinal bacteria into stool and urine. Therefore, bacteria appears in drinking water when water source is contaminated with feces.
- Some intestinal bacteria which are normal flora of intestine are not pathogenic while other bacteria causes serious disease when they are present in drinking water.

- Some pathogenic bacteria includes- *Salmonella, Shigella, Vibrio cholera, Yersinia enterocolitica.*
- These bacteria are only present in drinking water if source of water is contaminated with feces.
- Drinking water must be regularly check to detect intestinal pathogens. However all intestinal pathogens are difficult to cultivate and identify in routine examination. Therefore, presence of pathogenic intestinal bacteria is indirectly checked by detecting intestinal normal flora. Such organism which are routinely checked for quality of water is known as indicator organism for fecal contamination.
- Some indicator organism are fecal coliform (E. *coli*), fecal Streptococci (*Enterococcus*), *Clostridium perfringens*

Cysts

Cysts are associated with the reproductive stages of parasitic microorganisms (protozoans) which can cause acute diarrhea type illnesses; they come from farm animals, wild animals and people. Cysts are very resistant to normal disinfection processes but can be removed by advanced filtration processes installed in water treatment works. Cysts are rarely present in the public water supply. We will cover this area in the water monitoring section.


PRESENCE OF PATHOGENS IN WATER

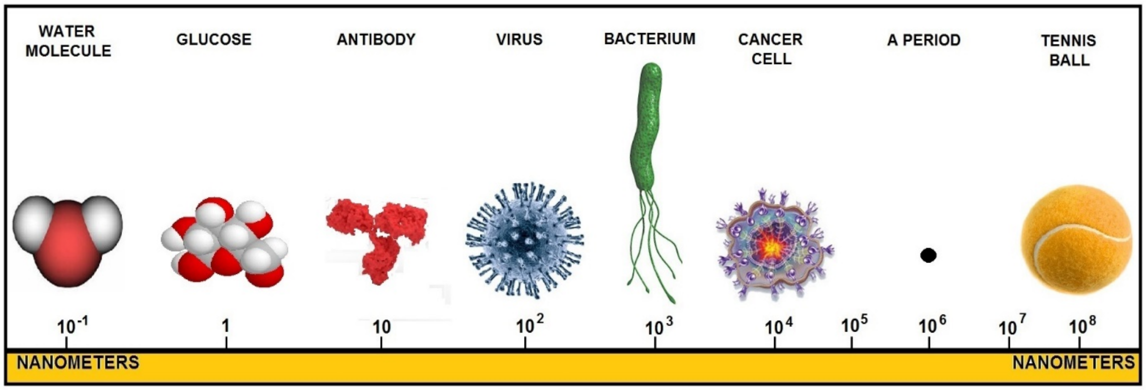
THE PRESENCE OF COLIFORM BACTERIA CAN INDICATE THERE MAY BE HARMFUL BACTERIA PATHOGENS IN THE WATER

THE PRINCIPAL REMOVAL PROCESSES ARE THOSE LIKELY USED TO REMOVE THE MAJORITY OF THE MICROBES IN WATER BEING TREATED

THE REMOVAL PROCESSES BEING UTILIZED ARE SEDIMENTATION, FLOTATION AND THE USE OF HIGH RATE GRANULAR MEDIA FILTRATION

DISINFECTION WITH IODINE OR CHLORINE IS THE MOST EFFECTIVE AT KILLING VIRUSES FOUND IN WATER.

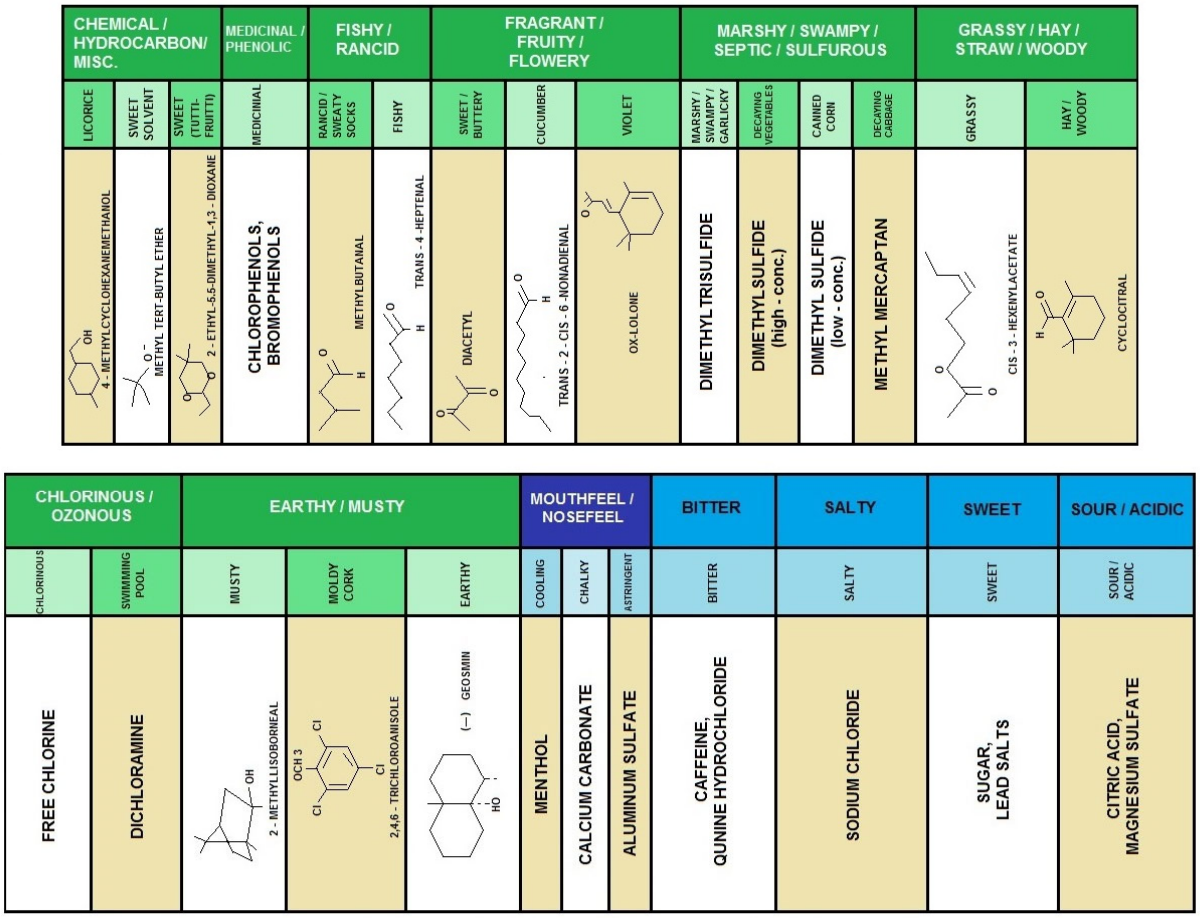
PATHOGENS FOUND IN WATER SUPPLIES



SIZE COMPARISON
HOW SMALL IS SMALL ?

Drinking Water Tastes and Odors

Health concerns are not the only criteria that we use to judge our drinking water. In fact, often the most noticeable qualities that determine whether water is acceptable to consumers are unpleasant taste or odor, staining, poor reaction with soap, or mineral buildup in pipes and plumbing. These problems result from elevated concentrations of "nuisance" constituents.



CHEMICAL / HYDROCARBON/ MISC.			MEDICINAL / PHENOLIC	FISHY / RANCID		FRAGRANT / FRUITY / FLOWERY			MARSHY / SWAMPY / SEPTIC / SULFUROUS				GRASSY / HAY / STRAW / WOODY	
LICORICE	SWEET SOLVENT	SWEET (TUTTI-FRUITTI)	MEDICINAL	RANCID / SWEATY SOCKS	FISHY	SWEET / BUTTERY	CUCUMBER	VIOLET	MARSHY / SWAMPY / GARLICKY	DECAYING VEGETABLES	CANNED CORN	DECAYING CABBAGE	GRASSY	HAY / WOODY
4 - METHYLCYCLOHEXANEMETHANOL	METHYL TERT-BUTYL ETHER	2 - ETHYL-5,5-DIMETHYL-1,3 - DIOXANE	CHLOROPHENOLS, BROMOPHENOLS	METHYLBUTANAL	TRANS - 4 -HEPTENAL	DIACETYL	TRANS - 2 - CIS - 6 -NONADIENAL	OX-LOLONE	DIMETHYL TRISULFIDE	DIMETHYLSULFIDE (high - conc.)	DIMETHYL SULFIDE (low - conc.)	METHYL MERCAPTAN	CIS - 3 - HEXENYLACETATE	CYCLOCITRAL

CHLORINOUS / OZONOUS		EARTHY / MUSTY			MOUTHFEEL / NOSEFEEL			BITTER	SALTY	SWEET	SOUR / ACIDIC
CHLORINOUS	SWIMMING POOL	MUSTY	MOLDY CORK	EARTHY	COOLING	CHALKY	ASTRINGENT	BITTER	SALTY	SWEET	SOUR / ACIDIC
FREE CHLORINE	DICHLORAMINE	2 - METHYLLISOBORNEAL	2,4,6 - TRICHLOROANISOLE	(–) GEOSMIN	MENTHOL	CALCIUM CARBONATE	ALUMINUM SULFATE	CAFFEINE, QUNINE HYDROCHLORIDE	SODIUM CHLORIDE	SUGAR, LEAD SALTS	CITRIC ACID, MAGNESIUM SULFATE

WATER AND TASTE DECODER

Most nuisance constituents occur naturally. These constituents are more likely to occur at nuisance concentrations in groundwater than surface water, because they result from the reaction of groundwater with aquifer rocks and sediments as the water moves underground.

Yellow Water Complaints

Dissolved iron in groundwater can stain laundry, sinks, bathtubs, and toilets a brownish red, and can degrade plumbing and heating systems. Iron also gives drinking water an unpleasant taste, making it undrinkable for many well owners. Manganese often co-occurs with iron and causes many of the same problems.

Hard Water

Hard water—defined by high concentrations of calcium and magnesium—causes water pipes and fixtures to become coated with scale, limits the ability of soaps and detergents to form suds, and can cause premature failure of plumbing and heating fixtures. pH outside of acceptable ranges can give water a metallic taste and can cause corrosion of pipes. A high dissolved solids concentration—a measure of all dissolved substances in water, also referred to as salinity—makes water taste disagreeably salty.

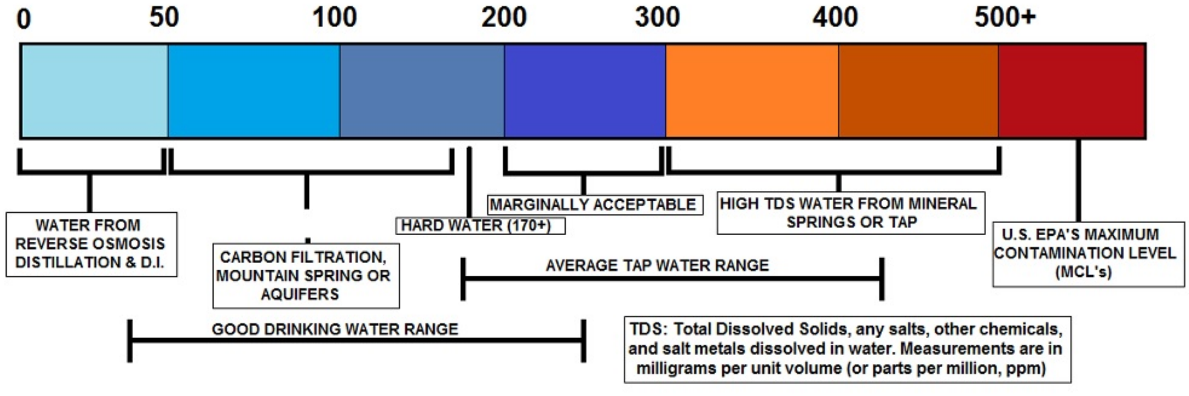
EPA Guidelines for Nuisance Constituents

The EPA recommends limits, called Secondary Maximum Contaminant Levels (SMCLs), for nuisance constituents in public water supplies. The SMCLs are non-health-based, non-enforceable guidelines for concentrations of 15 constituents in drinking water. These guidelines are designed to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color, and odor. These contaminants are not considered to present a risk to human health at the SMCL.

Because they can be smelled, tasted, or seen, nuisance constituents may be more likely to be noticed by consumers than contaminants that actually are a health risk. However, some constituents that have an SMCL also have a higher human-health benchmark. Manganese is one example—the black staining caused by manganese might be just a nuisance or might signal a concentration high enough to be a health risk.

Dissolved Solids

In other situations, the presence of nuisance constituents can signal geochemical conditions that promote high concentrations of other, more harmful contaminants. For example, high concentrations of dissolved solids are considered a nuisance because they cause water to taste salty, but high dissolved solids is not in itself a health concern. However, high dissolved solids can be an indication that there are elevated concentrations of arsenic, uranium, or other trace elements in the groundwater as well. The occurrence of nuisance constituents in drinking water therefore can indicate that testing for a broader range of constituents could be warranted to assess possible risks and to determine options for reducing those risks.



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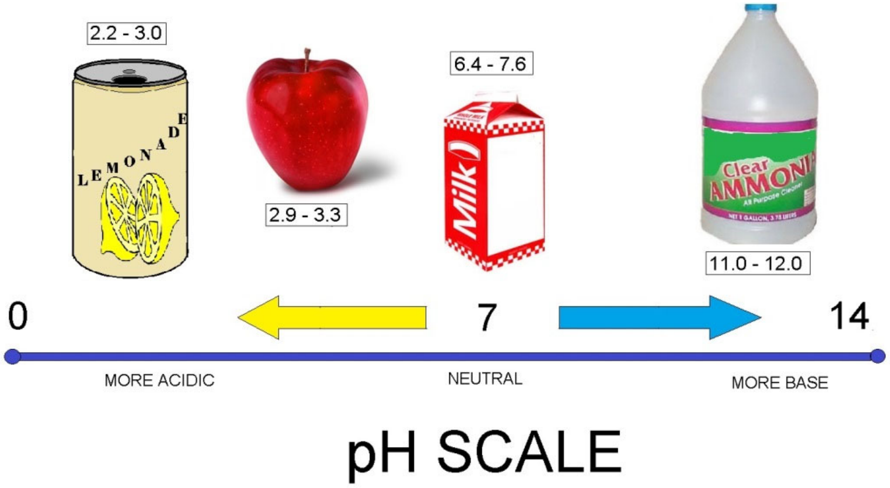
TDS (Total Dissolved Solids) Explained

pH Sub-Section

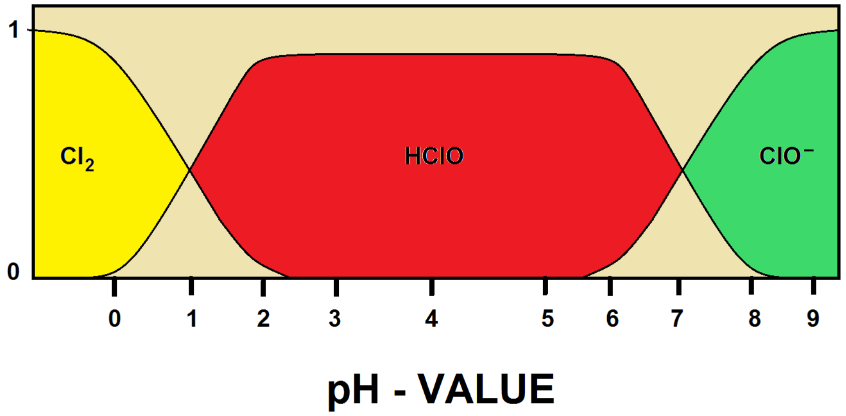


In water and wastewater processes, **pH** is a measure of the acidity or basicity of an aqueous solution. Solutions with a pH greater than 7 are basic or alkaline and solution or samples with a pH less than 7 are said to be acidic. Pure water has a pH very close to 7.

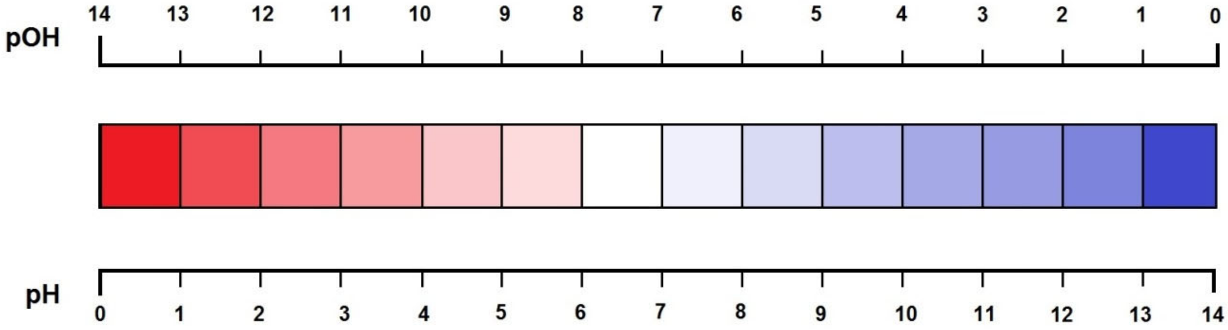
Primary pH standard values are determined using a concentration cell with transference, by measuring the potential difference between a hydrogen electrode and a standard electrode such as the silver chloride electrode. The pH scale is traceable to a set of standard solutions whose pH is established by international agreement.

Measurement of pH for aqueous solutions can be done with a glass electrode and a pH meter, or using indicators like strip test paper.

pH measurements are important in water and wastewater processes (sampling) but also in medicine, biology, chemistry, agriculture, forestry, food science, environmental science, oceanography, civil engineering, chemical engineering, nutrition, water treatment & water purification, and many other applications.



Mathematically, pH is the measurement of hydroxyl ion activity and expressed as the negative logarithm of the activity of the (solvated) hydronium ion, more often expressed as the measure of the hydronium ion concentration.



IN RELATION BETWEEN p(OH) AND p(H) (red= ACIDIC / blue= BASIC)

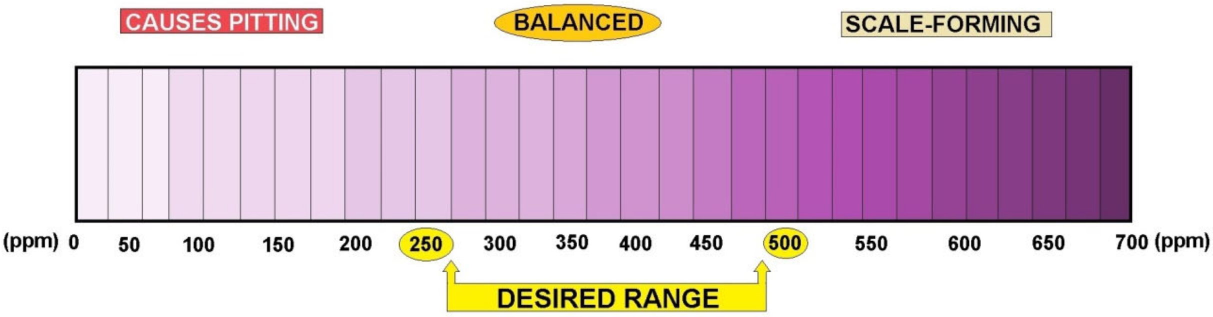
Contents

History

The scientific discovery of the p[H] concept of was first introduced by Danish chemist Søren Peder Lauritz Sørensen at the Carlsberg Laboratory back in 1909 and revised to the modern pH in 1924 to accommodate definitions and measurements in terms of electrochemical cells. In the first papers, the notation had the "H" as a subscript to the lowercase "p", as so: pH.

Alkalinity

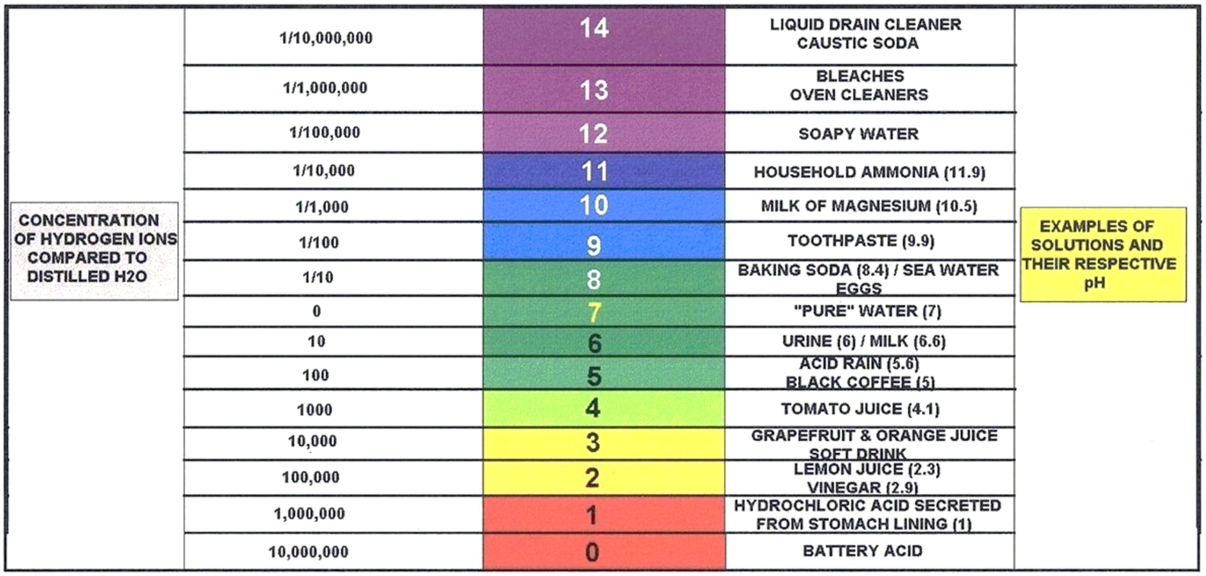
Alkalinity is the quantitative capacity of an aqueous solution to neutralize an acid. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It is one of the best measures of the sensitivity of the stream to acid inputs. There can be long-term changes in the alkalinity of rivers and streams in response to human disturbances.



CALCIUM HARDNESS MEASUREMENT

Reference. Bates, Roger G. Determination of pH: theory and practice. Wiley, 1973.

pH Definition and Measurement



CONCENTRATION OF HYDROGEN IONS COMPARED TO DISTILLED H2O		EXAMPLES OF SOLUTIONS AND THEIR RESPECTIVE pH
1/10,000,000	14	LIQUID DRAIN CLEANER CAUSTIC SODA
1/1,000,000	13	BLEACHES OVEN CLEANERS
1/100,000	12	SOAPY WATER
1/10,000	11	HOUSEHOLD AMMONIA (11.9)
1/1,000	10	MILK OF MAGNESIUM (10.5)
1/100	9	TOOTHPASTE (9.9)
1/10	8	BAKING SODA (8.4) / SEA WATER EGGS
0	7	"PURE" WATER (7)
10	6	URINE (6) / MILK (6.6)
100	5	ACID RAIN (5.6) BLACK COFFEE (5)
1000	4	TOMATO JUICE (4.1)
10,000	3	GRAPEFRUIT & ORANGE JUICE SOFT DRINK
100,000	2	LEMON JUICE (2.3) VINEGAR (2.9)
1,000,000	1	HYDROCHLORIC ACID SECRETED FROM STOMACH LINING (1)
10,000,000	0	BATTERY ACID

pH Scale

Technical Definition of pH

In technical terms, pH is defined as the decimal logarithm of the reciprocal of the hydrogen ion activity, *a*H+, in a solution.

$$pH = -\log_{10}(a_H+) = \log_{10}\left(\frac{1}{aH+}\right)$$

Ion-selective electrodes are often used to measure pH, respond to activity.

In this calculation of electrode potential, *E*, follows the Nernst equation, which, for the hydrogen ion can be written as

$$E = E^0 + \frac{RT}{F}\ln(a_H+) = E^0 - \frac{2.303RT}{F}pH$$

where E is a measured potential, E^0 is the standard electrode potential, R is the gas constant, T is the temperature in kelvin, F is the Faraday constant. For H^+ number of electrons transferred is one. It follows that electrode potential is proportional to pH when pH is defined in terms of activity.

International Standard ISO 31-8 is the standard for the precise measurement of pH as follows: A galvanic cell is set up to measure the electromotive force (EMF) between a reference electrode and an electrode sensitive to the hydrogen ion activity when they are both immersed in the same aqueous solution.

The reference electrode may be a silver chloride electrode or a calomel electrode. The hydrogen-ion selective electrode is a standard hydrogen electrode.

Reference electrode | concentrated solution of KCl || test solution | H_2 | Pt

Firstly, the cell is filled with a solution of known hydrogen ion activity and the emf, E_S, is measured. Then the emf, E_X, of the same cell containing the solution of unknown pH is measured.

$$pH(X) = pH(S) + \frac{E_s - E_x}{z}$$

The difference between the two measured emf values is proportional to pH. This method of calibration avoids the need to know the standard electrode potential. The proportionality

constant, *1/z* is ideally equal to $\frac{1}{2.303RT/F}$ the "Nernstian slope".

If you were to apply this practice the above calculation, a glass electrode is used rather than the cumbersome hydrogen electrode. A combined glass electrode has an in-built reference electrode. It is calibrated against buffer solutions of known hydrogen ion activity. IUPAC has proposed the use of a set of buffer solutions of known H^+ activity.

Two or more buffer solutions should be used in order to accommodate the fact that the "slope" may differ slightly from ideal.

The electrode is first immersed in a standard solution and the reading on a pH meter is adjusted to be equal to the standard buffer's value, to implement the proper calibration. The reading from a second standard buffer solution is then adjusted, using the "slope" control, to be equal to the pH for that solution. Further details, are given in the IUPAC recommendations.

When more than two buffer solutions are used the electrode is calibrated by fitting observed pH values to a straight line with respect to standard buffer values. Commercial standard buffer solutions usually come with information on the value at 25 °C and a correction factor to be applied for other temperatures. The pH scale is logarithmic and pH is a dimensionless quantity.

pH Indicators

Visual comparison of the color of a test solution with a standard color chart provides a means to measure pH accurate to the nearest whole number. Indicators may be used to measure pH, by making use of the fact that their color changes with pH. More precise measurements are possible if the color is measured spectrophotometrically, using a colorimeter of spectrophotometer. Universal indicator consists of a mixture of indicators such that there is a continuous color change from about pH 2 to pH 10. Universal indicator paper is made from absorbent paper that has been impregnated with universal indicator.

pOH

pOH is sometimes used as a measure of the concentration of hydroxide ions, OH^-, or alkalinity. pOH values are derived from pH measurements. The concentration of hydroxide ions in water is related to the concentration of hydrogen ions by

$$[\mathrm{OH}^-] = \frac{K_W}{[\mathrm{H}^+]}$$

where K_W is the self-ionization constant of water. Taking logarithms

$$\mathrm{pOH} = \mathrm{pK_W} - \mathrm{pH}$$

So, at room temperature pOH ≈ 14 − pH. However this relationship is not strictly valid in other circumstances, such as in measurements of soil alkalinity.

Extremes of pH

Measurement of pH below about 2.5 (ca. 0.003 mol dm^{-3} acid) and above about 10.5 (ca. 0.0003 mol dm^{-3} alkali) requires special procedures because, when using the glass electrode, the Nernst law breaks down under those conditions.

Extreme pH measurements imply that the solution may be concentrated, so electrode potentials are affected by ionic strength variation. At high pH the glass electrode may be affected by "alkaline error", because the electrode becomes sensitive to the concentration of cations such as Na^+ and K^+ in the solution. Specially constructed electrodes are available which partly overcome these problems. Runoff from industrial outfalls, restaurant grease, mines or mine tailings can produce some very low pH values.

Non-aqueous Solutions

Hydrogen ion concentrations (activities) can be measured in non-aqueous solvents. pH values based on these measurements belong to a different scale from aqueous pH values, because activities relate to different standard states. Hydrogen ion activity, $a_H{}^+$, can be defined as:

$$a_{H+} = \exp\left(\frac{\mu_{H+} - \mu^{\ominus}_{H+}}{RT}\right)$$

where $\mu_H{}^+$ is the chemical potential of the hydrogen ion, $\mu^{\mathrm{o}}{}_{\mathrm{H}}{}^+$ is its chemical potential in the chosen standard state, R is the gas constant and T is the thermodynamic temperature. Therefore pH values on the different scales cannot be compared directly, requiring an intersolvent scale which involves the transfer activity coefficient of hydrolyonium ion.

pH is an example of an acidity function. Other acidity functions can be defined. For example, the Hammett acidity function, H_0, has been developed in connection with superacids.

The concept of "Unified pH scale" has been developed on the basis of the absolute chemical potential of the proton. This scale applies to liquids, gases and even solids.

Applications

Water has a pH of $pK_w/2$, so the pH of pure water is about 7 at 25 °C; this value varies with temperature. When an acid is dissolved in water, the pH will be less than that of pure water. When a base, or alkali, is dissolved in water, the pH will be greater than that of pure water.

A solution of a strong acid, such as hydrochloric acid, at concentration 1 mol dm^{-3} has a pH of 0. A solution of a strong alkali, such as sodium hydroxide, at concentration 1 mol dm^{-3}, has a pH of 14. Thus, measured pH values will lie mostly in the range 0 to 14, though negative pH values and values above 14 are entirely possible.

Since pH is a logarithmic scale, a difference of one pH unit is equivalent to a tenfold difference in hydrogen ion concentration.

The pH of an aqueous solution of pure water is slightly different from that of, a salt such as sodium chloride even though the salt is neither acidic nor basic. In this case, the hydrogen and hydroxide ions' activity is dependent on ionic strength, so K_w varies with ionic strength. The pH of pure water decreases with increasing temperatures. One example is the pH of pure water at 50 °C is 6.55.

Seawater

The pH of seawater plays an important role in the ocean's carbon cycle, and there is evidence of ongoing ocean acidification caused by carbon dioxide emissions. pH measurement can be complicated by the chemical properties of seawater, and several distinct pH scales exist in chemical oceanography.

As part of its operational definition of the pH scale, the IUPAC defines a series of buffer solutions across a range of pH values (often denoted with NBS or NIST designation).

These solutions have a relatively low ionic strength (~0.1) compared to that of seawater (~0.7), and, as a consequence, are not recommended for use in characterizing the pH of seawater, since the ionic strength differences cause changes in electrode potential.

To resolve this problem, an alternative series of buffers based on artificial seawater was developed. This new series resolves the problem of ionic strength differences between samples and the buffers. The newest pH scale is referred to as the **total scale**, often denoted as **pH_T**.

Calculations of pH

The calculation of the pH of a solution containing acids and/or bases is an example of a chemical speciation calculation, that is, a mathematical procedure for calculating the concentrations of all chemical species that are present in the solution.

The complexity of the procedure depends on the nature of the solution.

If the pH of a solution contains a weak acid requires the solution of a quadratic equation.

If the pH of a solution contains a weak base may require the solution of a cubic equation.

For strong acids and bases no calculations are necessary except in extreme situations.

The general case requires the solution of a set of non-linear simultaneous equations.

A complicating factor is that water itself is a weak acid and a weak base. It dissociates according to the equilibrium

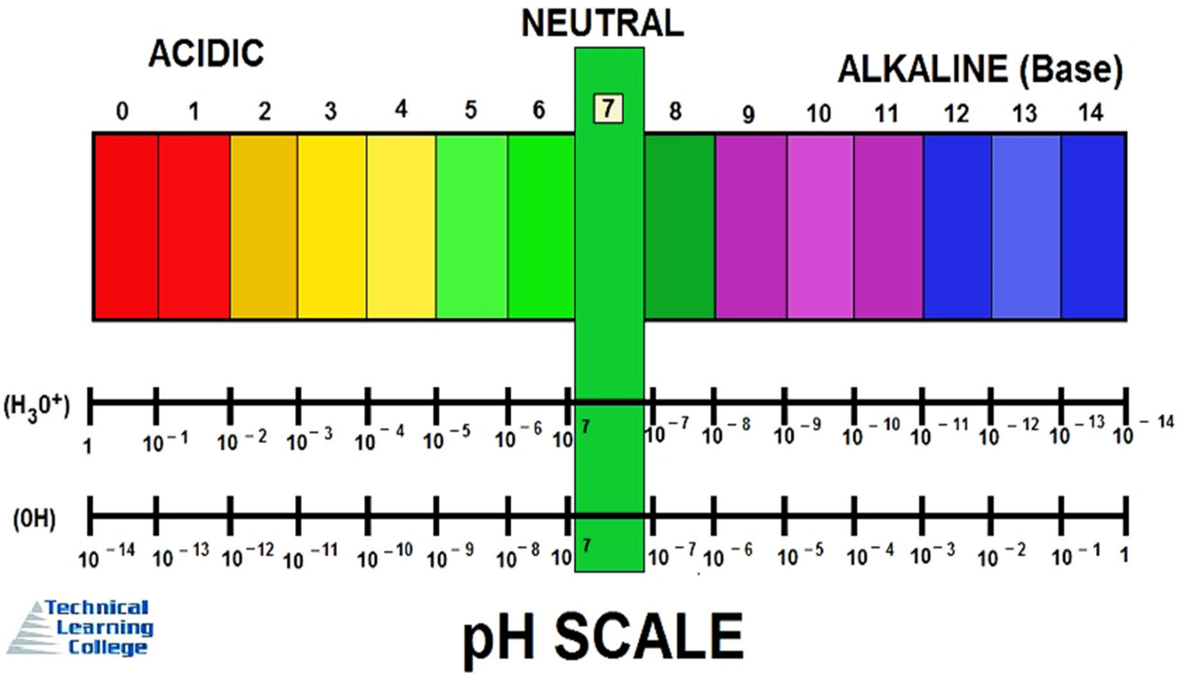
$$2H_2O \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

with a dissociation constant, K_w defined as

$$K_w = [H^+][OH^-]$$

where $[H^+]$ represents for the concentration of the aquated hydronium ion and $[OH^-]$ stands for the concentration of the hydroxide ion. K_w has a value of about 10^{-14} at 25 °C, so pure water has a pH of approximately 7.

This equilibrium needs to be considered at high pH and when the solute concentration is extremely low.



Hydrogen Ion pH Comparison Chart

pH	Hydrogen Ion Concentration, mmol/L
14	0.00000000000001
13	0.0000000000001
12	0.000000000001
11	0.00000000001
10	0.0000000001
9	0.000000001
8	0.00000001
7	0.0000001
6	0.000001
5	0.00001
4	0.0001
3	0.001
2	0.01
1	0.1

Strong Acids and Bases

Strong Acids and Bases
Strong acids and bases are compounds that, for practical purposes, are completely dissociated in water. Under normal circumstances this means that the concentration of hydrogen ions in acidic solution can be taken to be equal to the concentration of the acid. The pH is then equal to minus the logarithm of the concentration value.

Hydrochloric acid (HCl) is an example of a strong acid. The pH of a 0.01M solution of HCl is equal to $-\log_{10}(0.01)$, that is, pH = 2.

Sodium hydroxide, NaOH, is an example of a strong base. The p[OH] value of a 0.01M solution of NaOH is equal to $-\log_{10}(0.01)$, that is, p[OH] = 2.

From the definition of p[OH] above, this means that the pH is equal to about 12. For solutions of sodium hydroxide at higher concentrations the self-ionization equilibrium must be taken into account.

Weak Acids and Bases
A weak acid or the conjugate acid of a weak base can be treated using the same formalism.

Acid: $HA \rightleftharpoons H^+ + A^-$
Base: $HA^+ \rightleftharpoons H^+ + A$

First, an acid dissociation constant is defined as follows. Electrical charges are omitted from subsequent equations for the sake of generality

$$K_a = \frac{[H][A]}{[HA]}$$

and its value is assumed to have been determined by experiment. This being so, there are three unknown concentrations, [HA], [H^+] and [A^-] to determine by calculation. Two additional equations are needed.

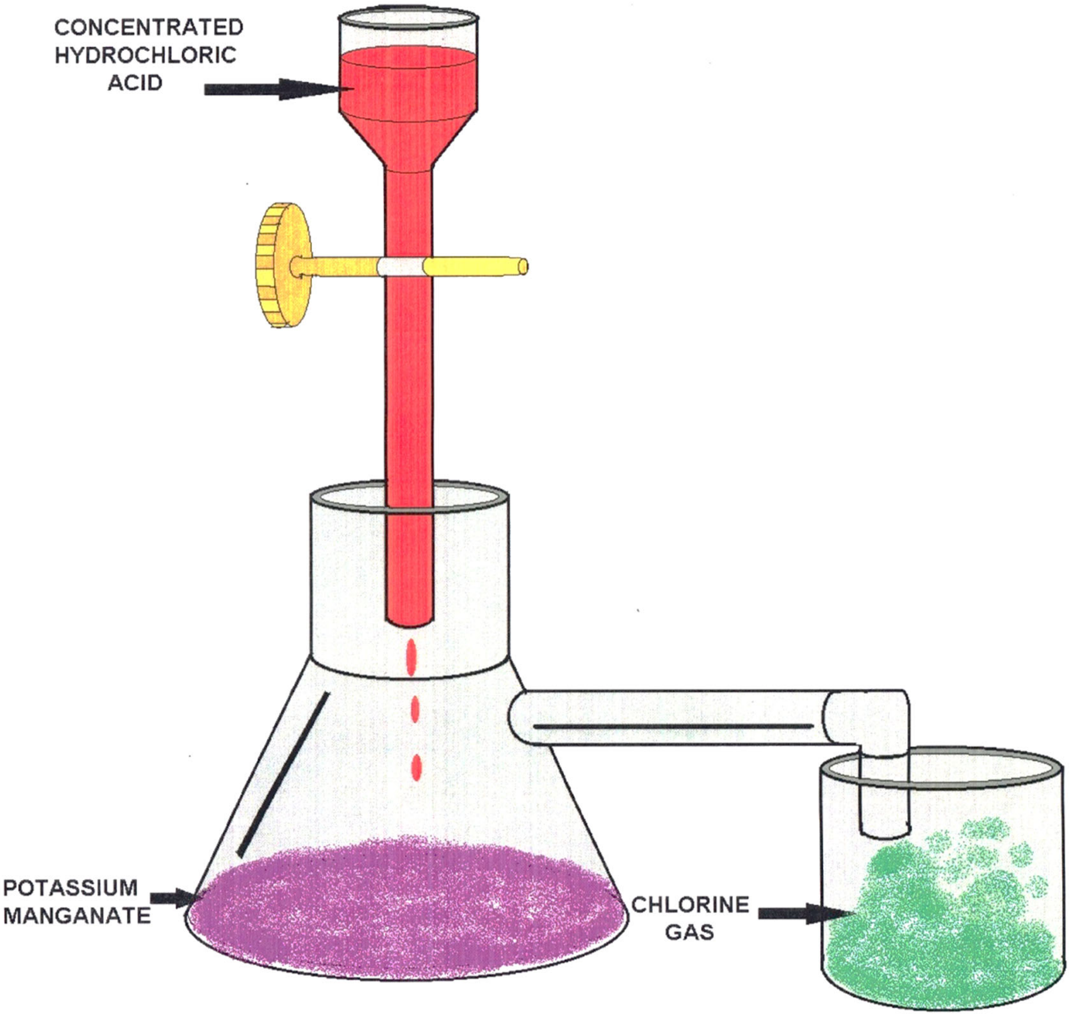
One way to provide them is to apply the law of mass conservation in terms of the two "reagents" H and A.

$$C_A = [A] + [HA]$$
$$C_H = [H] + [HA]$$

C stands for analytical concentration. In some texts one mass balance equation is replaced by an equation of charge balance. This is satisfactory for simple cases like this one, but is more difficult to apply to more complicated cases as those below.

Together with the equation defining K_a, there are now three equations in three unknowns. When an acid is dissolved in water $C_A = C_H = C_a$, the concentration of the acid, so [A] = [H]. After some further algebraic manipulation an equation in the hydrogen ion concentration may be obtained.

$$[H]^2 + K_a[H] - K_aC_a = 0$$



Alkalinity Sub-Section

Introduction

Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. The measured value may vary significantly with the end-point pH used. Alkalinity is a measure of an aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known.

Alkalinity and pH Adjustment

Adjusting pH and alkalinity is the most common corrosion control method because it is simple and inexpensive. pH is a measure of the concentration of hydrogen ions present in water; alkalinity is a measure of water's ability to neutralize acids.

Generally, water pH less than 6.5 is associated with uniform corrosion, while pH between 6.5 and 8.0 can be associated with pitting corrosion. Some studies have suggested that systems using only pH to control corrosion should maintain a pH of at least 9.0 to reduce the availability of hydrogen ions as electron receptors. However, pH is not the only factor in the corrosion equation; carbonate and alkalinity levels affect corrosion as well.

Generally, an increase in pH and alkalinity can decrease corrosion rates and help form a protective layer of scale on corrodible pipe material.

Chemicals commonly used for pH and alkalinity adjustment are hydrated lime ($CaOH_2$ or calcium hydroxide), caustic soda ($NaOH$ or sodium hydroxide), soda ash (Na_2CO_3 or sodium carbonate), and sodium bicarbonate ($NaHCO_3$, essentially baking soda).

Care must be taken, however, to maintain pH at a level that will control corrosion but not conflict with optimum pH levels for disinfection and control of disinfection by-products.

Corrosion Inhibitors

Inhibitors reduce corrosion by forming protective coatings on pipes. The most common corrosion inhibitors are inorganic phosphates, sodium silicates and mixtures of phosphates and silicates. These chemicals have proven successful in reducing corrosion in many water systems.

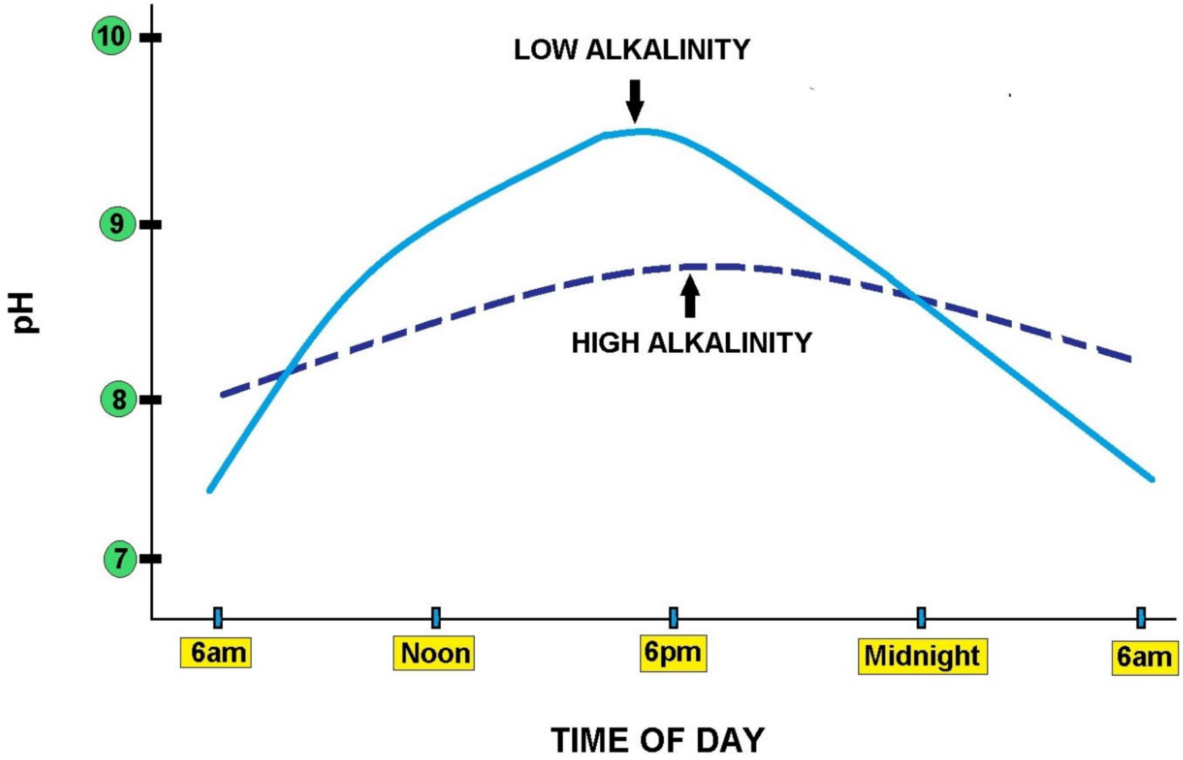
The phosphates used as corrosion inhibitors include polyphosphates, orthophosphates, glassy phosphates and bimetallic phosphates. In some cases, zinc is added in conjunction with orthophosphates or polyphosphates.

Glassy phosphates, such as sodium hexametaphosphate, effectively reduce iron corrosion at dosages of 20 to 40 mg/l.

Glassy phosphate has an appearance of broken glass and can cut the operator. Sodium silicates have been used for over 50 years to inhibit corrosion. The effectiveness depends on the water pH and carbonate concentration.

Sodium silicates are particularly effective for systems with high water velocities, low hardness, low alkalinity and a pH of less than 8.4.

Typical coating maintenance doses range from 2 to 12 mg/1. They offer advantages in hot water systems because of their chemical stability. For this reason, they are often used in the boilers of steam heating systems.



ALKALINITY CAN CHANGE THROUGHOUT THE DAY DIAGRAM

Alkalinity Testing

Titration Method

a. Principle

Hydroxyl ions present in a sample, as a result of dissociation or hydrolysis of solutes react with additions of standard acid. Alkalinity thus depends on the end-point pH used.

b. Reagents

i) Standard Hydrochloric Acid – 0.02 N.
ii) Methyl Orange Indicator – Dissolve 0.1 g of methyl orange in distilled water and dilute to 1 liter.
iii) Sodium carbonate solution, 0.02 N: Dry 3 to 5 g primary standard Na_2CO_3 at 250°C for 4 h and cool in a desiccator. Weigh 1.03 gm.
(to the nearest mg), transfer to a 1-L volumetric flask, fill flask to the mark with distilled water, dissolve and mix reagent. Do no keep longer than 1 week.

c. Procedure

Titrate over a white surface 100 ml of the sample contained in a 250-ml conical flask with standard hydrochloric acid using two or three drops of methyl orange Indicator. (**NOTE** – If more than 30 ml of acid is required for the titration, a smaller suitable aliquot of the sample shall be taken.)

d. Calculation

Total alkalinity (as $CaCO_3$), mg/l = 10 V or NxVx50x1000

$$\text{T.A. (as } CaCO_3) = \frac{}{\text{Sample Amount}}$$

Where N = Normality of HCl used
V = volume in ml of standard hydrochloric acid used in the titration.

Alkalinity to Phenolphthalein

The sample is titrated against standard acid using phenolphthalein indicator.

a. Reagents

i) Phenolphthalein Indicator Solution :
Dissolve 0.1 g of phenolphthalein in 60 ml of ETHANOL and dilute with Distilled water to 100 ml.
ii) Standard hydrochloric Acid – 0.02 N.

b. Procedure

Add 2 drops of phenolphthalein indicator solution to a sample of suitable size, 50 or 100 ml, in a conical flask and titrate over a while surface with standard hydrochloric acid.

c. Calculation

Alkalinity to phenolphthalein (as $CaCO_3$), mg/l $= \dfrac{1000\ V_1}{V_2}$

Where
V_1 = volume in ml of standard hydrochloric acid used in the titration, and
V_2 = Volume in ml of the sample taken for the test.

Caustic Alkalinity

a. General

Caustic alkalinity is the alkalinity corresponding to the hydroxides present in water and is calculated from total alkalinity (T) and alkalinity to phenolphthalein (P).

b. Procedure Determine total alkalinity and alkalinity to phenolphthalein and calculate caustic alkalinity as shown in Table below. Result of Titration Caustic Alkalinity or Hydroxide Alkalinity as $CaCO_3$ Carbonate Alkalinity as $CaCO_3$ Bicarbonate Concentration as $CaCO_3$ **Result of Titration**	**Caustic Alkalinity or Hydroxide Alkalinity as $CaCO_3$**	**Carbonate Alkalinity as $CaCO_3$**	**Bicarbonate Concentration as $CaCO_3$**
P=0	0	0	0
P<1/2T	0	2P	T-2P
P=1/2T	0	2P	0
P>1/2T	2P-T	2(T-P)	0
P=T	T	0	0

The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural water is due to the salts of carbonate, bicarbonate, borates, silicates and phosphates along with the hydroxyl ions in free state.

However, the major portion of the alkalinity in natural waters is caused by hydroxide, carbonate, and bicarbonates which may be ranked in order of their association with high pH values.

Alkalinity values provide guidance in applying proper doses of chemicals in water and waste water treatment processes, particularly in coagulation and softening.

Alkalinity (Total)

References: ASTM D 1067-92, Acidity or Alkalinity of Water.
APHA Standard Methods, 19th ed., p. 2-26, method 2320B (1995).
EPA Methods for Chemical Analysis of Water and Wastes, method 310.1 (1983).

The alkalinity of water is a measurement of its buffering capacity or ability to react with strong acids to a designated pH. Alkalinity of natural waters is typically a combination of bicarbonate, carbonate, and hydroxide ions. Sewage and wastewaters usually exhibit higher alkalinities either due to the presence of silicates and phosphates or to a concentration of the ions from natural waters.

Alkalinity inhibits corrosion in boiler and cooling waters and is therefore a desired quality which must be maintained. It is also measured as a means of controlling water and wastewater treatment processes or the quality of various process waters. In natural waters, excessive alkalinity can render water unsuitable for irrigation purposes and may indicate the presence of industrial effluents.

The Titrimetric Method. CHEMetrics' tests determine total or "M" alkalinity using an acid titrant and a pH indicator. The end point of the titration occurs at pH 4.5. Results are expressed as ppm (mg/L) CaCO3.

Hardness (calcium)

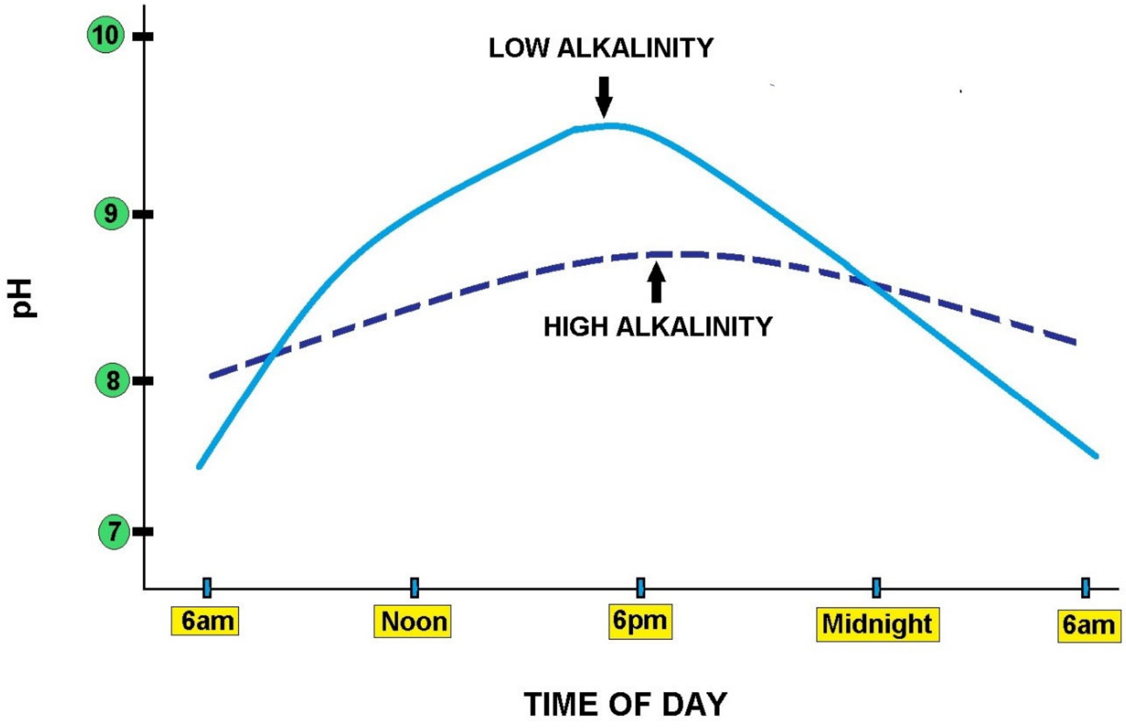
Reference: West, T. S., DSC, Ph.D., Complexometry with EDTA and Related Reagents, 3rd ed., p. 46, 164 (1969).

Originally described as water's capacity to precipitate soap, hardness is one of the most frequently determined qualities of water. It is a composite of the calcium, magnesium, strontium, and barium concentrations in a sample. The current practice is to assume total hardness refers to the calcium and magnesium concentrations only.

Completely de-hardened water, resulting from sodium zeolite or other suitable ion exchange treatment, is required for various processes-including power generation, printing and photo finishing, pulp and paper manufacturing, and food and beverage processing. Hard water can cause scale formation on heat exchange surfaces, resulting in decreased heat transfer and equipment damage.

The Titrimetric Method. This method is specific for calcium hardness. The EGTA titrant in alkaline solution is employed with zincon indicator. Results are expressed as ppm (mg/L) $CaCO_3$.

Shelf-life. 8 months. Although the reagent itself is stable, the end point indicator has a limited shelf-life. We recommend stocking quantities that will be used within 7 months.


10
9
8
7
pH
LOW ALKALINITY
HIGH ALKALINITY
6am
Noon
6pm
Midnight
6am
TIME OF DAY

ALKALINITY

Physical Characteristics of Water Review Section 2 Post Quiz

pH Section

1. In chemistry, _______________ is a measure of the acidity or basicity of an aqueous solution. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline. Pure water has a pH very close to 7.

A. Measurement of pH
B. pH
C. (Solvated) hydronium ion
D. Brønsted–Lowry acid–base theory
E. Acid-base behavior
F. None of the Above

2. ___________are determined using a concentration cell with transference, by measuring the potential difference between a hydrogen electrode and a standard electrode such as the silver chloride electrode.

A. Primary pH standard values
B. Alkalinity
C. pH
D. pH measurement(s)
E. Measurement of pH
F. None of the Above

3. Mathematically, pH is the negative logarithm of the activity of the (solvated) hydronium ion, more often expressed as the measure of the___________________.

A. Primary pH standard values
B. Alkalinity
C. Hydronium ion concentration
D. pH measurement(s)
E. Measurement of pH
F. None of the Above

Alkalinity

4. Alkalinity is the name given to the quantitative capacity of an aqueous solution to neutralize an _________________.

A. Acid
B. Base
C. pH
D. pH measurement(s)
E. Bond formation
F. None of the Above

5. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It is one of the best measures of the sensitivity of the stream to acid inputs. There can be long-term changes in the _________________ of rivers and streams in response to human disturbances.

A. Acid
B. Alkalinity
C. pH
D. pH measurement(s)
E. Bond formation
F. None of the Above

pH Definition and Measurement

6. pH is defined as the decimal logarithm of the reciprocal of the_____________, a_H+, in a solution.

A. Hydrogen ion activity
B. pH
C. (Solvated) hydronium ion
D. Brønsted–Lowry acid–base theory,
E. Acid-base behavior
F. None of the Above

pH Indicators

7. _______________may be used to measure pH, by making use of the fact that their color changes with pH.

A. Indicators	D. Excess of alkaline earth metal concentrations
B. pH	E. A set of non-linear simultaneous equations
C. Spectrophotometer	F. None of the Above

Calculations of pH

8. The calculation of the pH of a solution containing acids and/or bases is an example of a chemical speciation calculation, that is, a mathematical procedure for calculating the concentrations of all chemical species that are present in the solution. The complexity of the procedure depends on the____________________.

A. Universal indicator	D. Excess of alkaline earth metal concentrations
B. pH	E. A set of non-linear simultaneous equations
C. Nature of the solution	F. None of the Above

Strong Acids and Bases

9. Strong acids and bases are compounds that, for practical purposes, are completely dissociated in water. Under normal circumstances this means that the concentration of hydrogen ions in acidic solution can be taken to be equal to the concentration of the acid. The pH is then equal to minus the logarithm of__________.

A. The concentration value	D. Excess of alkaline earth metal concentrations
B. The pH	E. A set of non-linear simultaneous equations
C. The Spectrophotometer	F. None of the Above

Alkalinity

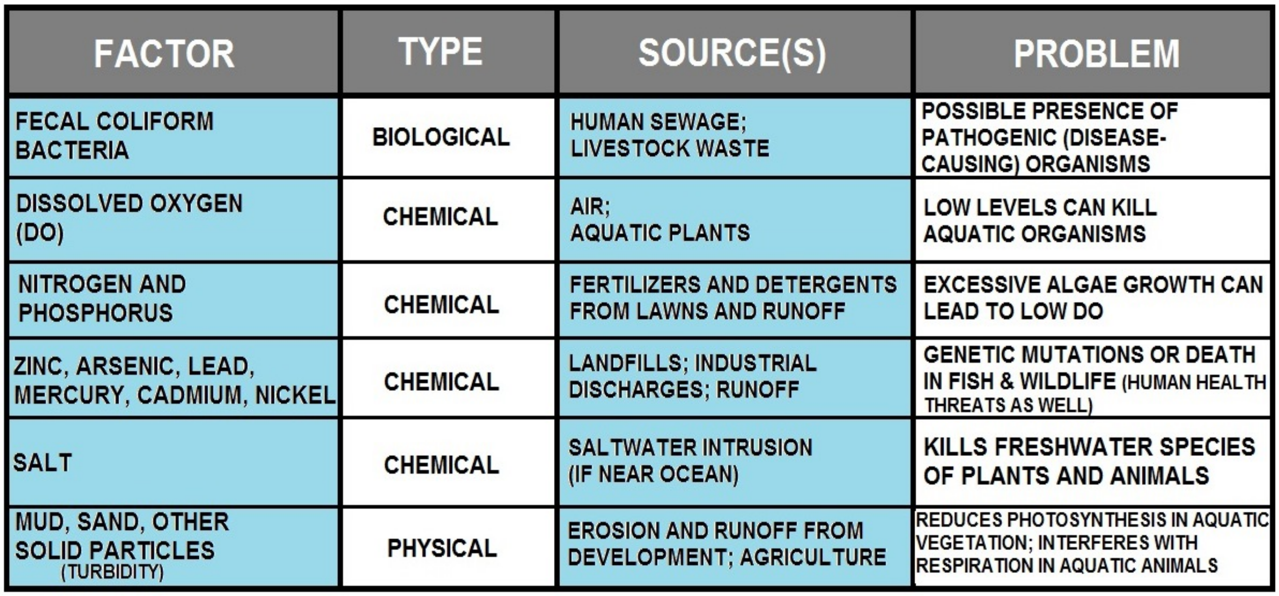
Introduction

10. Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. The measured value may vary significantly with the ___________used.

A. Acid	D. pH measurement(s)
B. Alkalinity	E. End-point pH
C. pH	F. None of the Above

Answers are found in the rear before the References.

Point-of-Use Water Treatment Section 3

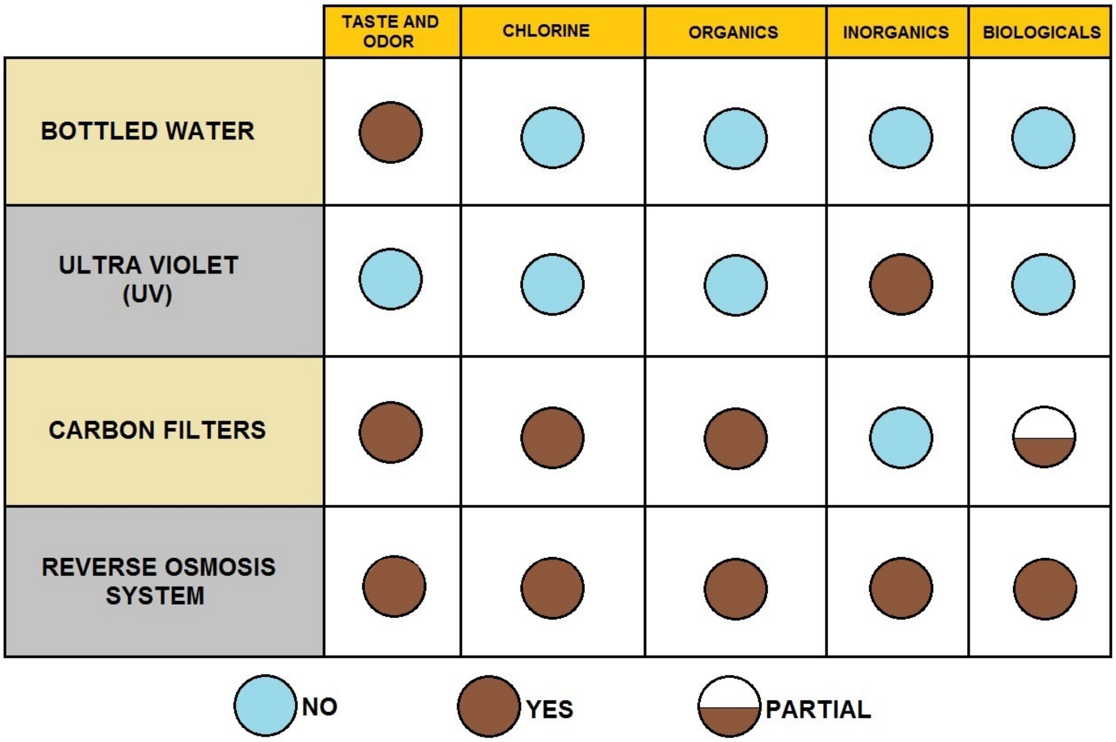


FACTOR	TYPE	SOURCE(S)	PROBLEM
FECAL COLIFORM BACTERIA	BIOLOGICAL	HUMAN SEWAGE; LIVESTOCK WASTE	POSSIBLE PRESENCE OF PATHOGENIC (DISEASE-CAUSING) ORGANISMS
DISSOLVED OXYGEN (DO)	CHEMICAL	AIR; AQUATIC PLANTS	LOW LEVELS CAN KILL AQUATIC ORGANISMS
NITROGEN AND PHOSPHORUS	CHEMICAL	FERTILIZERS AND DETERGENTS FROM LAWNS AND RUNOFF	EXCESSIVE ALGAE GROWTH CAN LEAD TO LOW DO
ZINC, ARSENIC, LEAD, MERCURY, CADMIUM, NICKEL	CHEMICAL	LANDFILLS; INDUSTRIAL DISCHARGES; RUNOFF	GENETIC MUTATIONS OR DEATH IN FISH & WILDLIFE (HUMAN HEALTH THREATS AS WELL)
SALT	CHEMICAL	SALTWATER INTRUSION (IF NEAR OCEAN)	KILLS FRESHWATER SPECIES OF PLANTS AND ANIMALS
MUD, SAND, OTHER SOLID PARTICLES (TURBIDITY)	PHYSICAL	EROSION AND RUNOFF FROM DEVELOPMENT; AGRICULTURE	REDUCES PHOTOSYNTHESIS IN AQUATIC VEGETATION; INTERFERES WITH RESPIRATION IN AQUATIC ANIMALS

WATER QUALITY DETERMINATION FACTORS

In this section, the student will understand and explain different and complex POU water treatment methods and terminology.

a. Point-of-Use Section
b. POU Terminology
c. POU Definitions
d. Microfiltration Section
e. Azeotropes
f. Membrane Filtration Processes
g. Membrane Filtration Operations
h. Microfiltration Specific Process
i. Microfiltration Membrane Configurations
j. Electrodialysis Section
k. Ultrafiltration Section
l. Application
m. Tubular Modules
n. Pretreatment
o. Multi-Stage, Multi-Module



	TASTE AND ODOR	CHLORINE	ORGANICS	INORGANICS	BIOLOGICALS
BOTTLED WATER	🟤	🔵	🔵	🔵	🔵
ULTRA VIOLET (UV)	🔵	🔵	🔵	🟤	🔵
CARBON FILTERS	🟤	🟤	🟤	🔵	◒
REVERSE OSMOSIS SYSTEM	🟤	🟤	🟤	🟤	🟤

🔵 NO 🟤 YES ◒ PARTIAL

TYPES OF WATER QUALITY FILTRATION TECHNOLOGIES AND EFFECTIVE USES

Aesthetic Objectives

Certain contaminants, such as iron and manganese, impart undesirable qualities to drinking water but do not represent a health threat. These are classified as secondary contaminants and do not have enforceable maximum contaminant levels.

Point-of-Use Water Treatment

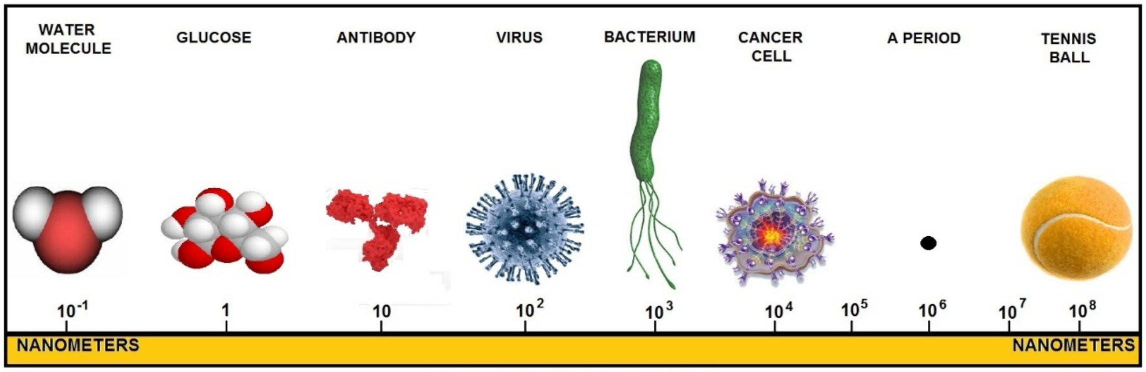
Introduction

For thousands of years, people have treated water intended for drinking to remove particles of solid matter, reduce health risks, and improve aesthetic qualities such as appearance, odor, color, and taste. As early as 2000 B.C., medical lore of India advised, *“Impure water should be purified by being boiled over a fire, or being heated in the sun, or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool.”*

The treatment needs of a water system are likely to differ depending on whether the system uses a groundwater or surface water source. Common surface water contaminants include turbidity, microbiological contaminants *(Giardia*, viruses and bacteria) and low levels of a large number of organic chemicals.

Groundwater contaminants include naturally occurring inorganic chemicals (such as arsenic, fluoride, radium, radon and nitrate) and a number of volatile organic chemicals (**VOCs**) that have recently been detected in localized areas. When selecting among the different treatment options, the water supplier must consider a number of factors.

These include regulatory requirements, characteristics of the raw water, configuration of the existing system, cost, operating requirements and future needs of the service area. In recent years, the public has shown increasing interest in installing special devices on their water service to further treat water supplied to them by a public water system. One reason is that they are not satisfied with the aesthetic qualities of the water, such as hardness, taste, and odor, and wish to improve the quality for their own use.



SIZE COMPARISON
HOW SMALL IS SMALL ?

Another major reason is fear that the water is harmfully contaminated. This idea is fostered primarily by media stories of water contamination at specific locations and advertising by some bottled water and point-of-use device companies. Home treatment devices are also widely used by owners of private wells to improve water quality.

All of this public interest in improving water quality has led to many new companies entering the field of providing small treatment units.

POU Terminology

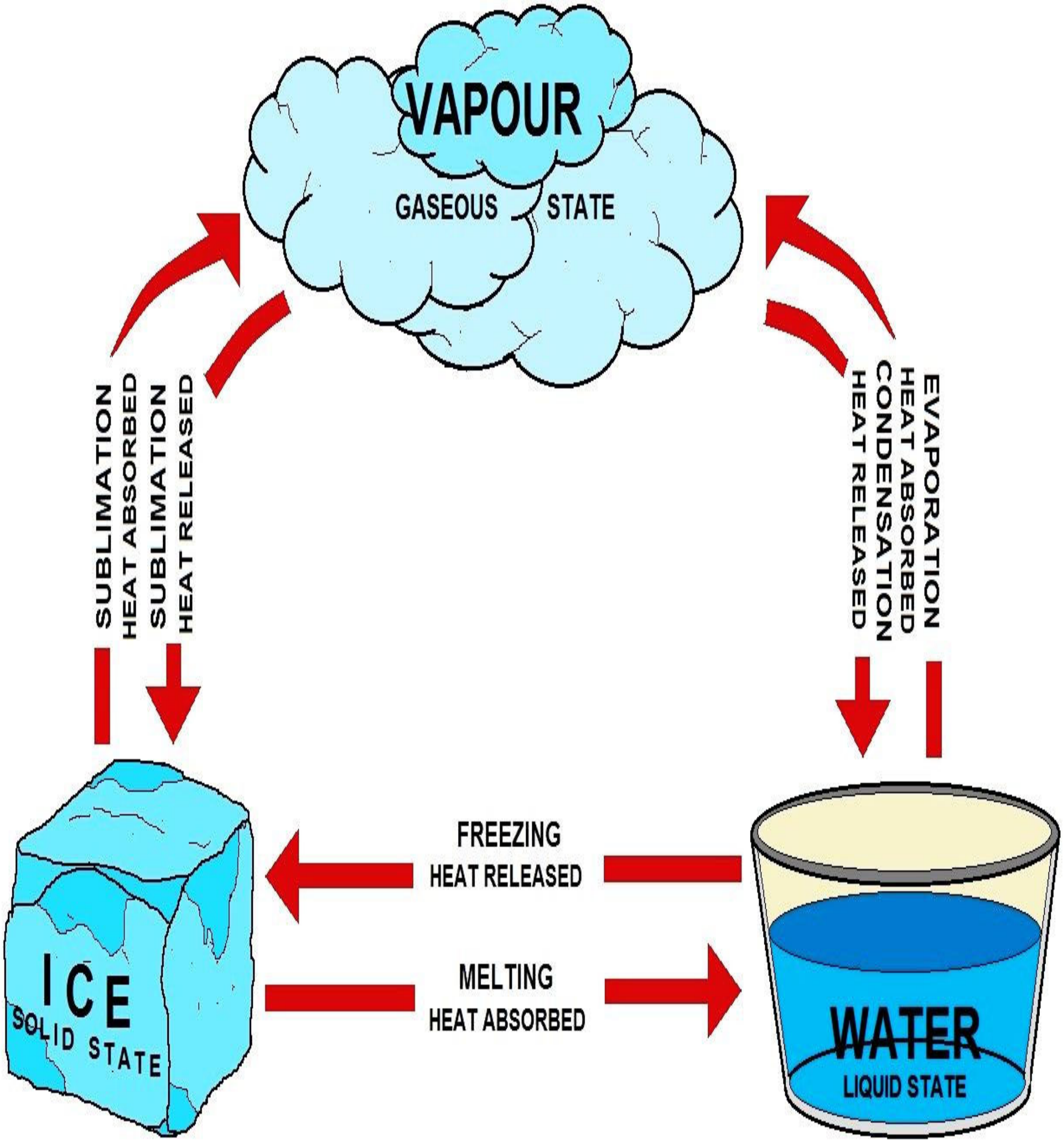
It is necessary to define the terms associated with these treatment devices. The term home drinking water treatment is fairly descriptive of the field. It covers the vast majority of uses, but many individual treatment devices are also installed in factories, offices, and other buildings. There is a need to differentiable between units installed to treat all of the water at a building and those at just one water tap, so the following definitions have come into general use.

Point-of-Entry (POE) devices are treatment units that are connected so they treat all of the water entering a building. A common example is a water softener installed to treat all of the water used in a building.

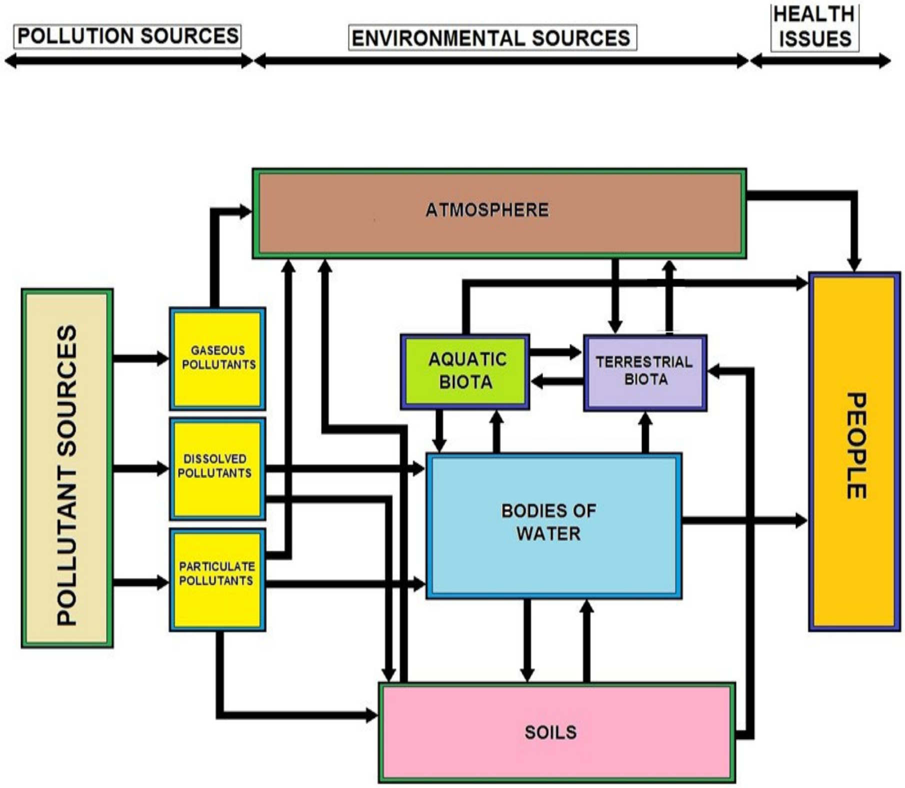
Point-of-Use (POU) devices are units connected to treat water at a single location in a building. POU devices can be further subdivided into the following categories:

- ***Stationary.*** An example is a treatment unit mounted under a kitchen sink to treat all water to the cold-water faucet.
- ***Line bypass.*** An example is a treatment unit, mounted under a kitchen sink, that takes water from the cold-water pipe but delivers into a separate, third faucet.
- ***Countertop****.* This generally refers to a small treatment unit that rests on the counter near the sink and is connected to the regular faucet by a hose when it is needed.
- ***Faucet mounted****.* This refers to a small treatment units that are clamped on the spout of the regular faucet. These units usually have a bypass valve to select either treated or untreated water.
- ***Pour-through***. These are portable, self-contained units, similar to a coffee maker. Water is poured through the unit for treatment.

Small RO commercial unit



VARIOUS STATES OF WATER



WATER QUALITY INDICATORS

POU Definitions **Larger Glossary in the rear.**

As used in EPA's 40 CFR 141, the term:

Best available technology* or *BAT means the best technology, treatment techniques, or other means which the Administrator finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (taking cost into consideration). For the purposes of setting MCLs for synthetic organic chemicals, any BAT must be at least as effective as granular activated carbon.

Community water system is a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

Compliance cycle is the nine-year calendar year cycle during which public water systems must monitor. Each compliance cycle consists of three three-year compliance periods. The first calendar year cycle began January 1, 1993 and ends December 31, 2001; the second begins January 1, 2002 and ends December 31, 2010; the third begins January 1, 2011 and ends December 31, 2019.

Compliance period is a three-year calendar year period within a compliance cycle. Each compliance cycle has three three-year compliance periods. Within the first compliance cycle, the first compliance period ran from January 1, 1993 to December 31, 1995; the second from January 1, 1996 to December 31, 1998; the third from January 1, 1999 to December 31, 2001.

Contaminant is any physical, chemical, biological, or radiological substance or matter in water.

Maximum contaminant level is the maximum permissible level of a contaminant in water which is delivered to any user of a public water system.

Maximum contaminant level goal* or *MCLG is the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and which allows an adequate margin of safety. Maximum contaminant level goals are non-enforceable health goals.

Non-transient non-community water system* or *NTNCWS is a public water system that is not a community water system and that regularly serves at least 25 of the same persons over 6 months per year.

Point-of-entry treatment device (POE) is a treatment device applied to the drinking water entering a house or building for the purpose of reducing contaminants in the drinking water distributed throughout the house or building.

Point-of-use treatment device (POU) is a treatment device applied to a single tap used for the purpose of reducing contaminants in drinking water at that one tap.

Public water system is a system for the provision to the public of water for human consumption through pipes or, after August 5, 1998, other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes: any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. Such term does not include any **"*special irrigation district*."**

A public water system is either a ***"community water system"*** or a ***"noncommunity water system."***

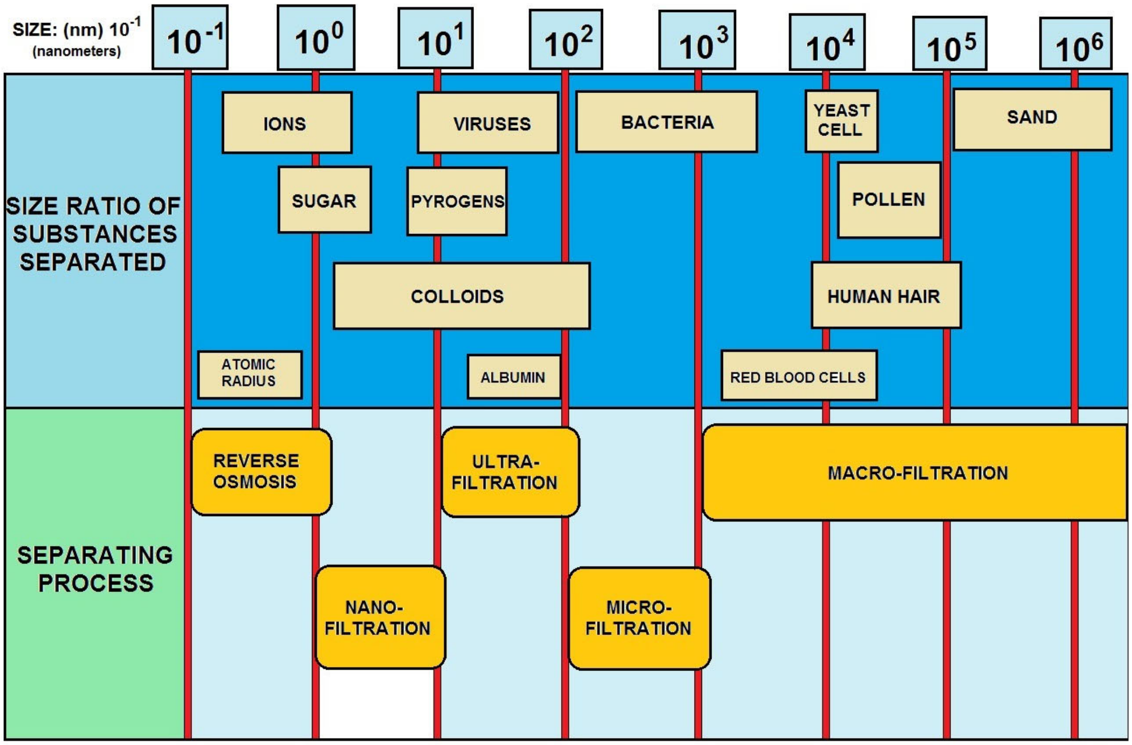
State means the agency of the State or Tribal government which has jurisdiction over public water systems. During any period when a State or Tribal government does not have primary enforcement responsibility pursuant to section 1413 of the Act, the term ***"State"*** means the Regional Administrator, of the U.S. Environmental Protection Agency.

Surface water means all water which is open to the atmosphere and subject to surface runoff.

Ion Exchange Units

Microfiltration Sub-Section

Filtration is the separation of two or more components from a fluid stream. A filtration membrane acts as a selective barrier, allowing the passage of certain components and retaining others components of a mixture. The most common membrane processes are microfiltration, ultrafiltration, and hyperfiltration (reverse osmosis).



FILTRATION SPECTRUM

Types of Processes
Membrane separation processes operate without heating and therefore use less energy than conventional thermal separation processes such as distillation, sublimation or crystallization. The separation process is purely physical and both fractions (permeate and retentate) can be used.

Cold separation using membrane technology is widely used in the food technology, biotechnology and pharmaceutical industries. Using membranes enables separations to take place that would be impossible using thermal separation methods. For example, it is impossible to separate the constituents of azeotropic liquids or solutes which form isomorphic crystals by distillation or recrystallization but such separations can be achieved using membrane technology.

Depending on the type of membrane, the selective separation of certain individual substances or substance mixtures is possible. Important technical applications include the production of drinking water by reverse osmosis (worldwide approximately 7 million cubic meters annually), filtrations in the food industry, the recovery of organic vapors such as petro-chemical vapor recovery and the electrolysis for chlorine production.

In wastewater treatment, membrane technology is becoming increasingly important. With the help of ultra/microfiltration it is possible to remove particles, colloids and macromolecules, so that waste-water can be disinfected in this way. This is needed if waste-water is discharged into sensitive waters especially those designated for contact water-sports and recreation.

Azeotropes

An **azeotrope** or a **constant boiling mixture** is a mixture of two or more liquids whose proportions cannot be altered by simple distillation. This happens because when an azeotrope is boiled, the vapor has the same proportions of constituents as the unboiled mixture.

Because their composition is unchanged by distillation, azeotropes are also called (especially in older texts) **constant boiling mixtures**. The word *azeotrope* is derived from the Greek words ζέειν (boil) and τρόπος (turning) combined with the prefix α- (no) to give the overall meaning, "no change on boiling".

The term "azeotrope" was coined in 1911 by English chemist John Wade (1864–1912) and Richard William Merriman.

Many azeotropic mixtures of pairs of compounds are known, and many azeotropes of three or more compounds are also known. In such a case it is not possible to separate the components by fractional distillation. There are two types of azeotropes: minimum boiling azeotrope and maximum boiling azeotrope.

A solution that shows greater positive deviation from Raoult's law forms a minimum boiling azeotrope at a specific composition. For example, an ethanol-water mixture (obtained by fermentation of sugars) on fractional distillation yields a solution containing approximately 95% by volume of ethanol.

Once this composition has been achieved, the liquid and vapor have the same composition, and no further separation occurs. A solution that shows large negative deviation from Raoult's law forms a maximum boiling azeotrope at a specific composition.

Nitric acid and water is an example of this class of azeotrope. This azeotrope has an approximate composition of 68% nitric acid and 32% water by mass, with a boiling point of 393.5 K.

Membrane Filtration Processes

In 1748, the French physicist Nollet first noted that water would diffuse through a pig bladder membrane into alcohol. This was the discovery of osmosis, a process in which water from a dilute solution will naturally pass through a porous membrane into a concentrate solution. Over the years, scientists have attempted to develop membranes that would be useful in industrial processes, but it wasn't until the late 1950s that membranes were produced that could be used for what is known as reverse osmosis. In reverse osmosis, water is forced to move through a membrane from a concentrate solution to a dilute solution.

Since that time, continual improvements and new developments have been made in membrane technology, resulting in ever-increasing uses in many industries. In potable water treatment, membranes have been used for desalinization, removal of dissolved inorganic and organic chemicals, water softening, and removal of fine solids.

In particular, membrane technology enables some water systems having contaminated water sources to meet new, more stringent regulations. In some cases, it can also allow secondary sources, such as brackish groundwater, to be used. There is great potential for the continuing wide use of membrane filtration processes in potable water treatment, especially as technology improves and costs are reduced.

Description of Membrane Filtration Processes

In the simplest membrane processes, water is forced through a porous membrane under pressure, while suspended solid, large molecules, or ions are held back or rejected.

Types of Membrane Filtration Processes

The two general classes of membrane processes, based on the driving force used to make the process work, are:

- Pressure-driven processes
- Electric-driven processes

Pressure-Driven Processes

The four general membrane processes that operate by applying pressure to the raw water are:

- Microfiltration
- Ultrafiltration
- Nanofiltration
- Reverse Osmosis

Short Summaries, we will cover these in detail later….

Microfiltration

Microfiltration (MF) is a process in which water is forced under pressure through a porous membrane. Membranes with a pore size of 0.45 µm (microns) are normally used; this size is relatively large compared with the other membrane filtration processes. This process has not been generally applicable to drinking water treatment because it either does not remove substances that require removal from potable water, or the problem substances can be removed more economically using other processes. The current primary use of MF is by industries to remove very fine particles from process water, such as in electronic manufacturing. In addition, the process has also been used as a pretreatment for other membrane processes. In particular, RO membranes are susceptible to clogging or filter binding unless the water being processed is already quite clean.

However, in recent years, microfiltration has been proposed as a filtering method for particles resulting from the direct filtration process. Traditionally, this direct filtration process has used the injection of coagulants such as alum or polymers into the raw water stream to remove turbidity such as clay or silts. The formed particles were then removed by rapid sand filters. The use of filter aids to improve filtering efficiency, especially for small particles that could contain bacterial and protozoan life are recommended.

Ultrafiltration

Ultrafiltration (UF) is a process that uses a membrane with a pore size generally below 0.1 µm. The smaller pore size is designed to remove colloids and substances that have larger molecules, which are called high-molecular-weight materials. UF membranes can be designed to pass material that weigh less than or equal to a certain molecular weight. This weight is called the molecular weight cutoff (MWC) of the membrane. Although UF does not generally work well for removal of salt or dissolved solids, it can be used effectively for removal or most organic chemicals.

Nanofiltration

Nanofiltration (NF) is a process using membranes that will reject even smaller molecules that UF. The process has been used primarily for water softening and reduction of total dissolved solids (TDS). NF operates with less pressure that reverse osmosis and is still able to remove a significant proportion of inorganic and organic molecules. This capability will undoubtedly increase the use of NF for potable water treatment.

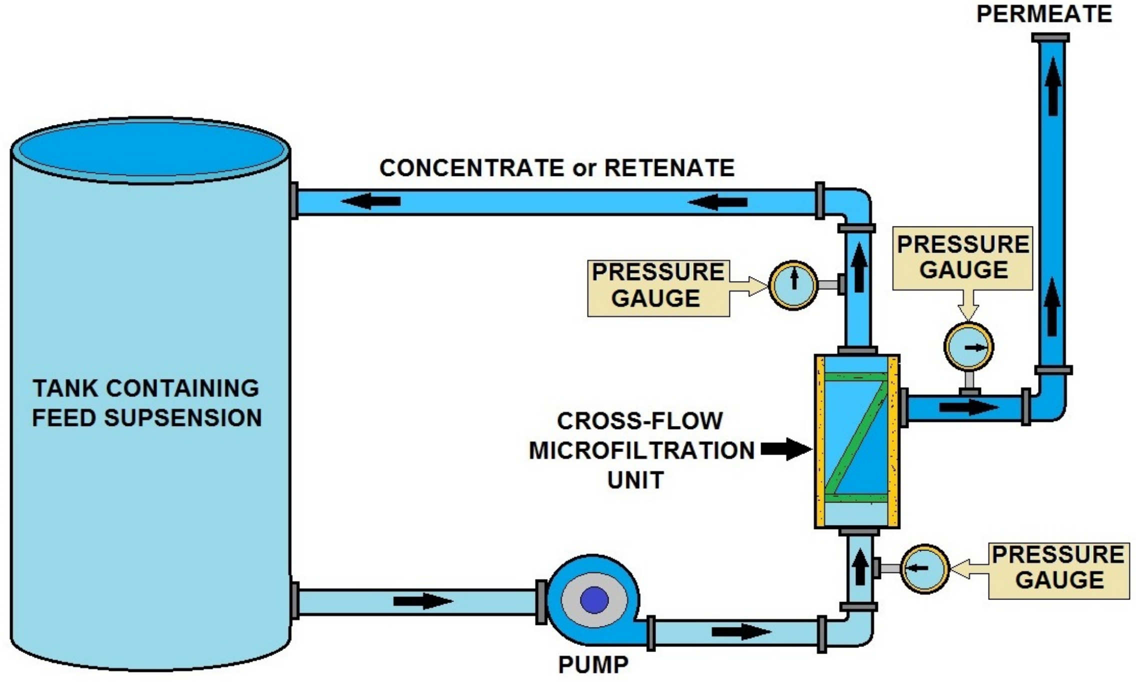
Reverse Osmosis

Reverse Osmosis (RO) is a membrane process that has the highest rejection capability of all the membrane processes. These RO membranes have a very low MWC pore size that can reject ions at very high rates, including chloride and sodium. Water from this process is very pure due to the high reject rates.

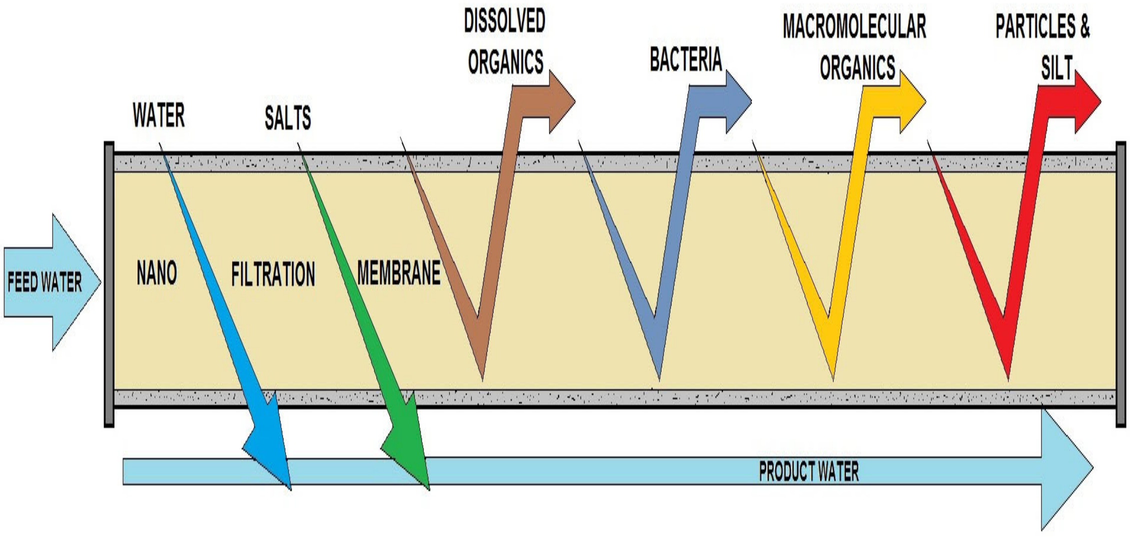
The process has been used primarily in the water industry for desalinization of seawater because the capital and operating costs are competitive with other processes for this service.

The RO also works most organic chemicals, and radionuclides and microorganisms. Industrial water uses such as semiconductor manufacturing also uses an the RO process.

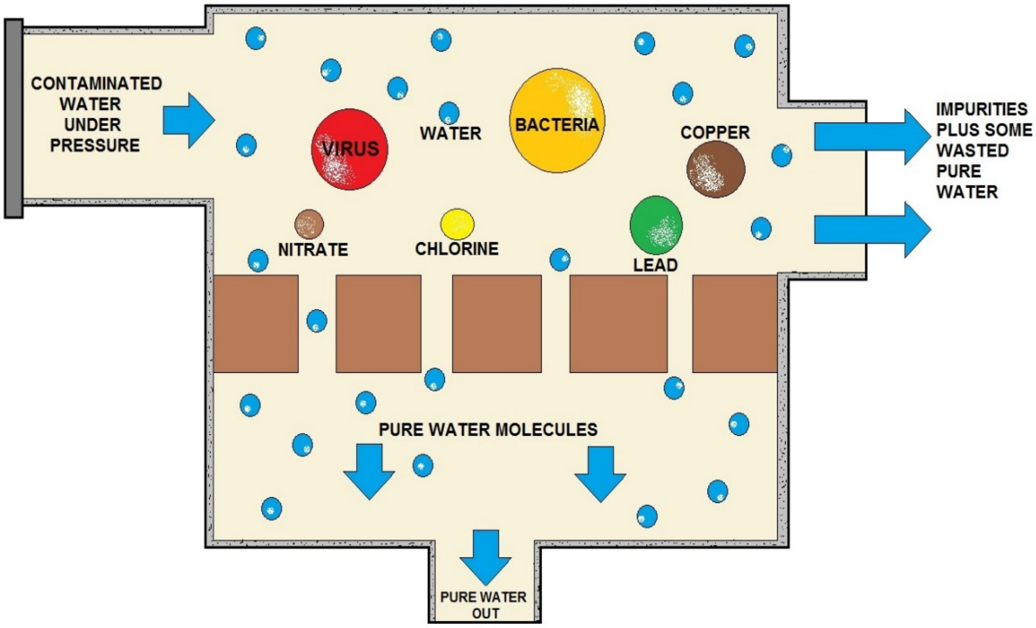
Microfiltration Diagrams



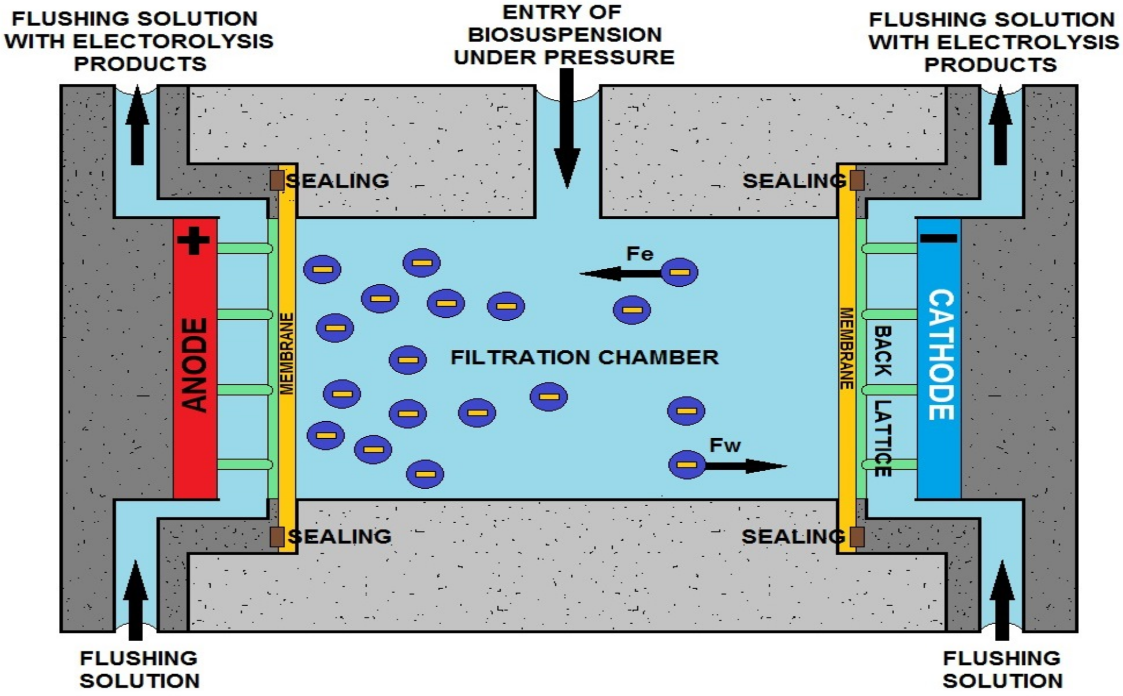
MICROFILTRATION SYSTEM



NANOFILTRATION



REVERSE OSMOSIS SYSTEM BASIC DESIGN



ELECTROFILTRATION CHAMBER

Common Membrane Filtration Operations

According to the driving force of the operation it is possible to distinguish:

- **Pressure driven operations**
    - microfiltration
    - ultrafiltration
    - nanofiltration
    - reverse osmosis
- **Concentration driven operations**
    - dialysis
    - pervaporation
    - forward osmosis
    - artificial lung
    - gas separation
- **Operations in an electric potential gradient**
    - electrodialysis
    - membrane electrolysis e.g. chloralkali process
    - electrodeionization
    - electrofiltration
    - fuel cell
- **Operations in a temperature gradient**
    - membrane distillation

Pore Size and Selectivity

Pore size	Molecular mass	Process	Filtration	Removal of
> 10		"Classic" filter		
> 0.1 µm	> 5000 kDa	microfiltration	< 2 bar	larger bacteria, yeast, particles
100-2 nm	5-5000 kDa	ultrafiltration	1-10 bar	bacteria, macromolecules, proteins, larger viruses
2-1 nm	0.1-5 kDa	nanofiltration	3-20 bar	viruses, 2- valent ions
< 1 nm	< 100 Da	reverse osmosis	10-80 bar	salts, small organic molecules

Filter membranes are divided into four classes according to pore size:

- The pore distribution of a fictitious ultrafiltration membrane with the nominal pore size and the D_{90}
- The pore sizes of technical membranes are specified differently depending on the manufacturer. One common distinction is by *nominal pore size*. It describes the maximum pore size distribution and gives only vague information about the retention capacity of a membrane. The exclusion limit or "cut-off" of the membrane is usually specified in the form of *NMWC* (nominal molecular weight cut-off, or *MWCO*, molecular weight cut off, with units in Dalton). It is defined as the minimum molecular weight of a globular molecule that is retained to 90% by the membrane. The cut-off, depending on the method, can be converted to so-called D_{90}, which is then expressed in a metric unit. In practice the MWCO of the membrane should be

at least 20% lower than the molecular weight of the molecule that is to be separated.

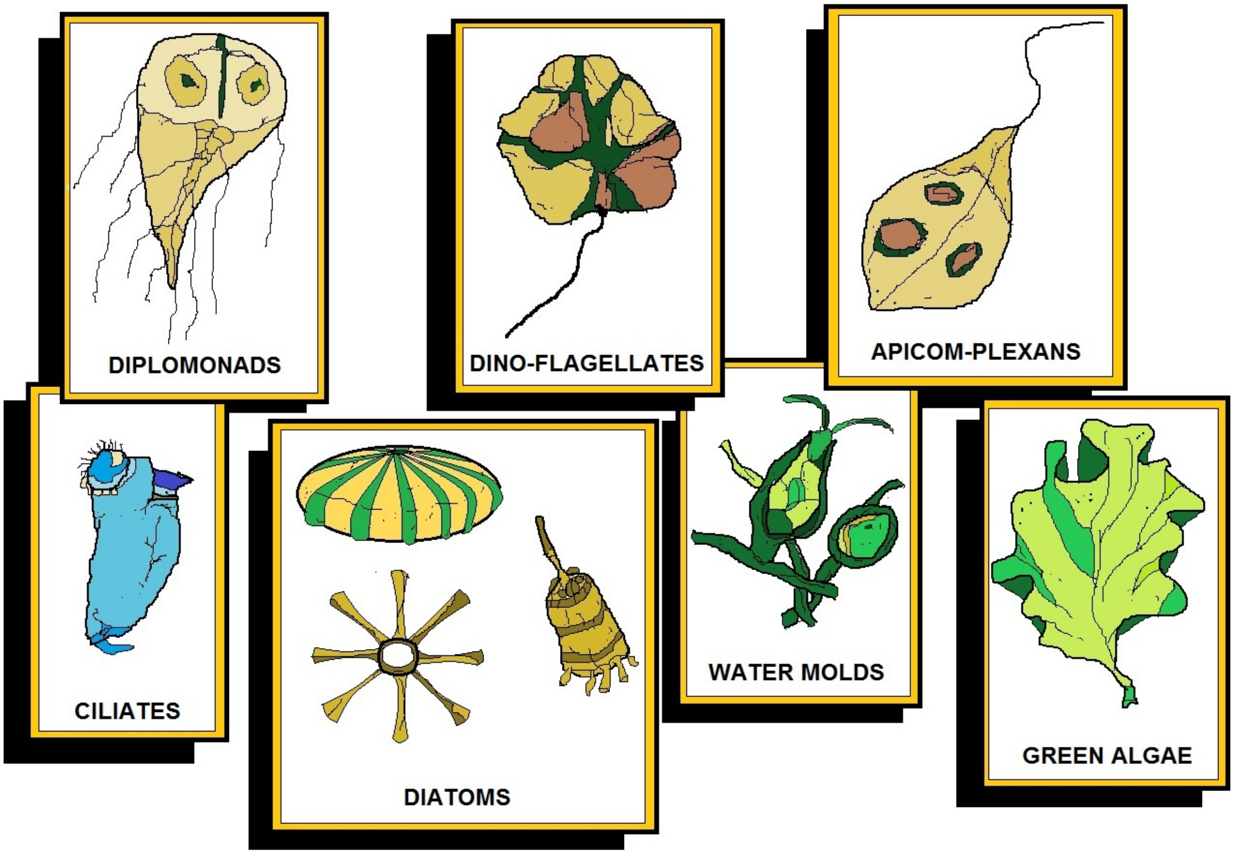
- The form and shape of the membrane pores are highly dependent on the manufacturing process and are often difficult to specify. Therefore, for characterization, test filtrations are carried out and the pore diameter refers to the diameter of the smallest particles which could not pass through the membrane.
- The rejection can be determined in various ways and provides an indirect measurement of the pore size. One possibility is the filtration of macromolecules (often dextran, polyethylene glycol or albumin), another is measurement of the cut-off by gel permeation chromatography. These methods are used mainly to measure membranes for ultrafiltration applications. Another testing method is the filtration of particles with defined size and their measurement with a particle sizer or by laser induced breakdown spectroscopy (LIBS). A vivid characterization is to measure the rejection of dextran blue or other colored molecules. The retention of bacteriophage and bacteria, the so-called "bacteria challenge test", can also provide information about the pore size.
- To determine the pore diameter, physical methods such as porosimetry (mercury, liquid-liquid porosimetry and Bubble Point Test) are also used, but a certain form of the pores (such as cylindrical or concatenated spherical holes) is assumed. Such methods are used for membranes whose pore geometry does not match the ideal, and we get "nominal" pore diameter, which characterizes the membrane, but does not necessarily reflect its actual filtration behavior and selectivity.
- The selectivity is highly dependent on the separation process, the composition of the membrane and its electrochemical properties in addition to the pore size. With high selectivity, isotopes can be enriched (uranium enrichment) in nuclear engineering or industrial gases like nitrogen can be recovered (gas separation). Ideally, even racemics can be enriched with a suitable membrane.
- When choosing membranes selectivity has priority over a high permeability, as low flows can easily be offset by increasing the filter surface with a modular structure. In gas phase filtration different deposition mechanisms are operative, so that particles having sizes below the pore size of the membrane can be retained as well.

Microfiltration Specific Process

Microfiltration (commonly abbreviated to MF) is a type of physical filtration process where a contaminated fluid is passed through a special pore-sized membrane to separate microorganisms and suspended particles from process liquid. It is commonly used in conjunction with various other separation processes such as ultrafiltration and reverse osmosis to provide a product stream which is free of undesired contaminants.

Microfiltration usually serves as a pre-treatment for other separation processes such as ultrafiltration, and a post-treatment for granular media filtration. The typical particle size used for microfiltration ranges from about 0.1 to 10 μm. In terms of approximate molecular weight these membranes can separate macromolecules of molecular weights generally less than 100,000 g/mol.

The filters used in the microfiltration process are specially designed to prevent particles such as, sediment, algae, protozoa or large bacteria from passing through a specially designed filter.



KINGDOM PROTISTA

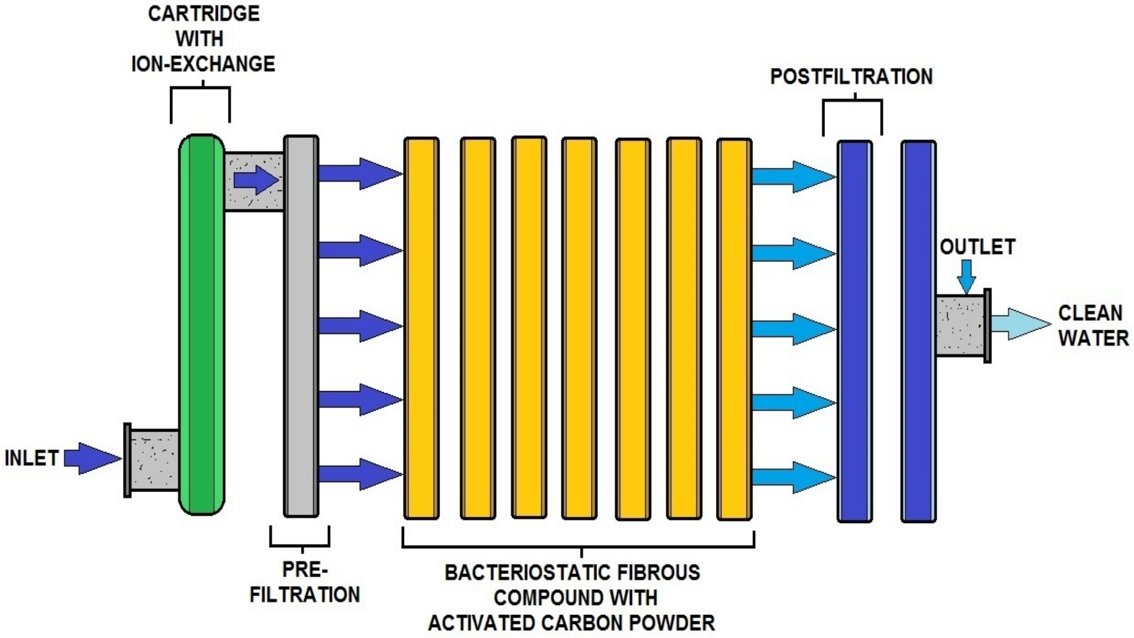
More microorganism information in the Appendix.

More microscopic, atomic or ionic materials such as water (H_2O), monovalent species such as Sodium (Na^+) or Chloride (Cl^-) ions, dissolved or natural organic matter, and small colloids and viruses will still be able to pass through the filter.

The suspended liquid is passed though at a relatively high velocity of around 1–3 m/s and at low to moderate pressures (around 100-400 kPa) parallel or tangential to the semi-permeable membrane in a sheet or tubular form.

A pump is commonly fitted onto the processing equipment to allow the liquid to pass through the membrane filter. There are also two pump configurations, either pressure driven or vacuum.

A differential or regular pressure gauge is commonly attached to measure the pressure drop between the outlet and inlet streams. The most abundant use of microfiltration membranes are in the water, beverage and bio-processing industries. The exit process stream after treatment using a micro-filter has a recovery rate which generally ranges to about 90-98 %



MICROFILTRATION
(VARIATION OF FILTER)

Common Applications

Water Treatment Process

Perhaps the most prominent use of microfiltration membranes pertains to the treatment of potable water supplies. The membranes are a key step in the primary disinfection of the uptake water stream. Such a stream might contain pathogens such as the protozoa Cryptosporidium and Giardia lamblia which are responsible for numerous disease outbreaks. Both species show a gradual resistance to traditional disinfectants (i.e. chlorine).

The use of MF membranes presents a physical means of separation (a barrier) as opposed to a chemical alternative. In this sense, both filtration and disinfection take place in a single step, reducing the cost of chemical dosage and the corresponding equipment needed for handling and storage.

Similarly, the MF membranes are used in secondary wastewater effluents to remove turbidity but also to provide treatment for disinfection. At this stage, coagulants (iron or aluminum) may potentially be added to precipitate species such as phosphorus and arsenic which would otherwise have been soluble.

Sterilization

Another crucial application of MF membranes lies in the cold sterilization of beverages and pharmaceuticals. Historically, heat was used to sterilize refreshments such as juice, wine and beer in particular, however a palatable loss in flavor was clearly evident upon heating. Similarly, pharmaceuticals have been shown to lose their effectiveness upon heat addition. MF membranes are employed in these industries as a method to remove bacteria and other undesired suspensions from liquids, a procedure termed as ‘cold sterilization’, which negates the use of heat.

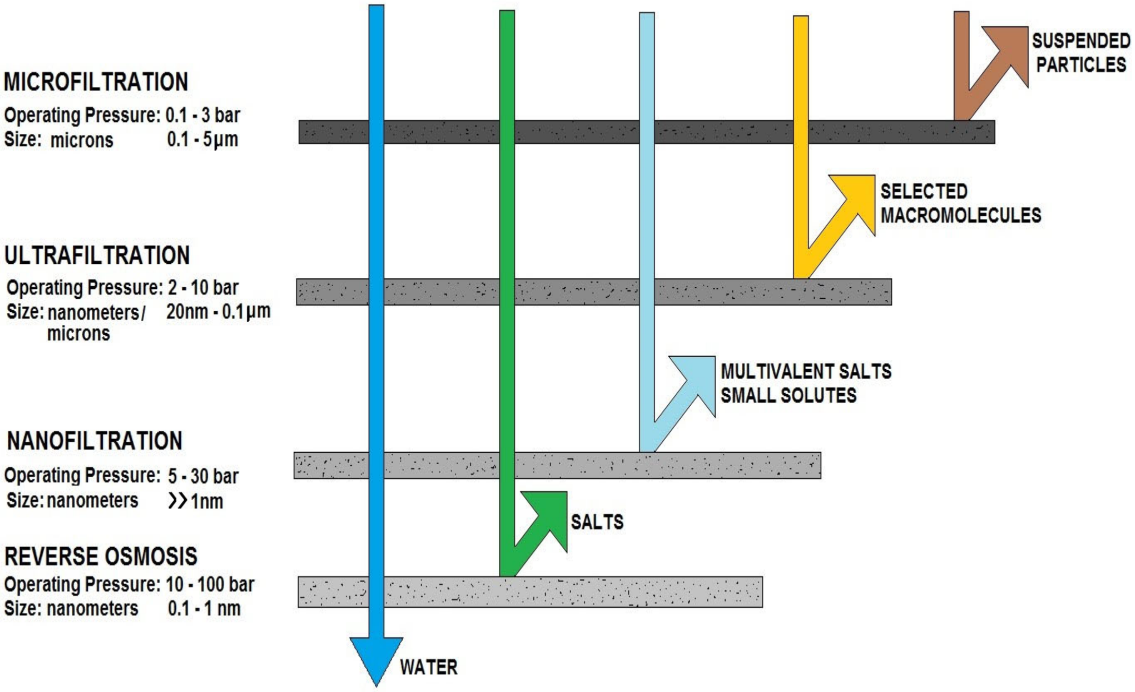
Driving Force, Retentate Stream and Permeate Streams

Membrane filtration processes can be distinguished by three major characteristics; Driving force, retentate stream and permeate streams. The microfiltration process is pressure driven with suspended particles and water as retentate and dissolved solutes plus water as permeate. The use of hydraulic pressure accelerates the separation process by increasing the flow rate (flux) of the liquid stream but does not affect the chemical composition of the species in the retentate and product streams.

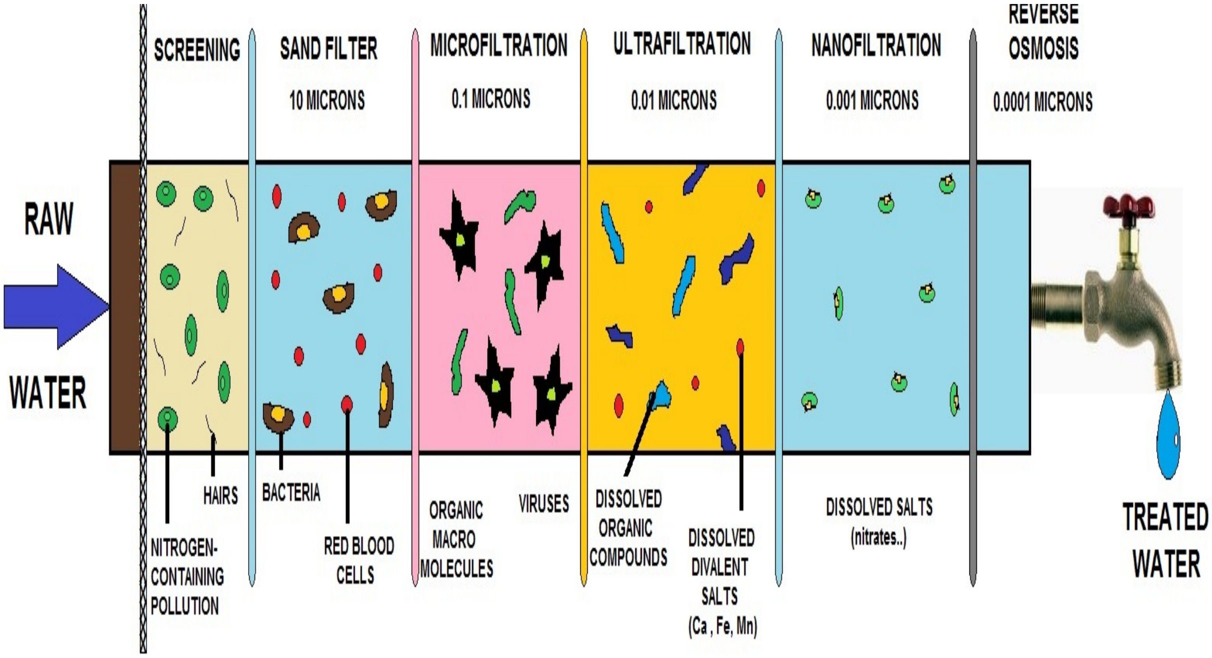
Fouling

A major characteristic that limits the performance of microfiltration or any membrane technology is a process known as fouling. Fouling describes the deposition and accumulation of feed components such as suspended particles, impermeable dissolved solutes or even permeable solutes, on the membrane surface and or within the pores of the membrane.

Fouling of the membrane during the filtration processes decreases the flux and thus overall efficiency of the operation. This is indicated when the pressure drop increases to a certain point. It occurs even when operating parameters are constant (pressure, flow rate, temperature and concentration) Fouling is eventually complete and irreversible although a portion of the fouling layer can be reversed by repeatedly cleaning the membranes.



FILTRATION TYPE COMPARISONS



FILTRATION METHODS AND REMOVAL SIZES

Microfiltration Membrane Configurations

Cross-flow Filtration

Where the fluid is passed through tangentially with respect to the membrane. Part of the feed stream containing the treated liquid is collected below the filter while parts of the water are passed through the membrane untreated. Cross flow filtration is understood to be a unit operation rather
than a process.

Dead-end Filtration

All of the process fluid flows and all particles larger than the pore sizes of the membrane are stopped at its surface. All of the feed water is treated at once subject to cake formation. This process is mostly used for batch or semi-continuous filtration of low concentrated solutions.

Process and Equipment Design

The major issues which influence the selection of the membrane include:

Site Specific Issues (Unique to the site where the plant is located)

- Capacity and demand of the facility.
- Percentage recovery and rejection.
- Fluid characteristics (viscosity, turbidity, density)
- Quality of the fluid to be treated
- Pre-treatment processes

Membrane Specific Issues (Unique to the manufacturer or supplier)

- Cost of material procurement and manufacture
- Operating temperature
- Trans-membrane pressure
- Membrane flux
- Handling fluid characteristics (Viscosity, Turbidity, Density)
- Monitoring and maintenance of the system
- Cleaning and treatment
- Disposal of process residuals

Process Design Variables (Regarding proper membrane selection)

- Operation and control of all processes in the system,
- Materials of construction
- Equipment and instrumentation (controllers, sensors) and their cost.

Fundamental Design Heuristics

- When treating raw contaminated fluids, hard sharp materials can wear and tear the porous cavities in the micro-filter, rendering it ineffective. Liquids must be subjected to pre-treatment before passage through the micro-filter. This may be achieved by a variation of macro separation processes such as screening, or granular media filtration.
- When undertaking cleaning regimes the membrane must not dry out once it has been contacted by the process stream. Thorough water rinsing of the membrane modules, pipelines, pumps and other unit connections should be carried out until the end water appears clean.

- Microfiltration modules are typically set to operate at pressures of 100 to 400 kPa. These pressures allow removal of materials such as sand, slits and clays, and also bacteria and protozoa.
- When the membrane modules are being used for the first time, i.e. during plant start-up, conditions need to be well devised. Generally, a slow-start is required when the feed is introduced into the modules, since even slight perturbations above the critical flux will result in irreversible fouling.

Like any other membranes Microfiltration membranes are prone to fouling. It is therefore necessary that regular maintenance be carried out to prolong the life of the membrane module.

- Routine ‘backwashing’, is used to achieve this. Depending on the specific application of the membrane, backwashing is carried out in short durations (typically 3 to 180 s) and in moderately frequent intervals (5 min to several hours). Turbulent flow conditions with Reynolds numbers greater than 2100, ideally between 3000 - 5000 should be used. This should not however be confused with ‘backflushing’, a more rigorous and thorough cleaning technique, commonly practiced in cases of particulate and colloidal fouling.
- When major cleaning is needed to remove entrained particles, a CIP (Clean In Place) technique is used. Cleaning agents/detergents, such as sodium hypochlorite, citric acid, caustic soda or even special enzymes are typically used for this purpose. The concentration of these chemicals is dependent on the type of the membrane (its sensitivity to strong chemicals), but also the type of matter (e.g. scaling due to the presence of calcium ions) to be removed.
- Another method to increase the lifespan of the membrane may be feasible to design two microfiltration membranes in series. The first filter would be used for pre-treatment of the liquid passing though the membrane, where larger particles and deposits are captured on the cartridge. The second filter would act as an extra “check” for particles which are able to pass through the first membrane as well as provide screening for particles on the lower spectrum of the range.

Design Economics

The cost to design and manufacture a membrane per unit of area are about 20% less compared to the early 1990s and in a general sense are constantly declining. Microfiltration membranes are more advantageous in comparison to conventional systems. Microfiltration systems do not require expensive extraneous equipment such as flocculates, addition of chemicals, flash mixers, settling and filter basins.

However, the cost of replacement of capital equipment costs (membrane cartridge filters etc.) might still be relatively high as the equipment may be manufactured specific to the application. Using the design heuristics and general plant design principles (mentioned above), the membrane life-span can be increased to reduce these costs.

Through the design of more intelligent process control systems and efficient plant designs some general tips to reduce operating costs are listed below.

- Running plants at reduced fluxes or pressures at low load periods (winter)
- Taking plant systems off-line for short periods when the feed conditions are extreme.
- A short shutdown period (approximately 1 hour) during the first flush of a river after rainfall (in water treatment applications) to reduce cleaning costs in the initial period.

- The use of more cost effective cleaning chemicals where suitable (sulfuric acid instead of citric/ phosphoric acids.)
- The use of a flexible control design system. Operators are able to manipulate variables and set-points to achieve maximum cost savings.

Microfiltration Summary
Membrane configuration can vary between manufacturers, but the "hollow fiber" type is the most commonly used. Membranes in the hollow fiber type are cast into small diameter tubes or straws, nominally one meter in length.

Thousands of these straws are bundled together and the ends are bonded into an epoxy bulkhead or "potting." The ends of potting are cut off to allow access to the inside of the fibers from the end of the potting. The bundles are then sealed into a housing which is usually PVC or stainless steel. The sealed potting creates a separate, sealed space in the module that isolates access to the inside of the fibers from access to the outside. This membrane and housing combination is called a module. It allows water to be forced through the fiber walls without short-circuiting.

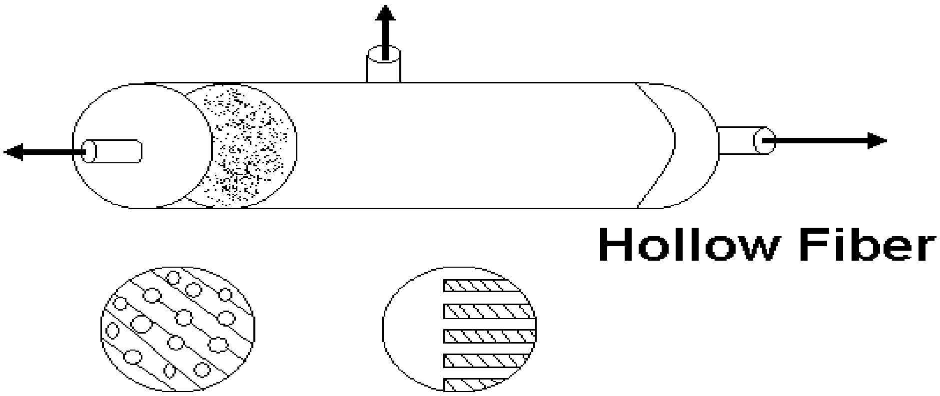
System design is done once the desired flow rate and water conditions are known and a pilot has been performed to determine the required number of modules. The modules are then piped together in a manner which will allow water to be forced from one side of the fibers through the membrane wall and collected from the filtrate side of the modules.

Typically, the water is pumped from the outside of the fibers, and the clean water is collected from the inside of the fibers. This is called "outside-to-inside" flow. This flow direction is sometimes reversed depending on manufacturer and membrane configuration.

Microfiltration membranes used in potable water applications usually operate in the "dead-end" flow regime. In dead-end flow, all of the water fed to the membrane is filtered through the membrane.

A filter cake that must be periodically backwashed from the membrane surface forms. Recovery rates are normally greater than 90 percent on sources which have fairly high quality, low turbidity feeds.

Membrane Configurations



Hollow Fiber

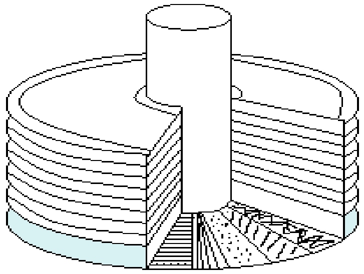
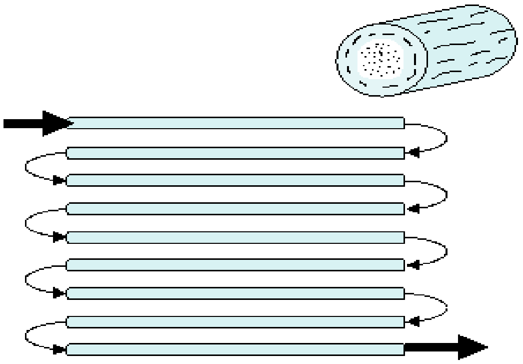
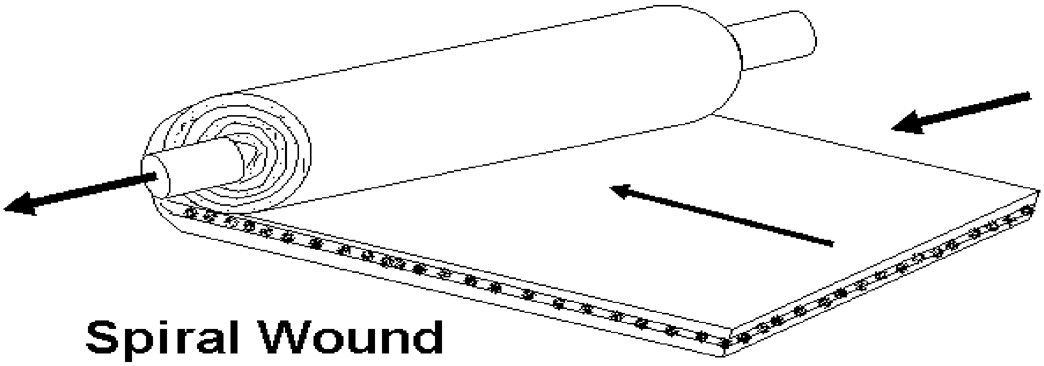


Plate and Frame



Tubular



Spiral Wound

Electric-Driven Processes

There are two membrane processes that purify a water stream by using an electric current to move ions across a membrane. These processes are:

- Electrodialysis
- Electrodialysis reversal

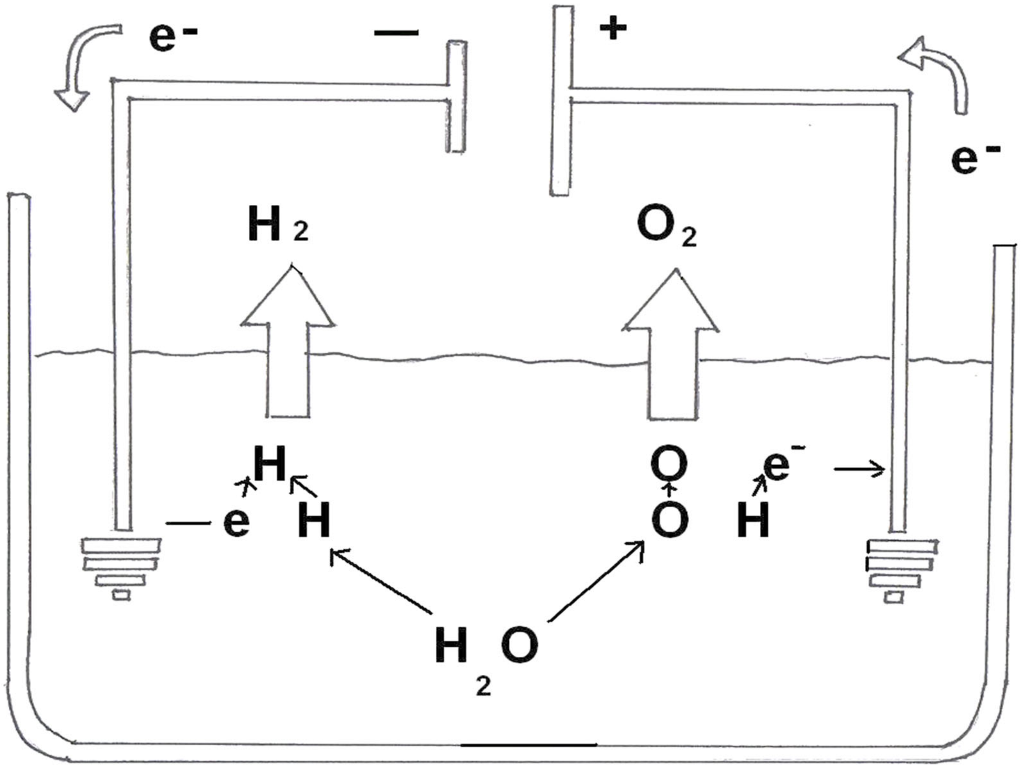
Electrodialysis Sub-Section

Electrodialysis (**ED**) is a process in which ions are transferred through a membrane as a result of direct electric current applied to the solution. The current carries the ions through a membrane from the less concentrated solution to the more concentrated one.

Electrodialysis Reversal

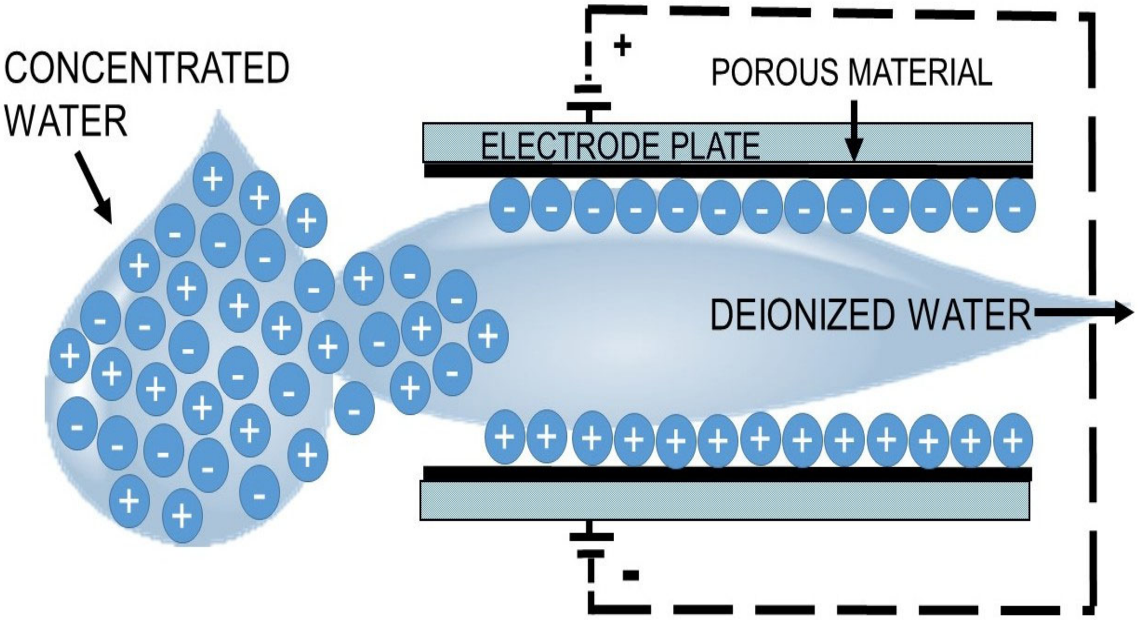
Electrodialysis Reversal (**EDR**) is a process similar to ED, except that the polarity of the direct current is periodically reversed. The reversal in polarity reverses the flow of ions between demineralizing compartments, which provides automatic flushing of scale-forming materials from the membrane surface.

As a result, EDR can often be used with little or no pretreatment of feedwater to prevent fouling. So far, ED and EDR have been used at only a few locations for drinking water treatment.



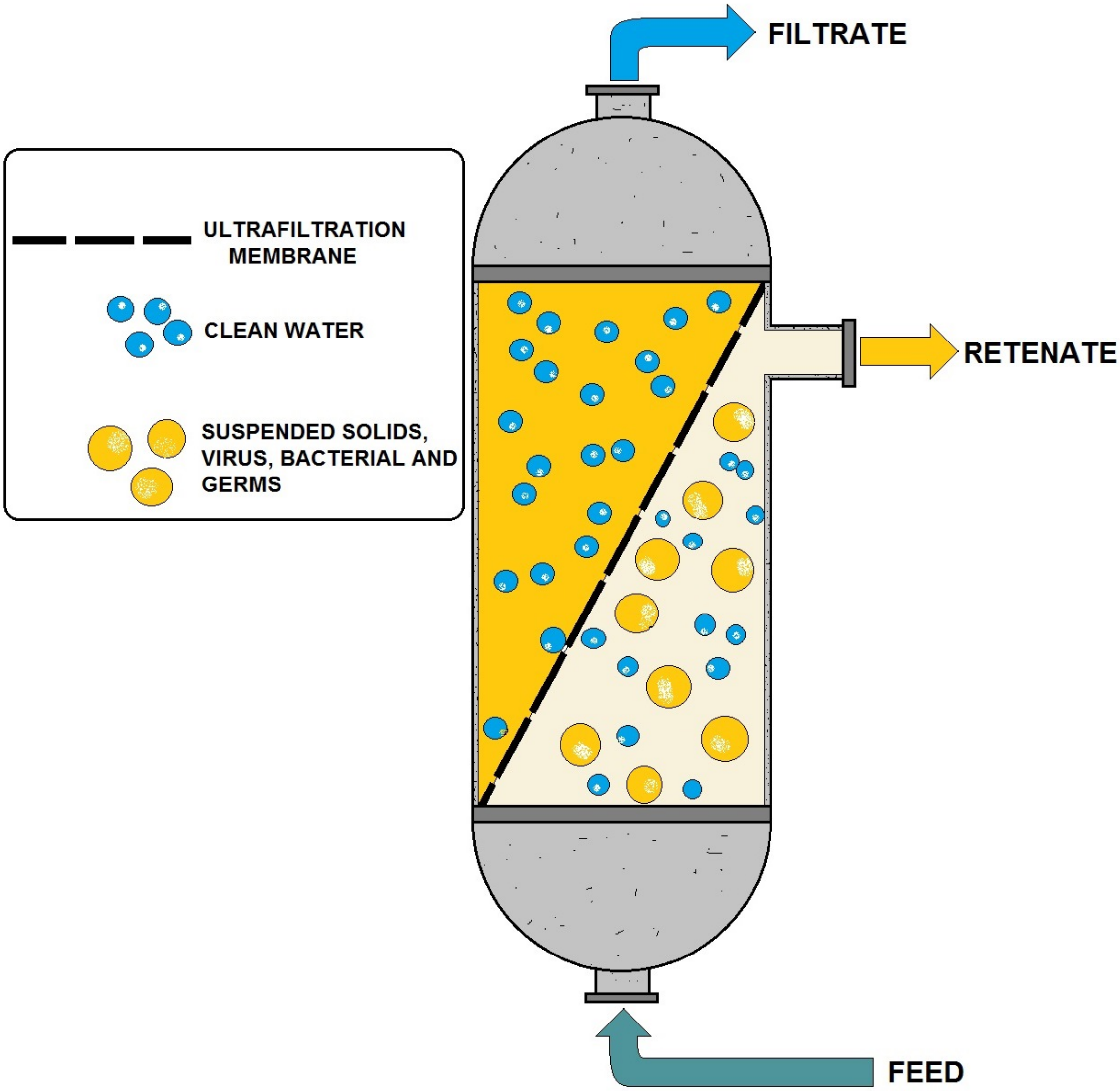
ELECTROLYSIS

(SPLITTING OF H2O WITH ELECTRICITY TO PRODUCE H2 & O2)



CAPACITIVE DEIONIZATION PROCESS

Ultrafiltration (UF) Sub-Section



ULTRAFILTRATION MEMBRANE SYSTEM

Ultrafiltration (UF) is a variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane.

Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate. This separation process is used in industry and research for purifying and concentrating macromolecular (10^3 - 10^6 Da) solutions, especially protein solutions.

Ultrafiltration is not fundamentally different from microfiltration. Both of these separate based on size exclusion or particle capture. It is fundamentally different from membrane gas separation, which separate based on different amounts of absorption and different rates of diffusion.

Ultrafiltration membranes are defined by the molecular weight cut-off (MWCO) of the membrane used. Ultrafiltration is applied in cross-flow or dead-end mode.

An ultrafiltration (UF) membrane removes undissolved, suspended or emulsified solids from water supplies without requiring coagulation.

The particles that UF retains have a molecular weight of 1000 to 1,000,000. It is most generally used in specialized applications requiring extremely high purity water, as pretreatment prior to reverse osmosis or for removal of colloidal silica from boiler feed water. Removal includes colloidal silica, synthetic and natural organics, including taste and odor causing compounds, SOCs and natural organic compounds that can serve as precursors to trihalomethanes and other DBPs.

Ultrafiltration generally works by pumping the feeding solution under pressure over the surface of a suitably supported membrane. The pressure gradient forces solvent and smaller species through the pores of the membrane, while the larger molecules are retained. The membranes are cleaned either by backflushing alone or with the addition of a chlorine solution, which restores the original porosity and allows continuous use for indefinite periods.

There are advantages and disadvantages to types of ultrafiltration membranes and the applications they are used for.

Applications
Industries such as chemical and pharmaceutical manufacturing, food and beverage processing, and waste water treatment, employ ultrafiltration in order to recycle flow or add value to later products.

Drinking Water
UF can be used for the removal of particulates and macromolecules from raw water to produce potable water. It has been used to either replace existing secondary (coagulation, flocculation, sedimentation) and tertiary filtration (sand filtration and chlorination) systems employed in water treatment plants or as standalone systems in isolated regions with growing populations. When treating water with high suspended solids, UF is often integrated into the process, utilizing primary (screening, flotation, filtration) and some secondary treatments as pre-treatment stages. UF processes are currently preferred over traditional treatment methods for the following reasons:

- No chemicals required (aside from cleaning)
- Constant product quality regardless of feed quality
- Compact plant size
- Capable of exceeding regulatory standards of water quality, achieving 90-100% pathogen removal

UF processes are currently limited by the high cost incurred due to membrane fouling and replacement. Additional pretreatment of feed water is required to prevent excessive damage to the membrane units.

In many cases UF is used for pre filtration in reverse osmosis (RO) plants to protect the RO membranes.

Compared to traditional methods, UF processes used for this application:

- Are more energy efficient
- Have consistent product quality, 35-80% protein product depending on operating conditions
- Do not denature proteins as they use moderate operating conditions

The potential for fouling is widely discussed, being identified as a significant contributor to decline in productivity.

Concentration Polarization

When filtration occurs the local concentration of rejected material at the membrane surface increases and can become saturated. In UF, increased ion concentration can develop an osmotic pressure on the feed side of the membrane. This reduces the effective TMP of the system, therefore reducing permeation rate. The increase in concentrated layer at the membrane wall decreases the permeate flux, due to increase in resistance which reduces the driving force for solvent to transport through membrane surface. CP affects almost all the available membrane separation process.

In RO, the solutes retained at the membrane layer results in higher osmotic pressure in comparison to the bulk stream concentration. So the higher pressures are required to overcome this osmotic pressure. Concentration polarization plays a dominant role in ultrafiltration as compared to microfiltration because of the small pore size membrane. It must be noted that concentration polarization differs from fouling as it has no lasting effects on the membrane itself and can be reversed by relieving the TMP. It does however have a significant effect on many types of fouling.

Types of Fouling

Particulate Deposition

The following models describe the mechanisms of particulate deposition on the membrane surface and in the pores:

- *Standard blocking*: macromolecules are uniformly deposited on pore walls
- *Complete blocking*: membrane pore is completely sealed by a macromolecule
- *Cake filtration*: accumulated particles or macromolecules form a fouling layer on the membrane surface, in UF this is also known as a gel layer
- *Intermediate blocking*: when macromolecules deposit into pores or onto already blocked pores, contributing to cake formation

Scaling

As a result of concentration polarization at the membrane surface, increased ion concentrations may exceed solubility thresholds and precipitate on the membrane surface. These inorganic salt deposits can block pores causing flux decline, membrane degradation and loss of production. The formation of scale is highly dependent on factors affecting both solubility and concentration polarization including pH, temperature, flow velocity and permeation rate.

Biofouling

Microorganisms will adhere to the membrane surface forming a gel layer – known as biofilm. The film increases the resistance to flow, acting as an additional barrier to permeation. In spiral-wound modules, blockages formed by biofilm can lead to uneven flow distribution and thus increase the effects of concentration polarization.

Membrane Arrangements

Depending on the shape and material of the membrane, different modules can be used for ultrafiltration process. Commercially available designs in ultrafiltration modules vary according to the required hydrodynamic and economic constraints as well as the mechanical stability of the system under particular operating pressures. The main modules used in industry include:

Tubular Modules

The tubular module design uses polymeric membranes cast on the inside of plastic or porous paper components with diameters typically in the range of 5 – 25 mm with lengths from 0.6 - 6.4 m. Multiple tubes are housed in a PVC or steel shell. The feed of the module is passed through the tubes, accommodating radial transfer of permeate to the shell side. This design allows for easy cleaning however the main drawback is its low permeability, high volume hold-up within the membrane and low packing density.

Hollow Fiber

This design is conceptually similar to the tubular module with a shell and tube arrangement. A single module can consist of 50 to thousands of hollow fibers and therefore are self-supporting unlike the tubular design. The diameter of each fiber ranges from 0.2 – 3 mm with the feed flowing in the tube and the product permeate collected radially on the outside.

The advantage of having self-supporting membranes is the ease at which it can be cleaned due to its ability to be backflushed. Replacement costs however are high, as one faulty fiber will require the whole bundle to be replaced. Considering the tubes are of small diameter, using this design also makes the system prone to blockage.

Spiral-wound Modules

Are composed of a combination of flat membrane sheets separated by a thin meshed spacer material which serves as a porous plastic screen support. These sheets are rolled around a central perforated tube and fitted into a tubular steel pressure vessel casing. The feed solution passes over the membrane surface and the permeate spirals into the central collection tube.

Spiral-wound modules are a compact and cheap alternative in ultrafiltration design, offer a high volumetric throughput and can also be easily cleaned. However, it is limited by the thin channels where feed solutions with suspended solids can result in partial blockage of the membrane pores.

Plate and Frame

This uses a membrane placed on a flat plate separated by a mesh like material. The feed is passed through the system from which permeate is separated and collected from the edge of the plate.

Channel length can range from 10 – 60 cm and channel heights from 0.5 – 1 mm. This module provides low volume hold-up, relatively easy replacement of the membrane and the ability to feed viscous solutions because of the low channel height, unique to this particular design.

Factor	Hollow Fiber	Spiral-wound	Ceramic Tubular
pH	2-13	2-11	3-7
Feed Pressure (psi)	9-15	<30-120	60-100
Backwash Pressure (psi)	9-15	20-40	10-30
Temperature (°C)	5-30	5-45	5-400
Total Dissolved Solids (mg/L)	<1000	<600	<500
Total Suspended Solids (mg/L)	<500	<450	<300
Turbidity (NTU)	<15	<1	<10
Iron (mg/L)	<5	<5	<5
Oils and Greases (mg/L)	<0.1	<0.1	<0.1
Solvents, phenols (mg/L)	<0.1	<0.1	<0.1

Process Characteristics

The process characteristics of a UF system are highly dependent on the type of membrane used and its application. Manufacturers' specifications of the membrane tend to limit the process to the following typical specifications:

Process Design Considerations

When designing a new membrane separation facility or considering its integration into an existing plant, there are many factors which must be considered. For most applications a heuristic approach can be applied to determine many of these characteristics to simplify the design process. Some design areas include:

Pre-treatment

Treatment of feed prior to the membrane is essential to prevent damage to the membrane and minimize the effects of fouling which greatly reduce the efficiency of the separation. Types of pre-treatment are often dependent on the type of feed and its quality. For example, in wastewater treatment, household waste and other particulates are screened. Other types of pre-treatment common to many UF processes include pH balancing and coagulation. Appropriate sequencing of each pre-treatment phase is crucial in preventing damage to subsequent stages. Pre-treatment can even be employed simply using dosing points.

Membrane Specifications

Material

Most UF membranes use polymer materials (polysulfone, polypropylene, cellulose acetate, polylactic acid) however ceramic membranes are used for high temperature applications.

Pore size

A general rule for choice of pore size in a UF system is to use a membrane with a pore size one tenth that of the particle size to be separated. This limits the number of smaller particles entering the pores and adsorbing to the pore surface. Instead they block the entrance to the pores allowing simple adjustments of cross-flow velocity to dislodge them.

Operation strategy

Flow type

UF systems can either operate with cross-flow or dead-end flow. In dead-end filtration the flow of the feed solution is perpendicular to the membrane surface. On the other hand, in cross flow systems the flow passes parallel to the membrane surface.

Dead-end configurations are more suited to batch processes with low suspended solids as solids accumulate at the membrane surface therefore requiring frequent backflushes and cleaning to maintain high flux. Cross-flow configurations are preferred in continuous operations as solids are continuously flushed from the membrane surface resulting in a thinner cake layer and lower resistance to permeation.

Flow velocity

Flow velocity is especially critical for hard water or liquids containing suspensions in preventing excessive fouling. Higher cross-flow velocities can be used to enhance the sweeping effect across the membrane surface therefore preventing deposition of macromolecules and colloidal material and reducing the effects of concentration polarization. Expensive pumps are however required to achieve these conditions.

Flow Temperature

To avoid excessive damage to the membrane, it is recommended to operate a plant at the temperature specified by the membrane manufacturer. In some instances, however temperatures beyond the recommended region are required to minimize the effects of fouling. Economic analysis of the process is required to find a compromise between the increased cost of membrane replacement and productivity of the separation.

Pressure

Pressure drops over multi-stage separation can result in a drastic decline in flux performance in the latter stages of the process. This can be improved using booster pumps to increase the TMP in the final stages. This will incur a greater capital and energy cost which will be offset by the improved productivity of the process.

With a multi-stage operation, retentate streams from each stage are recycled through the previous stage to improve their separation efficiency.

Multi-Stage, Multi-Module

Multiple stages in series can be applied to achieve higher purity permeate streams. Due to the modular nature of membrane processes, multiple modules can be arranged in parallel to treat greater volumes.

Post-treatment

Post-treatment of the product streams is dependent on the composition of the permeate and retentate and its end-use or government regulation. In cases such as milk separation both streams (milk and whey) can be collected and made into useful products.

Additional drying of the retentate will produce whey powder. In the paper mill industry, the retentate (non-biodegradable organic material) is incinerated to recover energy and permeate (purified water) is discharged into waterways. It is essential for the permeate water to be pH balanced and cooled to avoid thermal pollution of waterways and altering its pH.

Cleaning

Cleaning of the membrane is done regularly to prevent the accumulation of foulants and reverse the degrading effects of fouling on permeability and selectivity.

Regular backwashing is often conducted every 10 min for some processes to remove cake layers formed on the membrane surface. By pressurizing the permeate stream and forcing it back through the membrane, accumulated particles can be dislodged, improving the flux of the process.

Backwashing is limited in its ability to remove more complex forms of fouling such as biofouling, scaling or adsorption to pore walls.

These types of foulants require chemical cleaning to be removed. The common types of chemicals used for cleaning are:

- Acidic solutions for the control of inorganic scale deposits
- Alkali solutions for removal of organic compounds
- Biocides or disinfection such as Chlorine or peroxide when bio-fouling is evident

Cleaning Procedure

Cleaning Time

Adequate time must be allowed for chemicals to interact with foulants and permeate into the membrane pores. However, if the process is extended beyond its optimum duration it can lead to denaturation of the membrane and deposition of removed foulants. The complete cleaning cycle including rinses between stages may take as long as 2 hours to complete.

Aggressiveness of Chemical Treatment

With a high degree of fouling it may be necessary to employ aggressive cleaning solutions to remove fouling material. However, in some applications this may not be suitable if the membrane material is sensitive, leading to enhanced membrane ageing.

Disposal of Cleaning Effluent

The release of some chemicals into wastewater systems may be prohibited or regulated therefore this must be considered. For example, the use of phosphoric acid may result in high levels of phosphates entering water ways and must be monitored and controlled to prevent eutrophication.

Point-of-Use Water Treatment Section 3 Post Quiz

Microfiltration Section

1. Filtration is the separation of two or more components from a fluid stream. _____________acts as a selective barrier, allowing the passage of certain components and retaining others components of a mixture. The most common membrane processes are microfiltration, ultrafiltration, and hyperfiltration (reverse osmosis).

A. A filtration membrane
B. Fractional distillation
C. Large molecules, or ions
D. A selective barrier
E. Thermal separation method(s)
F. None of the Above

Types of Processes

2. _________________ operate without heating and therefore use less energy than conventional thermal separation processes such as distillation, sublimation or crystallization. The separation process is purely physical and both fractions (permeate and retentate) can be used.

A. Brackish groundwater
B. Macromolecule(s)
C. Membrane separation processes
D. Conventional thermal separation process(es)
E. RO membrane(s)
F. None of the Above

3. ________________using membrane technology is widely used in the food technology, biotechnology and pharmaceutical industries. Using membranes enables separations to take place that would be impossible using thermal separation methods.

A. The recovery of organic vapor(s)
B. Fractional distillation
C. Cold separation
D. A selective barrier
E. Thermal separation method(s)
F. None of the Above

4. It is impossible to separate the constituents of azeotropic liquids or solutes which form isomorphic crystals by distillation or recrystallization but such separations can be achieved using ___________.

A. Brackish groundwater
B. Macromolecule(s)
C. Membrane technology
D. Conventional thermal separation process(es)
E. RO membrane(s)
F. None of the Above

5. Important technical applications include the production of drinking water by _______________ (worldwide approximately 7 million cubic meters annually), filtrations in the food industry, the recovery of organic vapors such as petro-chemical vapor recovery and the electrolysis for chlorine production.

A. The recovery of organic vapor(s)
B. Fractional distillation
C. Reverse osmosis
D. A selective barrier
E. Thermal separation method(s)
F. None of the Above

6. In waste water treatment, membrane technology is becoming increasingly important. With the help of _______________ it is possible to remove particles, colloids and macromolecules, so that waste-water can be disinfected in this way.

A. Ultra/microfiltration
B. Macromolecule(s)
C. Solute(s)
D. Conventional thermal separation process(es)
E. RO membrane(s)
F. None of the Above

7. Many azeotropic mixtures of pairs of compounds are known, and many azeotropes of three or more compounds are also known. In such a case it is not possible to separate the components by _______________. There are two types of azeotropes: minimum boiling azeotrope and maximum boiling azeotrope.

A. The recovery of organic vapor(s)
B. Fractional distillation
C. Large molecules, or ions
D. A selective barrier
E. Thermal separation method(s)
F. None of the Above

Ultrafiltration

8. Ultrafiltration (**UF**) is a process that uses a membrane with a pore size generally below 0.1 µm. The smaller pore size is designed to remove colloids and substances that have larger molecules, which are called___________.

A. Reverse osmosis or RO
B. Potable water treatment
C. High-molecular-weight materials
D. Direct filtration process
E. Microfiltration or MF
F. None of the Above

9. UF membranes can be designed to pass material that weigh less than or______________ .

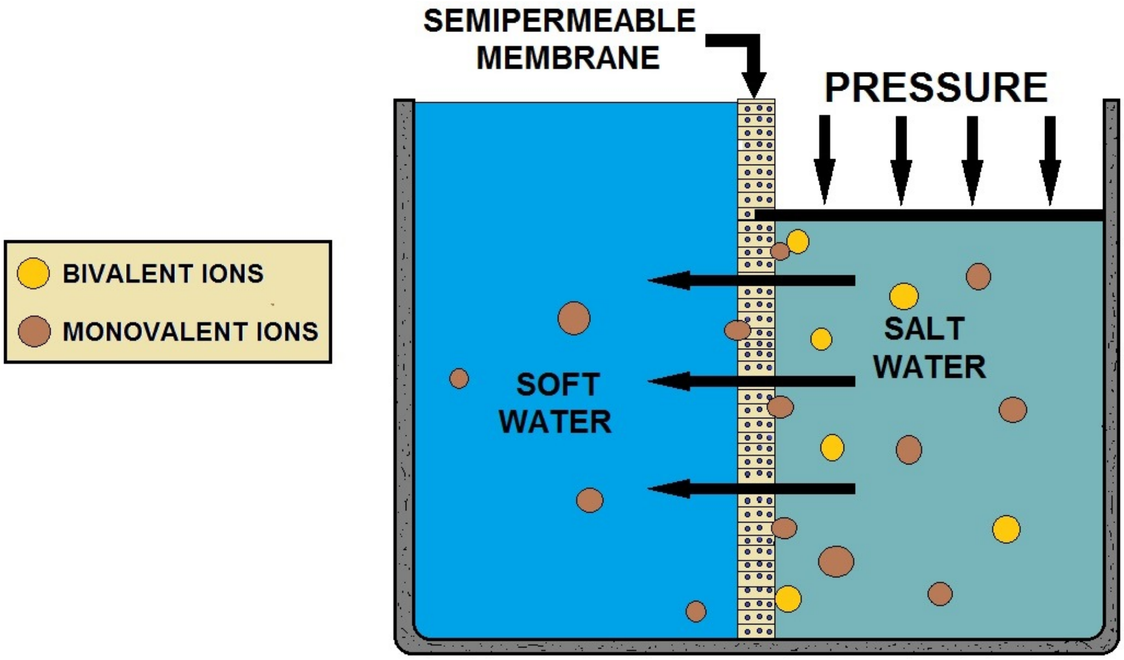
A. Process liquid
B. Chloride and sodium
C. Total dissolved solids (TDS)
D. Material
E. Equal to a certain molecular weight
F. None of the Above

10. This weight is called the molecular weight cutoff (MWC) of the membrane. Although UF does not generally work well for removal of________, it can be used effectively for removal or most organic chemicals.

A. Process liquid
B. Chloride and sodium
C. Total dissolved solids (TDS)
D. Material
E. Salt or dissolved solids
F. None of the Above

Answers are in the rear before the references.

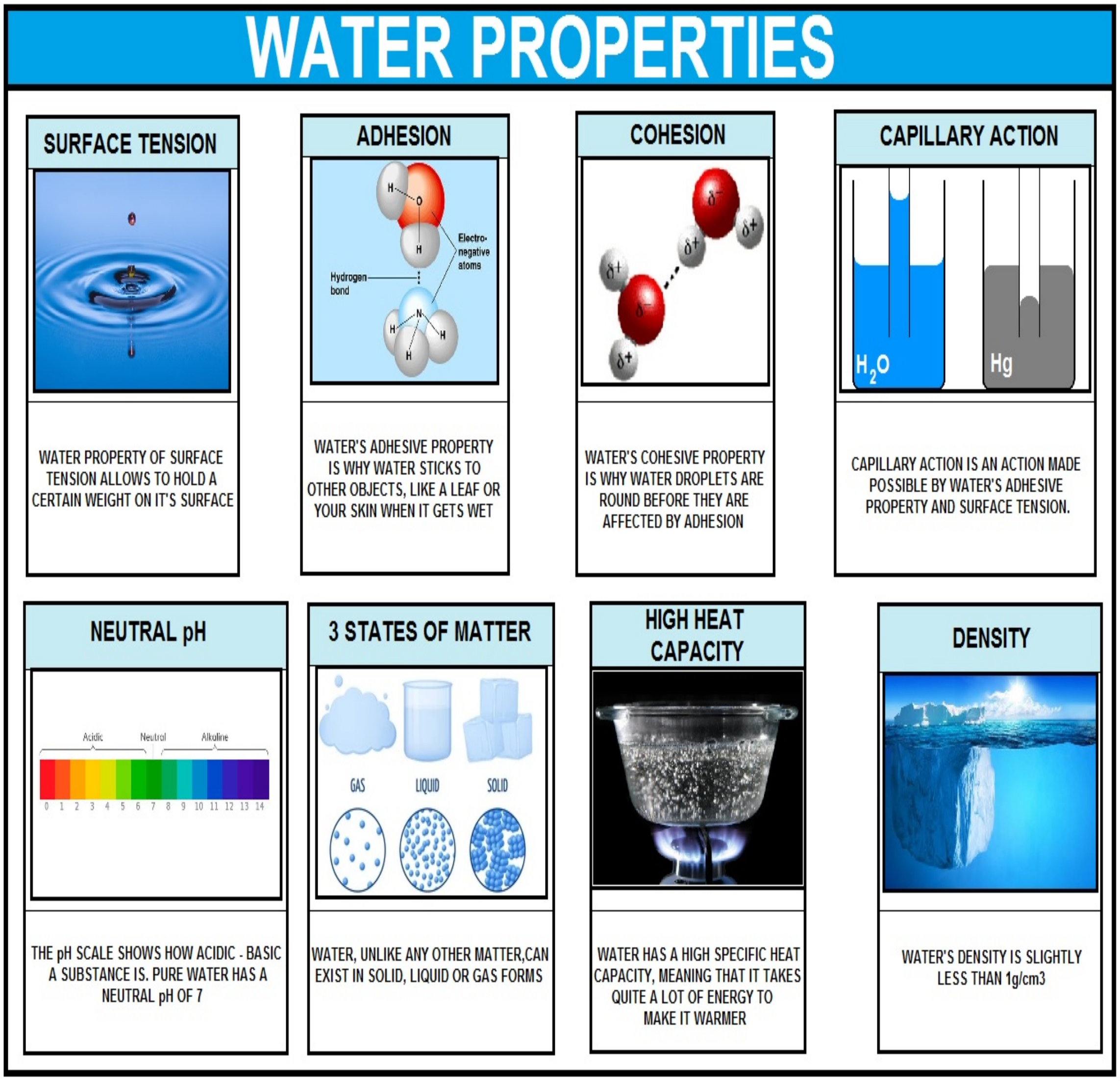
Nanofiltration (NF) Section 4



NANOFILTRATION

In this section, the student will understand and explain Nanofiltration treatment methods and terminology.

a. Range of Application
b. Spiral Wound Module
c. Performance Parameters
d. Van der waals
e. Anisotropic



WATER PROPERTIES

SURFACE TENSION

WATER PROPERTY OF SURFACE TENSION ALLOWS TO HOLD A CERTAIN WEIGHT ON IT'S SURFACE

ADHESION

WATER'S ADHESIVE PROPERTY IS WHY WATER STICKS TO OTHER OBJECTS, LIKE A LEAF OR YOUR SKIN WHEN IT GETS WET

COHESION

WATER'S COHESIVE PROPERTY IS WHY WATER DROPLETS ARE ROUND BEFORE THEY ARE AFFECTED BY ADHESION

CAPILLARY ACTION

CAPILLARY ACTION IS AN ACTION MADE POSSIBLE BY WATER'S ADHESIVE PROPERTY AND SURFACE TENSION.

NEUTRAL pH

THE pH SCALE SHOWS HOW ACIDIC - BASIC A SUBSTANCE IS. PURE WATER HAS A NEUTRAL pH OF 7

3 STATES OF MATTER

WATER, UNLIKE ANY OTHER MATTER,CAN EXIST IN SOLID, LIQUID OR GAS FORMS

HIGH HEAT CAPACITY

WATER HAS A HIGH SPECIFIC HEAT CAPACITY, MEANING THAT IT TAKES QUITE A LOT OF ENERGY TO MAKE IT WARMER

DENSITY

WATER'S DENSITY IS SLIGHTLY LESS THAN 1g/cm3

PROPERTIES OF WATER

Nanofiltration

Nanofiltration is a relatively recent membrane filtration process used most often with low total dissolved solids water such as surface water and fresh groundwater, with the purpose of softening (polyvalent cation removal) and removal of disinfection by-product precursors such as natural organic matter and synthetic organic matter.

Nanofiltration is also becoming more widely used in food processing applications such as dairy, for simultaneous concentration and partial (monovalent ion) demineralization.

Nanofiltration is a membrane filtration-based method that uses nanometer sized cylindrical through-pores that pass through the membrane at 90°.

Nanofiltration membranes have pore sizes from 1-10 nanometers, smaller than that used in **microfiltration** and **ultrafiltration**, but just larger than that in reverse osmosis. Membranes used are predominantly created from polymer thin films. Materials that are commonly use include polyethylene terephthalate or metals such as aluminum. Pore dimensions are controlled by pH, temperature and time during development with pore densities ranging from 1 to 106 pores per cm^2.

Membranes made from polyethylene terephthalate and other similar materials, are referred to as “track-etch” membranes, named after the way the pores on the membranes are made.

“Tracking” involves bombarding the polymer thin film with high energy particles. This results in making tracks that are chemically developed into the membrane, or “etched” into the membrane, which are the pores. Membranes created from metal such as alumina membranes, are made by electrochemically growing a thin layer of aluminum oxide from aluminum metal in an acidic medium.

Range of Applications

Historically, nanofiltration and other membrane technology used for molecular separation was applied entirely on aqueous systems. The original uses for nanofiltration were water treatment and in particular water softening. Nanofilters can “soften” water by retaining scale-forming, hydrated divalent ions (e.g. Ca^{2+}, Mg^{2+}) while passing smaller hydrated monovalent ions.

In recent years, the use of nanofiltration has been extended into other industries such as milk and juice production. Research and development in solvent-stable membranes has allowed the application for nanofiltration membranes to extend into new areas such as pharmaceuticals, fine chemicals, and flavor and fragrance industries. Development in organic solvent nanofiltration technology and commercialization of membranes used has extended possibilities for applications in a variety of organic solvents ranging from non-polar through polar to polar aprotic.

Advantages and Disadvantages

One of the main advantages of nanofiltration as a method of softening water is that during the process of retaining calcium and magnesium ions while passing smaller hydrated monovalent ions, filtration is performed without adding extra sodium ions, as used in ion exchangers.

Many separation processes do not operate at room temperature (e.g. distillation), which greatly increases the cost of the process when continuous heating or cooling is applied. Performing gentle molecular separation is linked with nanofiltration that is often not included with other forms of separation processes (centrifugation). These are two of the main benefits that are associated with nanofiltration.

Nanofiltration has a very favorable benefit of being able to process large volumes and continuously produce streams of have a Nanofiltration is the least used method of membrane filtration in industry as the membrane pores sizes are limited to only nanometers. Anything smaller, reverse osmosis is used and anything larger is used for ultrafiltration.

Ultrafiltration can also be used in cases where nanofiltration can be used, due to it being more conventional. A main disadvantage associated with nanotechnology, as with all membrane filter technology, is the cost and maintenance of the membranes used.

Nanofiltration membranes are an expensive part of the process. Repairs and replacement of membranes is dependent on total dissolved solids, flow rate and components of the feed. With nanofiltration being used across various industries, only an estimation of replacement frequency can be used. This causes nanofilters to be replaced a short time before or after their prime usage is complete.

Design and Operation

Industrial applications of membranes require hundreds to thousands of square meters of membranes and therefore an efficient way to reduce the footprint by packing them is required. Membranes first became commercially viable when low cost methods of housing in ‘modules’ were achieved. Membranes are not self-supporting. They need to be stayed by a porous support that can withstand the pressures required to operate the NF membrane without hindering the performance of the membrane.

To do this effectively, the module needs to provide a channel to remove the membrane permeation and provide appropriate flow condition that reduces the phenomena of concentration polarization. A good design minimizes pressure losses on both the feed side and permeate side and thus energy requirements. Leakage of the feed into the permeate stream must also be prevented. This can be done through either the use of permanent seals such as glue or replaceable seals such as O-rings.

Concentration Polarization

Concentration polarization describes the accumulation of the species being retained close to the surface of the membrane which reduces separation capabilities. It occurs because the particles are convected towards the membrane with the solvent and its magnitude is the balance between this convection caused by solvent flux and the particle transport away from the membrane due to the concentration gradient (predominantly caused by diffusion.) Although concentration polarization is easily reversible, it can lead to fouling of the membrane.

Spiral Wound Module

Spiral wound modules are the most commonly used style of module and are ‘standardized’ design, available in a range of standard diameters (2.5”, 4” and 8”) to fit standard pressure vessel that can hold several modules in series connected by O-rings.

The module uses flat sheets wrapped around a central tube. The membranes are glued along three edges over a permeate spacer to form ‘leaves’.

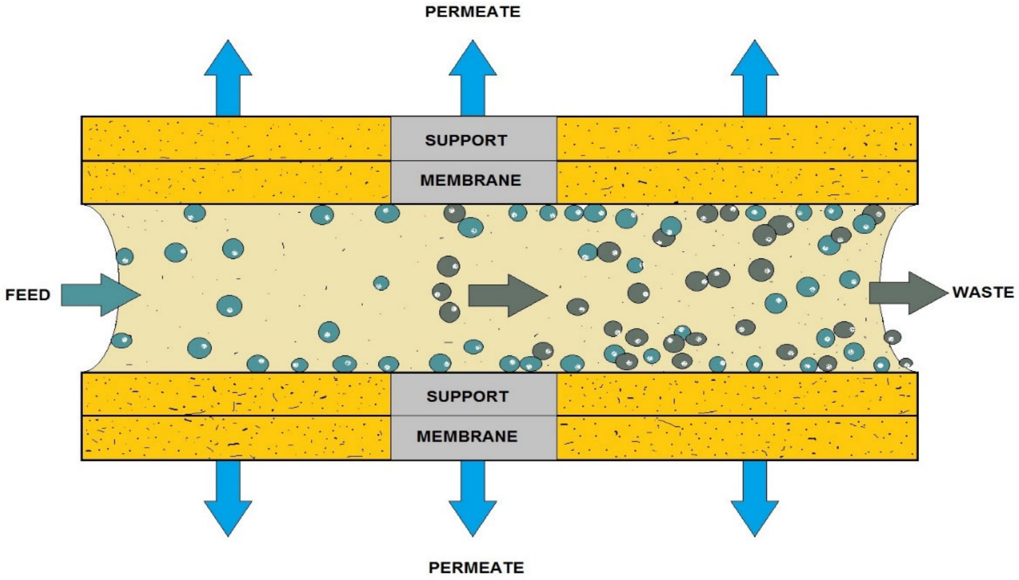
The permeate spacer supports the membrane and conducts the permeate to the central permeate tube. Between each leaf, a mesh like feed spacer is inserted. The reason for the mesh like dimension of the spacer is to provide a hydrodynamic environment near the surface of the membrane that discourages concentration polarization.

Once the leaves have been wound around the central tube, the module is wrapped in a casing layer and caps placed on the end of the cylinder to prevent ‘telescoping’ that can occur in high flow rate and pressure conditions.

Tubular Module

Tubular modules look similar to shell and tube heat exchangers with bundles of tubes with the active surface of the membrane on the inside. Flow through the tubes is normally turbulent, ensuring low concentration polarization but also increasing energy costs. The tubes can either be self-supporting or supported by insertion into perforated metal tubes. This module design is limited for nanofiltration by the pressure they can withstand before bursting, limiting the maximum flux possible.

Due to both the high energy operating costs of turbulent flow and the limiting burst pressure, tubular modules are more suited to ‘dirty’ applications where feeds have particulates such as filtering raw water to gain potable water in the Fyne process. The membranes can be easily cleaned through a ‘pigging’ technique with foam balls are squeezed through the tubes, scouring the caked deposits.



TUBULAR MEMBRANE FILTRATION

Flux Enhancing Strategies

These strategies work to reduce the magnitude of concentration polarization and fouling. There is a range of techniques available however the most common is feed channel spacers as described in spiral wound modules. All of the strategies work by increasing eddies and generating a high shear in the flow near the membrane surface. Some of these strategies include vibrating the membrane, rotating the membrane, having a rotor disk above the membrane, pulsing the feed flow rate and introducing gas bubbling close to the surface of the membrane.

Characterization

Many different factors must be taken into account in the design of NF membranes, since they vary so much in material, separation mechanisms, morphology and thus application. Two important parameters should be investigated during preliminary calculations, performance and morphology parameters.

Performance Parameters

Retention of both charged and uncharged solutes and permeation measurements can be categorized into performance parameters since the performance under natural conditions of a membrane is based on the ratio of solute retained/ permeated through the membrane.

For charged solutes, the ionic distribution of salts near the membrane-solution interface plays an important role in determining the retention characteristic of a membrane.

If the charge of the membrane and the composition and concentration of the solution to be filtered is known, the distribution of various salts can be found. This in turn can be combined with the known charge of the membrane and the Gibbs–Donnan effect to predict the retention characteristics for that membrane.

Uncharged solutes cannot be characterized simply by Molecular Weight Cut Off (MWCO,) although in general an increase in molecular weight or solute size leads to an increase in retention. The chemical structure, functional end-groups as well as pH of the solute, all play an important role in determining the retention characteristics and as such detailed information about the solute molecule characteristics must be known before implementing a NF design.

Molecular weight cut-off or **MWCO** refers to the lowest molecular weight solute (in daltons) in which 90% of the solute is retained by the membrane, or the molecular weight of the molecule (e.g. globular protein) that is 90% retained by the membrane.

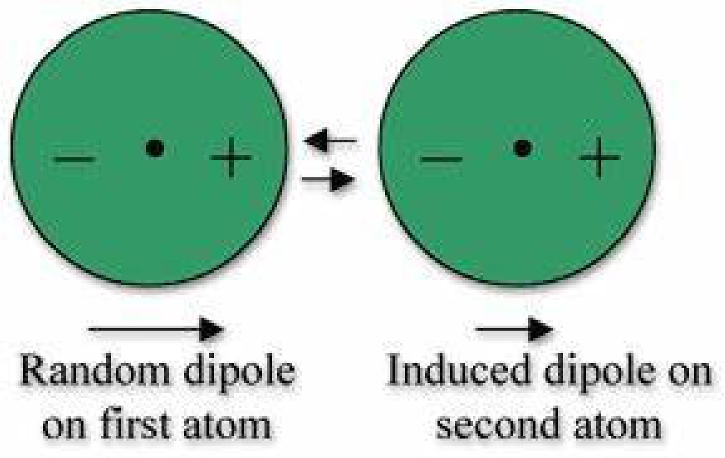
This definition is not however standardized, and MWCOs can also be defined as the molecular weight at which 80% of the analytes (or solutes) are prohibited from membrane diffusion. Commercially available microdialysis probes typically have molecular weight cutoffs that range from 1,000 to 300,000 Da, and larger thresholds of filtration are measured in µm.

Morphology Parameters

The morphology of a membrane must also be known in order to implement a successful design of a NF system, and this is usually done by microscopy. Atomic force microscopy (AFM) is one method used to characterize the surface roughness of a membrane by passing a small sharp tip (<100 Ă) across the surface of a membrane and measuring the resulting Van der Waals force between the atoms in the end of the tip and the surface. This is useful as a direct correlation between surface roughness and colloidal fouling has been developed.

Correlations also exist between fouling and other morphology parameters, such as hydrophobe, showing that the more hydrophobic a membrane is, the less prone to fouling it is. Methods to determine the porosity of porous membranes have also been found via permporometry, making use of differing vapor pressures to characterize the pore size and pore size distribution within the membrane.

Initially all pores in the membrane are completely filled with a liquid and as such no permeation of a gas occurs, but after reducing the relative vapor pressure some gaps will start to form within the pores as dictated by the Kelvin equation. Polymeric (non-porous) membranes cannot be subjected to this methodology as the condensable vapor should have a negligible interaction within the membrane



Van der Waals
Van der Waals forces include attraction and repulsions between atoms, molecules, and surfaces, as well as other intermolecular forces. They differ from covalent and ionic bonding in that they are caused by correlations in the fluctuating polarizations of nearby particles (a consequence of quantum dynamics).

Intermolecular forces have four major contributions:

1. A repulsive component resulting from the Pauli exclusion principle that prevents the collapse of molecules.
2. Attractive or repulsive electrostatic interactions between permanent charges (in the case of molecular ions), dipoles (in the case of molecules without inversion center), quadrupoles (all molecules with symmetry lower than cubic), and in general between permanent multipoles. The electrostatic interaction is sometimes called the Keesom interaction or Keesom force after Willem Hendrik Keesom.
3. Induction (also known as polarization), which is the attractive interaction between a permanent multipole on one molecule with an induced multipole on another. This interaction is sometimes called Debye force after Peter J.W. Debye.
4. Dispersion (usually named after Fritz London), which is the attractive interaction between any pair of molecules, including non-polar atoms, arising from the interactions of instantaneous multipoles.

Returning to nomenclature, different texts refer to different things using the term "van der Waals force." Some texts describe the van der Waals force as the totality of forces (including repulsion); others mean all the attractive forces (and then sometimes distinguish van der Waals-Keesom, van der Waals-Debye, and van der Waals-London).

Anisotropic
All intermolecular/van der Waals forces are anisotropic (except those between two noble gas atoms), which means that they depend on the relative orientation of the molecules. The induction and dispersion interactions are always attractive, irrespective of orientation, but the electrostatic interaction changes sign upon rotation of the molecules. That is, the electrostatic force can be attractive or repulsive, depending on the mutual orientation of the molecules.

When molecules are in thermal motion, as they are in the gas and liquid phase, the electrostatic force is averaged out to a large extent, because the molecules thermally rotate and thus probe both repulsive and attractive parts of the electrostatic force. Sometimes this effect is expressed by the statement that "random thermal motion around room temperature can usually overcome or disrupt them" (which refers to the electrostatic component of the van der Waals force).

Clearly, the thermal averaging effect is much less pronounced for the attractive induction and dispersion forces. The Lennard-Jones potential is often used as an approximate model for the isotropic part of a total (repulsion plus attraction) van der Waals force as a function of distance.

Van der Waals forces are responsible for certain cases of pressure broadening (van der Waals broadening) of spectral lines and the formation of van der Waals molecules. The London-van der Waals forces are related to the Casimir effect for dielectric media, the former being the microscopic description of the latter bulk property. The first detailed calculations of this were done in 1955 by E. M. Lifshitz. A more general theory of van der Waals forces has also been developed.

The main characteristics of van der Waals forces are:
- They are weaker than normal covalent ionic bonds.
- Van der Waals forces are additive and cannot be saturated.
- They have no directional characteristic.
- They are all short-range forces and hence only interactions between nearest need to be considered instead of all the particles. The greater is the attraction if the molecules are closer due to Van der Waals forces.
- Van der Waals forces are independent of temperature except dipole - dipole interactions.

Nanofiltration (NF) Section 4 Post Quiz

1. Nanofiltration is also becoming more widely used in food processing applications such as dairy, for ______________and partial (monovalent ion) demineralization.

A. Process liquid
B. Chloride and sodium
C. Material
D. Natural organic matter and synthetic organic matter
E. Simultaneous concentration
F. None of the Above

2. Materials that are commonly use include polyethylene terephthalate or metals such as aluminum. ____________ are controlled by pH, temperature and time during development with pore densities ranging from 1 to 106 pores per cm^2.

A. Gentle molecular separation
B. Method of softening water
C. Solvent-stable membrane(s)
D. Pore dimensions
E. Tracking
F. None of the Above

3. Membranes made from polyethylene terephthalate and other similar materials, are referred to as___________ , named after the way the pores on the membranes are made.

A. Track-etch" membrane(s)
B. Membrane(s)
C. Nanofilter(s)
D. Organic solvent nanofiltration technology
E. Nanofiltration
F. None of the Above

Range of Applications

4. Historically, nanofiltration and other membrane technology used for molecular separation was applied entirely on aqueous systems. The original uses for nanofiltration were water treatment and in particular ____________________.

A. Gentle molecular separation
B. Method of softening water
C. Solvent-stable membrane(s)
D. Water softening
E. Tracking
F. None of the Above

5. _____________can "soften" water by retaining scale-forming, hydrated divalent ions (e.g. Ca^{2+}, Mg^{2+}) while passing smaller hydrated monovalent ions.

A. Track-etch" membrane(s)
B. Membrane(s)
C. Nanofilter(s)
D. Organic solvent nanofiltration technology
E. Nanofiltration
F. None of the Above

6. Research and development in _______________has allowed the application for nanofiltration membranes to extend into new areas such as pharmaceuticals, fine chemicals, and flavor and fragrance industries.

A. Gentle molecular separation
B. Method of softening water
C. Solvent-stable membrane(s)
D. Water softening
E. Tracking
F. None of the Above

7. Development in organic solvent nanofiltration technology and ___________used has extended possibilities for applications in a variety of organic solvents ranging from non-polar through polar to polar aprotic.

A. Track-etch" membrane(s)
B. Membrane(s)
C. Nanofilter(s)
D. Commercialization of membranes
E. Nanofiltration
F. None of the Above

Advantages and Disadvantages

8. One of the main advantages of nanofiltration as a method of softening water is that during the process of retaining calcium and magnesium ions while passing smaller hydrated monovalent ions, filtration is performed without adding extra sodium ions, as used in_________________ .

A. Gentle molecular separation
B. Method of softening water
C. Ion exchangers
D. Water softening
E. Tracking
F. None of the Above

9. __________________has a very favorable benefit of being able to process large volumes and continuously produce streams of have a Nanofiltration is the least used method of membrane filtration in industry as the membrane pores sizes are limited to only nanometers.

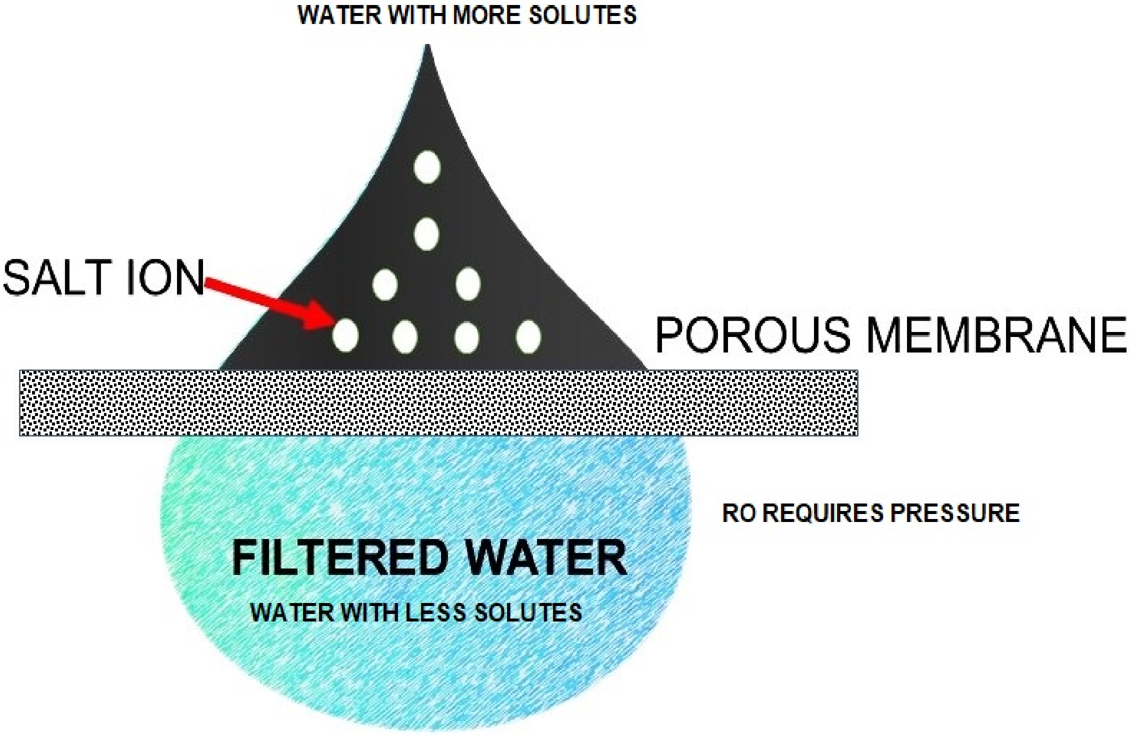
A. Reverse osmosis or RO
B. Potable water treatment
C. Nanofiltration
D. Direct filtration process
E. Microfiltration or MF
F. None of the Above

10. Anything smaller, reverse osmosis is used and anything larger is used for _____________.

A. Ultrafiltration
B. Potable water treatment
C. NF
D. Direct filtration process
E. Microfiltration or MF
F. None of the Above

Answers are found at the rear before the references.

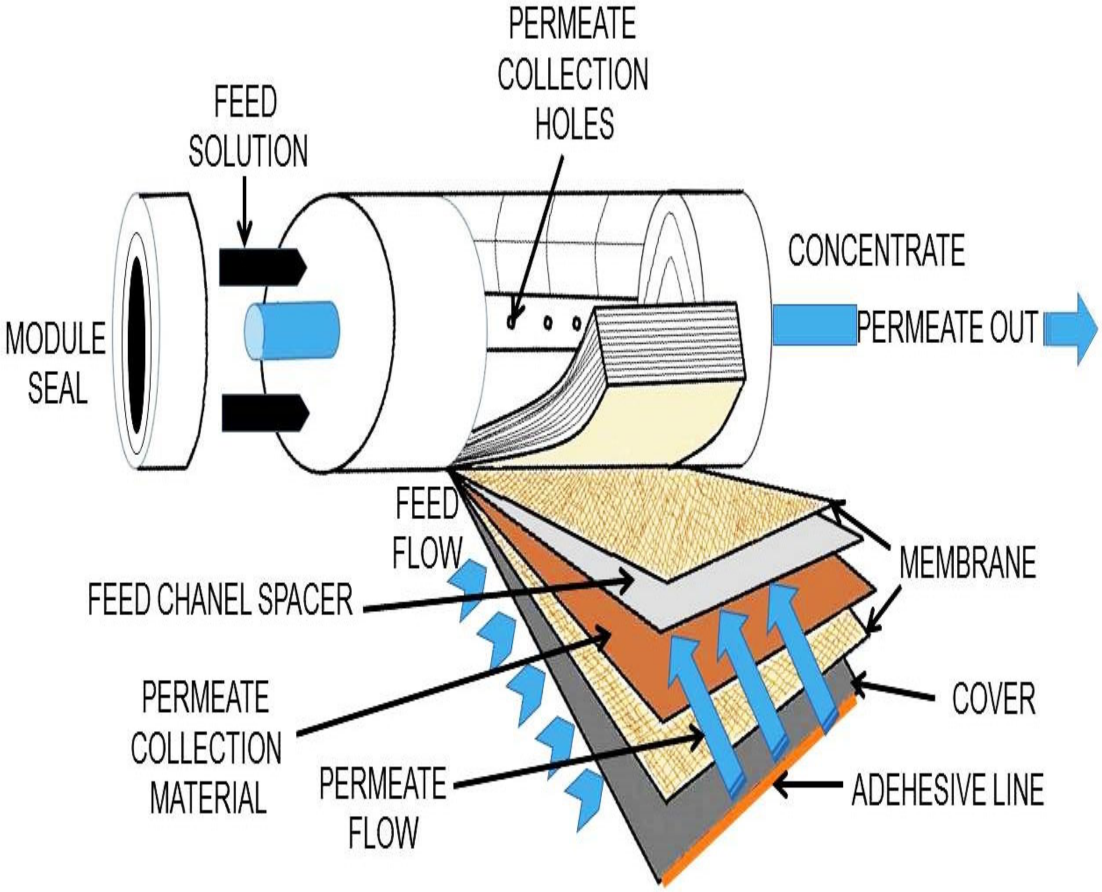
Osmotic Processes Section 5



OSMOSIS PROCESS DIAGRAM # 1

In this section, the student will understand and explain Forward and Reverse Osmosis treatment methods and terminology.

a. Forward Osmosis
b. Reverse Osmosis
c. Brine Channel
d. R/O Components
e. Clean-in-place System



REVERSE OSMOSIS MEMBRANE

Forward Osmosis (FO)

Osmotic processes manipulate the osmotic pressure gradient between solutions. Osmotic processes include reverse osmosis (RO), forward osmosis (FO), pressure enhanced osmosis (PEO) and pressure retarded osmosis (PRO).

Forward osmosis (FO) is an osmotic process that, like reverse osmosis (RO), uses a semi-permeable membrane to effect separation of water from dissolved solutes. The driving force for this separation is an osmotic pressure gradient, such that a "draw" solution of high concentration (relative to that of the feed solution), is used to induce a net flow of water through the membrane into the draw solution, thus effectively separating the feed water from its solutes. In contrast, the reverse osmosis process uses hydraulic pressure as the driving force for separation, which serves to counteract the osmotic pressure gradient that would otherwise favor water flux from the permeate to the feed. Hence significantly more energy is required for reverse osmosis compared to forward osmosis.

In FO processes we may have solute diffusion in both directions depending on the composition of the draw solution and the feed water. This does two things; the draw solution solutes may diffuse to the feed solution and the feed solution solutes may diffuse to the draw solution. Clearly, this phenomenon has consequences in terms of the selection of the draw solution for any particular FO process. For instance, the loss of draw solution may affect the feed solution perhaps due to environmental issues or contamination of the feed stream, such as in osmotic membrane bioreactors.

An additional distinction between the reverse osmosis (RO) and forward osmosis (FO) processes is that the permeate water resulting from an RO process is in most cases fresh water ready for use. In the FO process, this is not the case. The membrane separation of the FO process in effect results in a "trade" between the solutes of the feed solution and the draw solution.

Depending on the concentration of solutes in the feed (which dictates the necessary concentration of solutes in the draw) and the intended use of the product of the FO process, this step may be all that is required.

The forward osmosis process is also known as osmosis or in the case of a number of companies who have coined their own terminology 'engineered osmosis' and 'manipulated osmosis'.

FO Summary

Forward osmosis (FO) is an osmotic process that uses a semi-permeable membrane to effect separation of water from dissolved solutes. The driving force for this separation is an osmotic pressure gradient between a solution of high concentration, often referred to as a “draw” and a solution of lower concentration, referred to as the “feed”.

The osmotic pressure gradient is used to induce a net flow of water through the membrane into the draw, thus effectively concentrating the feed. The draw solution can consist of a single or multiple simple salts or can be a substance specifically tailored for forward osmosis applications. The feed solution can be a dilute product stream, a waste stream or seawater.

Most of the applications of FO, thus fall into three broad categories: product concentration, waste concentration or production of clean water as a bi-product of the concentration process. The most efficient FO applications combine all three. At its best, FO can concentrate waste, turning waste into a product all while producing clean water.

The Forward Osmosis process has applications in many different industries, including but not limited to: Water Reuse and Desalination; Food and Beverage; Mining; Oil and Gas; and the Power Industry.

FO Applications in Different Industries:

- ✓ Water Reuse
- ✓ Water Desalination
- ✓ Brine Concentration
- ✓ Product concentration (examples: juice, chemicals)
- ✓ Produced water treatment

RO produces clean water, FO produces clean draw, while PRO produces power.

Distinction Between RO and FO Processes

A major distinction between the RO and FO processes is that the water permeating the RO process is, in most cases, fresh water ready for use. In the FO process, this is not the case.

The membrane separation of the FO process in effect results in a “trade” between the solutes of the feed solution and the draw solution.

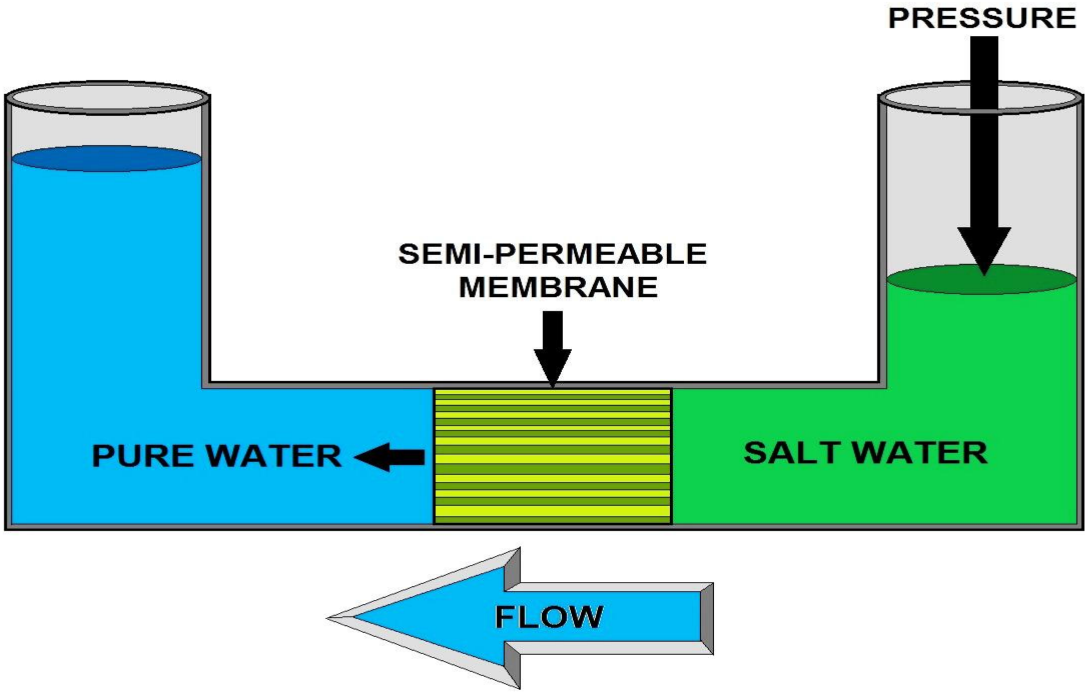
- ✓ Pressure Retarded Osmosis (PRO) may be used to convert salinity gradient into power.
- ✓ Forward osmosis is not a replacement for reverse osmosis.

In some applications FO complements RO. In others, specialized draw or salt is concentrated using different technologies. FO can also be used without the draw concentration step as an FO Concentrator if a brine stream with high osmotic pressure is available.

FO can concentrate waters with higher total dissolved solids (TDS) than RO using a high osmotic draw.

- ✓ Membranes used for RO do not work well for FO.
- ✓ Different materials and membrane structure are required to achieve good membrane productivity.
- ✓ FO fouls less than RO.

In contrast with forward osmosis, the reverse osmosis process uses hydraulic pressure as the driving force for separation, which serves to counteract the osmotic pressure gradient that would otherwise favor water flux from the permeate to the feed. One of the reasons that FO membranes are considerably less prone to fouling than membranes used in pressure driven processes is the absence of external pressure which compacts foulants into the membrane surface restricting flow.



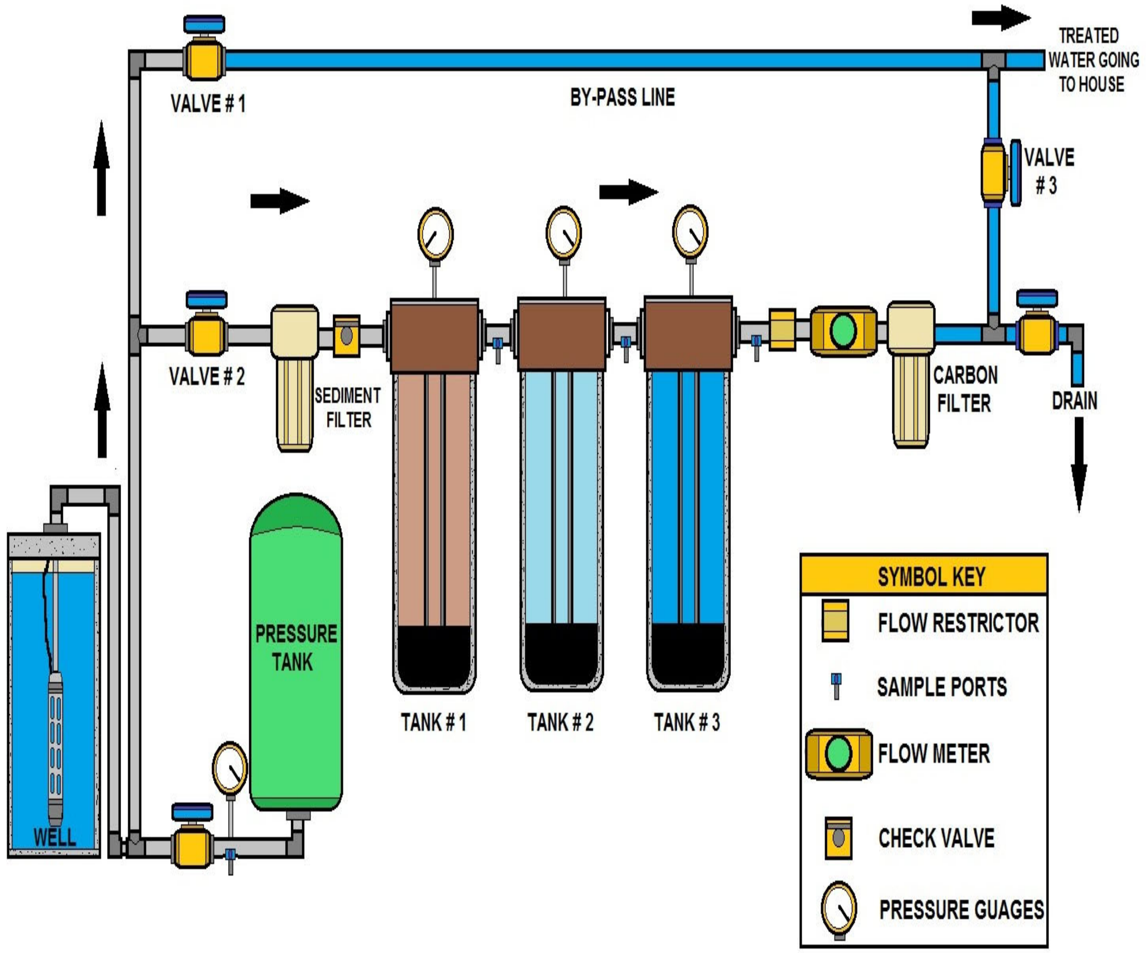
REVERSE OSMOSIS

Reverse Osmosis and Nanofiltration processes work in a similar way to an extremely fine filter but use a *"membrane"* to remove atoms which are larger than water molecules.

The mechanism requires sophisticated pumping and control. RO is therefore used to remove a wide range of contaminants, typically salts, hardness and large organic molecules where a very high level of purity is required. It is, of course, more expensive than conventional filtration and is used only where high purity is essential.

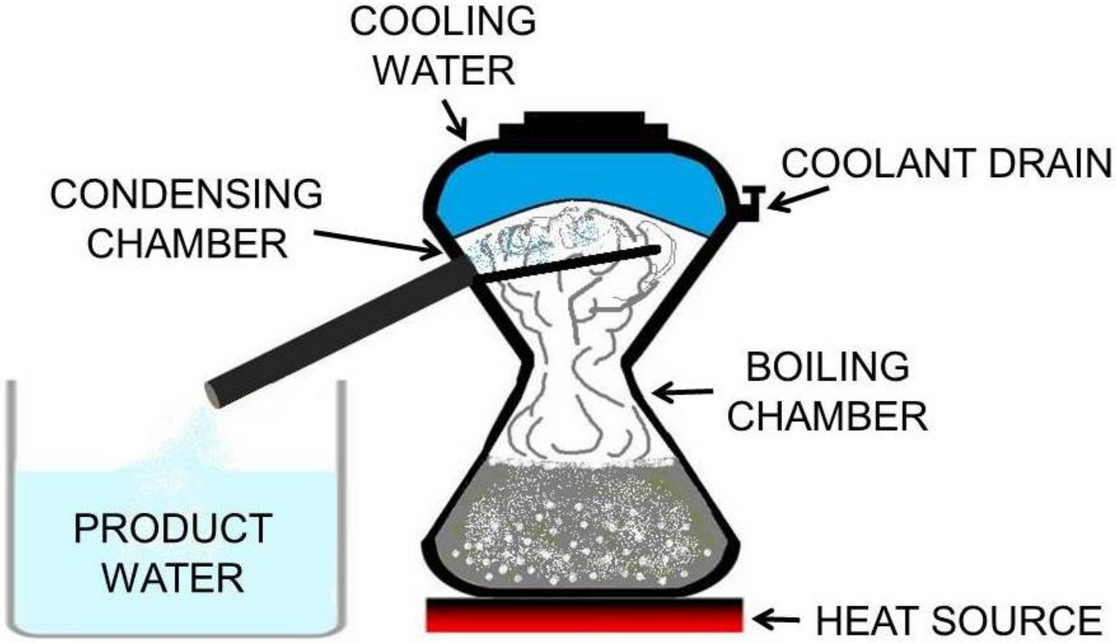
Disadvantages of using ultrafiltration, nanofiltration or reverse osmosis to treat water?

Reverse osmosis removes a number of healthy minerals from water, in addition to the harmful minerals and particles. The removal of these minerals, including calcium and magnesium, can actually make water unhealthy, especially for people with inadequate diets and people who live in hot climates, as water can provide these necessary minerals. The addition of calcium and magnesium, as described above, can resolve these concerns.



ARSENIC REMOVAL SYSTEM
(Point-Of-Entry)

Desalination



DESALINATION –DISTILLATION PROCESS

Desalinated water can be produced from the diluted draw / osmotic agent solution, using a second process. This may be by membrane separation, thermal method, physical separation or a combination of these processes. The process has the feature of inherently low fouling because of the forward osmosis first step, unlike conventional reverse osmosis desalination plants where fouling is often a problem.

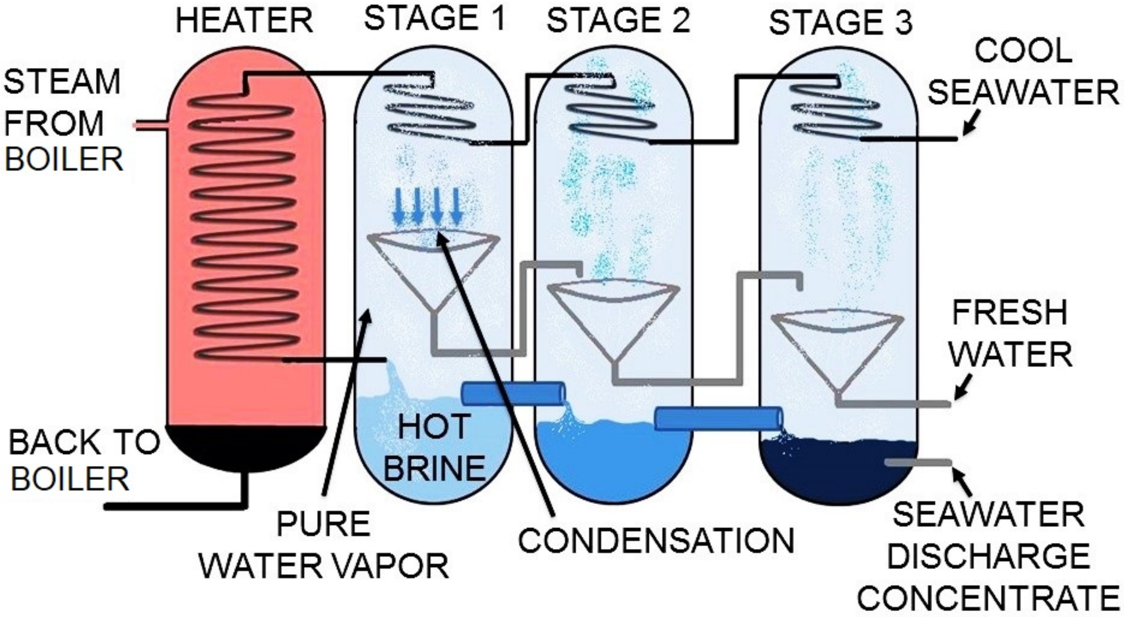
One other application developed, where only the forward osmosis step is used, is in evaporative cooling make-up water. In this case the cooling water is the draw solution and the water lost by evaporation is simply replaced using water produced by forward osmosis from a suitable source, such as seawater, brackish water, treated sewage effluent or industrial waste water. Thus in comparison with other 'desalination' processes that may be used for make-up water the energy consumption is a fraction of these with the added advantage of the low fouling propensity of a forward osmosis process.

Landfill Leachate Treatment

In the case where the desired product is fresh water which does not contain draw solutes, a second separation step is required. The first separation step of FO, driven by an osmotic pressure gradient, does not require a significant energy input (only unpressurized stirring or pumping of the solutions involved). The second separation step, however does typically require energy input. One method used for the second separation step is to employ RO. This approach has been used, for instance, in the treatment of landfill leachate. An FO membrane separation is used to draw water from the leachate feed into a saline (NaCl) brine. The diluted brine is then passed through a RO process to produce fresh water and a reusable brine concentrate. The advantage of this method is not a savings in energy, but rather in the fact that the FO process is more resistant to fouling from the leachate feed than a RO process alone.

Brine Concentration

Brine concentration using forward osmosis may be achieved using a high osmotic pressure draw solution with a means to recover and regenerate it. One unexploited application is to 'soften' or pre-treat the feedwater to multi stage flash (MSF) or multiple effect distillation (MED) plants by osmotically diluting the recirculating brine with the cooling water. This reduces the concentrations of scale forming calcium carbonate and calcium sulfate compared to the normal process, thus allowing an increase in top brine temperature (TBT), output and gained output ratio (GOR). Darwish et al. showed that the TBT could be raised from 110 °C to 135 °C whilst maintaining the same scaling index for calcium sulfate.

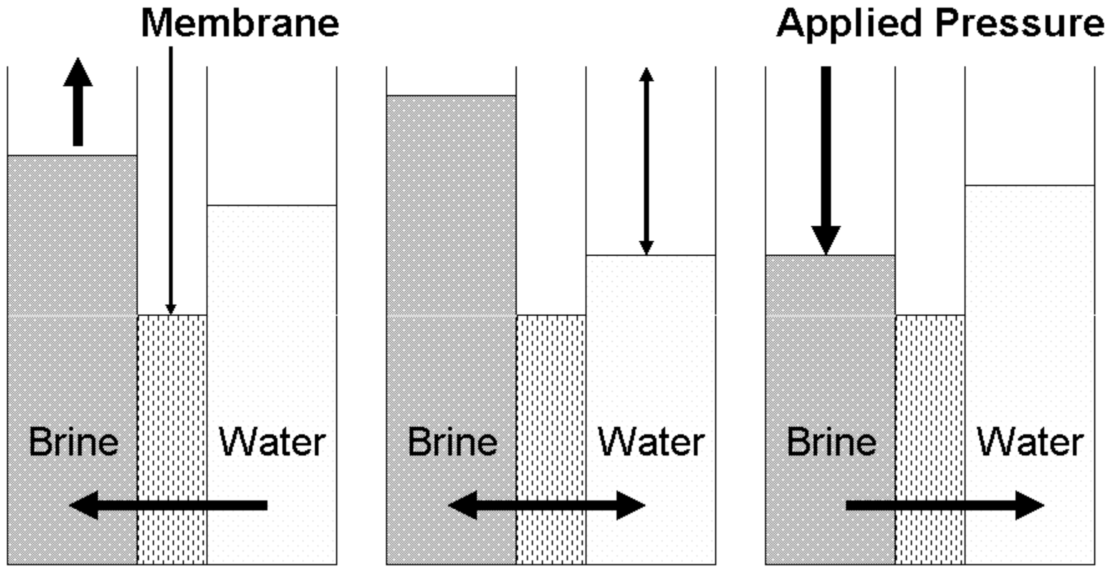


MULTISTAGE FLASH DISTILLATION PROCESS

Detailed Reverse Osmosis Process Sub-Section

Osmosis is a natural phenomenon in which a liquid - water in this case - passes through a semi-permeable membrane from a relatively dilute solution toward a more concentrated solution. This flow produces a measurable pressure, called osmotic pressure. If pressure is applied to the more concentrated solution, and if that pressure exceeds the osmotic pressure, water flows through the membrane from the more concentrated solution toward the dilute solution.

This process, called reverse osmosis, or RO, removes up to 98% of dissolved minerals, and virtually 100% of colloidal and suspended matter. RO produces high quality water at relatively low cost compared to other purifications processes.



Osmosis
Water flows from low to high concentration.

Equilibrium
Osmotic pressure stops water flow.

Reverse Osmosis
Greater pressure will reverse water flow.

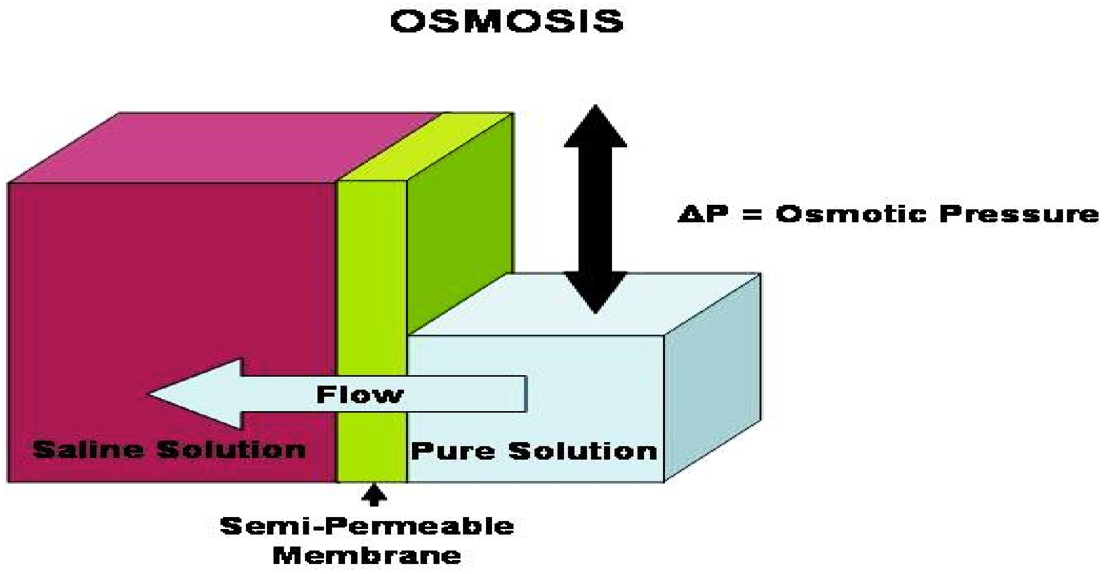
The membrane must be physically strong to stand up to high osmotic pressure - in the case of sea water, 2500 kg/m. Most membranes are made of cellulose acetate or polyamide composites cast into a thin film, either as a sheet or fine hollow fibers. The membrane is constructed into a cartridge called a reverse osmosis module.

After filtration to remove suspended particles, incoming water is pressurized with a pump to 200 - 400 psi (1380 - 2760 kPa) depending on the RO system model. This exceeds the water's osmotic pressure.

A portion of the water (**permeate**) diffuses through the membrane leaving dissolved salts and other contaminants behind with the remaining water where they are sent to drain as waste (**concentrate**).

Pretreatment is important because it influences permeate quality and quantity. It also affects the module's life because many water-borne contaminants can deposit on the membrane and foul it. Generally, the need for pretreatment increases as systems become larger and operate at higher pressures, and as permeate quality requirements become more demanding. Because reverse osmosis is the principal membrane filtration process used in water treatment, it is described here in greater detail.

To understand Reverse Osmosis, one must begin by understanding the process of osmosis, which occurs in nature. In living things, osmosis is frequently seen. The component parts include a pure or relatively pure water solution and a saline or contaminated water solution, separated by a semi-permeable membrane, and a container or transport mechanism of some type.



The semi-permeable membrane is so designated because it permits certain elements to pass through, while blocking others. The elements that pass through include water, usually smaller molecules of dissolved solids, and most gases. The dissolved solids are usually further restricted based on their respective electrical charge.

In osmosis, naturally occurring in living things, the pure solution passes through the membrane until the osmotic pressure becomes equalized, at which point osmosis ceases. The osmotic pressure is defined as the pressure differential required to stop osmosis from occurring. This pressure differential is determined by the total dissolved solids content of the saline solution, or contaminated solution on one side of the membrane.

The higher the content of dissolved solids, the higher the osmotic pressure. Each element that may be dissolved in the solution contributes to the osmotic pressure, in that the molecular weight of the element affects the osmotic pressure.

Generally, higher molecular weights result in higher osmotic pressures. Hence the formula for calculating osmotic pressure is very complex. However, approximate osmotic pressures are usually sufficient to design a system.

Common tap water as found in most areas may have an osmotic pressure of about 10 PSI (Pounds per Square Inch), or about 1.68 Bar. Seawater at 36,000 PPM typically has an osmotic pressure of about 376 PSI (26.75 Bar).

Thus, to reach the point at which osmosis stops for tap water, a pressure of 10 PSI would have to be applied to the saline solution, and to stop osmosis in seawater, a pressure of 376 PSI would have to be applied to the seawater side of the membrane.

Several decades ago, U.S. Government scientists had the idea that the principles of osmosis could be harnessed to purify water from various sources, including brackish water and seawater. In order to transform this process into one that purifies water, osmosis would have to be reversed, and suitable synthetic membrane materials would have to be developed. Additionally, ways of configuring the membranes would have to be engineered to handle a continuous flow of raw and processed water without clogging or scaling the membrane material.

These ideas were crystallized, and fueled by U.S. Government funding, usable membrane materials and designs resulted. One of the membrane designs was the spiral wound membrane element. This design enabled the engineers to construct a membrane element that could contain a generous amount of membrane area in a small package, and to permit the flow of raw water to pass along the length of the membrane. This permits flows and pressures to be developed to the point that ample processed or purified water is produced, while keeping the membrane surface relatively free from particulate, colloidal, bacteriological or mineralogical fouling.

The design features a perforated tube in the center of the element, called the product or permeate tube. Wound around this tube are one or more "**envelopes**" of membrane material, opening at the permeate tube. Each envelope is sealed at the incoming and exiting edge. Thus, when water penetrates or permeates though the membrane, it travels, aided by a fine mesh called the permeate channel, around the spiral and collects in the permeate tube. The permeate or product water is collected from the end of each membrane element, and becomes the product or result of the purification process.

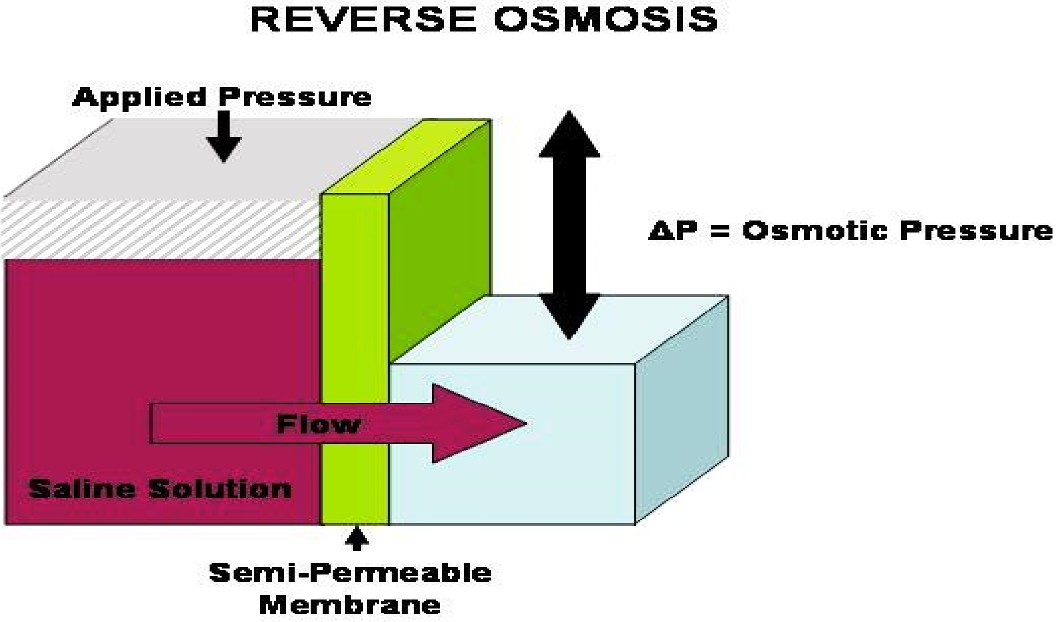
Brine Channel

Meanwhile, as the raw water flows along the "**brine channel**" or coarse medium provided to facilitate good flow characteristics, it gets more and more concentrated. This concentrated raw water is called the reject stream or concentrate stream. It may also be called brine if it is coming from a salt water source. The concentrate, when sufficient flows are maintained, serves to carry away the impurities removed by the membrane, thus keeping the membrane surface clean and functional. This is important, as buildup on the membrane surface, called fouling, impedes or even prevents the purification process.

The membrane material itself is a special thin film composite (**TFC**) polyamide material, cast in a microscopically thin layer on another, thicker cast layer of Polysulfone, called the microporous support layer. The microporous support layer is cast on sheets of paper-like material that are made from synthetic fibers such as polyester, and manufactured to the required tolerances.

Each sheet of membrane material is inspected at special light tables to ensure the quality of the membrane coating, before being assembled into the spiral wound element design.

To achieve Reverse Osmosis, the osmotic pressure must be exceeded, and to produce a reasonable amount of purified water, the osmotic pressure is generally doubled. Thus with seawater osmotic pressure of 376 PSI, a typical system operating pressure is about 800 PSI. Factors that affect the pressure required include raw water temperature, raw water TDS (Total Dissolved Solids), membrane age, and membrane fouling. The effect of temperature is that with higher temperatures, the salt passage increases, flux (permeate flow) increases, and operating pressure required is lower. With lower temperatures, the inverse occurs, in that salt passage decreases (reducing the TDS in the permeate or product water), while operating pressures increase. Or, if operating pressures do not increase, then the amount of permeate or product water is reduced.



In general, Reverse Osmosis (**R/O**) systems are designed for raw water temperatures of 25° C (77° F). Higher temperatures or lower temperatures can be accommodated with appropriate adjustments in the system design.

Membranes are available in "***standard rejection***" or "***high rejection***" models for seawater and brackish water. The rejection rate is the percentage of dissolved solids rejected, or prevented from passing through the membrane. For example, a membrane with a rejection rate of 99% (usually based on Na (Sodium)) will allow only 1% of the concentration of dissolved solids to pass through into the permeate. Hence, product water from a source containing 10,000 PPM would have 100 PPM remaining.

Of course, as the raw water is processed, the concentrations of TDS increase as it passes along the membrane's length and usually multiple membranes are employed, with each membrane in series seeing progressively higher dissolved solids levels.

Typically, starting with seawater of 36,000 PPM, standard rejection membranes produce permeate below 500 PPM, while high rejection membranes under the same conditions produce drinking water TDS of below 300 PPM.

There are many considerations when designing R/O systems that competent engineers are aware of. These include optimum flows and pressures, optimum recovery rates (the percentage of permeate from a given stream of raw water), prefiltration and other pretreatment considerations, and so forth.

Membrane systems in general cannot handle the typical load of particulate contaminants without prefiltration. Often, well designed systems employ multiple stages of prefiltration, tailored to the application, including multi-media filtration and one or more stages of cartridge filtration. Usually the last stage would be 5 microns or smaller to provide sufficient protection for the membranes.

Components

R/O systems typically have the following components: A supply pump or pressurized raw water supply, prefiltration in one or more stages, chemical injection of one or more pretreatment agents, a pressure pump suited to the application, a membrane array including one or more membranes installed in one or more pressure tubes (also called R/O pressure vessels, or similar), various gauges and flow meters, a pressure regulating valve, relief valve(s) and/or safety pressure switches, and usually some form of post treatment.

Post treatment should usually include a form of sterilization such as Chlorine, Bromine, Ultra-Violet (UV), or Ozone. Other types of post treatment may include carbon filters, pH adjustment, or mineral injection for some applications.

Packaged portable skid unit complete with treatment, instrumentation, UV, and softening.

Clean-In-Place" (CIP) System

Some very low cost R/O systems may dispense with most of the controls and instruments. However, systems installed in critical applications should be equipped with a permeate or product flow meter, a reject, concentrate or brine flow meter, multiple pressure gauges to indicate the pressure before and after each filtration device, and the system operation pressure in the membrane loop, preferably both before and after the membrane array. Another feature found in better systems is a provision to clean the membranes in place, commonly known as a "*Clean In Place*" (CIP) system. Such a system may be built right into the R/O system or may be provided as an attachment for use as required.

Reverse Osmosis has proved to be the most reliable and cost effective method of desalinating water, and hence its use has become more and more widespread. Energy consumption is usually some 70% less than for comparable evaporation technologies. Advancements have been made in membrane technology, resulting in stable, long lived membrane elements.

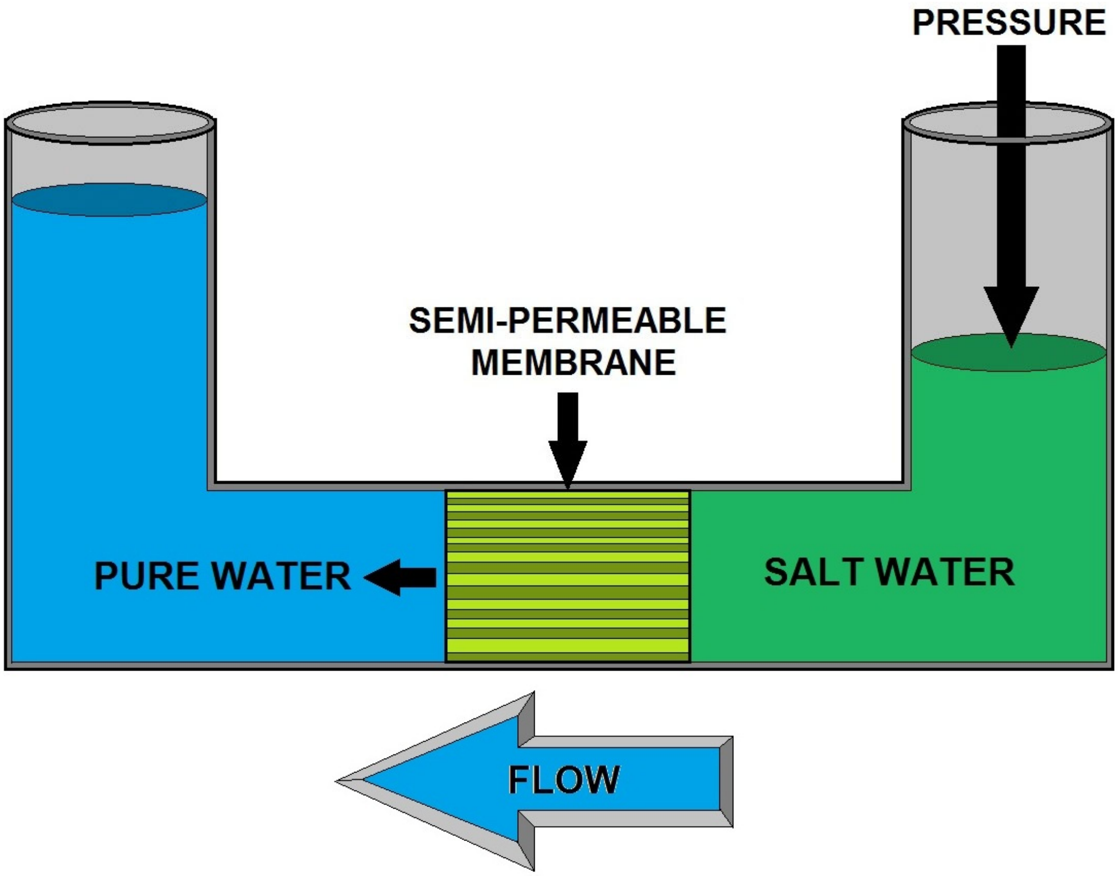
Component parts have been improved as well, reducing maintenance and down time. Additional advancements in pretreatment have been made in recent years, further extending membrane life and improving performance. Reverse Osmosis delivers product water or permeate having essentially the same temperature as the raw water source (an increase of 1° C or 1.8° F may occur due to pumping and friction in the piping). This is more desirable than the hot water produced by evaporation technologies. R/O Systems can be designed to deliver virtually any required product water quality. For these and other reasons, R/O is usually the preferred method of desalination today.

Reverse osmosis, also known as hyperfiltration, is the finest filtration known. This process will allow the removal of particles as small as ions from a solution. Reverse osmosis is used to purify water and remove salts and other impurities in order to improve the color, taste, or properties of the fluid. It can be used to purify fluids such as ethanol and glycol, which will pass through the reverse osmosis membrane, while rejecting other ions and contaminants from passing. The most common use for reverse osmosis is in purifying water. It is used to produce water that meets the most demanding specifications that are currently in place.

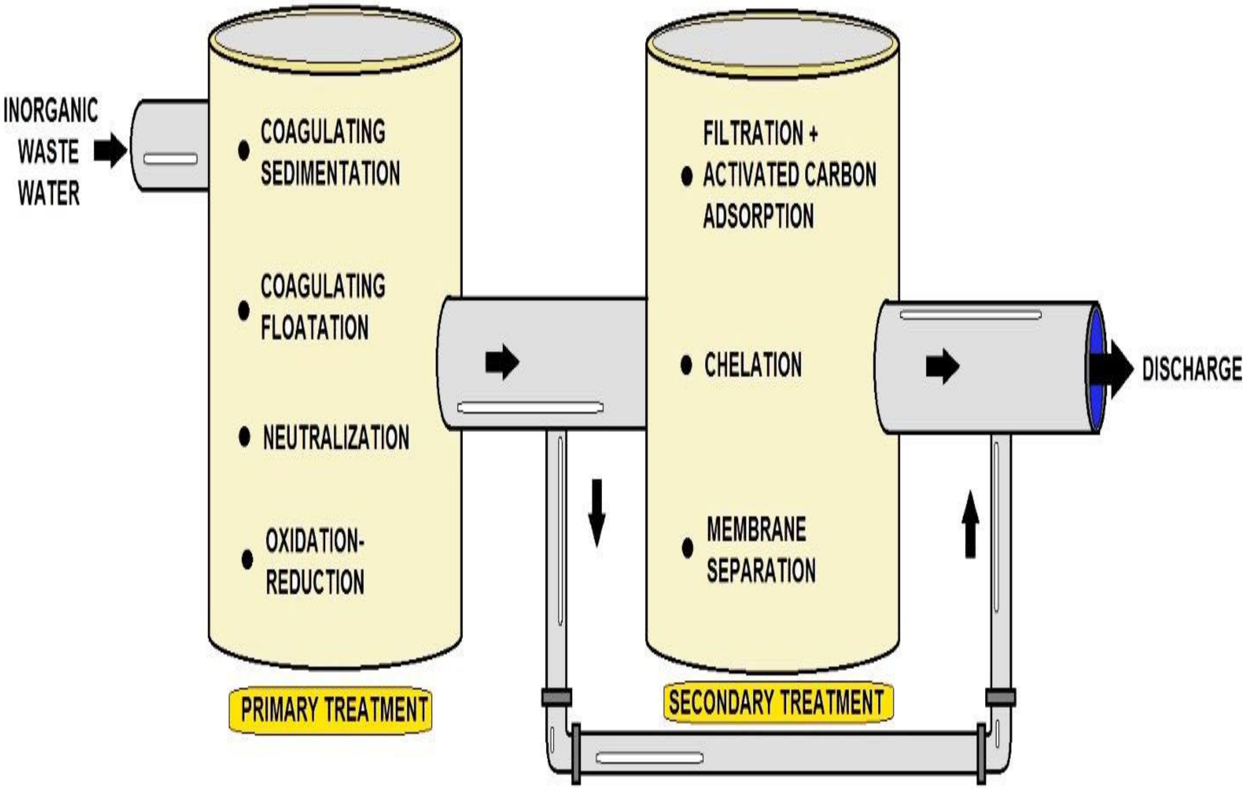
Reverse osmosis uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. Most reverse osmosis technology uses a process known as cross-flow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane. The process of reverse osmosis requires a driving force to push the fluid through the membrane, and the most common force is pressure from a pump. The higher the pressure, the larger the driving force. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases.

Reverse osmosis is capable of rejecting bacteria, salts, sugars, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 daltons. The separation of ions with reverse osmosis is aided by charged particles. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the more likely it will be rejected.

A Reverse Osmosis System removes virtually all: bad taste, odor, turbidity, organic compounds, herbicides, insecticides, pesticides, chlorine and THM's, bacteria, virus, cysts, parasites, arsenic, heavy metals, lead, cadmium, aluminum, dissolved solids, sodium, calcium, magnesium, inorganic dead dirt minerals, fluoride, sulfates, nitrates, phosphates, detergents, radioactivity and asbestos.



REVERSE OSMOSIS



PROCESS OF REMOVING INORGANIC WASTE (Flow Diagram)

Nanofiltration and Reverse Osmosis Comparisons

Nanofiltration and Reverse Osmosis are both techniques to bring into action univalent and bivalent ions.

Nanofiltration
Nanofiltration is a technique that has prospered over the past few years. Today, nanofiltration is mainly applied in drinking water purification process steps, such as water softening, decoloring and micro pollutant removal. During industrial processes nanofiltration is applied for the removal of specific components, such as coloring agents. Nanofiltration is a pressure related process, during which separation takes place, based on molecule size. Membranes bring about the separation. The technique is mainly applied for the removal of organic substances, such as micro pollutants and multivalent ions. Nanofiltration membranes have a moderate retention for univalent salts.

Other applications of nanofiltration are:

- ✓ The removal of pesticides from groundwater
- ✓ The removal of heavy metals from wastewater
- ✓ Wastewater recycling in laundries
- ✓ Water softening
- ✓ Nitrates removal

Reverse Osmosis (RO)
Reverse Osmosis is based upon the fundamental pursuit for balance. Two fluids containing different concentrations of dissolved solids that come in contact with each other will mix until the concentration is uniform. When these two fluids are separated by a semi permeable membrane (which lets the fluid flow through, while dissolved solids stay behind), a fluid containing a lower concentration will move through the membrane into the fluids containing a higher concentration of dissolved solids. (Binnie e.a., 2002)

After a while the water level will be higher on one side of the membrane. The difference in height is called the osmotic pressure.

By pursuing pressure upon the fluid column, which exceeds the osmotic pressure, one will get a reversed effect. Fluids are pressed back through the membrane, while dissolved solids stay behind in the column.

Using this technique, a larger part the salt content of the water can be removed.
1. Water flows from a column with a low dissolved solids content to a column with a high dissolved solids content
2. Osmotic pressure is the pressure that is used to stop the water from flowing through the membrane, in order to create balance
3. By pursuing pressure that exceeds the osmotic pressure, the water flow will be reversed; water flows from the column with a high dissolved solids content to the column with a low dissolved solids content

Reverse Osmosis is a technique that is mainly applied during drinking water preparation. The process of drinking water preparation from salty seawater is commonly known. Besides that, Reverse Osmosis is applied for the production of ultra-pure water and boiler feed water.

It is also applied in the food sector (concentration of fruit juice, sugar and coffee), in the galvanic industry (concentration of wastewater) and in the dairy industry (concentration of milk for cheese production).

Summarized, the applications of Reverse Osmosis application are:

- ✓ Water softening
- ✓ Drinking water production
- ✓ Process water production
- ✓ Ultra-pure water production (electronic industries)
- ✓ Concentration of molecular solvents for food and dairy industries

The pre-treatment of feed water for nanofiltration or Reverse Osmosis installations greatly influences the performance of the installation. The required form of pre-treatment depends on the feed water quality. The purpose of pre-treatment is reducing the organic matter content and the amount of bacteria, as well as lowering the MFI.

The organic matter content and the amounts of bacteria should be as low as possible to prevent the so-called biofouling of membranes.

The application of a pre-treatment has several benefits:

- ✓ Membranes have a longer life-span when pre-treatment is performed
- ✓ The production time of the installation is extended
- ✓ The management tasks become simpler
- ✓ The employment costs are lower

Next to pre-treatment one can perform a chemical dosage (acid, anti-scalent), to prevent scaling and precipitation of insoluble solids, such as calcium carbonate and barium sulfate on the membrane surface.

The applied acids are hydrochloric acid (HCl) and sulfuric acid (H2SO4).

Sulfuric acid is the most widely used chemical for this purpose. However, hydrochloric acid is applied more and more because sulfuric acid can negatively influence the fouling speed of a membrane. When the feed water contains high amounts of sulfate ions, hydrochloric acid replaces sulfuric acid. The dosage of sulfuric acid would enhance the chances of scaling by sulfate ions on the membranes in this case. (Baker, 2000)

Osmotic Processes Section 5 Post Quiz

Reverse Osmosis Process Section

1. Osmosis is a natural phenomenon in which a liquid - water in this case - passes through a semi-permeable membrane from a relatively dilute solution toward a more concentrated solution. This flow produces a_____________, called osmotic pressure.

A. Pressure differential
B. Measurable pressure
C. Higher molecular weights
D. Virtually 100% of colloidal and suspended matter
E. Waste (concentrate)
F. None of the Above

2. In osmosis, naturally occurring in living things, the pure solution passes through the membrane until the osmotic pressure becomes equalized, at which point osmosis ceases. The osmotic pressure is defined as the pressure differential required to stop osmosis from occurring. ______________is determined by the total dissolved solids content of the saline solution, or contaminated solution on one side of the membrane.

A. This pressure differential
B. Osmotic pressure
C. Higher molecular weights
D. Virtually 100% of colloidal and suspended matter
E. Waste (concentrate)
F. None of the Above

3. Common tap water as found in most areas may have an osmotic pressure of about 10 PSI (Pounds per Square Inch), or about __________________.

A. 36,000 PPM
B. A pressure of 10 PSI
C. Osmotic pressure(s)
D. 1.68 Bar
E. 376 PSI
F. None of the Above

Brine Channel

4. Meanwhile, as the raw water flows along the "brine channel" or coarse medium provided to facilitate good flow characteristics, it gets more and more concentrated. This concentrated raw water is called the reject stream or concentrate stream. It may also be called brine if it is coming from a________.

A. Each sheet of membrane material
B. Microporous support layer
C. Salt water source
D. Amount of permeate or product water
E. Concentrations of TDS
F. None of the Above

5. ________________, when sufficient flows are maintained, serves to carry away the impurities removed by the membrane, thus keeping the membrane surface clean and functional. This is important, as buildup on the membrane surface, called fouling, impedes or even prevents the purification process.

A. Pressure differential
B. Osmotic pressure
C. Higher molecular weights
D. The concentrate
E. Waste (concentrate)
F. None of the Above

Clean In Place" (CIP) System

6. ___________________ has proved to be the most reliable and cost effective method of desalinating water, and hence its use has become more and more widespread.

A. Reverse Osmosis
B. Potable water treatment
C. Nanofiltration
D. Direct filtration process
E. Microfiltration or MF
F. None of the Above

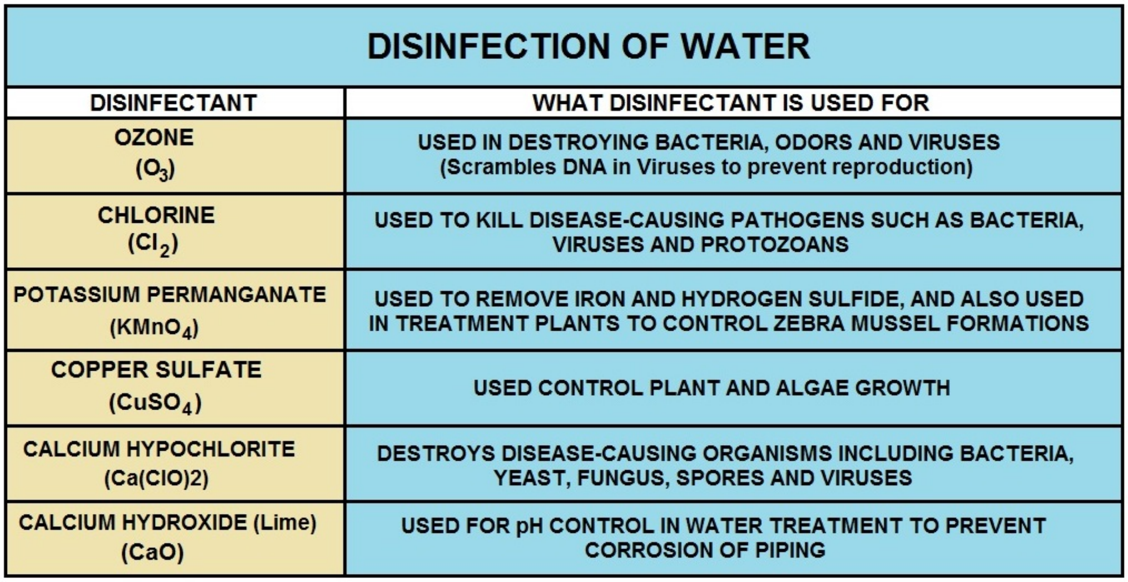
7. R/O Systems can be designed to deliver virtually any______________. For these and other reasons, R/O is usually the preferred method of desalination today.
A. Each sheet of membrane material
B. Microporous support layer
C. Required product water quality
D. Amount of permeate or product water
E. Concentrations of TDS
F. None of the Above

8. Reverse osmosis is capable of rejecting bacteria, salts, _________, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 daltons.
A. Percentage of permeate
B. Raw water
C. Seawater and brackish water
D. Sugars
E. Concentrate
F. None of the Above

9. The separation of ions with reverse osmosis is aided by__________. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the more likely it will be rejected.
A. Charged particles
B. The higher the pressure
C. A driving force
D. Purify fluid(s)
E. Cross-flow
F. None of the Above

10. A Reverse Osmosis System removes virtually all: bad taste, odor, turbidity, organic compounds, herbicides, insecticides, pesticides, chlorine and THM's, bacteria, virus, cysts, parasites, arsenic, heavy metals, lead, cadmium, aluminum, dissolved solids, sodium, calcium, magnesium, ___________________, fluoride, sulfates, nitrates, phosphates, detergents, radioactivity and asbestos.
A. Percentage of permeate
B. Raw water
C. Seawater and brackish water
D. Salt
E. Inorganic dead dirt minerals
F. None of the Above

Common Alternative Water Disinfectants Section 6



DISINFECTION OF WATER

DISINFECTANT	WHAT DISINFECTANT IS USED FOR
OZONE (O_3)	USED IN DESTROYING BACTERIA, ODORS AND VIRUSES (Scrambles DNA in Viruses to prevent reproduction)
CHLORINE (Cl_2)	USED TO KILL DISEASE-CAUSING PATHOGENS SUCH AS BACTERIA, VIRUSES AND PROTOZOANS
POTASSIUM PERMANGANATE ($KMnO_4$)	USED TO REMOVE IRON AND HYDROGEN SULFIDE, AND ALSO USED IN TREATMENT PLANTS TO CONTROL ZEBRA MUSSEL FORMATIONS
COPPER SULFATE ($CuSO_4$)	USED CONTROL PLANT AND ALGAE GROWTH
CALCIUM HYPOCHLORITE (Ca(ClO)2)	DESTROYS DISEASE-CAUSING ORGANISMS INCLUDING BACTERIA, YEAST, FUNGUS, SPORES AND VIRUSES
CALCIUM HYDROXIDE (Lime) (CaO)	USED FOR pH CONTROL IN WATER TREATMENT TO PREVENT CORROSION OF PIPING

TYPES OF DISINFECTION FOR WATER TREATMENT

In this section, the student will understand and explain Common Alternative Water Disinfectant methods and terminology.

a. Common Alternative Water Disinfectants
b. Ozone Section
c. Ozone Limitations
d. Ultraviolet Radiation
e. P.O.U. Home Treatment Methods
f. Distillers

More information on Chlorine and Bacteria Sampling in the Appendix

Chlorine

Many water suppliers add a disinfectant to drinking water to kill germs such as giardia and e coli. Especially after heavy rainstorms, your water system may add more disinfectant to guarantee that these germs are killed.

Chlorine Some people who use drinking water containing chlorine well in excess of the EPA's standard could experience irritating effects to their eyes and nose. Some people who drink water containing chlorine well in excess of EPA's standard could experience stomach discomfort.

Chloramine Some people who use drinking water containing chloramines well in excess of the EPA's standard could experience irritating effects to their eyes and nose. Some people who drink water containing chloramines well in excess of EPA's standard could experience stomach discomfort or anemia.

Chlorine Dioxide Some infants and young children who drink water containing chlorine dioxide in excess of the EPA's standard could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorine dioxide in excess of the EPA's standard. Some people may experience anemia.

Disinfection Byproducts

Disinfection byproducts form when disinfectants added to drinking water to kill germs react with naturally-occurring organic matter in water.

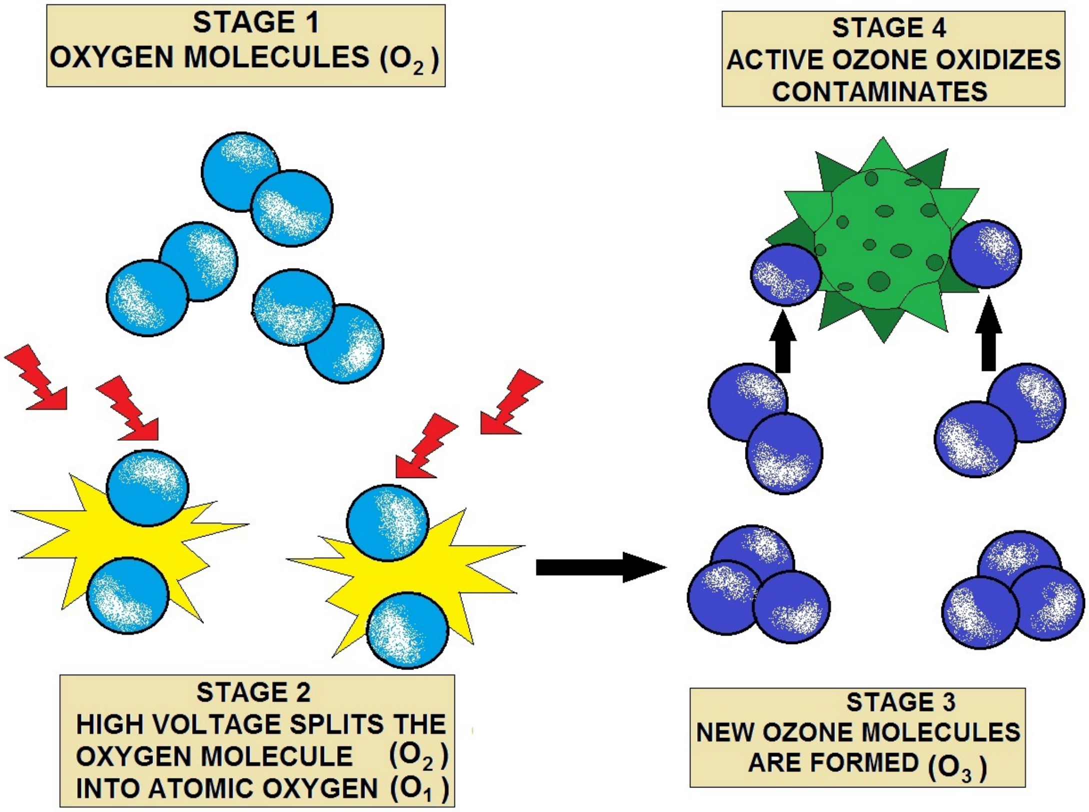
Total Trihalomethanes Some people who drink water containing trihalomethanes in excess of EPA's standard over many years may experience problems with their liver, kidneys, or central nervous systems, and may have an increased risk of getting cancer.

Haloacetic Acids Some people who drink water containing haloacetic acids in excess of the EPA's standard over many years may have an increased risk of getting cancer.

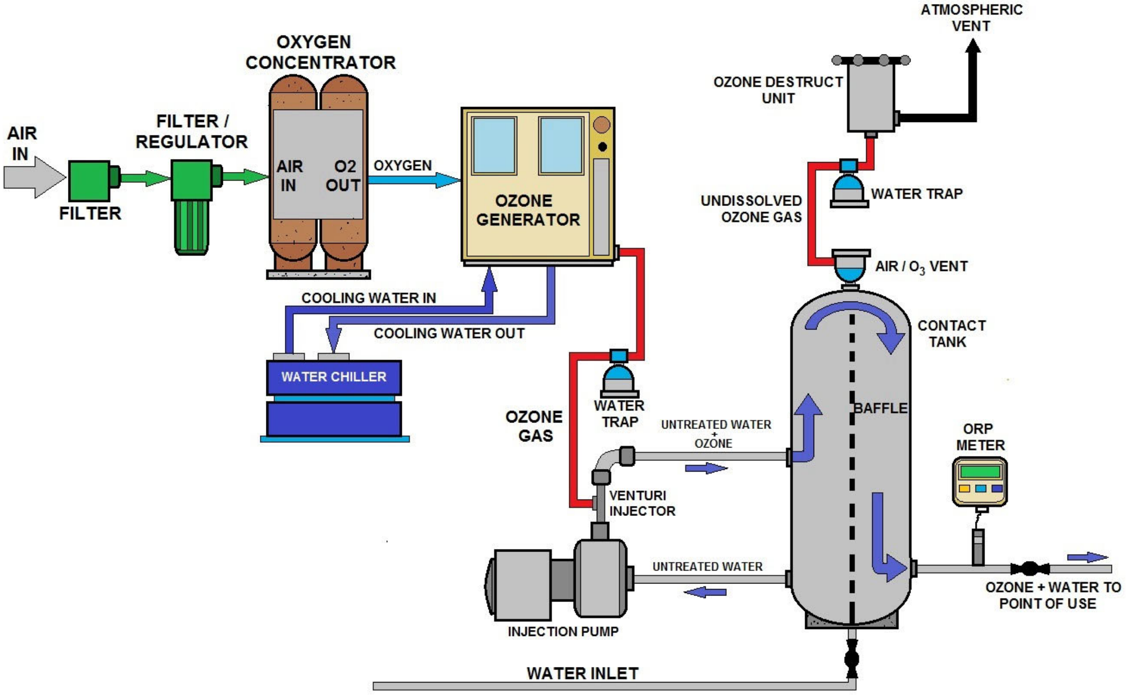
Bromate Some people who drink water containing bromate in excess of the EPA's standard over many years may have an increased risk of getting cancer.

Chlorite Some infants and young children who drink water containing chlorite in excess of the EPA's standard could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorite in excess of the EPA's standard. Some people may experience anemia.

Ozone generator and control panel.



HOW OZONE IS PRODUCED



OZONE GENERATION SYSTEM

Ozone Sub-Section

Ozone (**O_3**) is probably the strongest oxidizing agent available for water/wastewater treatment. Ozone is obtained by passing a flow or air of oxygen between two electrodes that are subjected to an alternating current in the order of 10,000 to 20,000 volts.

$$3O_2 + \text{electrical discharge} \rightarrow 2O_3$$

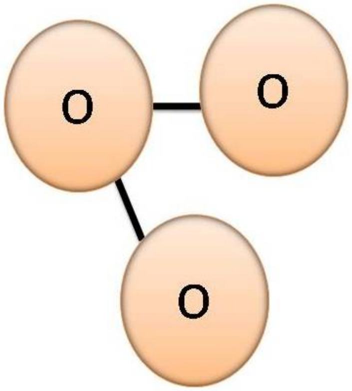
Liquid ozone is very unstable and can readily explode. As a result, it is not shipped and must be manufactured on-site. Ozone is a light blue gas at room temperature. It has a self-policing pungent odor similar to that sometimes noticed during and after heavy electrical storms. In use, ozone breaks down into oxygen and nascent oxygen.

$$O_3 \rightarrow O_2 + O$$

It is the nascent oxygen molecule that produces the high oxidation and disinfections, and even sterilization. Each water has its own ozone demand, in the order of 0.5 ppm to 5.0 ppm. Contact time, temperature, and pH of the water are factors to be determined.

Ozone acts as a complete disinfectant. It is an excellent aid to the flocculation and coagulation process, and will remove practically all color, taste, odor, iron, and manganese. It does not form chloramines or THMs, and while it may destroy some THMs, it may produce others when followed by chlorination.

Ozone is not practical for complete replacement of chlorine or chloramines, or of THM and other inorganics. Further, because of the possibility of formation of other carcinogens (such as aldehydes or phthalates) it falls into the same category as other disinfectants in that it can produce DBPs.


Ozone (O_3) Molecule

Significance of Ozone

Ozone is a very powerful oxidant, even more powerful than chlorine. Below is a table comparing the oxidizing potential of ozone to other oxidizing agents.

Oxidizing agent	Oxidation potential (volts)	Power relative to chlorine
Fluorine (F_2)	3.06	2.25
Ozone (O_3)	2.07	1.52
Hydrogen Peroxide (H_2O_2)	1.77	1.30
Potassium Permanganate ($KMnO_4$)	1.67	1.23
Chlorine (Cl_2)	1.36	1.00
Chlorine Dioxide(ClO_2)	1.27	0.93
Bromine (Br_2)	1.09	0.80

This table is courtesy of CEC the Ozone Company.

In Addition, Ozone:

- Oxidizes and mitigates pollutants from water and wastewater.
- Breaks down volatile organic compounds (VOC) such as, phenols, benzene, pesticides and other aromatic hydrocarbons.
- Breaks down inorganic compounds such as cyanides, sulfides, nitrites.
- Removes color.
- Bleaches.
- Removes taste and odor.
- Removes soluble iron and manganese indirectly by converting them to filterable insoluble solids.

Ozone is very friendly to the environment. The extra atom of oxygen makes ozone very unstable.

While it has a half-life of about 20 minutes in clean water, its half-life in dirty water is even shorter as it is consumed by the microorganisms, VOCs and other compounds.

Because it breaks down to oxygen, ozone does not leave any toxic or carcinogenic by-products. It does not impart any taste, odor, color or solids.

By comparison, chlorine forms carcinogenic by-products, such as trihalomethanes (THM) and other halogenated compounds.

When added to water, chlorine hydrolyzes to hypochlorous acid and then to hypochlorite ion, both of which can linger on and adversely affect our hydrological system.

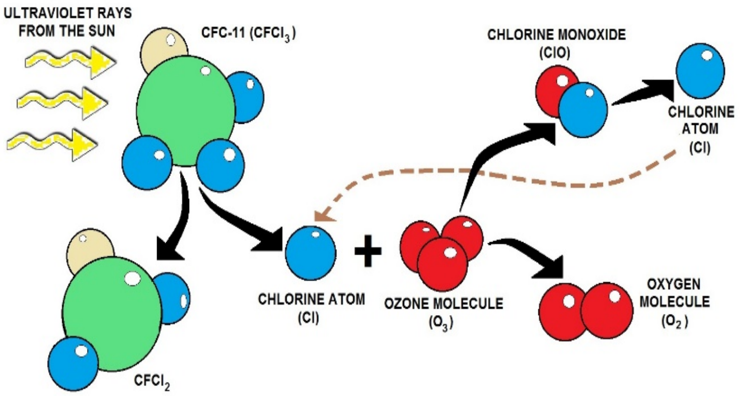
Since ozone reverts to oxygen very quickly it cannot be packaged and stored. Thus it must be generated on-site. In turn, this on-site generation eliminates any hazards associated with transportation, storing and handling.

Commercial Production

Ozone is produced commercially in the same way it is formed naturally by lightning or UV radiation from the sun. The commercial lightning method is called corona discharge. Dried air or oxygen is passed through an electrified field (corona) generated by a high voltage between positive and negative grids.

The high voltage splits the molecular oxygen into atomic oxygen. Some of the atomic oxygen merge with molecular oxygen to form ozone, while other oxygen atoms simply recombine to form O2. A fraction of oxygen in the air is transformed into ozone. When ambient air is used as a feed gas, you can get ozone between 1 and 2 percent by weight in air. When oxygen is used as a feed gas, you can get ozone between 6 and 12 percent by weight.

Natural UV radiation is simulated commercially by UV lamps.



OZONE DEPLETION

Air is passed through a chamber between the UV lamp and a shield. UV light can create or destroy ozone depending on the UV wavelength. Wavelengths of 185 nanometers (nm) are required for the generation of ozone and 254 nm for the destruction of ozone. This method produces a very low level of ozone and is usually suitable for small applications. In addition to these methods, ozone may also be made through electrolytic and chemical reactions.

Potential Health Hazards

According to the EPA, "the same chemical properties that allow high concentrations of ozone to react with organic material outside the body give it the ability to react with similar organic material that makes up the body.

"***When inhaled, ozone can damage the lungs. Relatively low amounts can cause chest pain, coughing, shortness of breath, and throat irritation. Ozone may worsen chronic respiratory diseases such as asthma and compromise the ability of the body to fight respiratory infections***."

The EPA makes a distinction between ozone in the upper and lower atmosphere. Ozone in the upper atmosphere, referred to as stratospheric ozone, helps filter out damaging ultraviolet radiation from the sun. Conversely, ozone in the lower atmosphere, – the air we breathe – can be harmful to the respiratory system.

OSHA has issued a threshold limit value (**TLV**) on ozone exposure to 0.1 ppm over eight hours per day and five days per week, or 0.3 ppm for a 15-minute continuous exposure.

Because of the potential health hazards, it is crucial to destroy any excess ozone in a safe way.

How is Ozone Injected?

Ozone is typically injected into water via a venturi. A side stream water pump is typically used to create the vacuum on the venturi with a static mixer installed after it to ensure adequate mixing, distribution and proper contact between the ozone and water.

Another less popular alternative is the diffuser method, where ozone is injected under pressure through diffusers creating bubble columns – much like air diffusers in aquariums.

Destroying Ozone

Ozone can be destroyed by catalytic conversion units, activated carbon filters, thermal destructors or by ultraviolet radiation.

Catalytic conversion is the most popular method of ozone destruction. Activated carbon filtration decomposes ozone but carbon is also consumed in the process. There’s also a risk of fire as carbon could ignite under high exothermic conditions.

In thermal destruction, ozone is destroyed by heating it in excess of 300 degrees Celsius. Ultraviolet radiation decomposes ozone at the wavelength of 254 nanometers.

Early Misconceptions

In cooling water applications, the most common problems encountered are scale deposition, corrosion, fouling and microbiological (bacteria, algae, fungi, etc.) growth. Today, there’s an even greater threat - the emergence of pathogenic bacteria like *Legionella*

Pneumophilia

Microbial is a concern because it contributes to and amplifies deposition, corrosion and fouling by acting as a nucleation point or catalyst for these problems. The effect of microbial on scale deposition and fouling is one of the early misconceptions of ozone.

Early applications showed that ozone also removed mineral deposits. Later, it was found that this removal was only true where the deposits were held in a bio-matrix. It is like the steel structure of a building that holds up all the bricks. By destroying the steel structure at strategic points, the whole building implodes.

Comparing this to the bio-induced deposits, the bio-matrix held the deposits together, acting like glue. When the ozone destroyed the bio-matrix, the attached crystals became dispersed.

Not understanding this phenomenon fully, some ozone manufacturers began marketing them as scale inhibitor. Needless to say, ozone failed to prevent mineral deposits under other conditions, such as super saturation, excessive hardness, and alkalinity.

Because microorganisms also induce other problems such as corrosion and fouling, ozone was also marketed early on as a corrosion and fouling inhibitor, under similar biological pretext. Likewise, ozone failed to prevent these problems under non-biological conditions.

Traditionally, non-oxidizing biocides and oxidizing biocides are used to control microbial. Typical non-oxidizing biocides are organo-sulfur compounds (carbamate based, thiocyanate), organotin, isothiazolone, organobromine (dibromonitrilopropionamide), organic thiocyano-azole (benzothiazole) glutaraldehyde and quaternary ammonia.

Typical oxidizing biocides are chlorine, bromine and chlorine dioxide. Most of these biocides have a long-term negative impact on the environment. As such, there is a growing pressure to reduce or restrict these biocides in the blowdown water, especially if the water is being discharged to a waterway.

In addition to the discharge burden, these biocides have to be stored, transported and handled, which increases potential health and injury risks to personnel.

Limitations

Because of its short life, ozone levels drop off rapidly as time progresses and as it moves away from the injection point, decreasing its disinfecting efficacy. In systems with long piping runs, ozone may not get far enough, leaving the farthest areas vulnerable to microbiological growth.

This situation may be remedied by injecting ozone at various strategic points throughout the water system. A bio-dispersant can be added to penetrate and disperse the sessile bacteria (growing on surfaces) so that they can become planktonic (floating in water), thus enabling the bacteria to be transported to the ozone injection point for destruction.

Increasing the ozone level at the injection point to raise residual levels downstream is not a good solution. The higher ozone concentration may destroy the water treatment chemicals, increase corrosion near the injection area and destroy seals, gaskets, etc.

Ozone does not do a good job penetrating biofilm. It may burn the surface of the biofilm, protecting the microorganisms underneath from further destruction. Therefore, they will survive and will likely continue to cause localized corrosion.

This situation may be remedied by adding a good bio-dispersant to penetrate and disperse the biofilm, including the bacteria living under the biofilm.

Ozone does not discriminate in terms of what it oxidizes. If ozone is used as a disinfectant in water loaded with other non-biological organic matters, they will also consume ozone. As such, there may not be enough ozone left to accomplish the intended disinfection.

The remedy is to generate more ozone to supply the total ozone demand. However, this increases costs in both operating and capital. As such, ozone may not be cost effective for these types of applications.

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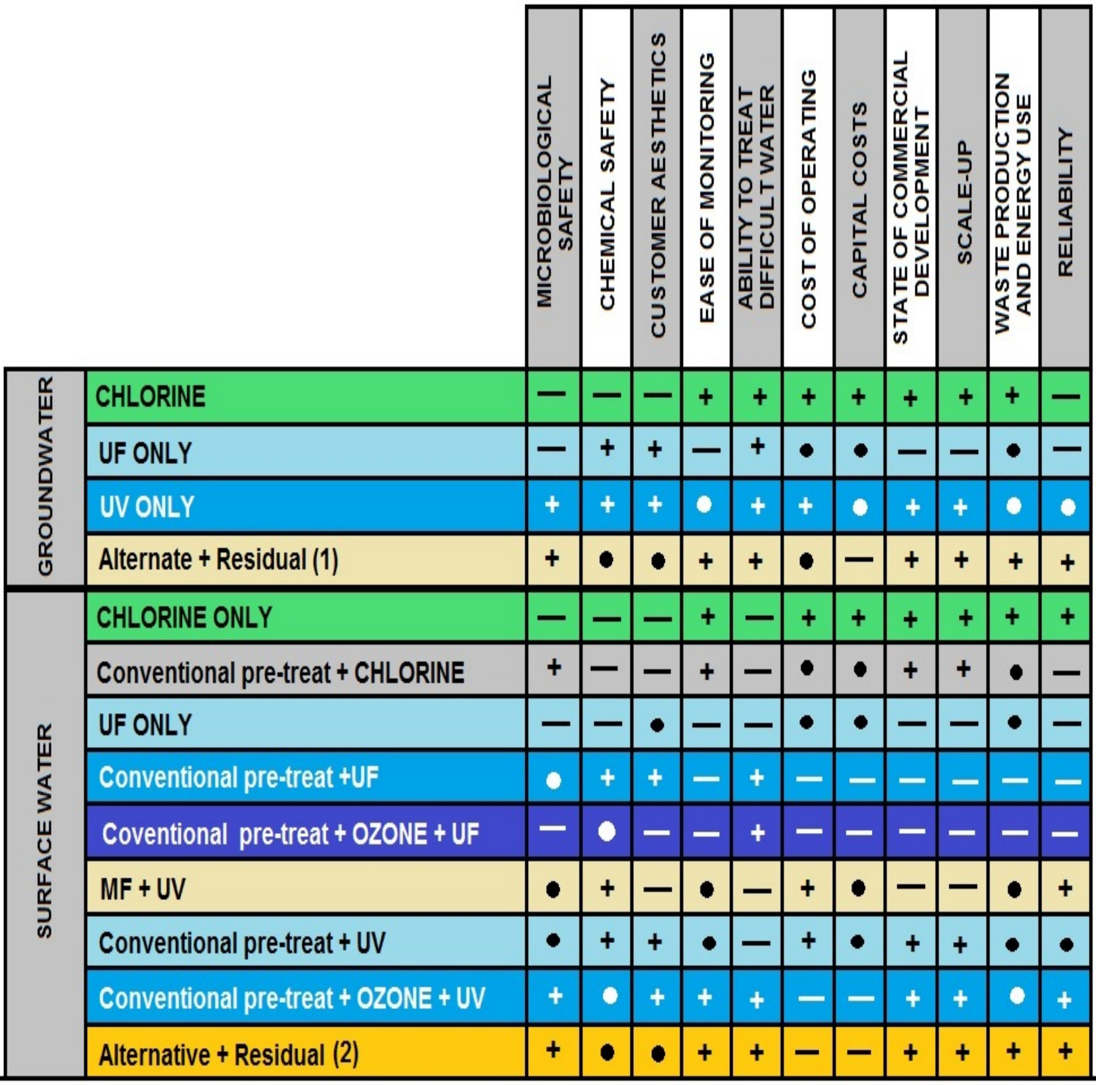


		MICROBIOLOGICAL SAFETY	CHEMICAL SAFETY	CUSTOMER AESTHETICS	EASE OF MONITORING	ABILITY TO TREAT DIFFICULT WATER	COST OF OPERATING	CAPITAL COSTS	STATE OF COMMERCIAL DEVELOPMENT	SCALE-UP	WASTE PRODUCTION AND ENERGY USE	RELIABILITY
GROUNDWATER	CHLORINE	—	—	—	+	+	+	+	+	+	+	—
	UF ONLY	—	+	+	—	+	●	●	—	—	●	—
	UV ONLY	+	+	+	●	+	+	●	+	+	●	●
	Alternate + Residual (1)	+	●	●	+	+	●	—	+	+	+	+
SURFACE WATER	CHLORINE ONLY	—	—	—	+	—	+	+	+	+	+	+
	Conventional pre-treat + CHLORINE	+	—	—	+	—	●	●	+	+	●	—
	UF ONLY	—	—	●	—	—	●	●	—	—	●	—
	Conventional pre-treat +UF	●	+	+	—	+	—	—	—	—	—	—
	Coventional pre-treat + OZONE + UF	—	●	—	—	+	—	—	—	—	—	—
	MF + UV	●	+	—	●	—	+	●	—	—	●	+
	Conventional pre-treat + UV	●	+	+	●	—	+	●	+	+	●	●
	Conventional pre-treat + OZONE + UV	+	●	+	+	+	—	—	+	+	●	+
	Alternative + Residual (2)	+	●	●	+	+	—	—	+	+	+	+

Conventional pre-treat = Coagulation / Sedimentation
UF - Ultafiltration   MF - Microfiltration
+ = Better than average
— = Worse than average
● = Average

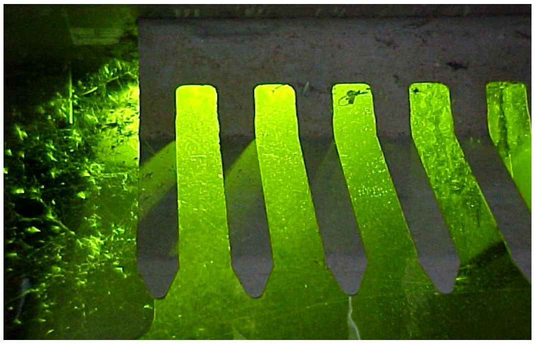
(1) UF + Chlorine residual or Conv + UV + Chlorine residual
(2) Conv pre-treat + UF + Chlorine residual or MF + UV
+ Chlorine residual or Conv pre-treat + UV + Residual

ASSESSMENT TO DETERMINE EFFECTIVE DISINFECTION METHODS

Ultraviolet Radiation Sub-Section

The enormous temperatures on the sun create ultraviolet (**UV**) rays in great amounts, and this radiation is so powerful that all life on earth would be destroyed if these rays were not scattered by the atmosphere and filtered out by the layers of ozone gas that float some 20 miles above the earth.

This radiation can be artificially produced by sending strong electric currents through various substances. A sun lamp, for example, sends out UV rays that when properly controlled result in a suntan. Of course, too much UV will cause sunburn.



Open contact chamber, beautiful green light that can burn your eyes.

The UV lamp that can be used for the disinfection of water depends upon the low-pressure mercury vapor lamp to produce the ultraviolet energy. A mercury vapor lamp is one in which an electric arc is passed through an inert gas. This in turn will vaporize the mercury contained in the lamp; and it is a result of this vaporization that UV rays are produced.

Enclosed lamp system, this one is on wastewater effluent.

The lamp itself does not come into contact with the water, the lamp is placed inside a quartz tube, and the water is in contact with the outside of the quartz tube. Quartz is used in this case since practically none of the UV rays are absorbed by the quartz, allowing all of the rays to reach the water. Ordinary glass cannot be used since it will absorb the UV rays, leaving little for disinfection.

The water flows around the ultraviolet contactor. The UV sterilizer will consist of a various number of lamps and tubes, depending upon the quantity of water to be treated. As water enters the sterilizer, it is given a tangential flow pattern so that the water spins over and around the quartz sleeves. In this way the microorganisms spend maximum time and contact with the outside of the quartz tube and the source of the UV rays.

The basic design flow of water of certain UV units is in the order of 2.0 gpm for each inch of the lamp. Further, the units are designed so that the contact or retention time of the water in the unit is not less than 15 seconds.

Most manufacturers claim that the UV lamps have a life of about 7,500 hours, which is about 1 years' time of continuous usage. The lamp must be replaced when it loses about 40% to 50% of its UV output; in any installation this is determined by means of a photoelectric cell and a meter that shows the output of the lamp. Each lamp is outfitted with its own photoelectric cell, and with its own alarm that will be activated when the penetration drops to a present level.

Ultraviolet radiation is an excellent disinfectant that is highly effective against viruses, molds, and yeasts and it is safe to use. It adds no chemicals to the water, it leaves no residual, and it does not form THMs. It is used to remove traces of ozone and chloramines from the finished water. Alone, UV radiation will not remove precursors, but in combination with ozone, it is said to be effective in the removal of THM precursors and THMs.

UV Trains and SCADA display.

The germicidal effect of UV is thought to be associated with its absorption by various organic components essential to the cell's functioning. For effective use of ultraviolet, the water to be disinfected must be clean, and free of any suspended solids. The water must also be colorless and must be free of any colloids, iron, manganese, taste, and odor.

These are conditions that must be met. Also, although a water may appear to be clear, such substances as excesses of chlorides, bicarbonates, and sulfates affect absorption of the ultraviolet ray. These parameters will probably require at least filtration of one type or another. The UV manufacturer will of course stipulate which pretreatment may be necessary.

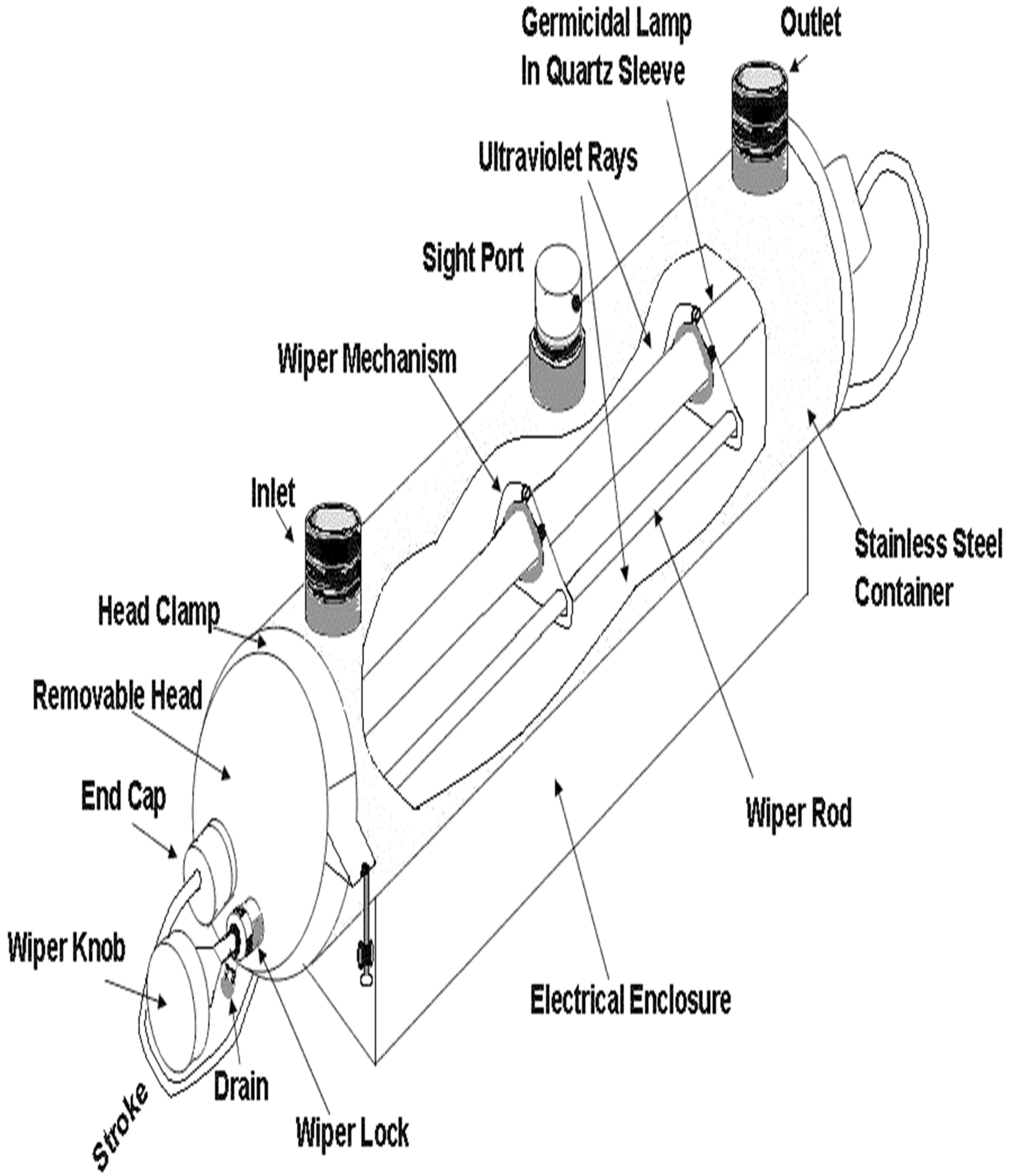
Removal of Disinfection By-products

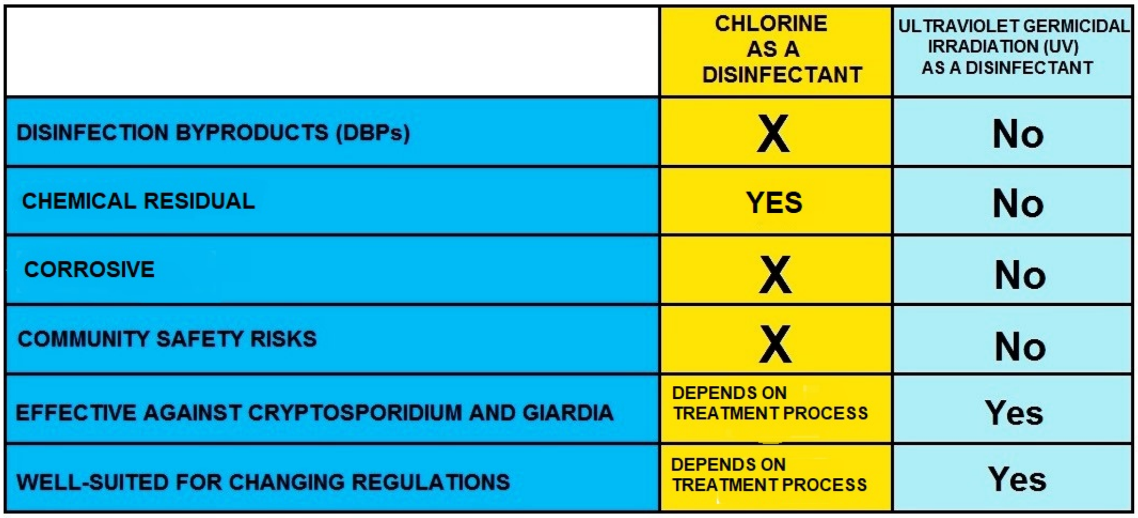
Disinfectant	***Disinfectant By-product***	***Disinfectant By-product Removal***
Chlorine (HOCl)	Trihalomethane (THM) Chloramine Chlorophenol	Granular Activated Carbon (GAC), resins, controlled coagulation, aeration. GAC-UV GAC
Chloramine (NH_xCl_y)	Probably no THM Others?	GAC UV?
Chlorine dioxide (ClO_2)	Chlorites Chlorates	Use of Fe2+ in coagulation, RO, ion-exchange
Permanganate ($KMnO_4$)	No THMs	
Ozone (O_3)	Aldehydes, Carboxylics, Phthalates	GAC
Ultraviolet (UV)	None known	GAC

The table indicates that most of the disinfectants will leave a by-product that is or would possibly be harmful to health. This may aid a decision as to whether or not precursors should be removed before these disinfectants are added to water.

If it is decided that removal of precursors is needed, research to date indicates that this removal can be attained through the application of controlled chlorination plus coagulation and filtration, aeration, reverse osmosis, nanofiltration, GAC or combinations of others processes.

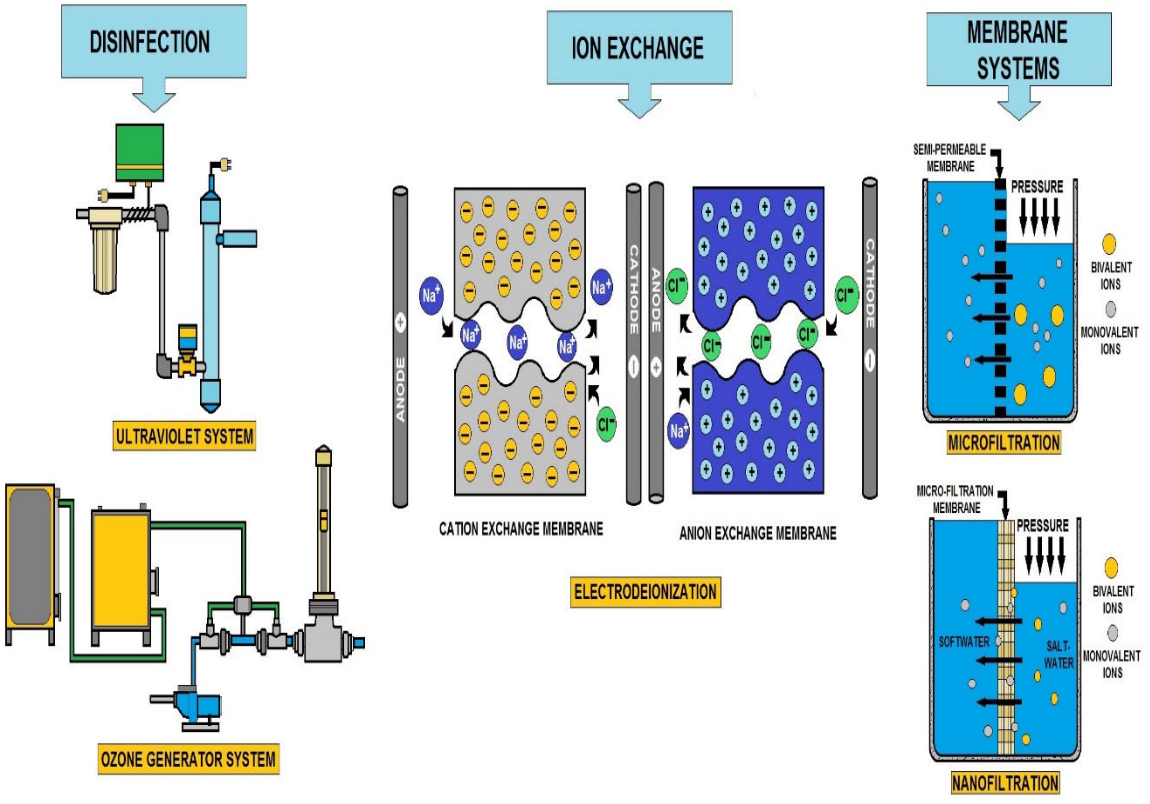
In conclusion, the literature is replete with the pursuit of newer processes, or combination of known processes, or the search for new methods for removal of the DBPs. These will all require laboratory, pilot plant, and field experience research will be more than a "*labor of love*."


Germicidal Lamp
In Quartz Sleeve
Outlet
Ultraviolet Rays
Sight Port
Wiper Mechanism
Inlet
Stainless Steel
Container
Head Clamp
Removable Head
End Cap
Wiper Rod
Wiper Knob
Electrical Enclosure
Stroke
Drain
Wiper Lock

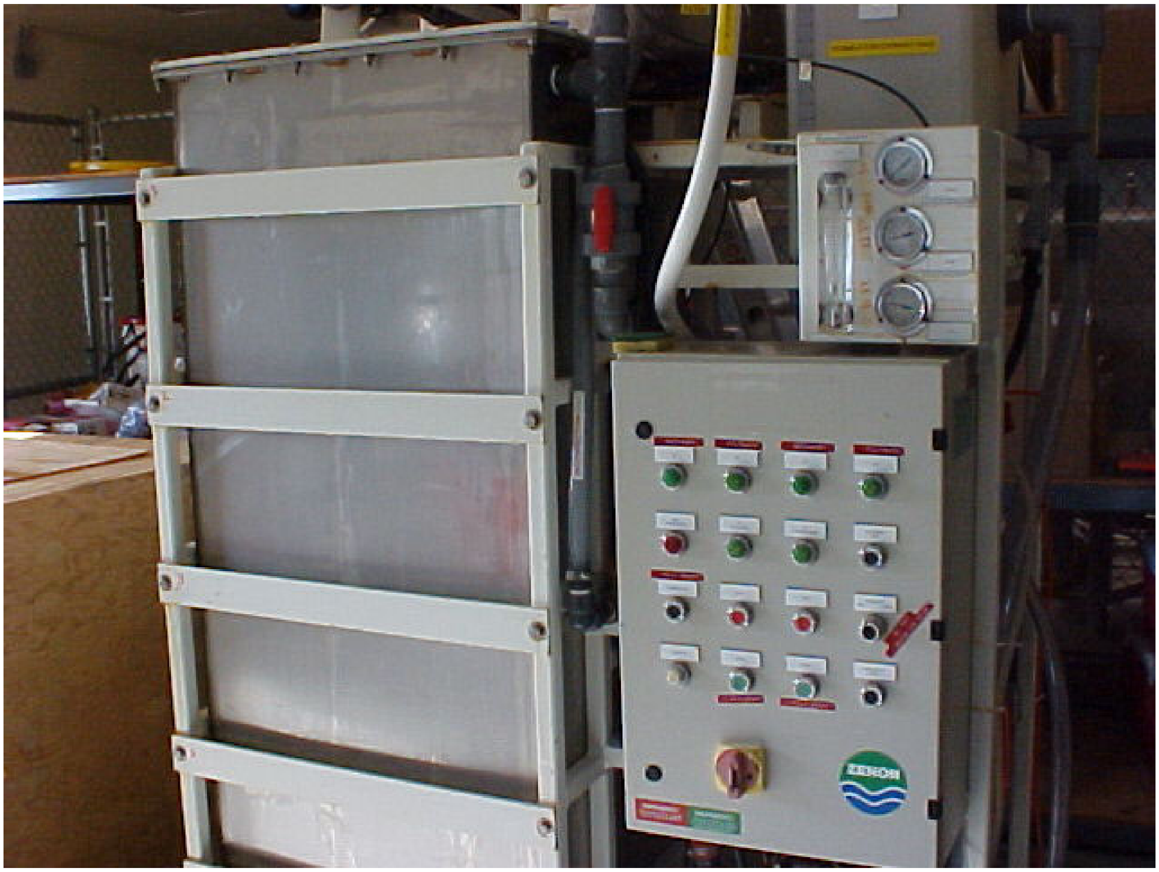


	CHLORINE AS A DISINFECTANT	ULTRAVIOLET GERMICIDAL IRRADIATION (UV) AS A DISINFECTANT
DISINFECTION BYPRODUCTS (DBPs)	X	No
CHEMICAL RESIDUAL	YES	No
CORROSIVE	X	No
COMMUNITY SAFETY RISKS	X	No
EFFECTIVE AGAINST CRYPTOSPORIDIUM AND GIARDIA	DEPENDS ON TREATMENT PROCESS	Yes
WELL-SUITED FOR CHANGING REGULATIONS	DEPENDS ON TREATMENT PROCESS	Yes

CHLORINE vs. UV FOR DISINFECTION



WATER QUALITY EQUIPMENT



This is an air stripper (stacked tray design), used to volatize VOC's to vapor phase.

POU Home Treatment Methods

This section discusses the principal types of **POE** and **POU** home treatment devices.

Water Softeners

Home-type water softeners generally use the ion exchange process. In addition to reducing hardness, they remove some other impurities. But at the same time, they increase the salt level in the treated water.

Coarse salt is typically used for regeneration, and most units are furnished with a time clock to operate the regeneration cycle automatically in the middle of the night on set days of the week.

Softeners are normally classified as POE devices because they are often installed to treat all water to the building. In other instances, softeners are connected to treat only the hot-water supply to a building.

Softener with brine tank on right

Physical Filters

Physical filters are rather like strainers in that they are intended to remove suspended matter from the water. Some can remove material as small as cysts, large bacteria, and asbestos fibers. Most units are designed to remove only larger particles such as grit, dirt, and rust.

The filter unit may be made of fabric, fiber, ceramic, screening, diatomaceous earth, or other materials. Physical filters are most often used as a pre-filter ahead of other treatment devices.

Activated Carbon Filters

As detailed before, activated carbon can remove many organic chemical contaminants from water – provided there is sufficient contact time with the water. Carbon filters can remove most taste, odors, and color as well as synthetic organic chemical such as pesticides and volatile organic chemicals (VOCs).

Carbon also effectively removes radon and chlorine from water. It does not effectively remove microorganisms. As a matter of fact, if there are any microorganisms in the source of water, they can actually thrive by feeding on the organic material that has previously been retained on the carbon particles.

The carbon in filters will eventually become loaded with contaminants so that the unit will no longer function. If a carbon unit is used after this point, it will periodically start to discharge quantities of organics into the effluent. As a result, the water being used from the unit may, at times, have a higher level of organics that the influent.

Unfortunately, there is no definite way of determining when carbon is exhausted. The life of the carbon in a unit depends on such factors as the concentration and types of contaminants in the water, the quantity of granular activated carbon (**GAC**) in the treatment unit, and the amount of water put through the unit. It is strongly recommended that when a GAC treatment unit is used, the carbon be changed frequently.

Reverse Osmosis

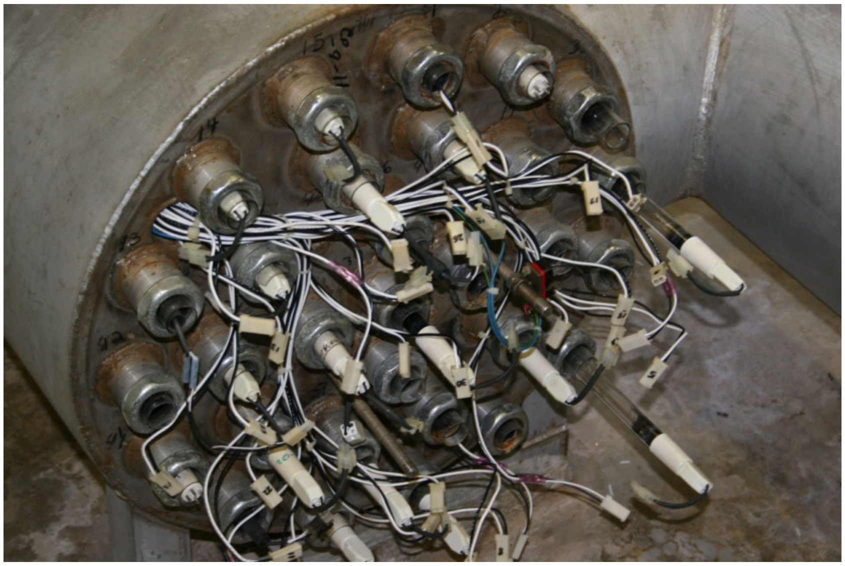
A reverse osmosis (RO) unit cannot be used by itself for water treatment. Some membranes will be destroyed by exposure to chlorine, and the efficiency of a membrane can be fouled by suspended matter in the influent water. For this reason, an RO module is always preceded by pre-filters.

As discussed before, RO units must be operated under pressure. Home-type RO units do not work very efficiently because they must operate on water system pressure, so about 75 percent of the water introduced to the unit is usually piped to waste.

Small RO units produce a very small flow, so the treated water is piped to a diaphragm pressure tank, which supplies water to a separate faucet. RO is effective in removing most inorganics, salts, metals, and organics having larger molecules. Although RO is known to effectively remove *Giardia lambia* cysts, bacteria, and viruses, it is not recommended for use on microbiologically unsafe water.

Ultraviolet Disinfection

Although the use of ultraviolet (UV) light is not cost effective for the treatment of any sizable quantities of water, it can be practically applied for home treatment use. Units consist of a UV light source enclosed in a protective transparent sleeve, mounted so that water can flow past the light. UV light destroys bacteria and inactivates viruses. However, its effectiveness against spores and cysts is questionable. Both dissolved solids and turbidity adversely affect the performance of UV disinfection. The most common operation problem is a buildup of dirt on the transparent shield, so units should frequently be inspected and cleaned.



Distillers

Various sizes of distillers are available for home use. They all work on the principle of vaporizing water and then condensing the vapor. In the process, dissolved solids such as salt, metals, minerals, asbestos fibers, and other particles are removed. Some organic chemicals are also removed, but those that are more volatile are often vaporized and condensed with the product water. Distillers are effective in killing all microorganisms.

The principal problem with a distiller is that a small unit can produce only 2-3 gal (7.5 -11 Lt) a day, and that the power cost for operation will be substantially higher than the operating cost of other types of treatment devices. Water Distillers have a high energy cost (approximately 20-30 cents per gallon).

They must be carbon filtered before and/or after to remove volatile chemicals. It is considered "dead" water because the process removes all extra oxygen and energy. It has no taste. It is still second only to reverse osmosis water for health. Diets should be rich in electrolytes as the aggressive nature of distilled water can "leach" electrolytes from the body.

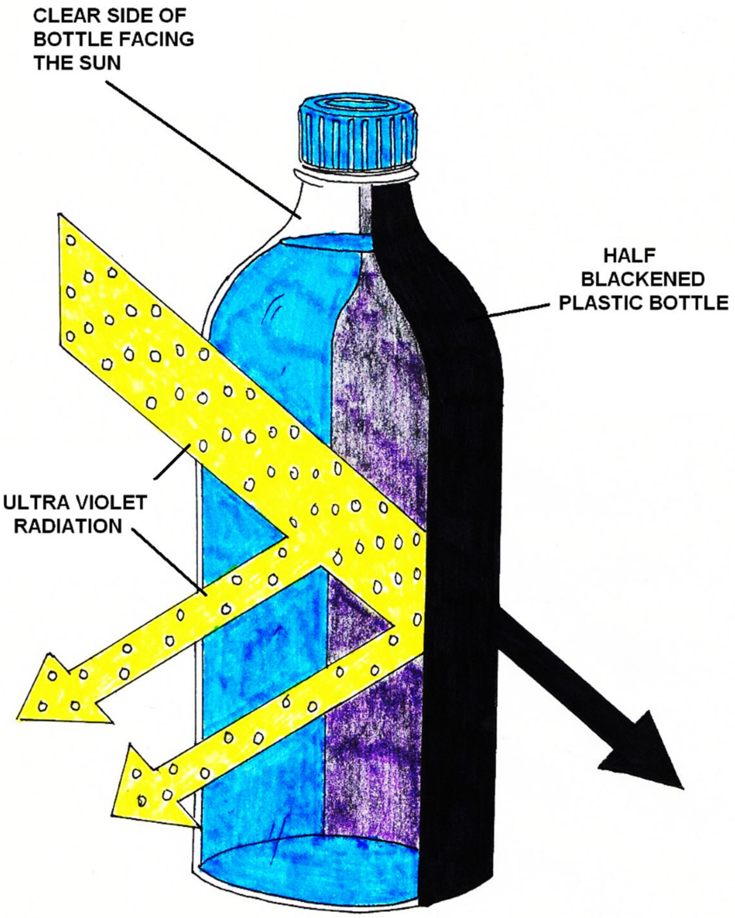
Special Treatment

Special treatment units for home use are also available for removal of methane, hydrogen sulfide, nitrate, fluoride, radon, and other objectionable contaminants. Most often, this type of treatment is used on private wells.

The Use of Point-of-Entry (POE) Treatment Instead of Central Treatment

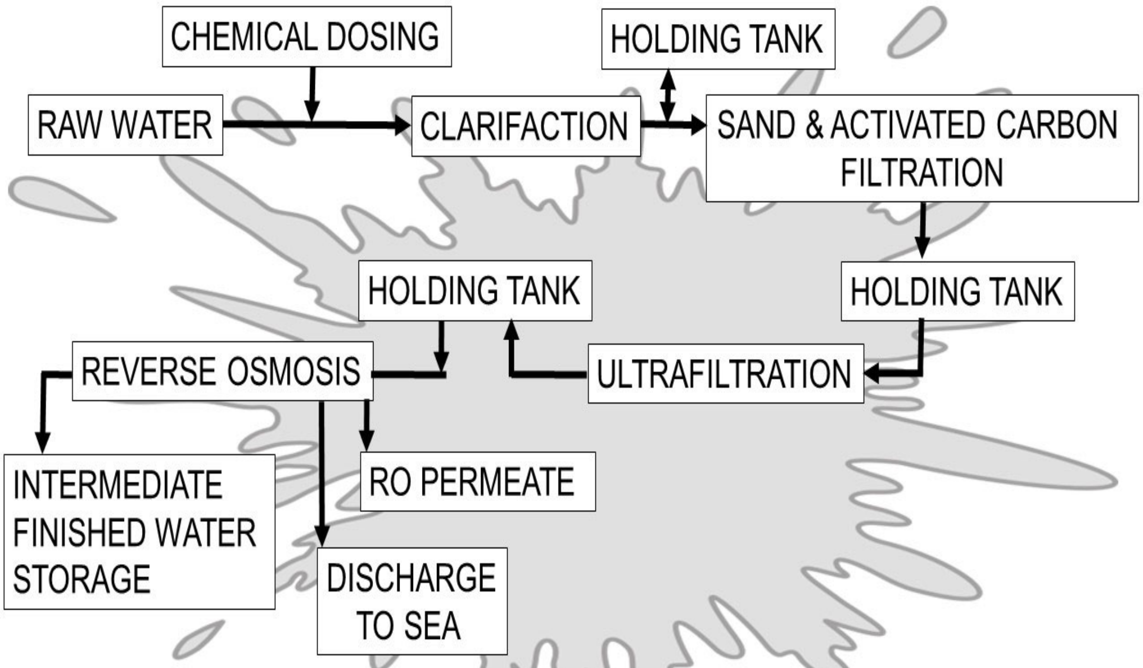
Under recent US Environmental Protection Agency (USEPA) regulations, water systems with a source water exceeding a maximum contaminant level (MCL) can install POE devices on all water services (instead of providing central treatment) to satisfy the requirement of providing water to the public below the MCL.

An example of where this might be a viable alternative is a system having water so hard that a large proportion of the customers have already installed home softeners. If the contaminant exceeding the MCL in the source water can be removed by ion exchange softening, the system might meet the federal requirements by ensuring that every customers has a softener installed.



SODIS - SYSTEM (basic principal)

At the same time, a number of problems must be overcome. It is difficult for the system to ensure that all drinking water furnished to the public is treated. Another problem is that the water system must have a plan for checking and maintaining all the units to ensure that they are always properly operated. It is expected that some very small systems may find this option workable under certain circumstances. The American Water Works Association has recommended that all treatment required for a public water supply be in the form of central treatment.



BASIC WATER TREATMENT SCHEME
FOR SEAWATER DESALINATION

Reverse Osmosis Home Filtration Devices

Reverse Osmosis home filtration devices are designed to fit neatly under almost any sink. The filter pack typically will slide to the back of the sink next to the garbage disposal. The tank tucks behind the plumbing and garbage disposal to the back of the sink. It uses very little of the sink's practical space.

The R/O connects to the cold water supply under the sink. First, water first passes through at a 1 micron sediment filter, which removes large particles that float in the water like silt, sand, rust, dirt, etc. We can see down to 40 microns (a human hair is about 80 microns and most bacteria is around 1 micron). This filter should be changed as needed by visually looking at it. (typically 6 months to 1 year).

Small under the sink home use unit.

Second, the water passes through a Bituminous granulated coal filter that removes chlorine, some pesticides, herbicides and toxic chemicals. This filter should be changed every 6 months religiously.

Both of the first two filters' main purpose is to protect the R/O membrane form chlorine and particles that can prematurely ruin the membrane. The R/O membrane is the heart of the system. It filters down to a molecular level (1/10,000/micron).

Water is basically forced through the membrane. The water that makes it through is the purified water and the water that doesn't make it is impure water and it is dumped down the drain. The water slows down to a drop at a time and is accumulated in a 3 gallon pressurized storage tank.

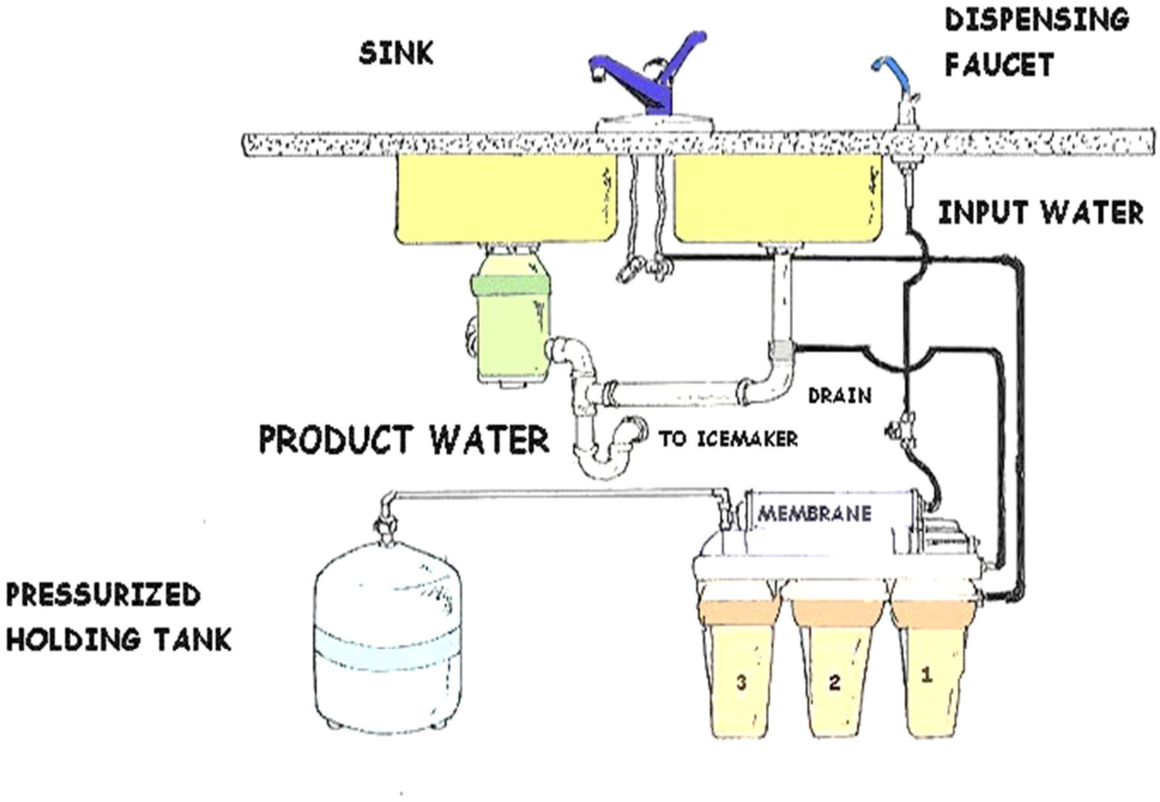
The water is then pushed out of the tank at about 40-60 psi through a 10-inch post coconut shell carbon filter designed to pick up anything missed by the previous filters insuring great taste on the way to the faucet. The faucet is an air gap faucet and meets all plumbing codes.

1-micron sediment filter
A micron is a unit of measure. People can see down to 40 microns. Most Bacteria is between 1-5 microns. The sediment filter consists of a poly spun fiber and removes sediment down to 1 micron.

Bituminous granulated coal filter
This carbon filter has 56 cubic inches of carbon, which is more than any other filter made with similar dimensions on the market. We use two different types of carbon in our system (post carbon filter is a coconut shell carbon). Different types of carbon have different adsorption rates and different removal rates of toxic chemicals, so by using two types of carbon, we get the highest adsorption rates possible.

R/O Membrane
R/O membranes are generally made of Thin Film Composite. (TFC for short). There are basically two types of membranes on the market -TFC and CTA (Cellulose Triacetate).

TFC membranes are simply more durable because they are made out of a plastic type of material. CTA's are made with a paper type of material. Anyone who knows the R/O business in areas of hard water will only use TFC membranes because CTA customers will be buying membranes typically every 1 to 3 years (that gets expensive), whereas TFC membranes will typically last 3 to 5 years.



REVERSE OSMOSIS SYSTEM

Homeowner’s Water Filtration Devices

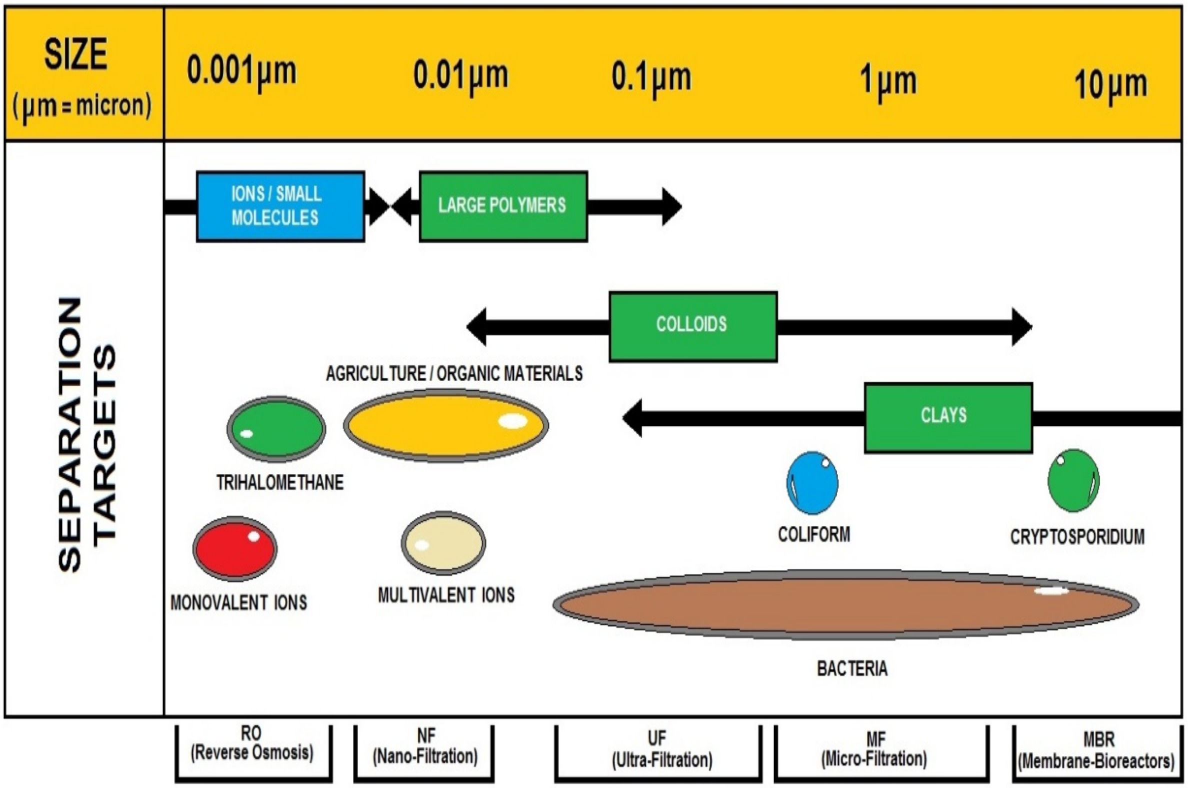
Carbon Block Filters improve taste and odor, reduce turbidity, remove chlorine and THM's, remove organic chemicals, pesticides, herbicides, and insecticides, and may remove some bacteria, cysts and parasites, radioactivity and asbestos fibers. A carbon-block filter can also remove some heavy metals. They do not remove fluorides, viruses, dissolved solids such as salt, sodium, calcium/magnesium and inorganic minerals as well as phosphates and detergents. Manganese, iron, metallic dead dirt minerals, hydrogen sulfide/sulfates, arsenic, aluminum, dissolved lead, nitrates and heavy metals also remain in the water. (Some specially treated carbon block units have excellent lead removal.)

Granular Activated Carbon Filters improve taste and odor, reduce turbidity, remove chlorine and THM's, organic chemicals, pesticides, herbicides, and insecticides. They may control bacteria growth when silver-impregnated. Mercury and radioactivity may also be reduced by this type of filter.

Granular Activated Carbon Filters do not remove fluorides, sulfates, nitrates, arsenic, aluminum, metallic dead dirt minerals, salts, sodium, heavy metals, lead, calcium, iron, magnesium, virus, bacteria, parasites, cysts, manganese, hydrogen sulfide or asbestos. Back flushing is often recommended for this type of filter. Bacteria may become a problem.

KDF/Carbon Combination is similar to a Granular Activated Carbon Filter with additional metal removal capabilities, including lead. Chlorine is converted to chloride by KDF (zinc/copper composite), extending the life of a carbon media bed.

This type of filtration helps to minimize biological activity. KDF/Carbon Filters do not remove salts, fluorides, sulfates, nitrates, arsenic, aluminum, dead dirt minerals, phosphates or detergents. They may or may not be effective at removing parasites, cysts, and asbestos.



REMOVAL METHODS

MICROORGANISMS: *More information in the Appendix*
Are very small animals and plants that are too small to be seen by the naked eye and must be observed using a microscope. Microorganisms in water include algae, bacteria, viruses, and protozoa. Algae growing in surface waters can cause off-taste and odor by producing the chemicals MIB and geosmin.

Certain types of bacteria, viruses, and protozoa can cause disease in humans. Bacteria are the most common microorganisms found in treated drinking water. The great majority of bacteria are not harmful.

In fact, humans would not be able to live without the bacteria that inhabit the intestines. However, certain types of bacteria called coliform bacteria can signal the presence of possible drinking water contamination.

KDF Process Media Section

KDF Process Media
As good as existing water treatment technologies are, most have limitations. They're short-lived, expensive, difficult to maintain, easily fouled by microorganisms, or just plain unable to perform up to anticipated stricter regulations.

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Improve your system's economy while improving performance
KDF® process media, however, improve water treatment performance by protecting, and in some cases replacing, existing filtration/purification technologies. The exceptional filtration/purification performance and versatility of KDF media make them an economical and easy-to-use water treatment technology in both new systems and retrofit applications.

Manufacturers, hospitals, beverage manufacturers, restaurants, municipal water treatment facilities, consumers, and others rely on KDF process media to safely reduce or remove chlorine, hydrogen sulfide, heavy metals, and bacteria from water.

When Used Alone, KDF media can remove more than 95% of chlorine, iron, heavy metals, hydrogen sulfide, and other contaminants from water.

- When used in combination with granular activated carbon (**GAC**), KDF media can significantly extend the life of the carbon.
- Used ahead of reverse osmosis (**RO**) and ion exchange systems, KDF process media also safeguard expensive membranes, resins and system components.
- Compared to other water treatment technologies, KDF process media offer reduced material requirements resulting in more compact and more economical systems. KDF process media also last longer than GAC, which means material replacement requirements are lower.
- Because KDF process media contain no chemical additives and are 100% recyclable, costly disposal requirements are eliminated. What's more, KDF process media are safer for the environment.

All Forms of KDF Media are guaranteed for product purity and a certified analysis sheet is provided with each manufacturing run.

Improve Water Treatment Performance and Reduce Expense

KDF® process media are available in several different forms to meet the requirements of specific applications.

- KDF 55 granules are designed for removing or reducing chlorine and soluble heavy metals. They are also used for controlling scale, bacteria, and algae.
- KDF 85 granules are used to remove or reduce iron and hydrogen sulfide from water supplies. They are also used for controlling scale, bacteria, and algae.
- KDF-F fine mesh granules can be incorporated into carbon blocks and other matrixes.
- KDF-C coarse mesh granules are used for removal or reduction of soluble heavy metals and chlorine. For use when less pressure drop is required.

Redox Action is the Science Behind KDF Process Media

KDF® process media are high-purity, copper-zinc formulations that reduce contaminants in water using an oxidation/reduction (redox) reaction.

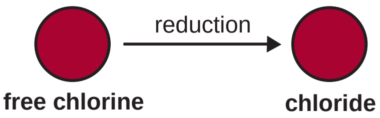
In other words, KDF media exchange electrons with contaminants, changing them into harmless components. For example, chlorine is changed into soluble chloride, soluble ferrous cations are changed into insoluble ferric hydroxide, and hydrogen sulfide is changed into insoluble copper sulfide. Insoluble reaction by-products are easily removed by periodic backwashing.

Other heavy metals such as mercury, copper, and nickel are removed simply by bonding to the KDF media. Microorganisms, however, are controlled two ways: First, the exchange of electrons in the redox reaction creates an electrolytic field that most microorganisms can't survive. Second, KDF process media may catalyze the formation of radicals and peroxides in certain circumstances. The radicals can interfere with microorganisms' ability to function.

Typical Redox Reactions

Harmful chlorine is removed by changing free chlorine into chloride ions.

KDF process media act as catalysts to change soluble ferrous cations into insoluble ferric hydroxide, which is easily removed by regular backwashing. KDF process media converts hydrogen sulfide to insoluble sulfide, which can be removed by backwashing.



Contaminants Removed by KDF Process Media

KDF® process media remove many of the most common impurities found in water supplies.

Chlorine Removal

KDF 55 medium can remove over 99% of free chlorine. This frees up granular activated carbon for more effective removal of organic contaminants, which affect water quality and foul downstream ion exchange resins and membranes.

KDF 55 medium can also be used to replace GAC entirely. Because KDF 55 medium provides more efficient chlorine removal, you'll benefit from a more cost effective water treatment system. Chlorine removal costs can be reduced 50% or more with KDF 55 medium.

Household Water Treatment

Both point-of-entry and point-of-use applications use KDF media to remove chlorine, lead, bacteria, iron, other heavy metals, and a variety of other impurities. For whole-house water systems, KDF media remove chlorine and other impurities from the water supply at the point-of-entry. KDF 55 medium delivers 10 times greater filter life than GAC.

Point-of-Use Applications

For chlorine removal in point-of-use applications, KDF media is incorporated into shower filters and into cartridges at the tap. KDF media are also used in water treatment systems in recreational vehicles.

In a controlled test under normal operating conditions, KDF process media delivered a filter life 10 times longer than GAC in chlorine removal service.

Water Treatment Costs with KDF 55 Medium *are less than half that of GAC*

In the same test, after treating two million gallons of water, chlorine removal cost is 50% lower with KDF process media.

A Kalamazoo, Michigan producer of bottled drinking water uses KDF media as a non-chemical method of removing chlorine and sequestered iron from 7,500 gallons of municipal water daily, extending the operating life of downstream RO membranes by as much as 10 years.

Iron Removal

Iron (Fe+2) or ferrous iron in groundwater can impart objectionable taste and color to potable water and can severely stain household fixtures. KDF® process media remove iron from water, either alone or in combination with other treatment technologies used at the point-of-entry.

KDF 85 medium removes more than 90% of iron from groundwater supplies.

Hydrogen Sulfide Removal

Hydrogen sulfide (H2S) is a highly corrosive gas formed in groundwater when bacteria decompose vegetation and other organic matter. H2S removal with KDF process media is both safe and economical.

KDF 85 medium eliminates H2S by converting the hydrogen sulfide gas to insoluble sulfide, an inert, harmless precipitant. KDF medium then filters the precipitant from the water. Periodic backwashing eliminates accumulations of the precipitant from the media bed.

In contrast, aeration towers and degasification systems are expensive and bulky H2S removal options. Using chlorine to oxidize H2S can leave trihalomethane levels exceeding U.S. Environmental Protection Agency (EPA) limits.

Heavy Metals Removal

Heavy metals in drinking water are a significant health threat.

KDF® 55, KDF 85 and KDF-C media can remove up to 98% of soluble lead, mercury, and other dissolved metals. KDF media can be used alone, or to protect existing water purification technologies to treat groundwater supplies containing soluble heavy metals or to remove heavy metals from process water before it is discharged.

Controlling Microorganisms

KDF media control the build-up of bacteria, algae and fungi in organic based media such as GAC beds, carbon block filters, and in-line carbon filters.

By controlling these microorganisms, KDF media significantly extend the life of the carbon, as well as protect downstream RO membranes and ion exchange resins from fouling.

KDF media also control scale, algae, and bacteria in cooling tower water and swamp coolers. Using KDF media to reduce the build-up of bacteria and other microorganisms eliminates the need for chemical treatment methods which are both costly and harmful to the environment.

Municipal Water Treatment

Many municipalities rely on the exceptional performance of KDF media to remove chlorine and other impurities from feedwater entering public utilities, schools, and businesses. KDF media are also cost-effective alternatives to greensand and other filtration methods traditionally used to remove iron from municipal water supplies.

Commercial Water Treatment

Water treatment systems serving commercial facilities such as hotels and restaurants use KDF process media to remove chlorine. These facilities benefit from better tasting water with less odor, as well as less wear on towels, bedding, napkins and other items that are laundered frequently on-site.

Process Water Treatment

KDF media remove chlorine and help control bacteria and scale build-up in large-scale industrial water treatment facilities serving cooling towers, food and beverage plants, and industrial laundry facilities.

KDF media can be used alone, or in combination with existing water treatment technologies to extend the life of granular activated carbon, and to protect downstream reverse osmosis membranes and ion exchange resins.

Medical Water Treatment

For medical labs and dialysis centers where water purity is crucial, KDF media provide exceptional water purification. KDF media also remove mercury and other soluble heavy metals from feedwater entering hospitals and from wastewater prior to discharge to public water treatment systems.

KDF Process Media Product Specifications

KDF 55 Process Medium
Applications: Chlorine, Heavy Metal Removal and Bacteria

KDF 85 Process Medium
Applications: Iron and Hydrogen Sulfide

The data included herein are based on outside laboratory tests. We believe the data are reliable, but recommend that users test performance on their own equipment. When using KDF media, proper backwash procedures should be applied.

Medium composition	atomized high purity copper/zinc alloy
Color	golden(55), reddish brown (85)
Physical form	granular
Screen size (U.S. mesh)	-10 + 100
Particle size range	0.149 mm to 2.00 mm
Apparent density	2.2-2.9 g/cc (171 lbs./cu.ft.)
Turbidity	<20 ntu
Skid	48-1/3 cu. ft. drums (2,736 lbs.)
Odor and tastes	none

Recommended Operating Conditions (use 3-cycle valve):

Service flow	15 gpm/sq. ft.
Backwash for 10 min. @	30 gpm/sq. ft.
Purge/rinse for 3 min. @	maximum
Bed expansion, backwash	10 to 15%
Free board	20%
Minimum bed depth (6"dia.)	10 inches
pH range: drinking water	6.5 to 8.5
Water temperature, influent	35° to 212°F.

To learn more...

To learn more about KDF process media and the results they can provide in your water treatment system, call 1-800-437-2745.

1500 KDF Drive
Three Rivers, MI 49093-9287
1-800-437-2745 • 269-273-3300
Fax: 1-800-533-3584 • 269-273-4400
E-mail: info@kdfft.com
Web address: www.kdfft.com

About KDF Fluid Treatment, Inc.

Founded in 1984 in Three Rivers, Michigan, KDF Fluid Treatment is a technological leader in the fluid treatment industry. KDF has obtained 15 patents, with other U.S. and foreign patents pending. KDF process media have earned NSF certification (ANSI/NSF Standard 61 for drinking water system components–health effects and Standard 42). Furthermore, KDF Fluid Treatment's process media have been ruled by the U.S. EPA as a "*Pesticidal Device*."

KDF Fluid Treatment offers superior customer service through an extensive distributor network. With distributors across North America, South America, Europe, and in Japan and China, KDF process media can meet your water filtration/purification needs globally. NOTICE: As of April 2003, KDF Fluid Treatment believes the data herein are reliable and accurate.

The data are based on outside and internal laboratory tests. Due to varying water chemistry, it is recommended that users test performance on their own equipment. As technical assistance is furnished by KDF Fluid Treatment at no charge to the user and since KDF Fluid Treatment has no control over engineering of hardware incorporating the KDF® media, KDF Fluid Treatment assumes no liability or responsibility for such assistance.

Due to synthetic procedures used by outside laboratories, KDF Fluid Treatment is not responsible for differing results in the field. KDF Fluid Treatment assumes no responsibility for user claims on the pesticidal abilities of KDF media because of varying water chemistry and users' applications. Since governmental regulations may differ from one location to another and may change from time to time, KDF Fluid Treatment is not responsible for users' manufacturing procedures, disposal practices, selection of media, or claims or advertising by the user. No warranty, express or implied is given nor is freedom from any patent owned by KDF Fluid Treatment or others to be inferred.

Alternative Water Disinfectant Section 6 Post Quiz

Disinfection Byproducts

1. ______________________ form when disinfectants added to drinking water to kill germs react with naturally-occurring organic matter in water.

A. Chlorite
B. Haloacetic Acids
C. Bromate
D. Total Trihalomethanes
E. Disinfection byproducts
F. None of the Above

2. _______________________Some infants and young children who drink water containing chlorite in excess of the EPA's standard could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorite in excess of the EPA's standard. Some people may experience anemia.

A. Chlorite
B. Haloacetic Acids
C. Bromate
D. Total Trihalomethanes
E. Disinfection byproducts
F. None of the Above

Ozone Sub-Section

3. ______________________ is probably the strongest oxidizing agent available for water treatment. Although it is widely used throughout the world, is has not found much application in the United States.

A. Oxygen and nascent oxygen
B. Oxygen
C. Ozone (O_3)
D. Chloramines or THMs
E. Liquid ozone
F. None of the Above

4. ______________________ is not practical for complete removal of chlorine or chloramines, or of THM and other inorganics. Further, because of the possibility of formation of other carcinogens (such as aldehydes or phthalates) it falls into the same category as other disinfectants in that it can produce DBPs.

A. Oxygen and nascent oxygen
B. Oxygen
C. Ozone
D. Chloramines or THMs
E. Liquid ozone
F. None of the Above

Significance of Ozone

5. Ozone is a very powerful oxidant, even more powerful than_________________.

A. VOCs and other compounds
B. Carcinogenic by-products
C. Chlorine
D. Oxygen
E. Cyanides, sulfides, nitrites
F. None of the Above

In Addition, Ozone:

6. While it has a half-life of about 20 minutes in____________, its half-life in dirty water is even shorter as it is consumed by the microorganisms, VOCs and other compounds.

A. Clean water
B. Carcinogenic by-products
C. Iron and manganese
D. Oxygen
E. Cyanides, sulfides, nitrites
F. None of the Above

Commercial Production

7. Ozone is produced commercially in the same way it is formed naturally by lightning or________________ . The commercial lightning method is called corona discharge.

A. Ozone
B. Natural UV radiation
C. O2
D. UV radiation from the sun
E. Radiation from the sun
F. None of the Above

8. _________________is passed through a chamber between the UV lamp and a shield. UV light can create or destroy ozone depending on the UV wavelength. Wavelengths of 185 nanometers (nm) are required for the generation of ozone and 254 nm for the destruction of ozone.

A. Thermal destruction
B. Ozone
C. Chemical reaction(s)
D. Corona discharge
E. Air
F. None of the Above

Potential Health Hazards

9. The EPA makes a distinction between ozone in the upper and lower atmosphere. Ozone in the upper atmosphere, referred to as________________, helps filter out damaging ultraviolet radiation from the sun. Conversely, ozone in the lower atmosphere, – the air we breathe – can be harmful to the respiratory system.

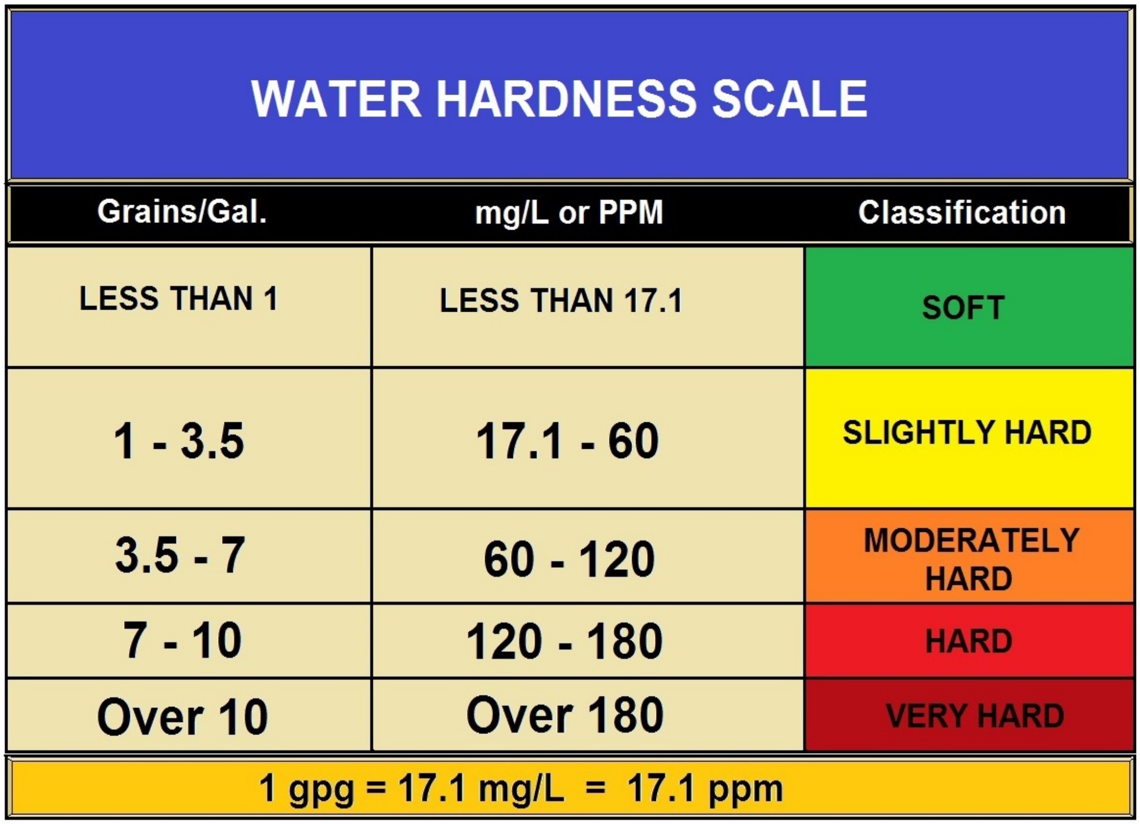
A. Stratospheric ozone
B. Ozone
C. Chemical reaction(s)
D. Corona discharge
E. O2
F. None of the Above

Ultraviolet Radiation Sub-Section

10. The enormous temperatures on the sun create ____________ in great amounts, and this radiation is so powerful that all life on earth would be destroyed if these rays were not scattered by the atmosphere and filtered out by the layers of ozone gas that float some 20 miles above the earth.

A. A mercury vapor lamp
B. Radiation
C. Ultraviolet (UV) rays
D. Ordinary glass
E. Quartz tube
F. None of the Above

Hard Water Section 7



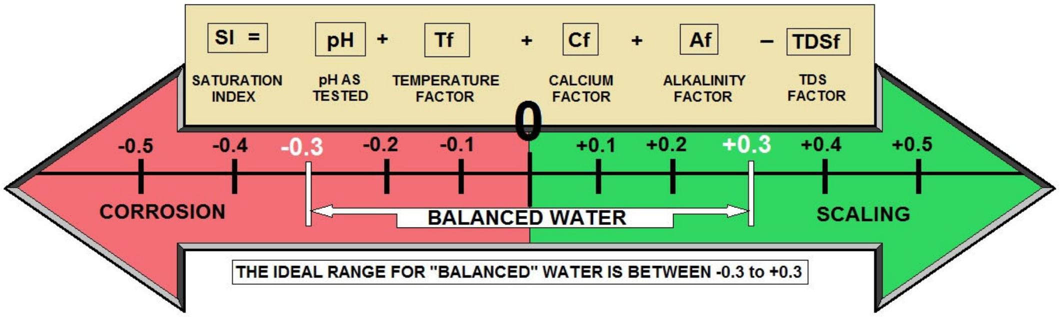
WATER HARDNESS SCALE

Grains/Gal.	mg/L or PPM	Classification
LESS THAN 1	LESS THAN 17.1	SOFT
1 - 3.5	17.1 - 60	SLIGHTLY HARD
3.5 - 7	60 - 120	MODERATELY HARD
7 - 10	120 - 180	HARD
Over 10	Over 180	VERY HARD

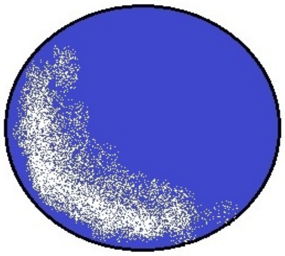
1 gpg = 17.1 mg/L = 17.1 ppm

In this section, the student will understand and explain hard water and its concerns relating to microfiltration and various water conditioning.

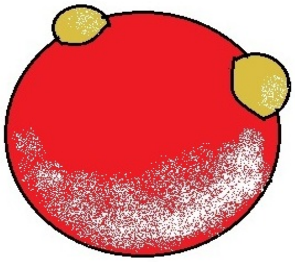
a. Types of Hardness
b. Carbonate – Noncarbonate Distinction
c. Water Softening



LANGELIER SATURATION INDEX

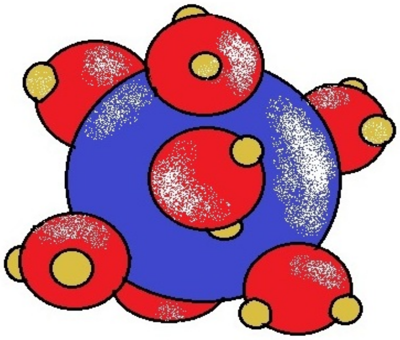


BARE CALCIUM ION

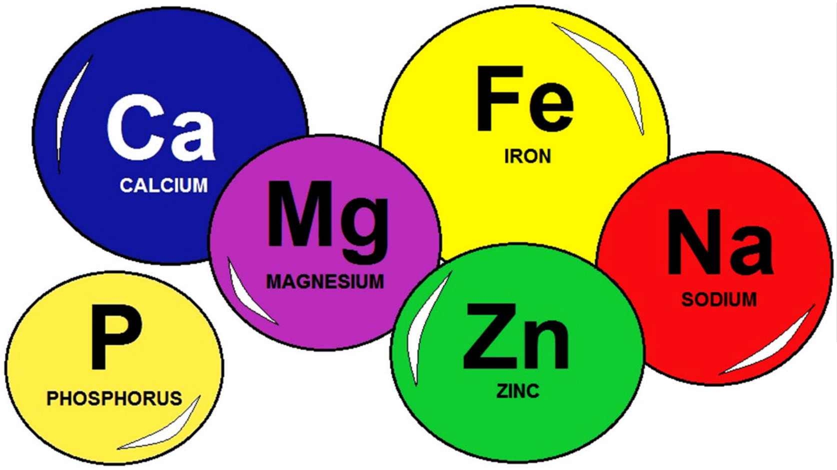


H_2O

WATER MOLECULE



HYDRATED CALCIUM ION



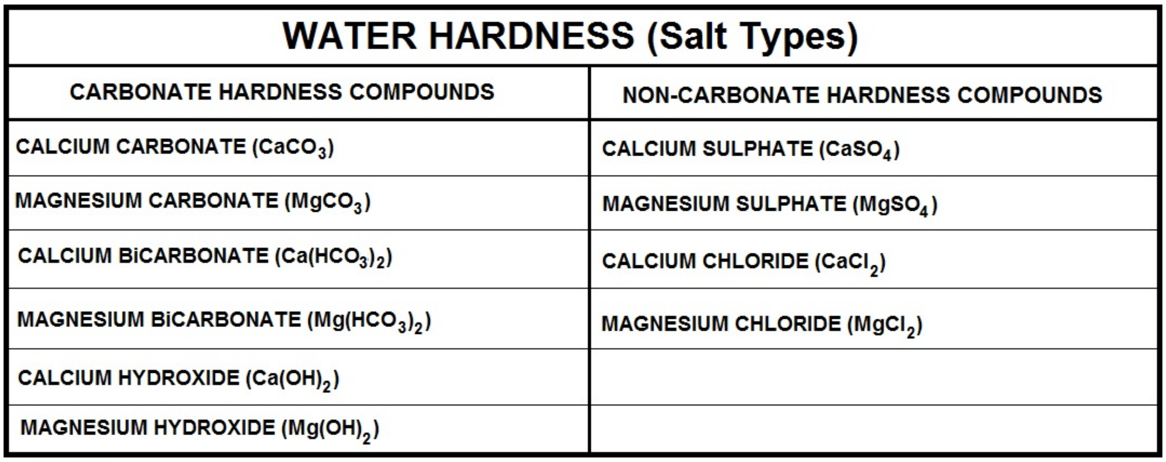
EXAMPLES OF TDS
(Total Dissolved Solids)
FOUND IN WATER SOURCES

CAN BE FROM AGRICULTURE OR URBAN RUNOFF, WHICH CARRY EXCESS MINERALS INTO THE WATER SOURCE

MINERAL SPRINGS CONTAIN HIGH LEVELS OF TDS BECAUSE THE ROCKS WHICH THE WATER SOURCE FLOWS THROUGH HAVE A HIGH SALT CONTENT

MINERALS THAT AFFECT THE QUALITY OF WATER SOURCE

Lead does not usually occur naturally in water supplies but is derived from lead distribution and domestic pipework and fittings. Water suppliers (distribution) have removed most of the original lead piping from the mains distribution system, many older properties still have lead service pipes and internal lead pipework. The pipework (including the service pipe) within the boundary of the property is the responsibility of the owner of the property, not the water supplier.

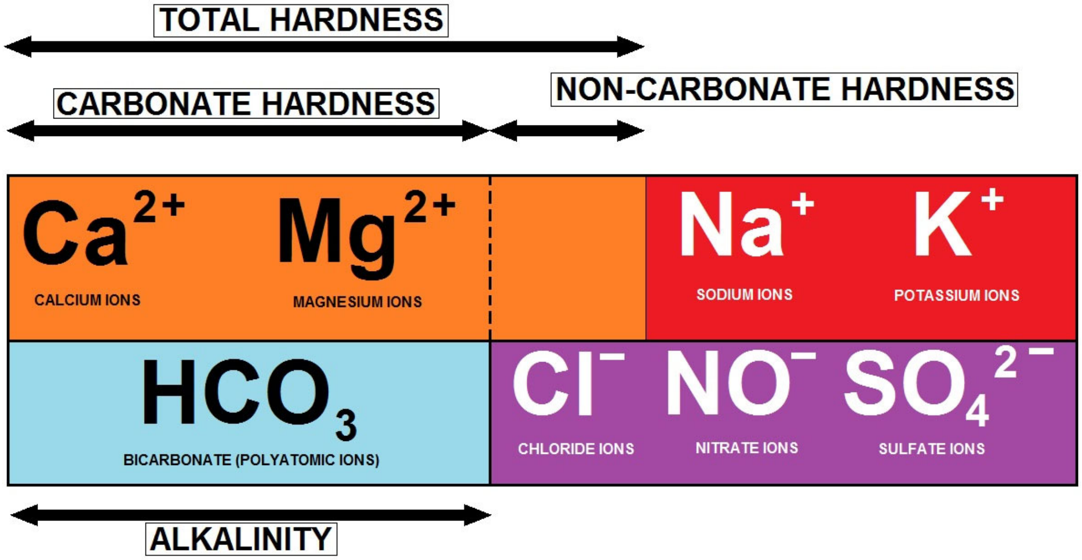


WATER HARDNESS (Salt Types)	
CARBONATE HARDNESS COMPOUNDS	NON-CARBONATE HARDNESS COMPOUNDS
CALCIUM CARBONATE ($CaCO_3$)	CALCIUM SULPHATE ($CaSO_4$)
MAGNESIUM CARBONATE ($MgCO_3$)	MAGNESIUM SULPHATE ($MgSO_4$)
CALCIUM BiCARBONATE ($Ca(HCO_3)_2$)	CALCIUM CHLORIDE ($CaCl_2$)
MAGNESIUM BiCARBONATE ($Mg(HCO_3)_2$)	MAGNESIUM CHLORIDE ($MgCl_2$)
CALCIUM HYDROXIDE ($Ca(OH)_2$)	
MAGNESIUM HYDROXIDE ($Mg(OH)_2$)	

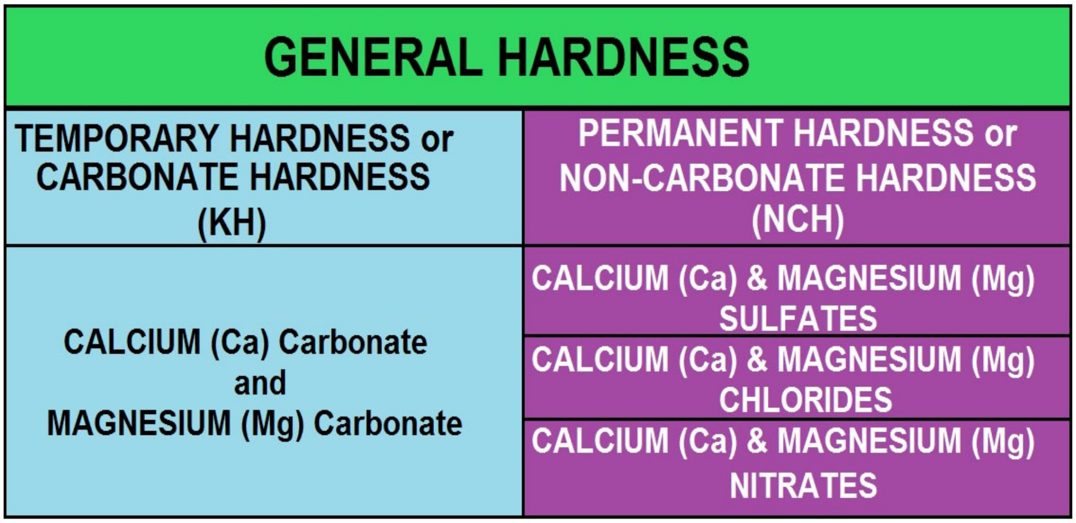
CAUSES OF HARDNESS THAT AFFECTS WATER QUALITY

Hardness

There are two types of hardness: temporary and permanent. Temporary hardness comes out of the water when it's heated and is deposited as scale and fur on kettles, coffee makers and taps and appears as a scum or film on tea and coffee. Permanent hardness is unaffected by heating. We will cover this in the advanced water treatment section.



CARBONATE HARDNESS CHART



GENERAL HARDNESS	
TEMPORARY HARDNESS or CARBONATE HARDNESS (KH)	PERMANENT HARDNESS or NON-CARBONATE HARDNESS (NCH)
CALCIUM (Ca) Carbonate and MAGNESIUM (Mg) Carbonate	CALCIUM (Ca) & MAGNESIUM (Mg) SULFATES
	CALCIUM (Ca) & MAGNESIUM (Mg) CHLORIDES
	CALCIUM (Ca) & MAGNESIUM (Mg) NITRATES

FORMS OF HARDNESS IN WATER

Hard Water Sub-Section

Water contains various amounts of dissolved minerals, some of which impart a quality known as hardness. Consumers frequently complain about problems attributed to hard water, such as the formation of scale in cooking utensils and hot water heaters.
In this document we will discusses the occurrence and effects of hard water and the hard water treatment or softening process that remove the hardness-causing minerals.

The precipitation process most frequently used is generally known as the lime process or lime soda process. Because of the special facilities required and the complexity of the process, it is generally applicable only to medium- or large-size water systems where all treatment can be accomplished at a central location.

This process will provide softened water at the lowest cost. Lime softening can be used for treatment of either groundwater or surface water sources.

The other commonly used method of softening involves the ion exchange process. This process has the advantages of a considerably lower initial cost and ease of use by small systems or by large systems at multiple locations.

The principal disadvantage is that operating costs are considerably higher. Ion exchange processes can typically be used for direct treatment of groundwater, so long as turbidity and iron levels are not excessive. For treatment of surface water, the process normally must be preceded by conventional treatment.

Softening can also be accomplished using membrane technology, electrodialysis, distillation, and freezing. Of these, the membrane methods seem to have the greatest use potential.

Occurrence of Hard Water

Hard water is caused by soluble, divalent, metallic cations, (positive ions having valence of 2). The principal chemicals that cause water hardness are calcium (Ca) and magnesium (Mg). Strontium, aluminum, barium, iron, are or are not usually not present in large enough concentrations to contribute significantly to the total hardness.

Water hardness varies considerably in different geographic areas of the contiguous 48 states. This is due to different geologic formations, and is also a function of the contact time between water and limestone deposits, which leech calcium into the water. Magnesium is dissolved as water passes over and through dolomite and other magnesium-bearing minerals. Because ground-water is in contact with these formations for a longer period of time than surface water, groundwater is normally harder than surface water.

Expressing Hardness Concentration

Water hardness is generally expressed as a concentration of calcium carbonate, in terms of milligrams per liter as $CaCO_3$. The degree of hardness that consumer consider objectionable will vary, depending on other qualities of the water and on the hardness to which they have become accustomed. We will show two different classifications of the relative hardness of water:

Comparative classifications of water for softness and hardness

Classification	mg/L as $CaCO_3$ *	mg/L as $CaCO_3$ +
Soft	0 – 75	0 – 60
Moderately hard	75 – 150	61 – 120
Hard	150 – 300	121 – 180
Very hard	Over 300	Over 180

Source: Adapted from sawyer 1960 and Briggs and Ficke 1977.

* Per Sawyer (1960)
+ Per Briggs and Ficke (1977)

Types of Hardness

Hardness can be categorized by either of two methods: calcium versus magnesium hardness and carbonate versus non-carbonate hardness.

The calcium-magnesium distinction is based on the minerals involved. Hardness caused by calcium is called calcium hardness, regardless of the salts associated with it, which include calcium sulfate ($CaSO_4$), calcium chloride ($CaCl_2$), and others. Likewise, hardness caused by magnesium is called magnesium hardness. Calcium and magnesium are normally the only significant minerals that cause hardness, so it is generally assumed that

Total hardness = calcium hardness + magnesium hardness

Carbonate-Noncarbonate Distinction

The carbonate-noncarbonate distinction, however, is based on hardness from either the bicarbonate salts of calcium or the normal salts of calcium and magnesium involved in causing water hardness. Carbonate hardness is caused primarily by the bicarbonate salts of calcium and magnesium, which are calcium bicarbonate, $Ca(HCO_3)_2$, and magnesium bicarbonate $Mg(HCO_3)_2$. Calcium and magnesium combined with carbonate (CO_3) also contribute to carbonate hardness.

Noncarbonate hardness is a measure of calcium and magnesium salts other than carbonate and bicarbonate salts. These salts are calcium sulfate, calcium chloride, magnesium sulfate ($MgSO_4$), and magnesium chloride ($MgCl_2$). Calcium and magnesium combined with nitrate may also contribute to noncarbonate hardness, although it is a very rare condition. For carbonate and noncarbonate hardness;

Total hardness = carbonate hardness + noncarbonate hardness

When hard water is boiled, carbon dioxide (CO_2) is driven off, bicarbonate salts of calcium and magnesium then settle out of the water to form calcium and magnesium carbonate precipitates. These precipitates form the familiar chalky deposits on teapots. Because it can be removes by heating, carbonate hardness is sometimes called ***"Temporary hardness."*** Because noncarbonated hardness cannot be removed or precipitated by prolonged boiling, it is sometimes called ***"permanent hardness."***

Objections to Hard Water

Scale Formation: Hard water forms scale, usually calcium carbonate, which causes a variety of problems. Left to dry on the surface of glassware and plumbing fixtures, including showers doors, faucets, and sink tops; hard water leaves unsightly white scale known as water spots. Scale that forms on the inside of water pipes will eventually reduce the flow capacity or possibly block it entirely. Scale that forms within appliances and water meters causes wear on moving parts.

When hard water is heated, scale forms much faster. In particular, when the magnesium hardness is more than about 40 mg/l (as $CaCO_3$), magnesium hydroxide scale will deposit in hot water heaters that are operated at normal temperature of 140-150°F (60-66°C). A coating of only 0.04 in. (1 mm) of scale on the heating surfaces of a hot water heater creates an insulation effect that will increase heating costs by about 10 percent.

Effect on Soap: The historical objection to hardness has been its effect on soap. Hardness ions form precipitates with soap. Causing unsightly "**curd**," such as the familiar bathtub ring, as well as reduced efficiency in washing and laundering. To counteract these problems, synthetic detergents have been developed and are now used almost exclusively for washing clothes and dishes.

These detergents have additives known as sequestering agents that ***"tie up"*** the hardness ions so that they cannot form the troublesome precipitates. Although modern detergents counteract many of the problems of hard water, many customers prefer softer water. These customers can install individual softening units or use water from another source, such as a cistern, for washing.

Hard Water Treatment Methods

There are many commercial ways of treating hard water including water filters, water softeners, electromagnetic water conditioners and reverse osmosis. In this section we will look at the pros and cons of several of the available methods to treat hard water.

Method	**Chemical Water Softeners**	**Water Filters**	**Mechanical Water Treatment Softeners**	**Magnetic Water Conditioners**
Description	Chemicals added in laundering process	Drinking water from the tap is filtered with a portable unit	Permanently installed in plumbing system to replace calcium and magnesium with sodium	Permanently installed in plumbing system to alter calcium ions so they cannot cause lime scale
Advantages	Removes Calcium and Magnesium and lengthens lifespan of clothes	Output water is fit for drinking Chlorine removed Water Softened	Prevents Lime scale Increases heating efficiency Lengthens lifespan of clothes	Output water is fit for drinking Prevents Lime scale Increases heating efficiency Lengthens lifespan of clothes Calcium retained, good for diet Low running cost
Disadvantages	Output water is not fit for drinking	Does not prevent lime scale deposits in pipes and heating system	Output water may not be suitable for drinking Expensive	
Approximate Cost		($0.09) / gallon	($1400) Unit + Installation ($140) / Year - Salt + Electricity	($90) Unit + Installation ($7) / Year - electricity

Water Softening Summary

We often need to soften the water before or after microfiltration, depending on the process.

Water softening is a method of removing from water the minerals that make it hard. Hard water does not dissolve soap readily. It forms scale in pipes, boilers, and other equipment in which it is used. The principal methods of softening water are the lime soda process and the ion exchange process.

In the ***lime soda process,*** soda ash and lime are added to the water in amounts determined by chemical tests. These chemicals combine with the calcium and magnesium in the water to make insoluble compounds that settle to the bottom of the water tank.

In the ***ion exchange process,*** the water filters through minerals called *zeolites.* As the water passes through the filter, the sodium ions in the zeolite are exchanged for the calcium and magnesium ions in the water, and the water is softened. After household softeners become exhausted, a strong solution of *sodium chloride* (salt) is passed through the filter to replace the sodium that has been lost. The use of two exchange materials makes it possible to remove both metal and acid ions from water. Some cities and towns, however, prohibit or restrict the use of ion exchange equipment on drinking water, pending the results of studies on how people are affected by the consumption of the added sodium in softened water.

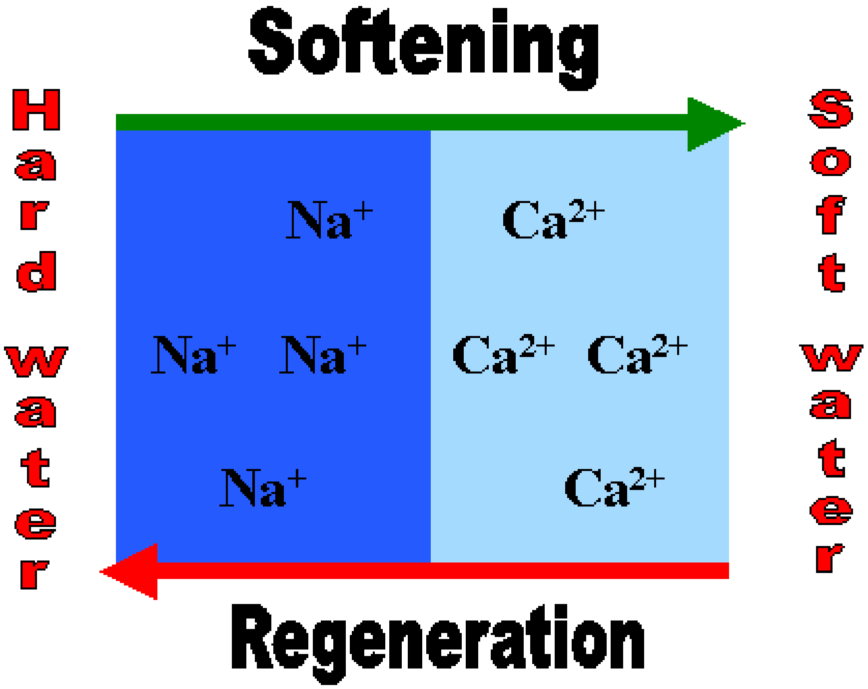
These commercial ion exchange containers hold the resin for the deionization.

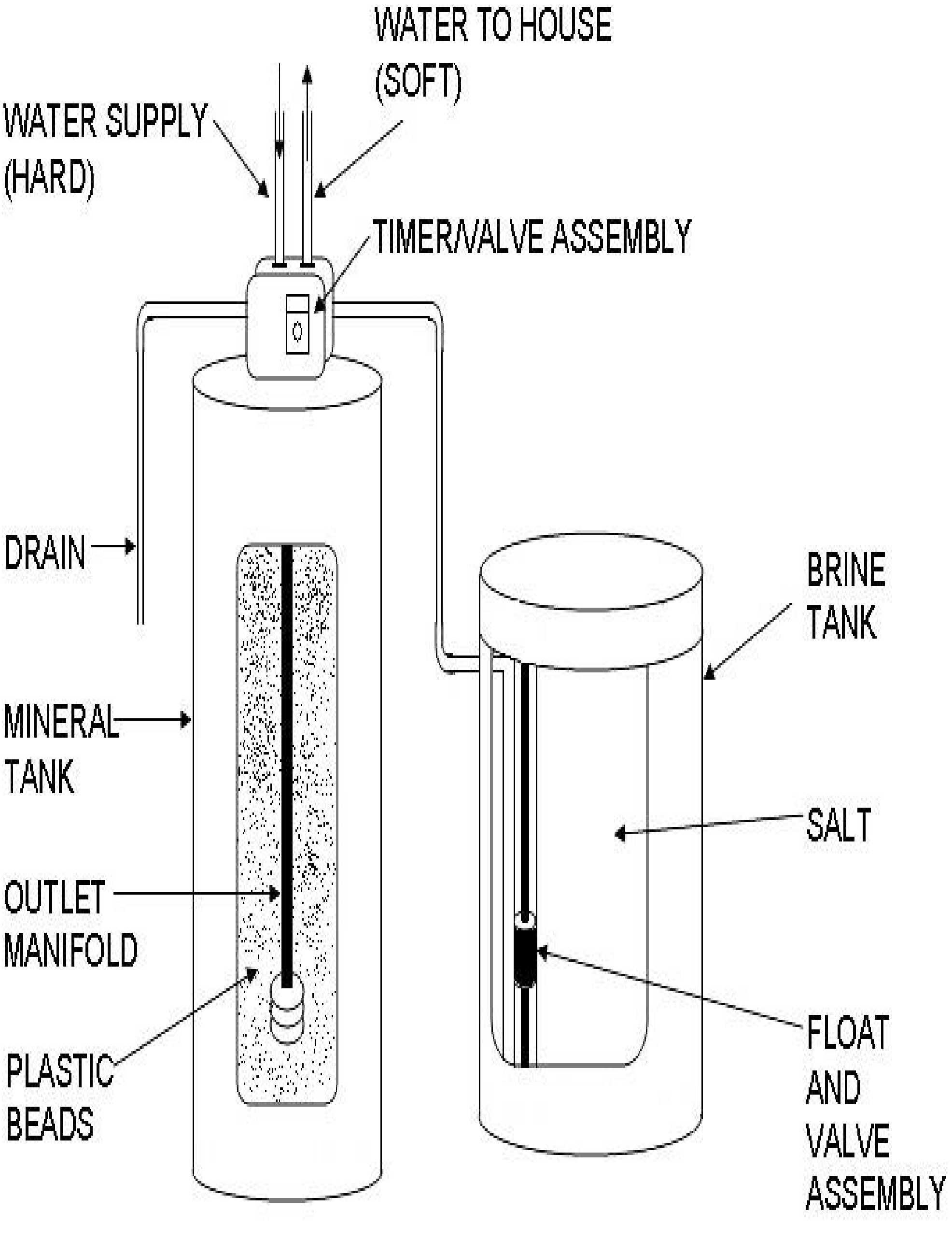
Calcium and magnesium in water create hard water, and at high levels can clog pipes. The best way to soften water is to use a water softener unit connected into the water supply line. You may want to consider installing a separate faucet for unsoftened water used for drinking and cooking. Water softening units also remove iron.

The most common way to soften household water is to use a water softener. Softeners may also be safely used to remove up to about 5 milligrams per liter of dissolved iron if the water softener is rated for that amount of iron removal. Softeners are automatic, semi-automatic, or manual. Each type is available in several sizes and is rated on the amount of hardness it can remove before regeneration is necessary. Using a softener to remove iron in naturally soft water is not advised. A green-sand filter is a better method. When the resin is filled to capacity, it must be recharged. Fully automatic softeners regenerate on a preset schedule and return to service automatically. Regeneration is usually started by a preset time clock; some units are started by water use meters or hardness detectors. Semi-automatic softeners have automatic controls for everything except for the start of regeneration. Manual units require manual operation of one or more valves to control back washing, brining and rinsing. In many areas, there are companies that provide a water softening service. For a monthly fee the company installs a softener unit and replaces it periodically with a freshly charged unit.

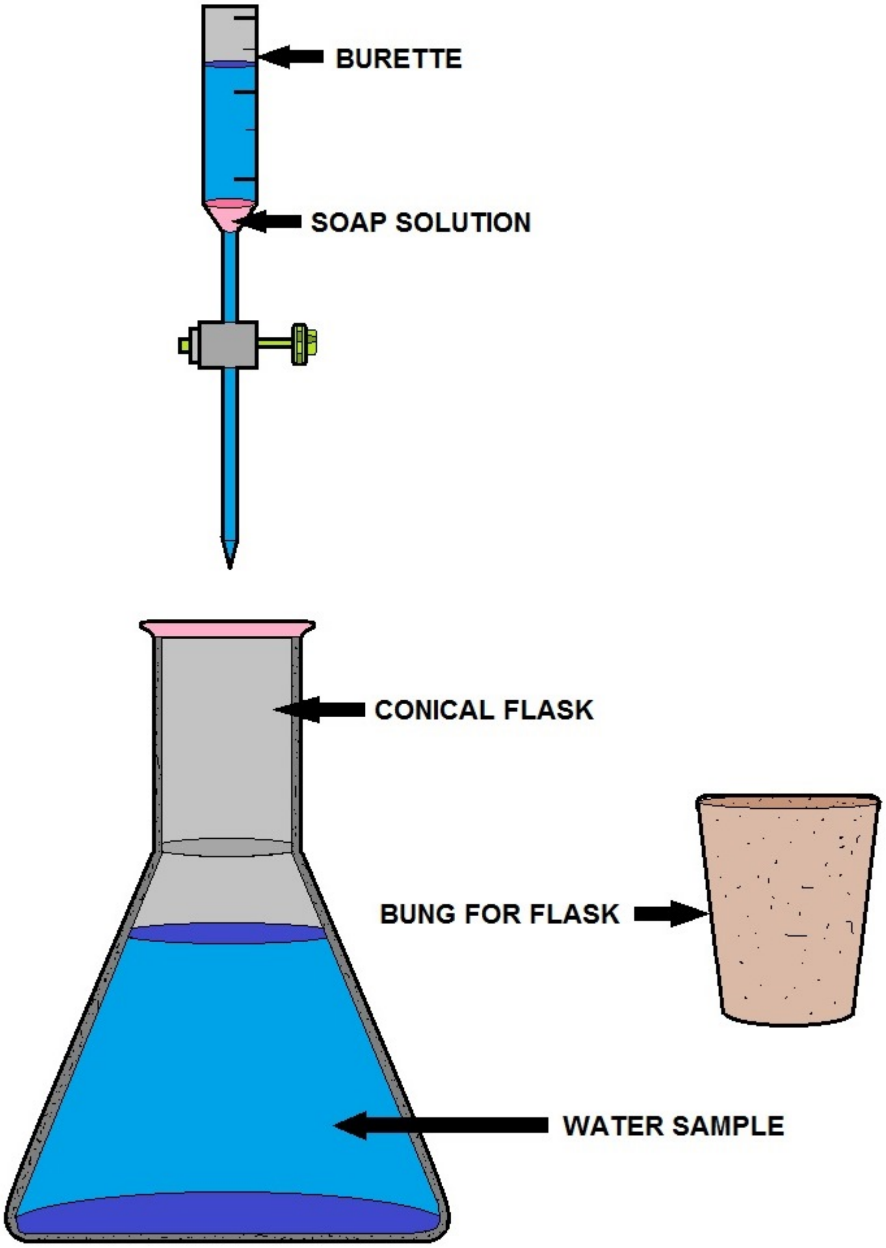
The principle behind water softening is really just simple chemistry. A water softener contains resin beads which hold electrically charged ions. When hard water passes through the softener, calcium and magnesium ions are attracted to the charged resin beads. It's the resulting removal of calcium and magnesium ions that produces "*soft water*." The diagram shows the exchange that takes place during the water softening process.

When the resin beads in your softener become saturated with calcium and magnesium ions, they need to be recharged. Sodium ions from the water softening salt reactivate the resin beads so they can continue to do their job. Without sufficient softening salt, your water softener is less efficient. As a rule, you should check your water softener once a week to be sure the salt level is always at least one quarter full.





Operation of a household water softener.



TESTING FOR THE HARDNESS OF WATER

Mechanical Water Treatment Softeners

Mechanical water treatment softening units can be permanently installed into the plumbing system to continuously remove calcium and magnesium.

Water treatment softeners operate on the ion exchange process. In this process, water passes through a media bed, usually sulfonated polystyrene beads. The beads are supersaturated with sodium. The ion exchange process takes place as hard water passes through the softening material. The hardness minerals attach themselves to the resin beads while sodium on the resin beads is released simultaneously into the water.

When the resin becomes saturated with calcium and magnesium, it must be recharged. The recharging is done by passing a salt (brine) solution through the resin. The sodium replaces the calcium and magnesium which are discharged in the waste water.

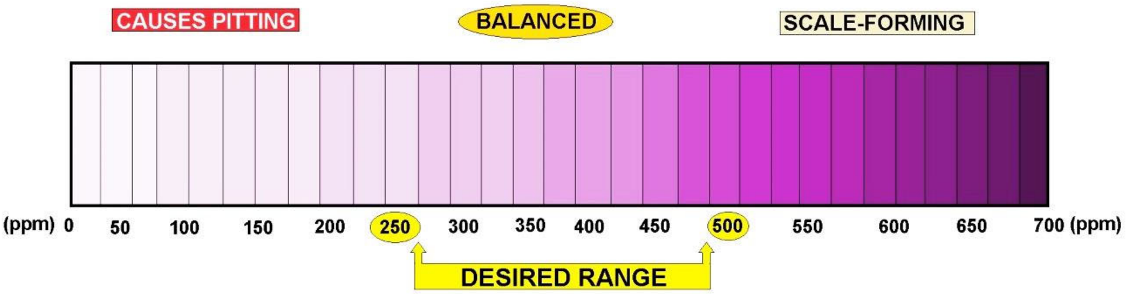
Hard water treated with an ion exchange water softener has sodium added. According to the Water Quality Association (WQA), the ion exchange softening process adds sodium at the rate of about 8 mg/liter for each grain of hardness removed per gallon of water.

For example, if the water has a hardness of 10 grains per gallon, it will contain about 80 mg/liter of sodium after being softened in an ion exchange water softener if all hardness minerals are removed.

Because of the sodium content of softened water, some individuals may be advised by their physician, not to install water softeners, to soften only hot water or to bypass the water softener with a cold water line to provide unsoftened water for drinking and cooking, usually to a separate faucet at the kitchen sink.

Mechanically softened water is not recommended for watering plants, lawns, and gardens due to its sodium content.

The container behind the salt pallet is a high concentration of salt and water. (Brine)

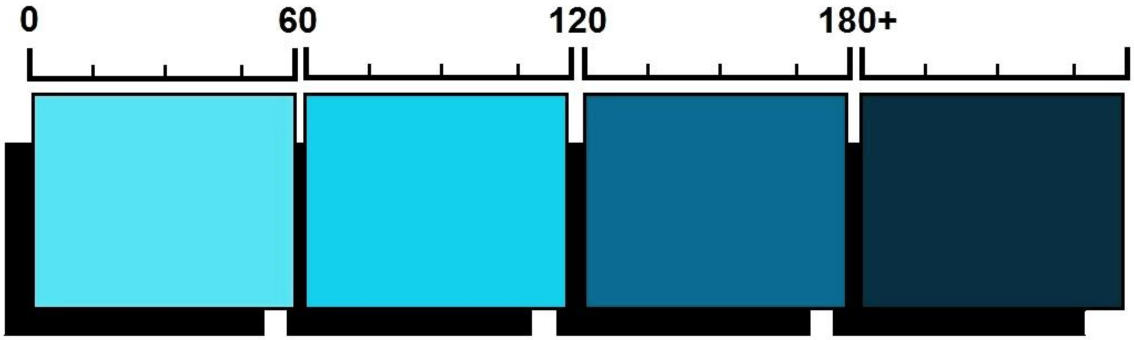


CALCIUM HARDNESS MEASUREMENT

WATER HARDNESS SCALE

Grains/Gal.	mg/L or PPM	Classification
LESS THAN 1	LESS THAN 17.1	SOFT
1 - 3.5	17.1 - 60	SLIGHTLY HARD
3.5 - 7	60 - 120	MODERATELY HARD
7 - 10	120 - 180	HARD
Over 10	Over 180	VERY HARD

1 gpg = 17.1 mg/L = 17.1 ppm



MEASURING HARDNESS OF WATER (Calcium Ions Present)

Small Water Filters

Water filters generally come in two forms. Portable ion exchange water filters, and reverse osmosis water filters. Both are used for *"point of use"* drinking water, that is, to filter out harmful or unwanted particles before the water is used for human consumption.

Reverse Osmosis works by forcing the water through a semi-permeable membrane that stops certain particles from passing through.

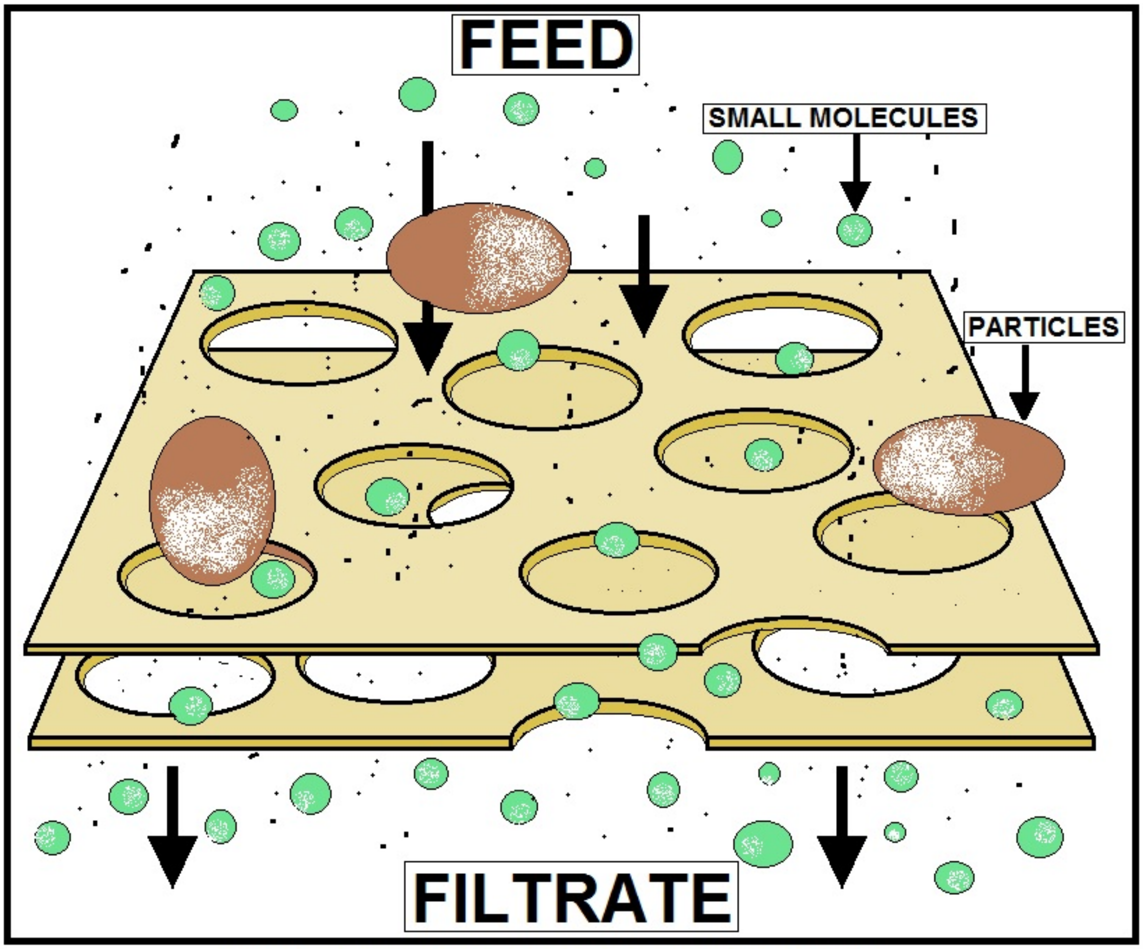
Portable water filters work using a cartridge containing activated carbon and ion exchange resin. The carbon absorbs and helps reduce the levels of chlorine and chlorine compounds, as well as pesticides, color and other organic substances. This improves taste and appearance. The ion exchange resin works to reduce temporary hardness.

Activated Carbon Filtration

Activated carbon has been used for many years to solve water problems. In the beginning, its use was more art than science. Today, however, we understand more about what activated carbon can remove and how it removes impurities.
Activated carbon quickly and effectively removes chlorine from water.

The presence of organic matter in water can cause color, taste, and odor complaints. Activated carbon adsorbs organic matter in its extensive network of pores. The adsorption process takes time, so service rates should be limited to 5 gpm/ft (12m/hr) or less for these applications.

A handful of GAC. Basically, just burnt coconut shells. This is used to remove tastes and odors and other long chained organic compounds from drinking water.



FILTRATION OPERATION EXAMPLE

Hard Water Section 7 Post Quiz

1. The precipitation process most frequently used is generally known as the______________. Because of the special facilities required and the complexity of the process, it is generally applicable only to medium- or large-size water systems where all treatment can be accomplished at a central location.

A. Hardness D. Softening
B. Precipitation process E. Lime process or lime soda process
C. Lime softening F. None of the Above

Occurrence of Hard Water

2. __________________is caused by soluble, divalent, metallic cations, (positive ions having valence of 2). The principal chemicals that cause water hardness are calcium (Ca) and magnesium (Mg). Strontium, aluminum, barium, iron, are or are not usually present in large enough concentrations to contribute significantly to the total hardness.

A. Hardness ions D. Carbonate hardness
B. Permanent hardness E. Hard water
C. Temporary hardness F. None of the Above

Expressing Hardness Concentration

3. Water hardness is generally expressed as a concentration of calcium carbonate, in terms of milligrams per liter as $CaCO_3$. ______________that consumer consider objectionable will vary, depending on other qualities of the water and on the hardness to which they have become accustomed.

A. The degree of hardness D. These salts
B. Water hardness E. Carbonate-noncarbonate
C. Calcium-magnesium F. None of the Above

Types of Hardness

4. Hardness can be categorized by either of two methods: calcium versus magnesium hardness and_______________________.

A. Hardness ions D. Carbonate hardness
B. Permanent hardness E. Carbonate versus non-carbonate hardness
C. Temporary hardness F. None of the Above

5. Hardness caused by calcium is called calcium hardness, regardless of the salts associated with it, which include calcium sulfate ($CaSO_4$), calcium chloride ($CaCl_2$), and others. Likewise, _____________________caused by magnesium is called magnesium hardness.

A. Hardness ions D. Carbonate hardness
B. Permanent hardness E. Hardness
C. Temporary hardness F. None of the Above

Carbonate-Noncarbonate Distinction

6. The carbonate-noncarbonate distinction, however, is based on hardness from either the bicarbonate salts of calcium or the _______________involved in causing water hardness.

A. $CaCO_3$ D. Normal salts of calcium and magnesium
B. Water hardness E. Carbonate-noncarbonate
C. Calcium-magnesium F. None of the Above

Objections to Hard Water

7. When hard water is heated, scale forms much faster. In particular, when the magnesium hardness is more than about 40 mg/l (as $CaCO_3$), _____________scale will deposit in hot water heaters that are operated at normal temperature of 140-150°F (60-66°C).

A. Magnesium hydroxide D. These salts
B. Water hardness E. Carbonate-noncarbonate
C. Calcium-magnesium F. None of the Above

Water Softening Summary

8. ________________is a method of removing from water the minerals that make it hard. Hard water does not dissolve soap readily. It forms scale in pipes, boilers, and other equipment in which it is used. The principal methods of softening water are the lime soda process and the ion exchange process.

A. Brine D. Hardness
B. Hard water E. Water softening
C. Soft water F. None of the Above

9. When the resin beads in your softener become saturated with calcium and magnesium ions, they need to be recharged. ________________from the water softening salt reactivate the resin beads so they can continue to do their job.

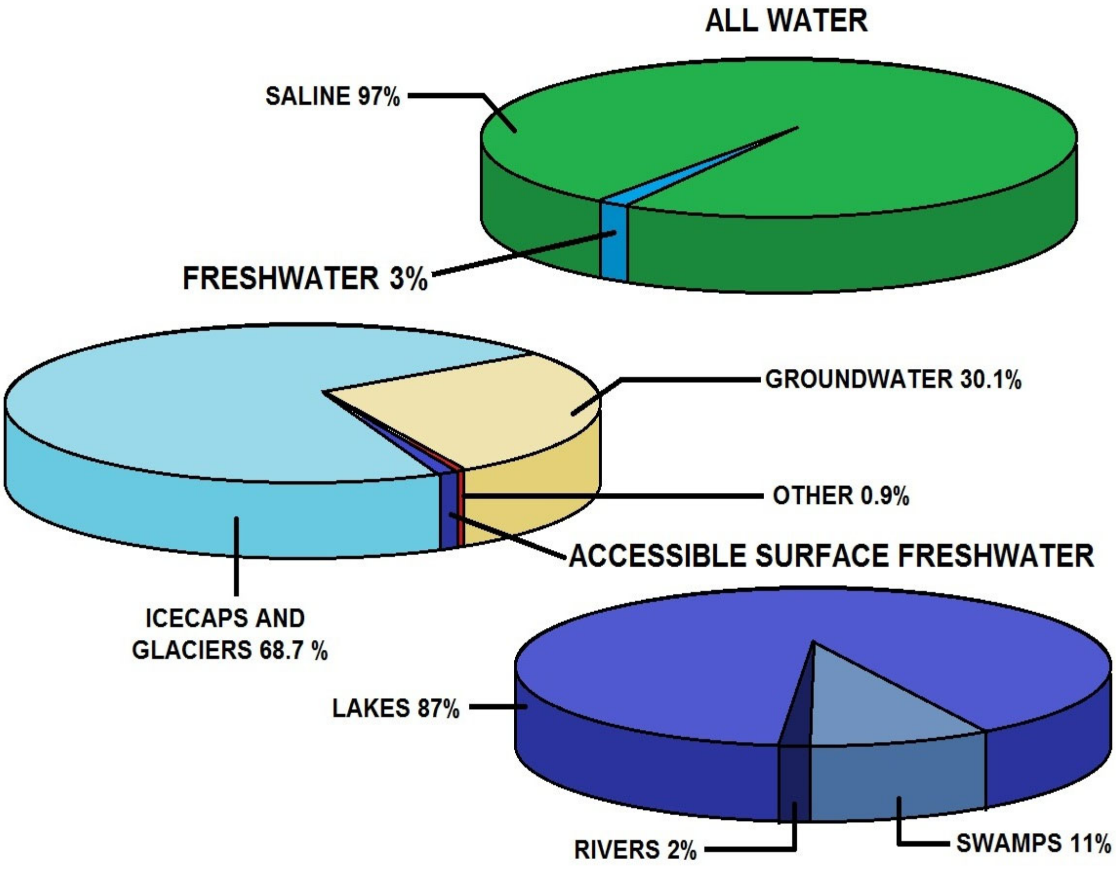
A. Sodium content D. Hardness
B. Hardness minerals E. Sodium ions
C. Calcium and magnesium F. None of the Above

Mechanical Water Treatment Softeners

10. Mechanical water treatment softening units can be permanently installed into the plumbing system to continuously remove _____________________.

A. Brine D. Hardness
B. Hard water E. Calcium and magnesium
C. Soft water F. None of the Above

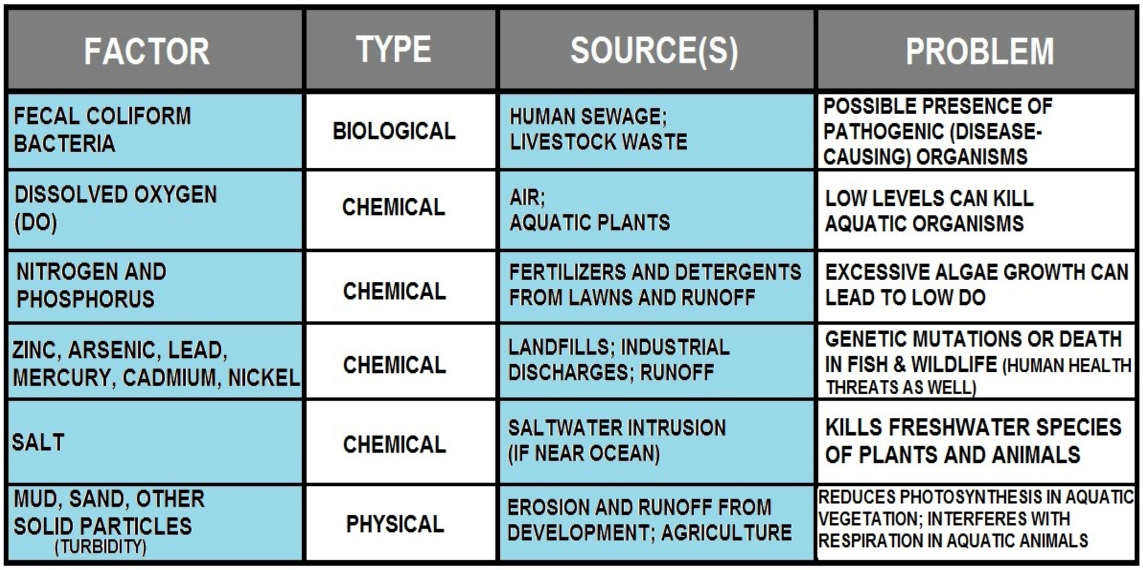
EPA Rule Section 8



FRESHWATER DISTRIBUTION BREAKDOWN

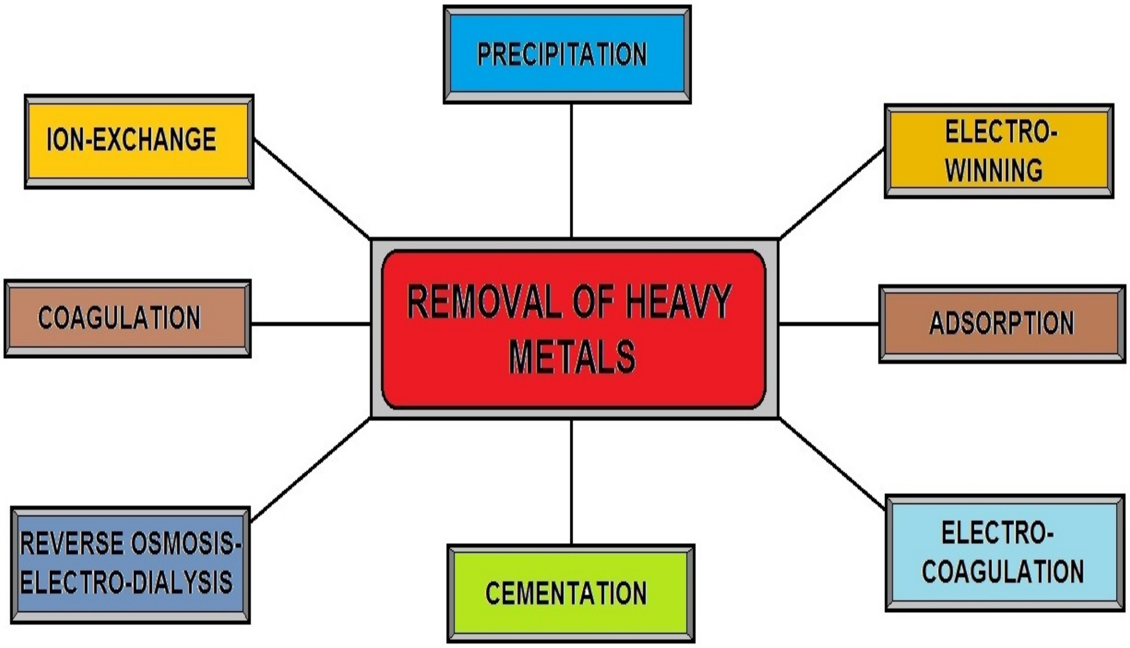
In this section, the student will understand and explain EPA's water quality concerns, rules and regulations, water quality contaminants, SOCs, VOCs, and IOCs.

a. Explain and explain various SOCs, VOCs, and IOCs associated with water and wastewater contamination.
b. Explain and Describe EPA's IOC Sampling Procedures.
c. Antimony
d. Arsenic
e. Asbestos
f. Barium
g. Cadmium
h. Chromium
i. Copper
j. Cyanide
k. Fluoride
l. Lead
m. Mercury
n. Nitrate
o. Nitrite
p. Selenium



FACTOR	TYPE	SOURCE(S)	PROBLEM
FECAL COLIFORM BACTERIA	BIOLOGICAL	HUMAN SEWAGE; LIVESTOCK WASTE	POSSIBLE PRESENCE OF PATHOGENIC (DISEASE-CAUSING) ORGANISMS
DISSOLVED OXYGEN (DO)	CHEMICAL	AIR; AQUATIC PLANTS	LOW LEVELS CAN KILL AQUATIC ORGANISMS
NITROGEN AND PHOSPHORUS	CHEMICAL	FERTILIZERS AND DETERGENTS FROM LAWNS AND RUNOFF	EXCESSIVE ALGAE GROWTH CAN LEAD TO LOW DO
ZINC, ARSENIC, LEAD, MERCURY, CADMIUM, NICKEL	CHEMICAL	LANDFILLS; INDUSTRIAL DISCHARGES; RUNOFF	GENETIC MUTATIONS OR DEATH IN FISH & WILDLIFE (HUMAN HEALTH THREATS AS WELL)
SALT	CHEMICAL	SALTWATER INTRUSION (IF NEAR OCEAN)	KILLS FRESHWATER SPECIES OF PLANTS AND ANIMALS
MUD, SAND, OTHER SOLID PARTICLES (TURBIDITY)	PHYSICAL	EROSION AND RUNOFF FROM DEVELOPMENT; AGRICULTURE	REDUCES PHOTOSYNTHESIS IN AQUATIC VEGETATION; INTERFERES WITH RESPIRATION IN AQUATIC ANIMALS

WATER QUALITY FACTORS



METHODS TO REMOVE HEAVY METALS IN WATER

EPA Rule Section

Arsenic

Arsenic is a chemical that occurs naturally in the earth's crust. When rocks, minerals, and soil erode, they release arsenic into water supplies. When people either drink this water or eat animals and plants that drink it, they are exposed to arsenic. For most people in the U.S., eating and drinking are the most common ways that people are exposed to arsenic, although it can also come from industrial sources. Studies have linked long-term exposure of arsenic in drinking water to a variety of cancers in humans.

To protect human health, an EPA standard limits the amount of arsenic in drinking water. Back in January 2001, EPA revised the standard from 50 parts per billion (**ppb**), ordering that it fall to 10 ppb by 2006. After adopting 10ppb as the new standard for arsenic in drinking water, EPA decided to review the decision to ensure that the final standard was based on sound science and accurate estimates of costs and benefits.

In October 2001, the EPA decided to move forward with implementing the 10ppb standard for arsenic in drinking water. More information on the rulemaking process and the costs and benefits of setting the arsenic limit in drinking water at 10ppb can be found at **www.epa.gov/safewater/arsenic.html**.

ICR

The EPA has collected data required by the Information Collection Rule (**ICR**) to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts.

The rule is intended to provide the EPA with information on chemical byproducts that form when disinfectants used for microbial control react with chemicals already present in source water (disinfection byproducts (**DBPs**); disease-causing microorganisms (pathogens), including Cryptosporidium; and engineering data to control these contaminants. Drinking water microbial and disinfection byproduct information collected for the ICR is now available in EPA's website Envirofacts Warehouse.

Gathering a water sample in the distribution system at a designated sample site.

Microbes *More on this section in the Appendix*

Bac-T bottles, once the laboratory obtains the sample, they will use Colilert to find the presence of bacteria. The yellow color indicates Coliform bacteria is present. If the sample fluoresces under a black light, this will indicate that the sample will contain fecal or E. Coli bacteria.

Coliform bacteria are common in the environment and are generally not harmful. However, the presence of these bacteria in drinking water is usually a result of a problem with the treatment system or the pipes which distribute water, and indicates that the water may be contaminated with germs that can cause disease.

Fecal Coliform and E coli are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes can cause short-term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms.

Turbidity has no health effects. However, turbidity can interfere with disinfection and provide a medium for microbial growth. Turbidity may indicate the presence of disease causing organisms. These organisms include bacteria, viruses, and parasites that can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.

Cryptosporidium is a parasite that enters lakes and rivers through sewage and animal waste. It causes cryptosporidiosis, a mild gastrointestinal disease. However, the disease can be severe or fatal for people with severely weakened immune systems. The EPA and CDC have prepared **advice for those with severely compromised immune systems** who are concerned about *Cryptosporidium*.

Giardia lamblia is a parasite that enters lakes and rivers through sewage and animal waste. It causes gastrointestinal illness (e.g. diarrhea, vomiting, and cramps).

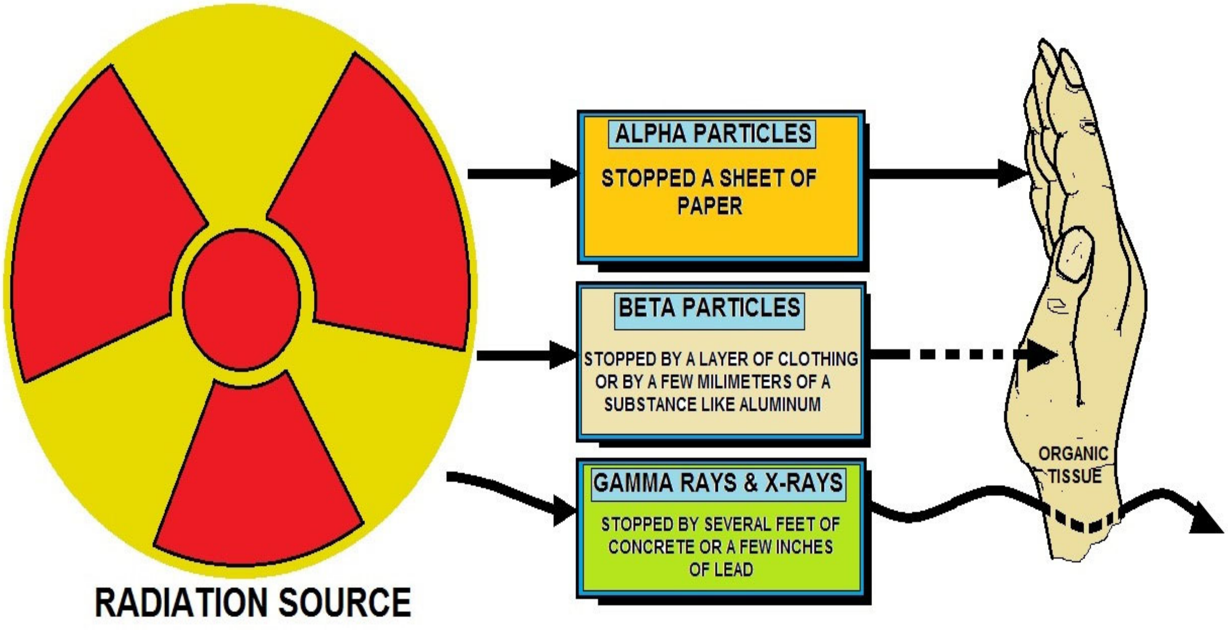
Radionuclides

Alpha Emitters. Certain minerals are radioactive and may emit a form of radiation known as alpha radiation. Some people who drink water containing alpha emitters in excess of the EPA's standard over many years may have an increased risk of getting cancer.

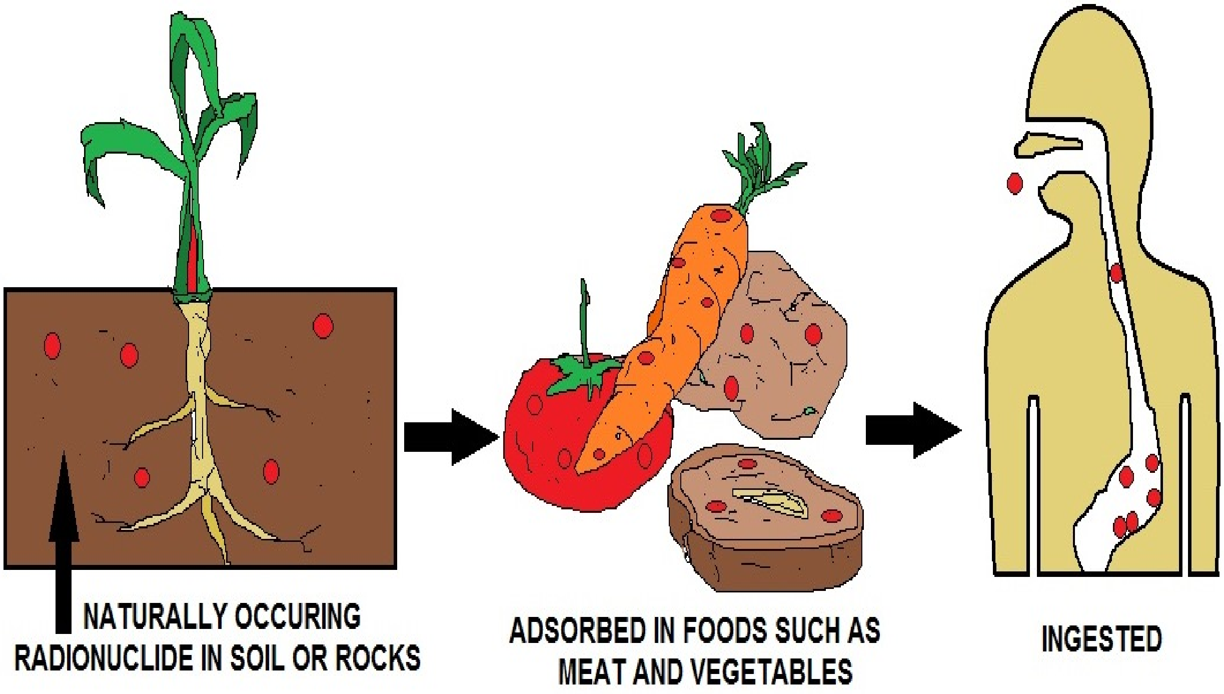
Beta/photon Emitters. Certain minerals are radioactive and may emit forms of radiation known as photons and beta radiation. Some people who drink water containing beta and photon emitters in excess of the EPA's standard over many years may have an increased risk of getting cancer.

Combined Radium 226/228. Some people who drink water containing radium 226 or 228 in excess of the EPA's standard over many years may have an increased risk of getting cancer.

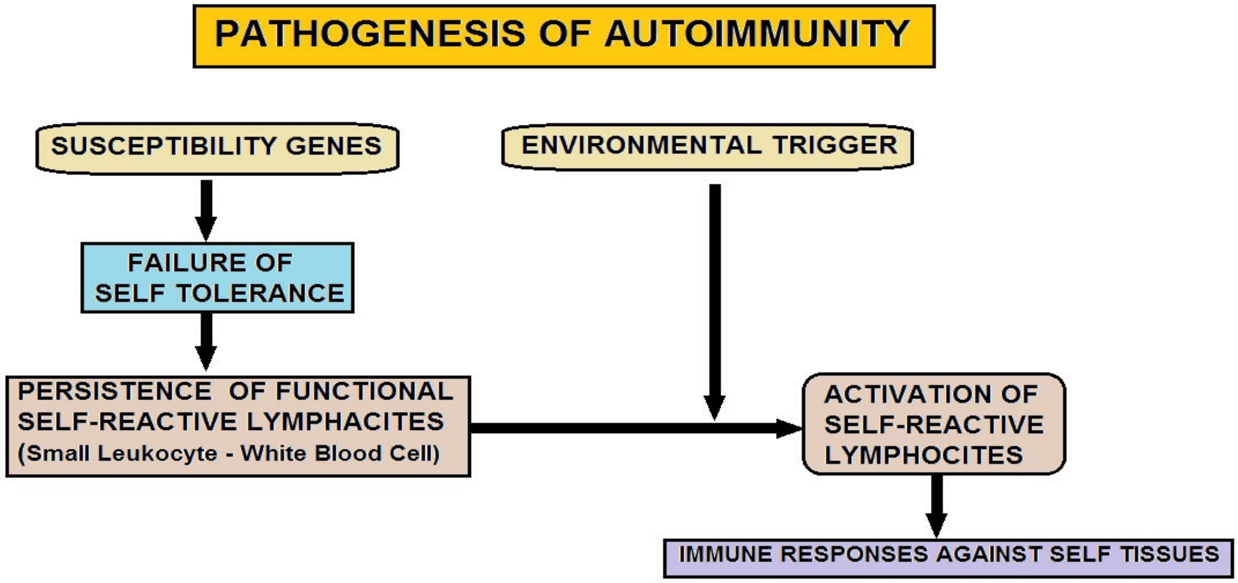
Radon gas can dissolve and accumulate in underground water sources, such as wells, and in the air in your home. Breathing radon can cause lung cancer. Drinking water containing radon presents a risk of developing cancer. Radon in air is more dangerous than radon in water.



PENETRATING POWER OF ALPHA / BETA PARTICLES AND GAMMA RAYS AND X-RAYS



RADIONUCLIDES



PATHOGENESIS
(The Manner in Which a Disease Develops)

Disinfection Byproduct Regulations

In December 1998, the EPA established the **Stage 1 Disinfectants/Disinfection Byproducts Rule** that requires public water systems to use treatment measures that reduce the formation of disinfection byproducts and to meet the following specific standards:

Total trihalomethanes (TTHM)	80 parts per billion (ppb)
Haloacetic acids (HAA5)	60 ppb
Bromate	10 ppb
Chlorite	1.0 parts per million (ppm)

Currently trihalomethanes are regulated at a maximum allowable annual average level of 100 parts per billion for water systems serving over 10,000 people under the Total Trihalomethane Rule finalized by the EPA in 1979.

The **Stage 1 Disinfectant/Disinfection Byproduct Rule** standards became effective for trihalomethanes and other disinfection byproducts listed above in December 2001 for large surface water public water systems. Those standards will become effective in December 2003 for small surface water and all ground water public water systems.

Disinfection byproducts are formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter (i.e., decaying vegetation) present in the source water. Different disinfectants produce different types or amounts of disinfection byproducts. Disinfection byproducts for which regulations have been established have been identified in drinking water, including trihalomethanes, haloacetic acids, bromate, and chlorite.

Trihalomethanes (THM) are a group of four chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

The EPA has published the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate total trihalomethanes (**TTHM**) at a maximum allowable annual average level of **80 parts per billion**. This standard did replace the current standard of a maximum allowable annual average level of 100 parts per billion in December 2001 for large surface water **public water systems**. The standard will become effective for the first time in December 2003 for small surface water and all ground water systems.

Haloacetic Acids (HAA5) are a group of chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The regulated haloacetic acids, known as HAA5, are: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. The EPA has published the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate HAA5 at **60 parts per billion** annual average.

This standard became effective for large surface water **public water systems** in December 2001 and for small surface water and all ground water public water systems in December 2003.

Bromate

Bromate is a chemical that is formed when ozone used to disinfect drinking water reacts with naturally occurring bromide found in source water. The EPA has established the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate bromate at an annual average of **10 parts per billion** in drinking water. This standard became effective for large **public water systems** December 2001 and for small surface water and all ground public water systems in December 2003.

Chlorite is a byproduct formed when chlorine dioxide is used to disinfect water. The EPA has published the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate chlorite at a monthly average level of 1 part per million in drinking water. This standard became effective for large surface water **public water systems** in December 2001 and small surface water and all ground water public water systems in December 2003.

Microbial Regulations

One of the key regulations developed and implemented by the United States Environmental Protection Agency (**USEPA**) to counter pathogens in drinking water is the **Surface Water Treatment Rule**. Among its provisions, the rule requires that a public water system, using surface water (or ground water under the direct influence of surface water) as its source, have sufficient treatment to reduce the source water concentration of ***Giardia*** and viruses by at least 99.9% and 99.99%, respectively.

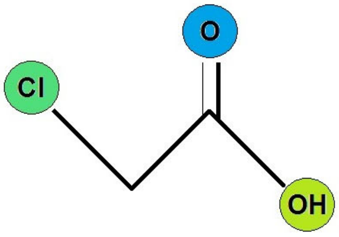
The Surface Water Treatment Rule specifies treatment criteria to assure that these performance requirements are met; they include turbidity limits, disinfectant residual, and disinfectant contact time conditions.

The **Interim Enhanced Surface Water Treatment Rule** was established in December 1998 to control ***Cryptosporidium***, and to maintain control of pathogens while systems lower disinfection byproduct levels to comply with the **Stage 1 Disinfectants/Disinfection Byproducts Rule**.

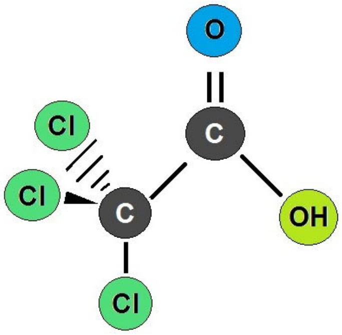
EPA established a Maximum Contaminant Level Goal (**MCLG**) of zero for all public water systems and a 99% removal requirement for Cryptosporidium in filtered public water systems that serve at least 10,000 people. The new rule tightened turbidity standards in December 2001. Turbidity is an indicator of the physical removal of particulates, including pathogens.

The EPA is also planning to develop other rules to further control pathogens. The EPA promulgated a Long Term 1 Enhanced Surface Water Treatment Rule, for systems serving fewer than 10,000 people, in November 2000 to improve physical removal of *Cryptosporidium*, and to maintain control of pathogens while systems comply with **Stage 1 Disinfectants/Disinfection Byproducts Rule**.

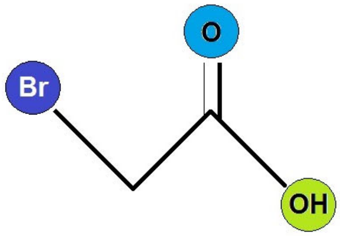
This course contains EPA's federal rule requirements. Please be aware that each state implements drinking water regulations that may be more stringent than EPA's regulations. Check with your state environmental agency for more information.



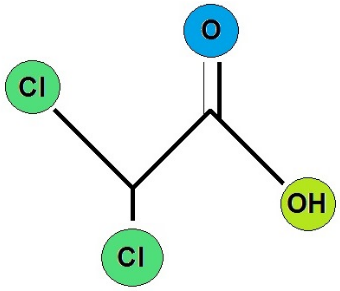
CHLOROACETIC ACID



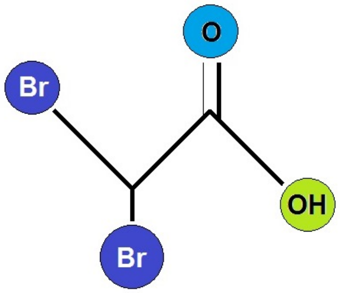
TRICHLOROACETIC ACID



BROMOACETIC ACID

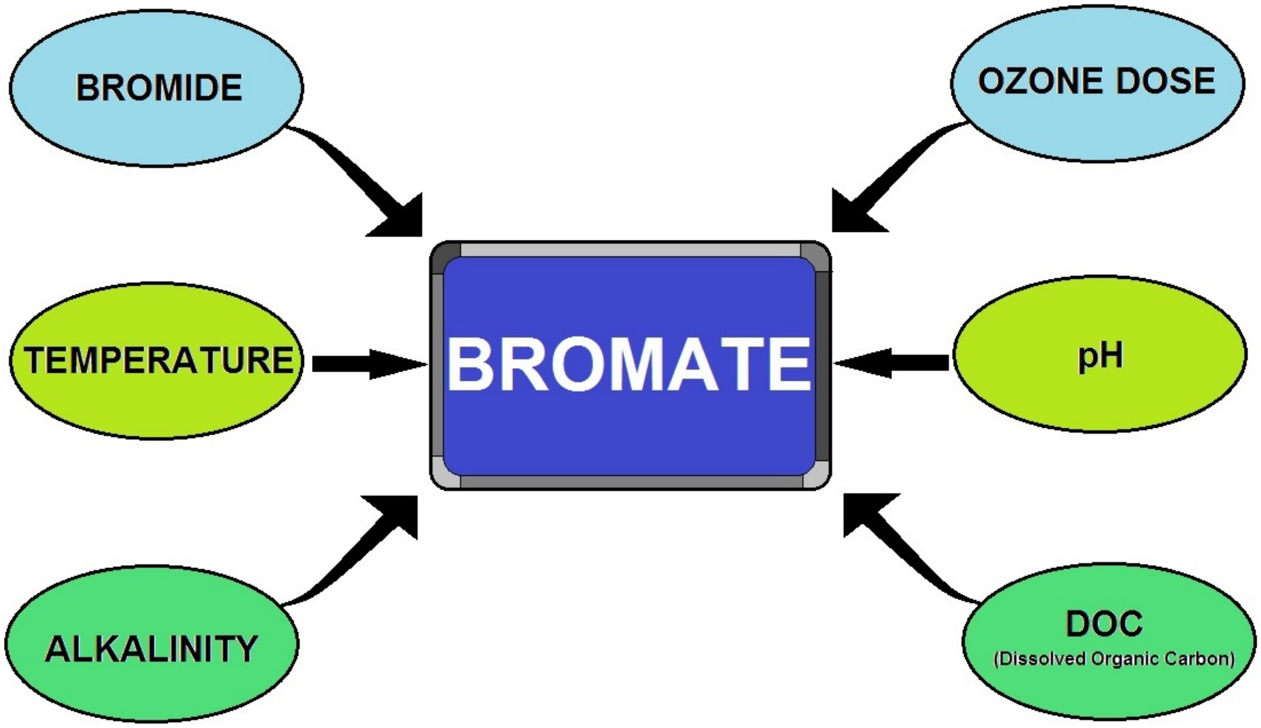


DICHLOROACETIC ACID

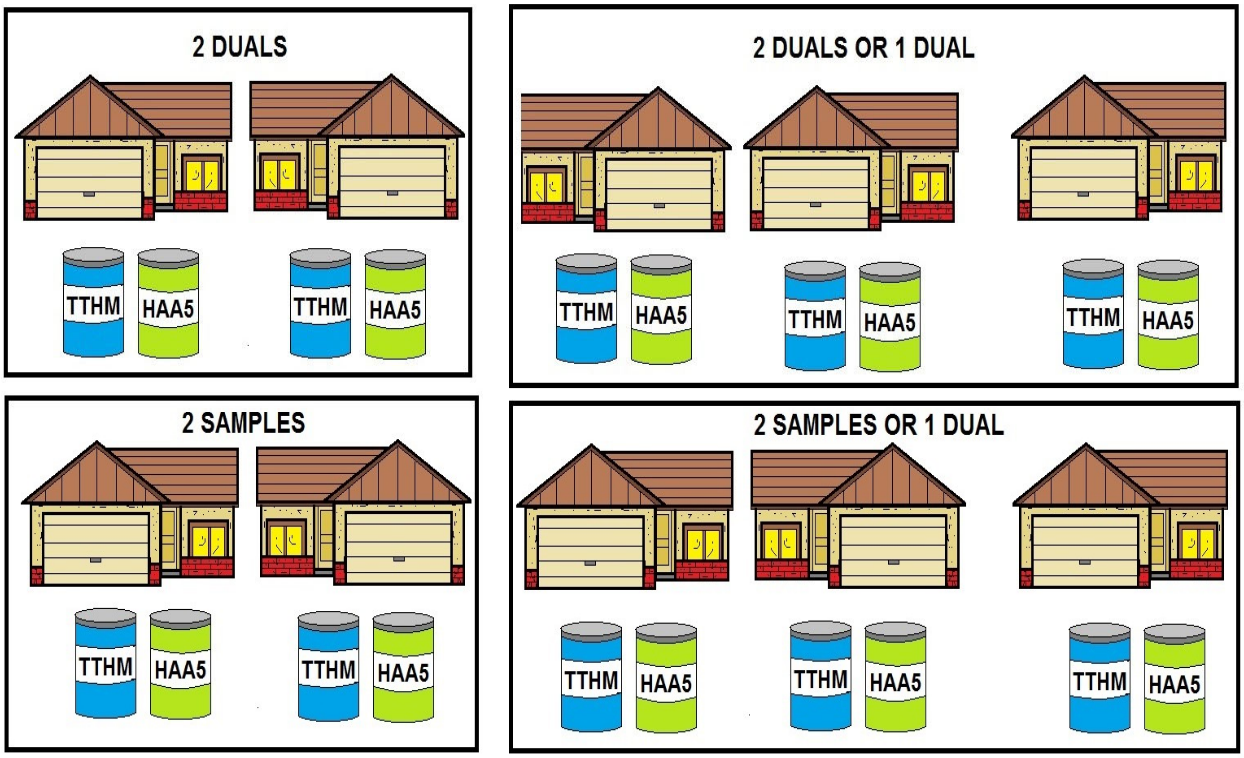


DIBROMOACETIC ACID

HALOACETIC ACIDS (HAA5)



BROMATE FORMATION FACTORS



STAGE 2 DISINFECTION BYPRODUCT RULE

DISINFECTANTS AND DISINFECTION BYPRODUCTS RULE			
DISINFECTION RESIDUAL	**MRDLG (mg/L)**	**MRDL (mg/L)**	**COMPLIANCE BASED ON:**
CHLORINE	4 (as Cl_2)	4.0 (as Cl_2)	ANNUAL AVERAGE
CHLORAMINE	4 (as Cl_2)	4.0 (as Cl_2)	ANNUAL AVERAGE
CHLORINE DIOXIDE	0.8 (as ClO_2)	0.8 (as ClO_2)	ANNUAL AVERAGE
DISINFECTION BYPRODUCTS	**MCLG (mg/L)**	**MCL (mg/L)**	**COMPLIANCE BASED ON:**
TOTAL TRIHALOMETHANES (TTHM)[1]	N/A	0.080	ANNUAL AVERAGE
- CHLOROFORM	***		
- BROMODICHLOROMETHANE	0		
- DIBROMOCHLOROMETHANE	0.06		
- BROMOFORM	0		
HALOACETIC ACIDS (five) (HAA5)[2]	N/A	0.60	ANNUAL AVERAGE
- DICHLOROACETIC ACID	0		
- TRICHLOROACETIC ACID	0.3		
CHLORITE	0.8	1.0	MONTHLY AVERAGE
BROMATE	0	0.010	ANNUAL AVERAGE

DISINFECTION BYPRODUCTS RULE PARAMETERS EXAMPLE

New EPA Rules for Distribution
Reduction of Lead in Drinking Water Act

Congress passed Public Law 111-380 or The Reduction of Lead in Drinking Water Act, in 2010. It went into effect Jan. 4, 2014, which means municipalities, water districts and developers who work with and pay for water infrastructure need have lead compliance.

Lead, a metal found in natural deposits, is commonly used in household plumbing materials and water service lines. The greatest exposure to lead is swallowing or breathing in lead paint chips and dust.

But lead in drinking water can also cause a variety of adverse health effects. In babies and children, exposure to lead in drinking water above the action level can result in delays in physical and mental development, along with slight deficits in attention span and learning abilities. In adults, it can cause increases in blood pressure. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Lead is rarely found in source water, but enters tap water through corrosion of plumbing materials. Homes built before 1986 are more likely to have lead pipes, fixtures and solder. However, new homes are also at risk: even legally "lead-free" plumbing may contain up to 8 percent lead. The most common problem is with brass or chrome-plated brass faucets and fixtures which can leach significant amounts of lead into the water, especially hot water.

Congress enacted the Reduction of Lead in Drinking Water Act on January 4, 2011, to amend Section 1417 of the Safe Drinking Water Act (SDWA) regarding the use and introduction into commerce of lead pipes, plumbing fittings or fixtures, solder and flux. The Act established an effective date of January 4, 2014, which provided a three year timeframe for affected parties to transition to the new requirements.

Pervasive Environmental Contaminant

Lead is a pervasive environmental contaminant. The adverse health effects of lead exposure in children and adults are well documented, and no safe blood lead threshold in children has been identified. Lead can be ingested from various sources, including lead paint and house dust contaminated by lead paint, as well as soil, drinking water, and food. The concentration of lead, total amount of lead consumed, and duration of lead exposure influence the severity of health effects. Because lead accumulates in the body, all sources of lead should be controlled or eliminated to prevent childhood lead poisoning.

Beginning in the 1970s, lead concentrations in air, tap water, food, dust, and soil began to be substantially reduced, resulting in significantly reduced blood lead levels (BLLs) in children throughout the United States. However, children are still being exposed to lead, and many of these children live in housing built before the 1978 ban on lead-based residential paint. These homes might contain lead paint hazards, as well as drinking water service lines made from lead, lead solder, or plumbing materials that contain lead. Adequate corrosion control reduces the leaching of lead plumbing components or solder into drinking water.

The majority of public water utilities are in compliance with the Safe Drinking Water Act Lead and Copper Rule (LCR) of 1991. However, some children are still exposed to lead in drinking water. EPA is reviewing LCR, and additional changes to the rule are expected that will further protect public health.

Childhood lead poisoning prevention programs should be made aware of the results of local public water system lead monitoring measurement under LCR and consider drinking water as a potential cause of increased BLLs, especially when other sources of lead exposure are not identified.

This review describes a selection of peer-reviewed publications on childhood lead poisoning, sources of lead exposure for adults and children, particularly children aged <6 years, and LCR. What is known and unknown about tap water as a source of lead exposure is summarized, and ways that children might be exposed to lead in drinking water are identified.

This report does not provide a comprehensive review of the current scientific literature but builds on other comprehensive reviews, including the *Toxicological Profile for Lead* and the 2005 CDC statement *Preventing Lead Poisoning Among Young Children*). When investigating cases of children with BLLs at or above the reference value established as the 97.5 percentile of the distribution of BLLs in U.S. children aged 1–5 years, drinking water should be considered as a source. The recent recommendations from the CDC Advisory Committee on Childhood Lead Poisoning Prevention to reduce or eliminate lead sources for children before they are exposed underscore the need to reduce lead concentrations in drinking water as much as possible.

Background

Lead is a relatively corrosion-resistant, dense, ductile, and malleable metal that has been used by humans for at least 5,000 years. During this time, lead production has increased from an estimated 10 tons per year to 1,000,000 tons per year, accompanying population and economic growth. The estimated average BLL for Native Americans before European settlement in the Americas was calculated as 0.016 *µ*g/dL. During 1999–2004, the estimated average BLL was 1.9 *µ*g/dL for the non-institutionalized population aged 1–5 years in the United States, approximately 100 times higher than ancient background levels, indicating that substantial sources of lead exposure exist in the environment.

January 4, 2014

On January 4, 2014, the "Reduction of Lead in Drinking Water Act" becomes effective nationwide. This amendment to the 1974 Safe Drinking Water Act reduces the allowable lead content of drinking water pipes, pipe fittings and other plumbing fixtures. Specifically, as of January 4, 2014, it shall be illegal to install pipes, pipe fittings, and other plumbing fixtures that are not "lead free." "Lead free" is defined as restricting the permissible levels of lead in the wetted surfaces of pipes, pipe fittings, other plumbing fittings and fixtures to a weighted average of not more than 0.25%.

This new requirement does not apply to pipes, pipe fittings, plumbing fittings or fixtures that are used exclusively for non-potable services such as manufacturing, industrial processing, irrigation, outdoor watering, or any other uses where water is not anticipated to be used for human consumption. The law also excludes toilets, bidets, urinals, fill valves, flushometer valves, tub fillers, shower valves, service saddles, or water distribution main gate valves that are 2 inches in diameter or larger.

Accordingly, effective January 4, 2014, only accepted products that are "lead free" may be utilized with regards to any plumbing providing water for human consumption (unless meeting the exception outlined above). Installers and inspectors may check their products to determine if they meet these requirements by looking to see if the products are certified to the following standards:

A. NSF/ANSI 61-G;
B. NSF/ANSI 61, section 9-G; OR
C. Both NSF/ANSI 61 AND NSF/ANSI 372.

As existing products may still be utilized for non-potable purposes. The burden of following these requirements shall be on installers. Plumbing inspectors (who will be covering these requirements in continuing education) shall have the right to question installers, who must be able to prove that no non-compliant products are installed on or after January 4, 2014.

What does the law say?
It reduces the maximum amount of lead that can be used in the wetted surfaces of service brass from 8 percent to 0.25 percent. It prohibits the sale of traditional brass pipe fittings, valves and meters for potable water applications as well as their installation after Jan. 4, 2014.

Does The Reduction of Lead in Drinking Water Act apply to all water infrastructure?
No. Service brass used in industrial or non-potable infrastructure is exempt from the law. Also, the law only applies to wetted surfaces. Saddles and other exterior pipe are also exempt.

Are there any exceptions to the New Regulations?
Exceptions to the new lead-free law include: pipes, pipe fittings, plumbing fittings, or fixtures, including backflow preventers, that are used exclusively for non-potable services such as manufacturing, industrial processing, irrigation, outdoor watering, or any other uses where the water is not anticipated to be used for human consumption. In addition, toilets, bidets, urinals, fill valves, flushometer valves, tub fillers, shower valves, service saddles, or water distribution main gate valves that are 2 inches in diameter or larger are excluded from the new lead-free law.

Who does the New Regulations apply to?
If you use or introduce into commerce any pipe, valves, plumbing fittings or fixtures, solder, or flux intended to convey or dispense water for human consumption, your products must comply with the law. Additionally, if you introduce into commerce solder or flux, your products must comply with the law.

If I am a homeowner, how do I know my water system is lead-free?
Many manufacturers have already complied with the January 4th, 2014 implementation date of the federal "Reduction of Lead in Drinking Water Act." Even without federal certification requirements regarding the lead content of plumbing products, California's mandate for third-party certification will be followed by most manufacturers seeking a single approval path that covers both federal and state requirements. For that reason, it is important to use and install only clearly marked low-lead products.

If you are a homeowner and are concerned about potential lead exposure from your private water system, have your water tested by a state certified water testing laboratory in your area.

Is there a difference between low-lead and no-lead brass?
No. There are several terms flying around to refer to the low-lead service brass products – no lead, lead free, low lead, and others. They all refer to the same products: service brass with 0.25 percent or less lead on wetter surfaces.

How are the new alloys different?
Functionally, there is almost no difference. For water utilities and contractors working with the material, it will handle just like traditional service brass. The difference is in the manufacturing. Lead has traditionally been used to fill gaps, seal the surface and create a smooth pipe interior that doesn't have gaps or pits where debris can settle and erode the metal.

Instead of lead, manufacturers will have to use different and more expensive materials and take more care in the manufacturing process. That means the cost of the new low-lead brass will be 25 to 40 percent higher than traditional brass pipe fittings and meters.

What are the biggest concerns for developers, municipalities and water districts?

There are two big concerns that should inspire anyone responsible for laying water infrastructure to act soon. If you have inventory of traditional services brass, now is the time to find a place to use it. Work ahead on projects if you can because that inventory will be wasted if you don't use it before January 2014.

The second concern is cost. If you don't have an inventory of traditional brass but you have upcoming projects, this might be the ideal time to start them. Order traditional brass pipe fittings and meters from suppliers who are offering their traditional service brass at steep discounts ahead of the new law. After the law goes into effect, service brass costs will skyrocket and significantly increase your costs.

Lead-free Alternatives

There are several materials that utilities should consider when selecting a lead-free meter alternative. Various options include epoxy coated ductile and cast iron, stainless steel, low lead bronze and composite.

When choosing a lead-free alternative material, utilities must consider traditional meter requirements such as strong flow capability and durability. However, the difference between lead-free and zero lead meters should also be considered. Some "lead-free" meters contain as much as 0.25 percent lead.

While a 0.25 percentage of lead in meters allows utilities to meet current regulations, implementing these "lead-free" meters could put utilities at risk for the cost of another meter change out should future regulations require complete lead elimination from water meters.

Most water meters are expected to last more than 20 years, meaning that the next amendment to SDWA could come before the meter fleet must be replaced. This could be potentially devastating for utility companies still using older systems should completely lead-free meters become mandated.

Composite Meters

Composite meters are one example of a zero lead alternative that is not susceptible to future no-lead regulations. This meter material is also gaining popularity due to its strength and cost stability. Composite meters do not depend on metal pricing fluctuations and, more importantly, have zero lead as opposed to low lead or even bronze meters.

Made of materials that have already proven their strength and durability in the automotive and valve industries, composite meters boast longevity and resistance to corrosion from aggressive water and from the chlorinated chemicals used to make water drinkable. Composite meters are also equipped to withstand the pressure required to maintain a water system.

Composite meters are constructed using a blend of plastic and fiberglass. When compared to bronze water meter products, composites are lighter and require less time and energy to manufacture, ship and install. Composite meters attached with composite threads have been found to eliminate the "friction feeling" typically experienced with metal threads and metal couplings, facilitating easier installation.

Through comprehensive testing, composite meters have demonstrated a burst pressure that is significantly greater than bronze and an equal longevity. Composite technology today allows for better, more environmentally friendly composite products that will last up to 25 years in residential applications. Manufacturers have a wide range of "lead-free" or zero lead products on the market and it is critical that utilities consider all of their options when selecting a new fleet of meters.

Most importantly, everyone deserves access to safe, clean water. It is essential that manufacturers continually develop and deliver products that meet the highest standards for safety, quality, reliability and accuracy to ensure availability to, and conservation of, this most precious resource.

Lead in Drinking Water

Lead is unlikely to be present in source water unless a specific source of contamination exists. However, lead has long been used in the plumbing materials and solder that are in contact with drinking water as it is transported from its source into homes. Lead leaches into tap water through the corrosion of plumbing materials that contain lead. The greater the concentration of lead in drinking water and the greater amount of lead-contaminated drinking water consumed, the greater the exposure to lead. In children, lead in drinking water has been associated both with BLLs ≥10 *µ*g/dL as well as levels that are higher than the U.S. GM level for children (1.4 *µ*g/dL) but are <10 *µ*g/dL.

History of Studies on Lead in Water

In 1793, the Duke of Württemberg, Germany, warned against the use of lead in drinking water pipes, and in 1878, lead pipes were outlawed in the area as a result of concerns about the adverse health effects of lead in water. In the United States, the adverse health consequences of lead-contaminated water were recognized as early as 1845.

A survey conducted in 1924 in the United States indicated that lead service lines were more prevalent in New England, the Midwest, Montana, New York, Oklahoma, and Texas.

A nationwide survey conducted in 1990 indicated that 3.3 million lead service lines were in use, and the areas where they were most likely to be used were, again, the Midwestern and northeastern regions of the United States. This survey also estimated that approximately 61,000 lead service lines had been removed through voluntary programs during the previous 10 years.

Research on exposure to lead in water increased as concern about the topic increased, and efforts were made to establish a level of lead in water that, at the time of the studies, was considered acceptable. A 1972 study in Edinburgh, Scotland, obtained 949 first-flush water samples (i.e., samples of water from the tap that have been standing in the plumbing pipes for at least 6 hours) matched with 949 BLLs, as well as 205 running water samples matched to 205 BLLs . No dose-response relationship could be determined when comparing BLLs with four levels of lead in both first-flush water and in running water (<0.24 *µ*mol/L; 0.24–0.47 *µ*mol/L; 0.48–1.43 *µ*mol/l; and ≥1.44 *µ*mol/L).

The study concluded that the findings challenged whether it was necessary to lower the water lead concentration to <100 ppb, which at that time was the acceptable concentration established by the World Health Organization. However, the study also reported that low levels of environmental lead exposure could have adverse health effects; therefore, knowing the degree of lead exposure from household water relative to other sources is important. Another study, in 1976, of 129 randomly selected homes in Caernarvonshire, England, reported a similar finding, describing the relationship between blood and water lead as slight.

Monitoring and Reporting

To ensure that drinking water supplied by **all** public water supply systems as defined by the EPA meet Federal and State requirements, water system operators are required to collect samples regularly and have the water tested.

The regulations specify minimum sampling frequencies, sampling locations, testing procedures, methods of keeping records, and frequency of reporting to the State. The regulations also mandate special reporting procedures to be followed if a contaminant exceeds an MCL.

All systems must provide periodic monitoring for microbiological contaminants and some chemical contaminants. The frequency of sampling and the chemicals that must be tested for depend on the physical size of the water system, the water source, and the history of analyses. General sampling procedures are covered in more detail under the topic of Public Health Considerations to follow.

State policies vary on providing laboratory services. Some States have laboratory facilities available to perform all required analyses or, in some cases, a certain number of the required analyses for a system. In most States, there is a charge for all or some of the laboratory services. Sample analyses that are required and cannot be performed by a State laboratory must be taken or sent to a State-certified private laboratory.

If the analysis of a sample exceeds an MCL, resampling is required, and the State should be contacted immediately for special instructions. There is always the possibility that such a sample was caused by a sampling or laboratory error, but it must be handled as though it actually was caused by contamination of the water supply.

The results of all water analyses must be periodically sent to the State of origin. Failure to have the required analysis performed or to report the results to the State usually will result in the water system being required to provide PN. States typically have special forms for submitting data, and specify a number of days following the end of the monitoring period by which the form is due.

General Disinfection Requirements

Disinfection is absolutely required for all water systems using surface water sources. Various chemicals other than chlorine can be used for treatment of surface water, but as the water enters the distribution system, it must carry a continuous chlorine residual that will be retained throughout the distribution system. Water samples from points on the distribution system must be analyzed periodically to make sure an adequate chlorine residual is being maintained.

In spite of the fact that use of chlorine has almost completely eliminated occurrences of waterborne diseases in the United States, there is no concern for byproducts formed when chlorine reacts with naturally occurring substances in raw water (such as decaying vegetation containing humic and fulvic acids).

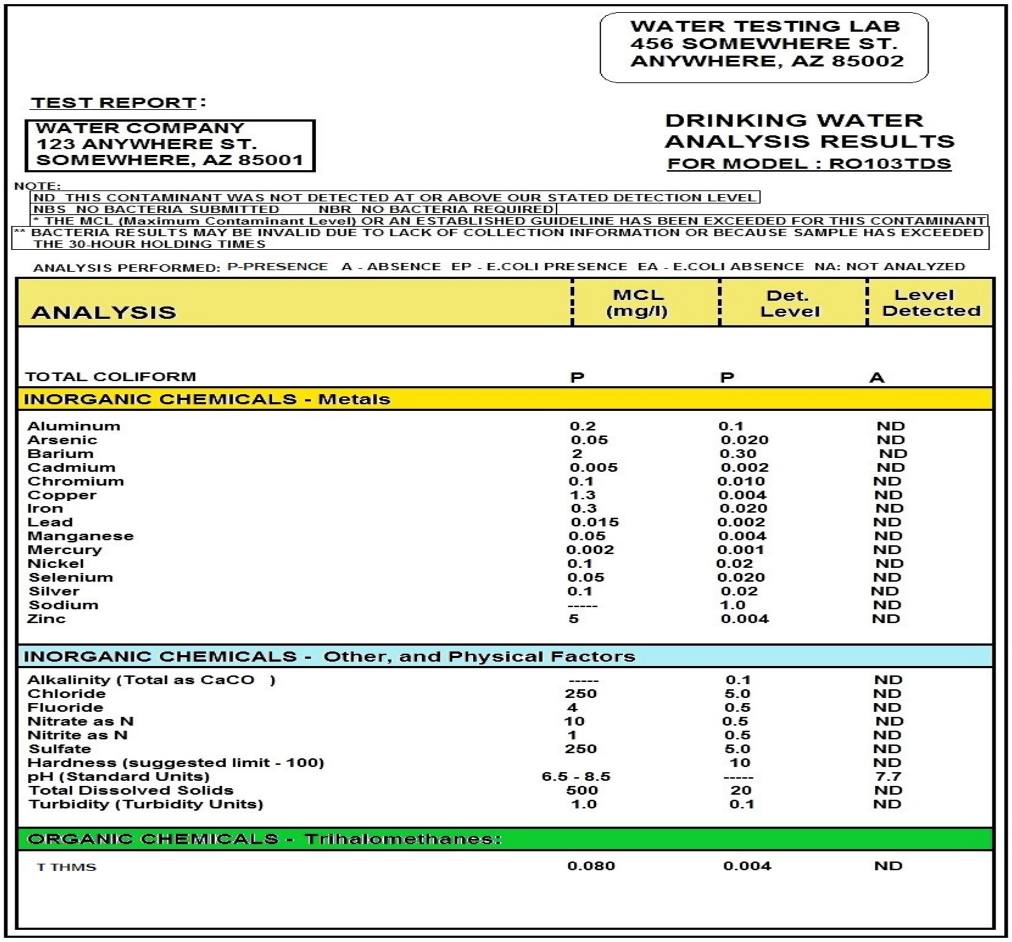
The first group of byproduct chemicals identified was tri-halo-methane (THM), a group of organic chemicals that are known carcinogens (cancer-forming) to some animals, so they are assumed also to be carcinogenic to humans. Other byproducts of disinfection have been identified that may be harmful, and there also is concern now that disinfectants themselves may cause some adverse health reactions.

Consumer Confidence Reports

One of the very significant provisions of the 1996 SDWA amendments is the consumer confidence report (CCR) requirement. The purpose of the CCR is to provide all water customers with basic facts regarding their drinking water so that individuals can make decisions about water consumption based on their personal health. This directive has been likened to the requirement that packaged food companies disclose what is in their food product.

The reports must be prepared yearly by every community water supply system. Water systems serving more than 10,000 people must mail the report to customers. Small systems must notify customers as directed by the State primacy agency. Beginning in the year 2000, reports were to be delivered by July 1 of the calendar year.

A water system that only distributes purchased waster (i.e., a satellite system) must prepare the report for their consumers. Information on the source water and chemical analyses must be furnished to the satellite system by the system selling the water (parent company).



WATER TESTING LAB
456 SOMEWHERE ST.
ANYWHERE, AZ 85002

TEST REPORT:

WATER COMPANY
123 ANYWHERE ST.
SOMEWHERE, AZ 85001

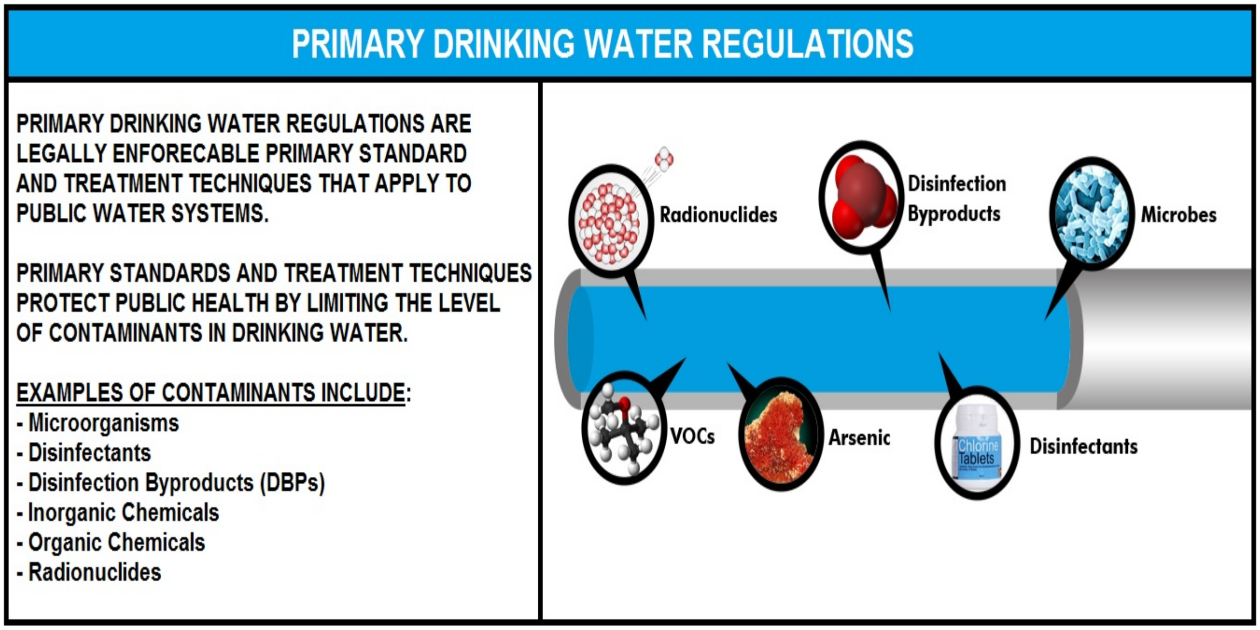
DRINKING WATER
ANALYSIS RESULTS
FOR MODEL : RO103TDS

NOTE:
ND THIS CONTAMINANT WAS NOT DETECTED AT OR ABOVE OUR STATED DETECTION LEVEL
NBS NO BACTERIA SUBMITTED NBR NO BACTERIA REQUIRED
* THE MCL (Maximum Contaminant Level) OR AN ESTABLISHED GUIDELINE HAS BEEN EXCEEDED FOR THIS CONTAMINANT
** BACTERIA RESULTS MAY BE INVALID DUE TO LACK OF COLLECTION INFORMATION OR BECAUSE SAMPLE HAS EXCEEDED THE 30-HOUR HOLDING TIMES

ANALYSIS PERFORMED: P-PRESENCE A - ABSENCE EP - E.COLI PRESENCE EA - E.COLI ABSENCE NA: NOT ANALYZED

ANALYSIS	MCL (mg/l)	Det. Level	Level Detected
TOTAL COLIFORM	P	P	A
INORGANIC CHEMICALS - Metals			
Aluminum	0.2	0.1	ND
Arsenic	0.05	0.020	ND
Barium	2	0.30	ND
Cadmium	0.005	0.002	ND
Chromium	0.1	0.010	ND
Copper	1.3	0.004	ND
Iron	0.3	0.020	ND
Lead	0.015	0.002	ND
Manganese	0.05	0.004	ND
Mercury	0.002	0.001	ND
Nickel	0.1	0.02	ND
Selenium	0.05	0.020	ND
Silver	0.1	0.02	ND
Sodium	-----	1.0	ND
Zinc	5	0.004	ND
INORGANIC CHEMICALS - Other, and Physical Factors			
Alkalinity (Total as CaCO)	-----	0.1	ND
Chloride	250	5.0	ND
Fluoride	4	0.5	ND
Nitrate as N	10	0.5	ND
Nitrite as N	1	0.5	ND
Sulfate	250	5.0	ND
Hardness (suggested limit - 100)		10	ND
pH (Standard Units)	6.5 - 8.5	-----	7.7
Total Dissolved Solids	500	20	ND
Turbidity (Turbidity Units)	1.0	0.1	ND
ORGANIC CHEMICALS - Trihalomethanes:			
T THMS	0.080	0.004	ND

WATER ANALYSIS REPORT



PRIMARY DRINKING WATER REGULATIONS

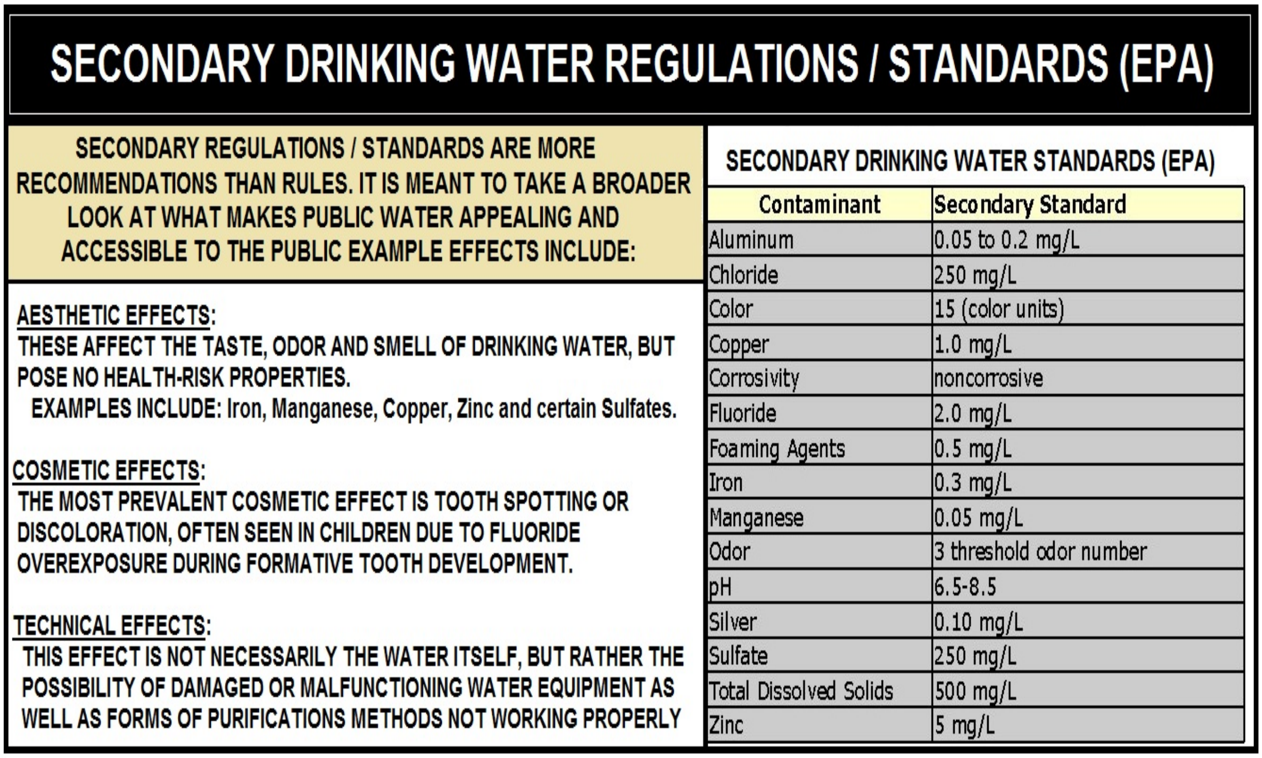
PRIMARY DRINKING WATER REGULATIONS ARE LEGALLY ENFORECABLE PRIMARY STANDARD AND TREATMENT TECHNIQUES THAT APPLY TO PUBLIC WATER SYSTEMS.

PRIMARY STANDARDS AND TREATMENT TECHNIQUES PROTECT PUBLIC HEALTH BY LIMITING THE LEVEL OF CONTAMINANTS IN DRINKING WATER.

EXAMPLES OF CONTAMINANTS INCLUDE:

- Microorganisms
- Disinfectants
- Disinfection Byproducts (DBPs)
- Inorganic Chemicals
- Organic Chemicals
- Radionuclides

PRIMARY DRINKING WATER REGULATIONS / STANDARDS



SECONDARY DRINKING WATER REGULATIONS / STANDARDS (EPA)

SECONDARY REGULATIONS / STANDARDS ARE MORE RECOMMENDATIONS THAN RULES. IT IS MEANT TO TAKE A BROADER LOOK AT WHAT MAKES PUBLIC WATER APPEALING AND ACCESSIBLE TO THE PUBLIC EXAMPLE EFFECTS INCLUDE:

AESTHETIC EFFECTS:
THESE AFFECT THE TASTE, ODOR AND SMELL OF DRINKING WATER, BUT POSE NO HEALTH-RISK PROPERTIES.
EXAMPLES INCLUDE: Iron, Manganese, Copper, Zinc and certain Sulfates.

COSMETIC EFFECTS:
THE MOST PREVALENT COSMETIC EFFECT IS TOOTH SPOTTING OR DISCOLORATION, OFTEN SEEN IN CHILDREN DUE TO FLUORIDE OVEREXPOSURE DURING FORMATIVE TOOTH DEVELOPMENT.

TECHNICAL EFFECTS:
THIS EFFECT IS NOT NECESSARILY THE WATER ITSELF, BUT RATHER THE POSSIBILITY OF DAMAGED OR MALFUNCTIONING WATER EQUIPMENT AS WELL AS FORMS OF PURIFICATIONS METHODS NOT WORKING PROPERLY

SECONDARY DRINKING WATER STANDARDS (EPA)

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

EPA SECONDARY DRINKING WATER REGULATIONS / STANDARDS

Distribution System Water Quality Problems

Reasons we need microfiltration

Turbidity

Turbidity is caused by particles suspended in water. These particles scatter or reflect light rays, making the water appear cloudy. Turbidity is expressed in nephelometric turbidity units (ntu) and a reading in excess of 5 ntu is generally noticeable to water system customers.

Besides the appearance being unpleasant to customers, turbidity in water is significant from a public health standpoint because suspended particles could shelter micro-organisms from the disinfectant and allow them to still be viable when they reach the customer.

EPA regulations direct that, for most water systems, the turbidity of water entering the distribution system must be equal or less than 0.5 ntu in at least 95 percent of the measurements taken each month. At no time may the turbidity exceed 5 ntu.

Turbidity changes in the distribution system can indicate developing problems. Increases in turbidity may be caused by changes in velocity or inadequate flushing following main replacement.

Hardness

Hardness is a measure of the concentration of calcium and magnesium in water.

Water hardness usually comes from water contacting rock formations, such as water from wells in limestone formations. Soft ground water may occur where topsoil is thin and limestone formations are sparse or absent. Most surface water is of medium hardness.

Hard and soft water are both satisfactory for human consumption, but customers may object to very hard water because of the scale it forms in plumbing fixtures and on cooking utensils.

Hardness is also a problem for some industrial and commercial users because of scale buildup in boilers and other equipment.

Water generally is considered most satisfactory for household use when the hardness is between 75 and 100 mg/L as calcium carbonate ($CaCO3$). Water with 300 mg/L of hardness usually is considered **hard**. Very soft water of 30 mg/L or less is found in some section of the United States. Soft water usually is quite corrosive, and may have to be treated to reduce the corrosivity.

Iron

Iron occurs naturally in rocks and soils and is one of the most abundant elements. It occurs in two forms. Ferrous iron (Fe_2) is in a dissolved state, and water containing ferrous iron is colorless. Ferric iron (Fe_3) has been oxidized, and water containing it is rust-colored. Water from some well sources contains significant levels of dissolved iron, which is colorless, but rapidly turns brown as air reaches the water and oxidizes the iron.

There are no known harmful effects to humans from drinking water containing iron, but NSDWR suggest a limit of 0.5 mg/L. At high levels, the staining of plumbing fixtures and clothing becomes objectionable. Iron also provides nutrient source for some bacteria that grow in distribution systems and wells. Iron bacteria, such as Gallionella, cause red water, tastes and odors, clogged pipes, and pump failure.

Whenever tests on water samples show increased iron concentrations between the point where water enters the distribution system and the consumer's tap, either corrosion, iron bacteria, or both are probably taking place. If the problem is caused by bacteria, flushing mains, shock chlorination, and carrying increased residual chlorine are alternatives to consider.

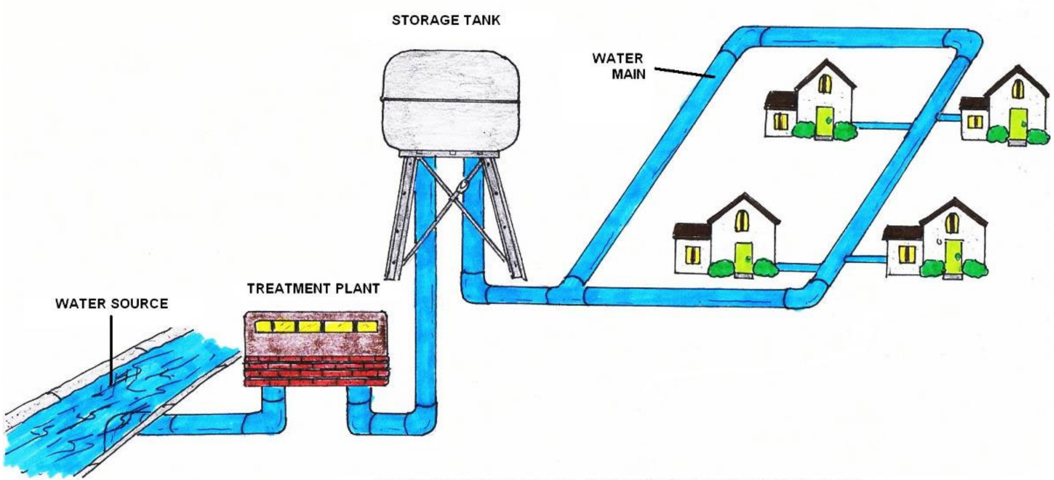
Manganese

Manganese in ground water creates problems similar to iron. It does not usually discolor the water, but will stain washed clothes and plumbing fixtures black; this is very unpopular with customers. Consumption of manganese has no known harmful effects on humans, but the NSDWR recommend a concentration not to exceed 0.05 mg/L to avoid customer complaints.

Water Quality Safeguards

The **critical** safeguard for water distribution system operations are

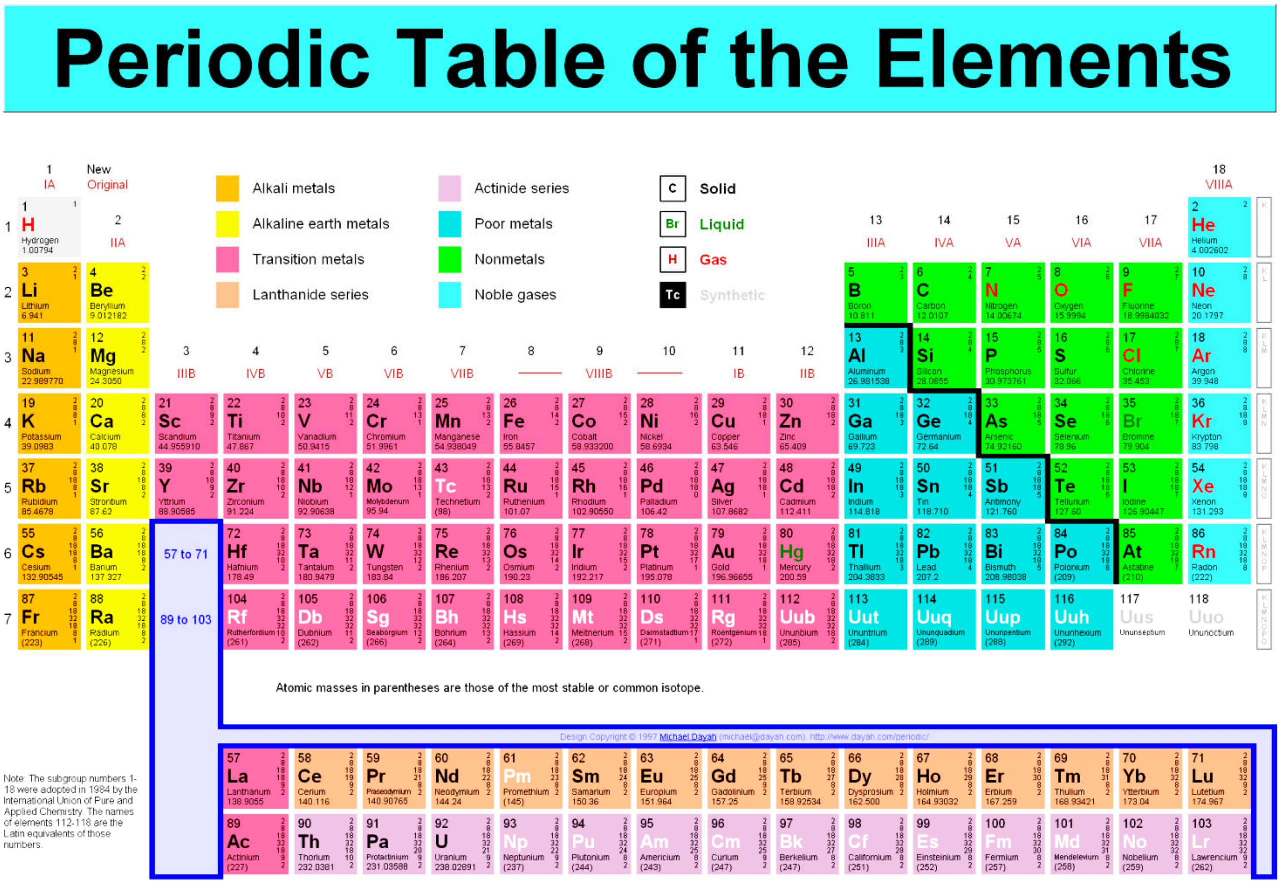
- continuous positive pressure in the mains; 20 pounds per square inch (psi) minimum residual pressure is recommended;
- maintenance of chlorine residual;
- cross-connection control; and
- frequent testing.



WATER SUPPLY DISTRIBUTION SYSTEM

IOC Section

Information in this section comes from the EPA https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants



Left, Tellurium, right Astatine with Fluorine

Common water sample bottles for distribution systems.

Radiochems, VOCs, (Volatile Organic Compounds), TTHMs, Total Trihalomethanes), Nitrate, Nitrite.

Most of these sample bottles will come with the preservative already inside the bottle.

Some bottles will come with a separate preservative (acid) for the field preservation.

Slowly add the acid or other preservative to the water sample; not water to the acid or preservative.

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0[7]	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[7]; Action Level=1.3	Short term exposure: Gastrointestinal distress Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero	TT[7]; Action Level=0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

This course contains EPA's federal rule requirements. Please be aware that each state implements drinking water regulations that may be more stringent than EPA's regulations. Check with your state environmental agency for more information.

Synthetic Organic Chemicals

Synthetic organic chemicals (**SOC**) include all man-made organics, some of which are volatile organic compounds (**VOC**). Activated carbon can substantially reduce many VOCs such as benzene, trichlorethane and carbon tetrachloride. Activated carbon also removes SOCs such as Alachlor, EDB and toluene. The EPA is establishing limits for these chemicals in public drinking water supplies.

Before recommending treatment, water suspected of containing any of these and other substances must be analyzed to determine their concentrations and whether they exceed the EPA standards.

Activated carbon beds compact with use so they may need occasional backwashing, however, backwash carbon as little as possible to prevent loss of the fragile material. Also, contaminant-laden carbon may migrate toward the bottom of the bed during backwash and reduce filter performance. When operating a carbon filter or system on turbid water supplies, remove suspended particles with a depth filter before treating it with activated carbon. A carbon filter typically backwashes at 10 gpm/ft (25 m/hr) for about 10 minutes, followed by a 5 minute downflow rinse.

Over a period of several months to two years, the carbon's adsorption capacity diminishes. The exhausted carbon bed should be replaced with fresh carbon. The old carbon should be hauled to an approved disposal facility.

IOC Sample Collection – Things to Remember

Sample instructions should be supplied with the sample containers from the laboratory. If the laboratory fails to include sample instructions, contact the laboratory and request sample instructions.

Some general practices to remember:

- Samples should be collected at the entry point to the distribution system after all treatment(finished water)
- Select a sampling faucet that does NOT have an aerator (sampling must be done with minimum aeration
- Run the water until the temperature is as cold as it gets
- Just before sample collection, adjust to a very low flow. Do not change the flow while collecting the sample
- Routine nitrate and nitrite samples should be collected on a Monday or a Tuesday
- When filling sample bottle, tip bottle slightly so that water flows down the side wall of the container. Bring bottle to an upright position as it fills
- Call the laboratory if bottles are received broken (or break while collecting samples)
- The owner or operator of a water supply must maintain chemical analysis reports (results) or a summary of those reports for at least 10 years

Chemical Monitoring

The final federal rules regarding Phase II and V contaminants were promulgated by the U.S. EPA in 1992 and initial monitoring began in January 1993. This group of contaminants consists of Inorganic Chemicals (**IOC**), Volatile Organic Chemicals (**VOC**) and Synthetic Organic Chemicals (**SOC**) and the rule applies to all community and non-transient non-community public water systems.

The monitoring schedule for these contaminants is phased in by water system population size according to a "**standardized monitoring framework**" established by the U.S. EPA. This standardized monitoring framework establishes nine-year compliance cycles consisting of three 3-year compliance periods. The first compliance cycle began in January 1993 and ended December 31, 2001, with subsequent compliance cycles following the nine-year timeframe. The three-year compliance period of each cycle is the standard monitoring period for the water system.

Turbidity Monitoring

Monitoring for turbidity is applicable to all public water systems using surface water sources or ground water sources under the direct influence of surface water in whole or part. Check with your state drinking water section or health department for further instructions.

The maximum contaminant level for turbidity for systems that provide filtration treatment:

1. Conventional or direct filtration: less than or equal to 0.5 NTU in at least 95% of the measurements taken each month. Conventional filtration treatment plants should be able to achieve a level of 0.1 NTU with proper chemical addition and operation.
2. Slow sand filtration, cartridge and alternative filtration: less than or equal to 1 NTU in at least 95% of the measurements taken each month. The turbidity levels must not exceed 5 NTU at any turbidity measurements must be performed on representative samples of the filtered water every four (4) hours that the system serves water to the public. A water system may substitute continuous turbidity monitoring for grab sample monitoring if it validates the continuous measurement for accuracy on a regular basis using a protocol approved by the Health or Drinking Water Agency, such as confirmation by a bench top turbidimeter. For systems using slow sand filtration, cartridge, or alternative filtration treatment the Health or Drinking Water Agency may reduce the sampling frequency to once per day if it determines that less frequent monitoring is sufficient to indicate effective filtration performance.

Inorganic Chemical Monitoring

All systems must monitor for inorganics. The monitoring for these contaminants is also complex with reductions, waivers and detections affecting the sampling frequency. Please refer to the monitoring schedules provided by your state health or drinking water sections for assistance in determining individual requirements. All transient non-community water systems are required to complete a one-time inorganic chemical analysis. The sample is to be collected at entry points (**POE**) to the distribution system representative of each source after any application of treatment.

Nitrates

Nitrate is an inorganic chemical that occurs naturally in some groundwater but most often is introduced into ground and surface waters by man. The most common sources are from fertilizers and treated sewage or septic systems. At high levels (over 10 mg/l) it can cause the "**blue baby**" syndrome in young infants, which can lead to serious illness and even death. It is regarded as an "**acute health risk**" because it can quickly cause illness.

Every water system must test for ***Nitrate*** at least yearly. Systems that use ground water only must test yearly. Systems that use surface water and those that mix surface and ground water must test every quarter. A surface water system may go to yearly testing if community and nontransient noncommunity water must do quarterly monitoring whenever they exceed 5 mg/l in a test. After 4 quarters of testing and the results show that the nitrate level is not going up, they may go back to yearly testing.

Radiological Contaminants

All community water systems shall monitor for gross alpha activity every four years for each source. Depending on your state rules, compliance will be based on the annual composite of 4 consecutive quarters or the average of the analyses of 4 quarterly samples. If the average annual concentration is less than one half the MCL, an analysis of a single sample may be substituted for the quarterly sampling procedure.

Total Trihalomethanes (TTHM)

All community water systems serving a population of 10,000 or more and which add a disinfectant in any part of the drinking water treatment process shall monitor for total trihalomethanes (**TTHM**). The MCL is 0.1 mg/l and consists of a calculation of the running average of quarterly analyses of the sum of the concentrations of bromodichloromethane, di-bromochloromethane, bromoform and chloroform.

Lead and Copper Rule

The Lead and Copper Rule was promulgated by the U.S. EPA on June 7, 1991, with monitoring to begin in January 1992 for larger water systems. This rule applies to all community and nontransient, noncommunity water systems and establishes action levels for these two contaminants at the consumer's tap. Action levels of 0.015 mg/l for lead and 1.3 mg/l for copper have been established.

This rule establishes maximum contaminant level goals (**MCLGs**) for lead and copper, treatment technique requirements for optimal corrosion control, source water treatment, public education and lead service line replacement. Whenever an action level is exceeded, the corrosion control treatment requirement is triggered. This is determined by the concentration measured in the 90th percentile highest sample from the samples collected at consumers' taps. Sample results are assembled in ascending order (lowest to highest) with the result at the 90th percentile being the action level for the system. For example, if a water system collected 20 samples, the result of the 18th highest sample would be the action level for the system.

The rule also includes the best available technology (**BAT**) for complying with the treatment technique requirements, mandatory health effects language for public notification of violations and analytical methods and laboratory performance requirements.

Initial monitoring began in January 1992 for systems with a population of 50,000 or more, in July 1992 for medium-sized systems (3,300 to 50,000 population) and in July 1993 for small-sized systems (less than 3,300 population),

One-liter tap water samples are to be collected at high-risk locations by either water system personnel or residents. Generally, high-risk locations are homes with lead-based solder installed after 1982 or with lead pipes or service lines. If not enough of these locations exist in the water system, the rule provides specific guidelines for selecting other sample sites.

The water must be allowed to stand motionless in the plumbing pipes for at least six (6) hours and collected from a cold water tap in the kitchen or bathroom. It is a first draw sample, which means the line is not to be flushed prior to sample collection.

The number of sampling sites is determined by the population of the system and sample collection consists of two, six-month monitoring periods; check with your state rule or drinking water section for more information.

Sampling Sites by Population
System size - No. of sites - No. of sites
(no. of persons served) (standard monitoring) (reduced monitoring)

>100,000	100	50
10,001-100,000	60	30
3,301 to 10,000	40	20
501 to 3,300	20	10
101 to 500	10	5
< 100	5	5

If a system meets the lead and copper action levels or maintains optimal corrosion control treatment for two consecutive six-month monitoring periods, then reduced monitoring is allowed and sampling frequency drops to once per year.

After three consecutive years of reduced monitoring, sample frequency drops to once every three years.

In addition to lead and copper testing, all large water systems and those medium- and small-sized systems that exceed the lead or copper action levels will be required to monitor for the following water quality parameters: pH, alkalinity, calcium, conductivity, orthophosphate, silica and water temperature.

These parameters are used to identify optimal corrosion control treatment and determine compliance with the rule once treatment is installed. The sampling locations for monitoring water quality parameters are at entry points and representative taps throughout the distribution system.

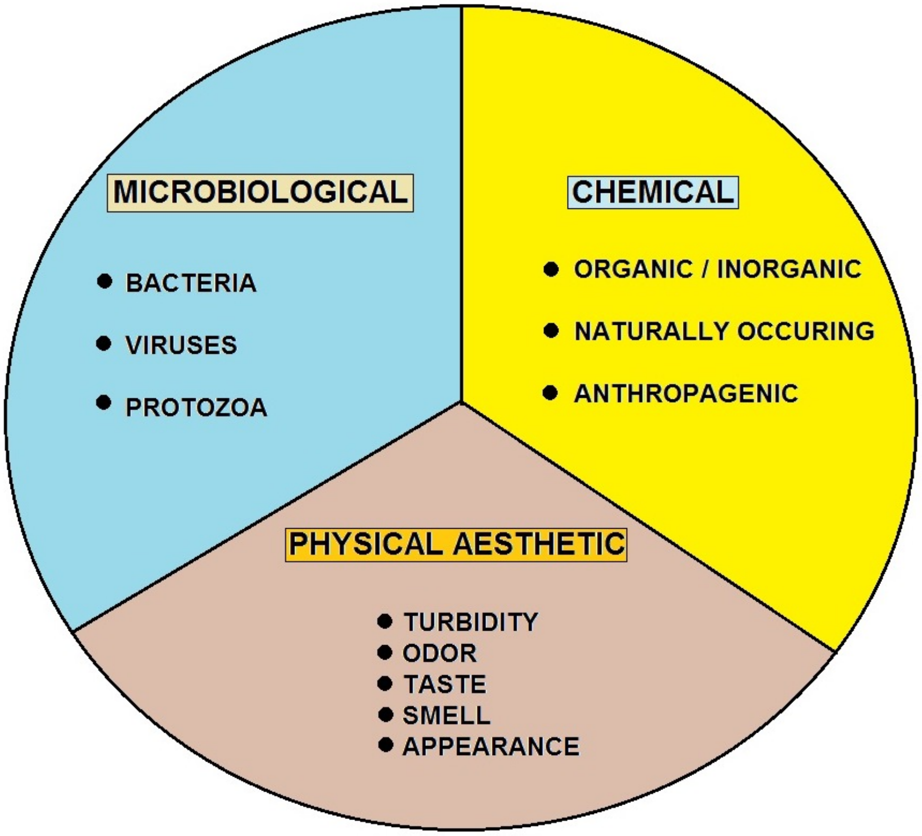
Coliform sampling sites can be used for distribution system sampling. The number of sites required for monitoring water quality during each six-month period is shown below.

Number of Water Quality Parameters per Population
System size # of sites for water (no. of persons served) quality parameters

>100,000	25
10,001-100,000	10
3,301 to 10,000	3
501 to 3,300	2
101 to 500	1
<100	1

Water systems which maintain water quality parameters reflecting optimal corrosion control for two consecutive six-month monitoring periods qualify for reduced monitoring. After three consecutive years, the monitoring frequency can drop to once per year.

All large water systems must demonstrate that their water is minimally corrosive or install corrosion control treatment regardless of lead and copper sampling results.



WATER QUALITY BROKEN DOWN INTO 3 BROAD CATEGORIES

Antimony - Inorganic Contaminant 0.006 mg/L MCL
Metalloid

Antimony is a toxic chemical element with symbol **Sb** and atomic number 51. A lustrous gray metalloid, it is found in nature mainly as the sulfide mineral stibnite (Sb_2S_3). Antimony compounds have been known since ancient times and were used for cosmetics; metallic antimony was also known, but it was erroneously identified as lead. It was established to be an element around the 17th century.

For some time, China has been the largest producer of antimony and its compounds, with most production coming from the Xikuangshan Mine in Hunan. The industrial methods to produce antimony are roasting and subsequent carbothermal reduction or direct reduction of stibnite with iron.

What are EPA's drinking water regulations for antimony?

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for antimony is 0.006 mg/L or 6 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for antimony, called a maximum contaminant level (MCL), at 0.006 mg/L or 6 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase V Rule, the regulation for antimony, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed antimony as part of the Six Year Review and determined that the 0.006 mg/L or 6 ppb MCLG and 0.006 mg/L or 6 ppb MCL for antimony are still protective of human health.

Applications

The largest applications for metallic antimony are as alloying material for lead and tin and for lead antimony plates in lead-acid batteries. Alloying lead and tin with antimony improves the properties of the alloys which are used in solders, bullets and plain bearings.

Antimony compounds are prominent additives for chlorine- and bromine-containing fire retardants found in many commercial and domestic products. An emerging application is the use of antimony in microelectronics.

Antimony is in the nitrogen group (group 15) and has an electronegativity of 2.05. As expected by periodic trends, it is more electronegative than tin or bismuth, and less electronegative than tellurium or arsenic. Antimony is stable in air at room temperature, but reacts with oxygen if heated to form antimony trioxide, Sb_2O_3. Antimony is a silvery, lustrous gray metal that has a Mohs scale hardness of 3. Therefore, pure antimony is not used to make hard objects: coins made of antimony were issued in China's Guizhou province in 1931, but because of their rapid wear, their minting was discontinued. Antimony is resistant to attack by acids.

Four allotropes of antimony are known, a stable metallic form and three metastable forms, explosive, black and yellow. Metallic antimony is a brittle, silver-white shiny metal. When molten antimony is slowly cooled, metallic antimony crystallizes in a trigonal cell, isomorphic with that of the gray allotrope of arsenic.

A rare explosive form of antimony can be formed from the electrolysis of antimony (III) trichloride. When scratched with a sharp implement, an exothermic reaction occurs and white fumes are given off as metallic antimony is formed; when rubbed with a pestle in a mortar, a strong detonation occurs.

Black antimony is formed upon rapid cooling of vapor derived from metallic antimony. It has the same crystal structure as red phosphorus and black arsenic; it oxidizes in air and may ignite spontaneously. At 100 °C, it gradually transforms into the stable form. The yellow allotrope of antimony is the most unstable. It has only been generated by oxidation of stibine (SbH_3) at −90 °C. Above this temperature and in ambient light, this metastable allotrope transforms into the more stable black allotrope.

Metallic antimony adopts a layered structure (space group R3m No. 166) in which layers consist of fused ruffled six-membered rings. The nearest and next-nearest neighbors form a distorted octahedral complex, with the three atoms in the same double-layer being slightly closer than the three atoms in the next. This relatively close packing leads to a high density of 6.697 g/cm^3, but the weak bonding between the layers leads to the low hardness and brittleness of antimony.

Isotopes

Antimony exists as two stable isotopes, ^{121}Sb with a natural abundance of 57.36% and ^{123}Sb with a natural abundance of 42.64%. It also has 35 radioisotopes, of which the longest-lived is ^{125}Sb with a half-life of 2.75 years. In addition, 29 metastable states have been characterized.

The most stable of these is ^{124}Sb with a half-life of 60.20 days, which has an application in some neutron sources. Isotopes that are lighter than the stable ^{123}Sb tend to decay by β^+ decay, and those that are heavier tend to decay by β^- decay, with some exceptions.

Occurrence

The abundance of antimony in the Earth's crust is estimated at 0.2 to 0.5 parts per million, comparable to thallium at 0.5 parts per million and silver at 0.07 ppm. Even though this element is not abundant, it is found in over 100 mineral species. Antimony is sometimes found natively, but more frequently it is found in the sulfide stibnite (Sb_2S_3) which is the predominant ore mineral.

Antimony compounds are often classified into those of Sb(III) and Sb(V). Relative to its congener arsenic, the +5 oxidation state is more stable.

Oxides and hydroxides

Antimony trioxide (Sb_4O_6) is formed when antimony is burnt in air. In the gas phase, this compound exists as Sb_4O_6, but it polymerizes upon condensing. Antimony pentoxide (Sb_4O_{10}) can only be formed by oxidation by concentrated nitric acid. Antimony also forms a mixed-valence oxide, antimony tetroxide (Sb_2O_4), which features both Sb(III) and Sb(V). Unlike phosphorus and arsenic, these various oxides are amphoteric, do not form well-defined oxoacids and react with acids to form antimony salts.

Antimonous acid $Sb(OH)_3$ is unknown, but the conjugate base sodium antimonite ($[Na_3SbO_3]_4$) forms upon fusing sodium oxide and Sb_4O_6. Transition metal antimonites are also known. Antimonic acid exists only as the hydrate $HSb(OH)_6$, forming salts containing the antimonate anion Sb(OH)−6. Dehydrating metal salts containing this anion yields mixed oxides. Many antimony ores are sulfides, including stibnite (Sb_2S_3), pyrargyrite (Ag_3SbS_3), zinkenite, jamesonite, and boulangerite. Antimony pentasulfide is non-stoichiometric and features antimony in the +3 oxidation state and S-S bonds. Several thioantimonides are known, such as $[Sb_6S_{10}]^{2-}$ and $[Sb_8S_{13}]^{2-}$.

Halides

Antimony forms two series of halides, SbX_3 and SbX_5. The trihalides SbF_3, $SbCl_3$, $SbBr_3$, and SbI_3 are all molecular compounds having trigonal pyramidal molecular geometry. The trifluoride SbF_3 is prepared by the reaction of Sb_2O_3 with HF:

$$\mathbf{Sb_2O_3 + 6\ HF \rightarrow 2\ SbF_3 + 3\ H_2O}$$

It is Lewis acidic and readily accepts fluoride ions to form the complex anions SbF−4 and SbF2−5. Molten SbF_3 is a weak electrical conductor. The trichloride $SbCl_3$ is prepared by dissolving Sb_2S_3 in hydrochloric acid:

$$\mathbf{Sb_2S_3 + 6\ HCl \rightarrow 2\ SbCl_3 + 3\ H_2S}$$

The pentahalides SbF_5 and $SbCl_5$ have trigonal bipyramidal molecular geometry in the gas phase, but in the liquid phase, SbF_5 is polymeric, whereas $SbCl_5$ is monomeric. SbF_5 is a powerful Lewis acid used to make the super acid fluoroantimonic acid ("$HSbF_6$").

Oxyhalides are more common for antimony than arsenic and phosphorus. Antimony trioxide dissolves in concentrated acid to form oxoantimonyl compounds such as SbOCl and $(SbO)_2SO_4$.

Antimonides, hydrides, and organoantimony compounds

Compounds in this class generally are described as derivatives of Sb^{3-}. Antimony forms antimonides with metals, such as indium antimonide (InSb) and silver antimonide (Ag_3Sb). The alkali metal and zinc antimonides, such as Na_3Sb and Zn_3Sb_2, are more reactive. Treating these antimonides with acid produces the unstable gas stibine, SbH_3:

$$\mathbf{Sb^{3-} + 3\ H^+ \rightarrow SbH_3}$$

Stibine can also be produced by treating Sb^{3+} salts with hydride reagents such as sodium borohydride. Stibine decomposes spontaneously at room temperature. Because stibine has a positive heat of formation, it is thermodynamically unstable and thus antimony does not react with hydrogen directly.

Organoantimony compounds are typically prepared by alkylation of antimony halides with Grignard reagents. A large variety of compounds are known with both Sb(III) and Sb(V) centers, including mixed chloro-organic derivatives, anions, and cations. Examples include $Sb(C_6H_5)_3$ (triphenylstibine), $Sb_2(C_6H_5)_4$ (with an Sb-Sb bond), and cyclic $[Sb(C_6H_5)]_n$. Pentacoordinated organoantimony compounds are common, examples being $Sb(C_6H_5)_5$ and several related halides.

History

Antimony(III) sulfide, Sb_2S_3, was recognized in predynastic Egypt as an eye cosmetic (kohl) as early as about 3100 BC, when the cosmetic palette was invented.

An artifact, said to be part of a vase, made of antimony dating to about 3000 BC was found at Telloh, Chaldea (part of present-day Iraq), and a copper object plated with antimony dating between 2500 BC and 2200 BC has been found in Egypt. Austen, at a lecture by Herbert Gladstone in 1892 commented that "we only know of antimony at the present day as a highly brittle and crystalline metal, which could hardly be fashioned into a useful vase, and therefore this remarkable 'find' (artifact mentioned above) must represent the lost art of rendering antimony malleable."

Moorey was unconvinced the artifact was indeed a vase, mentioning that Selimkhanov, after his analysis of the Tello object (published in 1975), "attempted to relate the metal to Transcaucasian natural antimony" (i.e. native metal) and that "the antimony objects from Transcaucasia are all small personal ornaments." This weakens the evidence for a lost art "of rendering antimony malleable."

The first European description of a procedure for isolating antimony is in the book *De la pirotechnia* of 1540 by Vannoccio Biringuccio; this predates the more famous 1556 book by Agricola, *De re metallica*. In this context Agricola has been often incorrectly credited with the discovery of metallic antimony.

The book *Currus Triumphalis Antimonii* (The Triumphal Chariot of Antimony), describing the preparation of metallic antimony, was published in Germany in 1604. It was purported to have been written by a Benedictine monk, writing under the name Basilius Valentinus, in the 15th century; if it were authentic, which it is not, it would predate Biringuccio.

The first natural occurrence of pure antimony in the Earth's crust was described by the Swedish scientist and local mine district engineer Anton von Swab in 1783; the type-sample was collected from the Sala Silver Mine in the Bergslagen mining district of Sala, Västmanland, Sweden.

Arsenic- Inorganic Contaminant 0.010 mg/L MCL
Metalloid

Arsenic is a chemical element with symbol **As** and the atomic number is 33. Arsenic occurs in many minerals, usually in conjunction with sulfur and metals, and also as a pure elemental crystal. It was first documented by Albertus Magnus in 1250. Arsenic is a metalloid. It can exist in various allotropes, although only the gray form has important use in industry.

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG).

Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for arsenic is zero. EPA has set this level of protection based on the best available science to prevent potential health problems. Based on the MCLG, EPA has set an enforceable regulation for arsenic, called a maximum contaminant level (MCL), at 0.010 mg/L or 10 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

The Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring Final Rule, the regulation for arsenic, became effective in 2002.

The Safe Drinking Water Act requires EPA to periodically review and revise contaminants, if appropriate, based on new scientific data. The regulation for arsenic will be included in a future review cycle.

The main uses of metallic arsenic is for strengthening alloys of copper and especially lead (for example, in car batteries). Arsenic is a common n-type dopant in semiconductor electronic devices, and the optoelectronic compound gallium arsenide is the most common semiconductor in use after doped silicon. Arsenic and its compounds, especially the trioxide, are used in the production of pesticides (treated wood products), herbicides, and insecticides. These applications are declining, however.

Arsenic is notoriously poisonous to multicellular life, although a few species of bacteria are able to use arsenic compounds as respiratory metabolites. Arsenic contamination of groundwater is a problem that affects millions of people across the world.

Arsenic, a naturally occurring element, is found throughout the environment; for most people, food is the major source of exposure. Acute (short-term) high-level inhalation exposure to arsenic dust or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain); central and peripheral nervous system disorders have occurred in workers acutely exposed to inorganic arsenic. Chronic (long-term) inhalation exposure to inorganic arsenic in humans is associated with irritation of the skin and mucous membranes. Chronic oral exposure has resulted in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, and liver or kidney damage in humans. Inorganic arsenic exposure in humans, by the inhalation route, has been shown to be strongly associated with lung cancer, while ingestion of inorganic arsenic in humans has been linked to a form of skin cancer and also to bladder, liver, and lung cancer. EPA has classified inorganic arsenic as a Group A, human carcinogen.

Contamination of Groundwater

Arsenic contamination of groundwater is often due to naturally occurring high concentrations of arsenic in deeper levels of groundwater. It is a high-profile problem due to the use of deep tubewells for water supply in the Ganges Delta, causing serious arsenic poisoning to large numbers of people. In addition, mining techniques such as hydraulic fracturing mobilize arsenic in groundwater and aquifers due to enhanced methane 28 transport and resulting changes in redox conditions, and inject fluid containing additional arsenic.

A 2007 study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning of drinking water. Arsenic contamination of ground water is found in many countries throughout the world, including the USA.

Approximately 20 incidents of groundwater arsenic contamination have been reported from all over the world. Of these, four major incidents were in Asia, including locations in Thailand, Taiwan, and Mainland China. In South America, Argentina and Chile are affected. There are also many locations in the United States where the groundwater contains arsenic concentrations in excess of the Environmental Protection Agency standard of 10 parts per billion adopted in 2001. Millions of private wells have unknown arsenic levels, and in some areas of the US, over 20% of wells may contain levels that are not safe.

Arsine

Arsine is a gas consisting of arsenic and hydrogen. It is extremely toxic to humans, with headaches, vomiting, and abdominal pains occurring within a few hours of exposure. EPA has not classified arsine for carcinogenicity.

Drinking water regulations require public water systems to monitor for arsenic at the entry point to the distribution system. There is no federal requirement for systems to monitor for arsenic within the distribution system. You may, however, want to test your distribution system water for arsenic to be sure that the water being delivered has arsenic levels below the MCL. If you decide to monitor your distribution system, consider testing for arsenic at locations where the settling and accumulation of iron solids or pipe scales are likely (i.e., areas with cast iron pipe, ductile iron pipe, or galvanized iron pipe).

If your water system has installed some form of arsenic treatment, keep in mind that the treatment you installed may change the water quality in other ways. It might cause the water to react differently in the distribution system. Depending on the kind of treatment you’ve installed, consider what distribution system problems might result.

A change in the taste, odor or appearance of the water at customers' taps may be the first indication of a problem. Some water quality parameters to consider monitoring, depending on your arsenic treatment technology, include iron, pH, manganese, alkalinity, and aluminum.

The current drinking water standard or Maximum Contaminant Level (MCL) set by the U.S. Environmental Protection Agency (EPA) is 0.010 mg/L or parts per million (ppm). This is equivalent to 10 ug/L (micrograms per liter) or 10 ppb. In 2001, the U.S. Environmental Protection Agency (EPA) reduced the regulatory MCL from 50 ppb to 10 ppb on the basis on bladder and lung cancer risks. The MCL is based on the average individual consuming 2 liters of water a day for a lifetime. Long term exposure to drinking water containing arsenic at levels higher than 10 ppb increases the chances of getting cancer, while for lower arsenic water levels the chances are less.

If your water has arsenic levels above 10 ppb, you should obtain drinking water from another source or install a home treatment device. Concentrations above 10 ppb will increase the risk of long-term or chronic health problems, the higher the level and length of exposure, the greater the risk. It is especially important to reduce arsenic water concentrations if you have children or are pregnant. Children are at greater risk (to any agent in water) because of their greater water consumption on a per unit body weight basis.

Pregnant women may wish to reduce their arsenic exposures because arsenic has been found at low levels in mother's milk and will cross the placenta, increasing exposures and risks for the fetus. If your water has arsenic levels above 200 ppb, you should immediately stop drinking the water until you can either obtain water from another source or install and maintain treatment.

Physical Characteristics

The three most common arsenic allotropes are *metallic gray*, *yellow* and *black arsenic*, with gray being the most common. *Gray arsenic* (α-As, space group R3m No. 166) adopts a double-layered structure consisting of many interlocked ruffled six-membered rings. Because of weak bonding between the layers, gray arsenic is brittle and has a relatively low Mohs hardness of 3.5. Nearest and next-nearest neighbors form a distorted octahedral complex, with the three atoms in the same double-layer being slightly closer than the three atoms in the next. This relatively close packing leads to a high density of 5.73 g/cm^3. Gray arsenic is a semimetal, but becomes a semiconductor with a bandgap of 1.2–1.4 eV if amorphized. *Yellow arsenic* is soft and waxy, and somewhat similar to tetraphosphorus (P_4). Both have four atoms arranged in a tetrahedral structure in which each atom is bound to each of the other three atoms by a single bond. This unstable allotrope, being molecular, is the most volatile, least dense and most toxic. Solid yellow arsenic is produced by rapid cooling of arsenic vapor, As_4. It is rapidly transformed into the gray arsenic by light. The yellow form has a density of 1.97 g/cm^3. *Black arsenic* is similar in structure to red phosphorus.

Isotopes

Naturally occurring arsenic is composed of one stable isotope, ^{75}As. As of 2003, at least 33 radioisotopes have also been synthesized, ranging in atomic mass from 60 to 92. The most stable of these is ^{73}As with a half-life of 80.3 days. Isotopes that are lighter than the stable ^{75}As tend to decay by β^+ decay, and those that are heavier tend to decay by β^- decay, with some exceptions.

At least 10 nuclear isomers have been described, ranging in atomic mass from 66 to 84. The most stable of arsenic's isomers is ^{68m}As with a half-life of 111 seconds.

Chemistry

When heated in air, arsenic oxidizes to arsenic trioxide; the fumes from this reaction have an odor resembling garlic. This odor can be detected on striking arsenide minerals such as arsenopyrite with a hammer.

Arsenic (and some arsenic compounds) sublimes upon heating at atmospheric pressure, converting directly to a gaseous form without an intervening liquid state at 887 K (614 °C). The triple point is 3.63 MPa and 1,090 K (820 °C). Arsenic makes arsenic acid with concentrated nitric acid, arsenious acid with dilute nitric acid, and arsenic trioxide with concentrated sulfuric acid.

Compounds

Arsenic compounds resemble in some respects those of phosphorus, which occupies the same group (column) of the periodic table. Arsenic is less commonly observed in the pentavalent state, however. The most common oxidation states for arsenic are: −3 in the arsenides, such as alloy-like intermetallic compounds; and +3 in the arsenites, arsenates (III), and most organoarsenic compounds. Arsenic also bonds readily to itself as seen in the square As3−
4 ions in the mineral skutterudite. In the +3 oxidation state, arsenic is typically pyramidal, owing to the influence of the lone pair of electrons.

Inorganic

Arsenic forms colorless, odorless, crystalline oxides As_2O_3 ("white arsenic") and As_2O_5, which are hygroscopic and readily soluble in water to form acidic solutions. Arsenic (V) acid is a weak acid. Its salts are called arsenates, which is the basis of arsenic contamination of groundwater, a problem that affects many people. Synthetic arsenates include Paris Green (copper(II) acetoarsenite), calcium arsenate, and lead hydrogen arsenate. The latter three have been used as agricultural insecticides and poisons.

The protonation steps between the arsenate and arsenic acid are similar to those between phosphate and phosphoric acid. Unlike phosphorus acid, arsenous acid is genuinely tribasic, with the formula $As(OH)_3$.

A broad variety of sulfur compounds of arsenic are known. Orpiment (As_2S_3) and realgar (As_4S_4) are somewhat abundant and were formerly used as painting pigments. In As_4S_{10}, arsenic has a formal oxidation state of +2 in As_4S_4, which features As-As bonds so that the total covalency of As is still three.

The trifluoride, trichloride, tribromide, and triiodide of arsenic (III) are well known, whereas only Arsenic pentafluoride (AsF_5) is the only important pentahalide. Again reflecting the lower stability of the 5+ oxidation state, the pentachloride is stable only below −50 °C.

Organoarsenic Compounds

A large variety of organoarsenic compounds are known. Several were developed as chemical warfare agents during World War I, including vesicants such as lewisite and vomiting agents such as adamsite. Cacodylic acid, which is of historic and practical interest, arises from the methylation of arsenic trioxide, a reaction that has no analogy in phosphorus chemistry.

Alloys

Arsenic is used as the group 5 element in the III-V semiconductors gallium arsenide, indium arsenide, and aluminum arsenide. The valence electron count of GaAs is the same as a pair of Si atoms, but the band structure is completely different, which results distinct bulk properties. Other arsenic alloys include the II-IV semiconductor cadmium arsenide.

Occurrence and Production

Minerals with the formula MAsS and MAs_2 (M = Fe, Ni, Co) are the dominant commercial sources of arsenic, together with realgar (an arsenic sulfide mineral) and native arsenic. An illustrative mineral is arsenopyrite (FeAsS), which is structurally related to iron pyrite. Many minor As-containing minerals are known.

Arsenic also occurs in various organic forms in the environment. Inorganic arsenic and its compounds, upon entering the food chain, are progressively metabolized to a less toxic form of arsenic through a process of methylation.

Other naturally occurring pathways of exposure include volcanic ash, weathering of arsenic-containing minerals and ores, and dissolved in groundwater. It is also found in food, water, soil, and air. Arsenic is absorbed by all plants, but is more concentrated in leafy vegetables, rice, apple and grape juice, and seafood. An additional route of exposure is through inhalation.

In 2005, China was the top producer of white arsenic with almost 50% world share, followed by Chile, Peru, and Morocco, according to the British Geological Survey and the United States Geological Survey. Most operations in the US and Europe have closed for environmental reasons. The arsenic is recovered mainly as a side product from the purification of copper. Arsenic is part of the smelter dust from copper, gold, and lead smelters.

On roasting in air of arsenopyrite, arsenic sublimes as arsenic (III) oxide leaving iron oxides, while roasting without air results in the production of metallic arsenic. Further purification from sulfur and other chalcogens is achieved by sublimation in vacuum or in a hydrogen atmosphere or by distillation from molten lead-arsenic mixture.

Health Hazard Information

Arsenic

Arsenic is known to cause cancer, as well as many other serious health problems. Here we review the hazards of arsenic exposure and ways people can protect themselves from these hazards.

Arsenic is an element in the environment that can be found naturally in rocks and soil, water, air, and in plants and animals. It can also be released into the environment from some agricultural and industrial sources.

Arsenic has no taste or smell. Although sometimes found in its pure form as a steel grey metal, arsenic is usually part of chemical compounds. These compounds are divided into 2 groups:

- Inorganic compounds (combined with oxygen, iron, chlorine, and sulfur)
- Organic compounds (combined with carbon and other atoms)

Inorganic arsenic compounds are found in industry, in building products (in some "pressure-treated" woods), and in arsenic-contaminated water. This is the form of arsenic that tends to be more toxic and has been linked to cancer.

Organic arsenic compounds are much less toxic than the inorganic arsenic compounds and are not thought to be linked to cancer. These compounds are found in some foods, such as fish and shellfish.

While arsenic levels may fluctuate over time, what is most significant from the standpoint of cancer risk is long-term exposure.

For water systems in the 25 states that reported arsenic data to the EPA, we have calculated two estimates of average long-term levels: one is a very conservative estimate, the other our best estimate, based on what we believe to be the most reasonable analytical techniques (details on how we arrived at the estimates are included with the charts).

The table below shows the lifetime risks of dying of cancer from arsenic in tap water, based on the National Academy of Sciences' 1999 risk estimates.

Arsenic Level in Tap Water (in parts per billion, or ppb)	Approximate Total Cancer Risk (assuming 2 liters consumed/day)
0.5 ppb	1 in 10,000
1 ppb	1 in 5,000
3 ppb	1 in 1,667
4 ppb	1 in 1,250
5 ppb	1 in 1,000
10 ppb	1 in 500
20 ppb	1 in 250
25 ppb	1 in 200
50 ppb	1 in 100

Arsenic Diabetes

New research findings from the National Health and Nutrition Examination Survey suggest that exposure to levels of arsenic commonly found in drinking water may be a risk factor for type 2 diabetes. The findings suggest that millions of Americans may be at increased risk for type 2 diabetes based on the level of arsenic in their drinking water.

Data on the nearly 800 participants in the study for which urinary arsenic concentrations were available, indicated that urine levels of arsenic were significantly associated with the prevalence of type 2 diabetes.

After splitting the subjects into 5 groups based on the level of arsenic in their urine, the researchers determined that those in the highest category were more than three and one-half times more likely to have diabetes. The strength of arsenic as a risk factor for diabetes is similar to other factors such as obesity.

Inorganic arsenic in drinking water at concentrations higher than 100 parts per million has been linked to type 2 diabetes in studies that took place in Taiwan, Mexico, and Bangladesh where drinking water is commonly contaminated with high levels of arsenic.

The US drinking water standard is currently 10 parts per million, but most people on private wells have not had their water tested and aren’t required to. The researchers estimate that about 13 million Americans live in areas where public water systems exceed the EPA standard for arsenic and this number does not included private wells and water systems.

Animal studies have shown that arsenic affects the production of glucose, insulin secretion and can cause insulin resistance. The current findings reinforce the need to evaluate the role of arsenic in diabetes development in prospective epidemiologic studies conducted in populations exposed to a wide range of arsenic levels.

Acute Effects:

Inorganic Arsenic

- Acute inhalation exposure of workers to high levels of arsenic dusts or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain), while acute exposure of workers to inorganic arsenic has also resulted in central and peripheral nervous system disorders.
- Acute oral exposure to inorganic arsenic, at doses of approximately 600 micrograms per kilogram body weight per day (µg/kg/d) or higher in humans, has resulted in death. Oral exposure to lower levels of inorganic arsenic has resulted in effects on the gastrointestinal tract (nausea, vomiting), central nervous system (CNS) (headaches, weakness, delirium), cardiovascular system (hypotension, shock), liver, kidney, and blood (anemia, leukopenia).
- Acute animal tests in rats and mice have shown inorganic arsenic to have moderate to high acute toxicity.

Arsine

- Acute inhalation exposure to arsine by humans has resulted in death; it has been reported that a half-hour exposure to 25 to 50 parts per million (ppm) can be lethal.
- The major effects from acute arsine exposure in humans include headaches, vomiting, abdominal pains, hemolytic anemia, hemoglobinuria, and jaundice; these effects can lead to kidney failure.
- Arsine has been shown to have extreme acute toxicity from acute animal tests.

Chronic Effects (Non-cancer):

Inorganic arsenic

- Chronic inhalation exposure to inorganic arsenic in humans is associated with irritation of the skin and mucous membranes (dermatitis, conjunctivitis, pharyngitis, and rhinitis).
- Chronic oral exposure to inorganic arsenic in humans has resulted in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, gangrene of the extremities, vascular lesions, and liver or kidney damage.
- No chronic inhalation exposure studies have been performed in animals for any inorganic arsenic compound.
- Some studies have suggested that inorganic arsenic is an essential dietary nutrient in goats, chicks, and rats. However, no comparable data are available for humans. EPA has concluded that essentiality, although not rigorously established, is plausible.
- EPA has not established a Reference Concentration (RfC) for inorganic arsenic.
- The California Environmental Protection Agency (CalEPA) has established a chronic inhalation reference level of 0.00003 milligrams per cubic meter (mg/m^3) based on developmental effects in mice. The CalEPA reference exposure level is a concentration at or below which adverse health effects are not likely to occur. It is not a direct estimator of risk, but rather a reference point to gauge the potential effects. At lifetime exposures increasingly greater than the reference exposure level, the potential for adverse health effects increases.
- The Reference Dose (RfD) for inorganic arsenic is 0.0003 milligrams per kilogram body weight per day (mg/kg/d) based on hyperpigmentation, keratosis, and possible vascular complications in humans. The RfD is an estimate (with uncertainty spanning perhaps an order of

magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime.

- EPA has medium confidence in the study on which the RfD for inorganic arsenic was based because, although an extremely large number of people were included in the assessment (>40,000), the doses were not well characterized and other contaminants were present. The supporting human toxicity database, while extensive, is somewhat flawed and, consequently, EPA has assigned medium confidence to the RfD.

Arsine

- No information is available on the chronic effects of arsine in humans.
- The RfC for arsine is 0.00005 mg/m^3 based on increased hemolysis, abnormal red blood cell morphology, and increased spleen weight in rats, mice, and hamsters.
- EPA has medium confidence in the RfC based on: (1) high confidence in the studies on which the RfC for arsine was based because the sample sizes were adequate, statistical significance was reported, concentration dose-response relationships were documented, three species were investigated, and both a no-observed-adverse-effect level (NOAEL) and a lowest-observed-adverse-effect level (LOAEL) were identified, and (2) medium confidence in the database because while there were three inhalation animal studies and a developmental/ reproductive study, there were no data available on human exposure.

Reproductive/Developmental Effects:

Inorganic arsenic

- Several studies have suggested that women who work in, or live near, metal smelters may have higher than normal spontaneous abortion rates, and their children may exhibit lower than normal birth weights. However, these studies are limited because they were designed to evaluate the effects of smelter pollutants in general, and are not specific for inorganic arsenic.
- Ingested inorganic arsenic can cross the placenta in humans, exposing the fetus to the chemical.
- Oral animal studies have reported inorganic arsenic at very high doses to be fetotoxic and to cause birth defects.

Arsine

- Human studies have indicated higher than expected spontaneous abortion rates in women in the microelectronics industry who were exposed to arsine. However, these studies have several limitations, including small sample size and exposure to other chemicals in addition to arsine.

Cancer Risk:

Inorganic arsenic

- Human, inhalation studies have reported inorganic arsenic exposure to be strongly associated with lung cancer.
- Ingestion of inorganic arsenic in humans has been associated with an increased risk of nonmelanoma skin cancer and also to an increased risk of bladder, liver, and lung cancer.
- Animal studies have not associated inorganic arsenic exposure via the oral route with cancer, and no cancer inhalation studies have been performed in animals for inorganic arsenic.
- EPA has classified inorganic arsenic as a Group A, human carcinogen.
- EPA used a mathematical model, using data from an occupational study of arsenic-exposed copper smelter workers, to estimate the probability of a person developing cancer from continuously breathing air containing a specified concentration of inorganic arsenic. EPA calculated an inhalation unit risk estimate of $4.3 \times 10^{-3}(\mu g/m^3)^{-1}$. EPA estimates that, if an individual were to continuously breathe air containing inorganic arsenic at an average of 0.0002 µg/m^3 (2×10^{-7} mg/m^3) over his or her entire lifetime, that person would theoretically have no more

than a one-in-a-million increased chance of developing cancer as a direct result of breathing air containing this chemical. Similarly, EPA estimates that continuously breathing air containing 0.002 µg/m^3 (2×10^{-6} mg/m^3) would result in not greater than a one-in-a-hundred thousand increased chance of developing cancer, and air containing 0.02 µg/m^3 (2×10^{-5} mg/m^3) would result in not greater than a one-in-ten thousand increased chance of developing cancer. For a detailed discussion of confidence in the potency estimates, please see IRIS.

- EPA has calculated an oral cancer slope factor of 1.5 $(mg/kg/d)^{-1}$ for inorganic arsenic.

Arsine

- No cancer inhalation studies in humans or animals are available for arsine.
- EPA has not classified arsine for carcinogenicity.

Physical Properties

- Inorganic arsenic is a naturally occurring element in the earth's crust.
- Pure inorganic arsenic is a gray-colored metal, but inorganic arsenic is usually found combined with other elements such as oxygen, chlorine, and sulfur.
- The chemical symbol for inorganic arsenic is As, and it has an atomic weight of 74.92 g/mol.
- The chemical formula for arsine is AsH_3, and it has a molecular weight of 77.95 g/mol.
- Arsine is a colorless gas with a disagreeable garlic odor.
- Arsenic combined with elements such as oxygen, chlorine, and sulfur forms inorganic arsenic; inorganic arsenic compounds include arsenic pentoxide, arsenic trioxide, and arsenic acid. Arsenic combined with carbon and hydrogen forms organic arsenic; organic arsenic compounds include arsanilic acid, arsenobetaine, and dimethylarsinic acid.

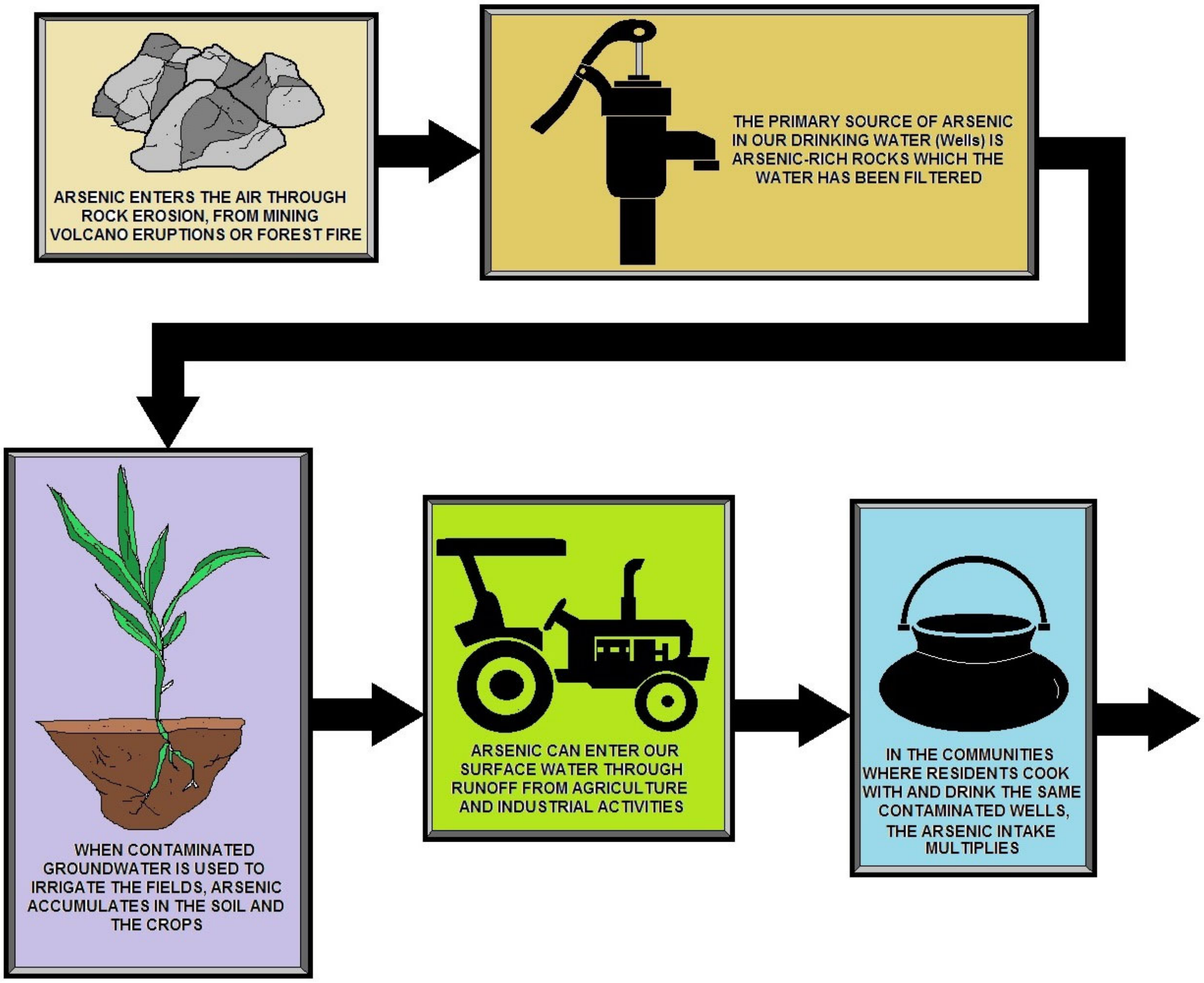
History

The word “Arsenic“ was adopted in Latin *arsenicum* and Old French *arsenic,* from which the English word *arsenic* is derived. Arsenic sulfides (orpiment, realgar) and oxides have been known and used since ancient times. Zosimos (circa 300 AD) describes roasting *sandarach* (realgar) to obtain *cloud of arsenic* (arsenious oxide), which he then reduces to metallic arsenic. As the symptoms of arsenic poisoning were somewhat ill-defined, it was frequently used for murder until the advent of the Marsh test, a sensitive chemical test for its presence. (Another less sensitive but more general test is the Reinsch test.) Owing to its use by the ruling class to murder one another and its potency and discreetness, arsenic has been called the *Poison of Kings* and the *King of Poisons*.

During the Bronze Age, arsenic was often included in bronze, which made the alloy harder (so-called "arsenical bronze"). Albertus Magnus (Albert the Great, 1193–1280) is believed to have been the first to isolate the element from a compound in 1250, by heating soap together with arsenic trisulfide. In 1649, Johann Schröder published two ways of preparing arsenic.

Crystals of elemental (native) arsenic are found in nature, although rare. Cadet's fuming liquid (impure cacodyl), often claimed as the first synthetic organometallic compound, was synthesized in 1760 by Louis Claude Cadet de Gassicourt by the reaction of potassium acetate with arsenic trioxide.

In the Victorian era, "arsenic" ("white arsenic" or arsenic trioxide) was mixed with vinegar and chalk and eaten by women to improve the complexion of their faces, making their skin paler to show they did not work in the fields. Arsenic was also rubbed into the faces and arms of women to "improve their complexion". The accidental use of arsenic in the adulteration of foodstuffs led to the Bradford sweet poisoning in 1858, which resulted in approximately 20 deaths.



ARSENIC IN DRINKING WATER

Arsenic Applications

Agricultural

The toxicity of arsenic to insects, bacteria and fungi led to its use as a wood preservative. In the 1950s a process of treating wood with chromated copper arsenate (also known as CCA or Tanalith) was invented, and for decades this treatment was the most extensive industrial use of arsenic. An increased appreciation of the toxicity of arsenic resulted in a ban for the use of CCA in consumer products; the European Union and United States initiated this process in 2004. CCA remains in heavy use in other countries however, e.g. Malaysian rubber plantations.

Arsenic was also used in various agricultural insecticides, termination and poisons. For example, lead hydrogen arsenate was a common insecticide on fruit trees, but contact with the compound sometimes resulted in brain damage among those working the sprayers. In the second half of the 20th century, monosodium methyl arsenate (MSMA) and disodium methyl arsenate (DSMA) – less toxic organic forms of arsenic – have replaced lead arsenate in agriculture.

Arsenic is still added to animal food, in particular in the US as a method of disease prevention and growth stimulation. One example is roxarsone, which is used as a broiler starter by about 70% of the broiler growers since 1995. The Poison-Free Poultry Act of 2009 proposes to ban the use of roxarsone in industrial swine and poultry production. Alpharma, a subsidiary of Pfizer Inc., which produces Roxarsone, has voluntarily suspended sales of the drug in response to studies showing elevated levels of arsenic in treated chickens.

Medical use

During the 18th, 19th, and 20th centuries, a number of arsenic compounds have been used as medicines, including arsphenamine (by Paul Ehrlich) and arsenic trioxide (by Thomas Fowler). Arsphenamine as well as neosalvarsan was indicated for syphilis and trypanosomiasis, but has been superseded by modern antibiotics.

Arsenic trioxide has been used in a variety of ways over the past 500 years, but most commonly in the treatment of cancer. The US Food and Drug Administration in 2000 approved this compound for the treatment of patients with acute promyelocytic leukemia that is resistant to ATRA.

It was also used as Fowler's solution in psoriasis. Recently new research has been done in locating tumors using arsenic-74 (a positron emitter). The advantages of using this isotope instead of the previously used iodine-124 is that the signal in the PET scan is clearer as the body tends to transport iodine to the thyroid gland producing a lot of noise. In subtoxic doses, soluble arsenic compounds act as stimulants, and were once popular in small doses as medicine by people in the mid-18th century.

Alloys

The main use of metallic arsenic is for alloying with lead. Lead components in car batteries are strengthened by the presence of a few percent of arsenic. Dezincification can be strongly reduced by adding arsenic to brass, a copper-zinc alloy. Gallium arsenide is an important semiconductor material, used in integrated circuits. Circuits made from GaAs are much faster (but also much more expensive) than those made in silicon. Unlike silicon it has a direct bandgap, and so can be used in laser diodes and LEDs to directly convert electricity into light.

Military

After World War I, the United States built up a stockpile of 20,000 tons of lewisite ($ClCH=CHAsCl_2$), a chemical weapon that is a vesicant (blister agent) and lung irritant. The stockpile was neutralized with bleach and dumped into the Gulf of Mexico after the 1950s. During the Vietnam War the United States used Agent Blue, a mixture of sodium cacodylate and its acid form, as one of the rainbow herbicides to deprive invading North Vietnamese soldiers of foliage cover and rice.

Other uses

- Copper acetoarsenite was used as a green pigment known under many names, including 'Paris Green' and 'Emerald Green'. It caused numerous arsenic poisonings. Scheele's Green, a copper arsenate, was used in the 19th century as a coloring agent in sweets.
- Also used in bronzing and pyrotechnics.
- Up to 2% of arsenic is used in lead alloys for lead shots and bullets.
- Arsenic is added in small quantities to alpha-brass to make it dezincification resistant. This grade of brass is used to make plumbing fittings or other items that are in constant contact with water.
- Arsenic is also used for taxonomic sample preservation.
- Until recently arsenic was used in optical glass. Modern glass manufacturers, under pressure from environmentalists, have removed it, along with lead.

Bacteria

Some species of bacteria obtain their energy by oxidizing various fuels while reducing arsenate to arsenite. Under oxidative environmental conditions some bacteria use arsenite, which is oxidized to arsenate as fuel for their metabolism. The enzymes involved are known as arsenate reductases (Arr).

In 2008, bacteria were discovered that employ a version of photosynthesis in the absence of oxygen with arsenites as electron donors, producing arsenates (just as ordinary photosynthesis uses water as electron donor, producing molecular oxygen). Researchers conjecture that, over the course of history, these photosynthesizing organisms produced the arsenates that allowed the arsenate-reducing bacteria to thrive. One strain PHS-1 has been isolated and is related to the Gammaproteobacterium *Ectothiorhodospira shaposhnikovii*. The mechanism is unknown, but an encoded Arr enzyme may function in reverse to its known homologues. Although the arsenate and phosphate anions are similar structurally, no evidence exists for the replacement of phosphate in ATP or nucleic acids by arsenic.

It is known that even if your water has detectable levels of arsenic that are below the 0.010 mg/L MCL, and you have iron pipes or components in your distribution system, your system's pipes may have arsenic-rich scales attached to them. As long as the scales are not disturbed, they will remain attached to the pipes or other distribution system components. Certain conditions, such as flushing of mains or fire flow conditions, may result in those scales being sloughed off and suspended in the water, releasing the arsenic. Other conditions, such as changes in water chemistry, may result in some of the arsenic dissolving back into the water. Both of these situations could cause high arsenic levels at consumers' taps.

Arsenic Control Measures Can Affect Finished Water Quality

Public water systems installing arsenic treatment should be informed about possible changes to their finished water that may result from the arsenic treatment they install. For example, systems may need to adjust their finished water quality to address new concerns about corrosion.

Changes in water chemistry due to using new sources, blending different source waters, or installing arsenic treatment are some of the factors that can affect distribution system water quality. In some cases, this may cause an increase in arsenic levels in the distribution system or create simultaneous compliance issues with other drinking water regulations.

Water systems may also find deposits of arsenic-rich particles in their storage tanks or at locations in their distribution system with low flows. If the flow is increased or a storage tank is drawn down to a low level, these arsenic-rich particles can get stirred up and transported to consumers' taps. This situation occurs primarily when iron media used in treatment are released into the distribution system, or when iron particles are not properly filtered out during iron removal treatment. If these treatment technologies are operated correctly, this should not be a problem for most water systems.

Is Arsenic in your Storage Tank?

Is Your Ground Water System Installing Disinfection for Pathogen Control?

Water systems that disinfect their water should be aware of the possibility of an increase in arsenic concentrations in their distribution system, particularly if the water contains high concentrations of dissolved iron. When chlorinated, the dissolved iron forms particles on which arsenic can accumulate. As a result, high arsenic concentrations may occur in distribution system water even if arsenic concentrations in the raw water are below the MCL.

This happened to a small community water system in the Midwest that began chlorinating water from a series of wells that had raw water arsenic levels between 0.003 and 0.008 mg/L and iron concentrations up to 0.4 mg/L. At the same time, the system installed a polyphosphate feed system for corrosion control. Soon after chlorination began, the system received intermittent colored-water complaints from its customers with increasing frequency across the distribution system.

Samples collected from several representative locations throughout the service area had a reddish-brown color and contained particles. A metals analysis showed high levels of copper and iron oxides in the finished water, along with arsenic concentrations approaching 5 mg/L. Because of the water's colored appearance, it was considered unlikely that customers would consume the water. Doctors and health care professionals were notified of the situation and instructed to watch for signs of arsenic poisoning.

Researchers found that chlorinating the water caused the formation of ferri-hydroxide solids. The minimal arsenic present in the groundwater was being concentrated as it absorbed onto the solids. Copper oxide particulates also formed and were released. To some extent, the polyphosphates served a useful role by keeping iron in solution and counteracting the tendency for the iron oxides to form, but additional steps were needed. For six months the system alternated their chlorination schedule: on for one day then off two days. The system then returned to full-time chlorination, starting with a low distribution system residual of0.2 mg/L and gradually increasing it to 0.5 mg/L. The system continued to flush water mains on a semi-annual schedule using a unidirectional approach. In the last year, the system received only one colored water complaint.

Heredity

Arsenic has been linked to epigenetic changes, heritable changes in gene expression that occur without changes in DNA sequence. These include DNA methylation, histone modification, and RNA interference. Toxic levels of arsenic cause significant DNA hypermethylation of tumor suppressor genes p16 and p53, thus increasing risk of carcinogenesis. These epigenetic events have been studied *in vitro* using human kidney cells and *in vivo* using rat liver cells and peripheral blood leukocytes in humans.

Inductive coupled plasma mass spectrometry (ICP-MS) is used to detect precise levels of intracellular arsenic and its other bases involved in epigenetic modification of DNA. Studies investigating arsenic as an epigenetic factor will help in developing precise biomarkers of exposure and susceptibility.

The Chinese brake fern (*Pteris vittata*) hyperaccumulates arsenic present in the soil into its leaves and has a proposed use in phytoremediation.

Biomethylation

Inorganic arsenic and its compounds, upon entering the food chain, are progressively metabolized through a process of methylation. For example, the mold Scopulariopsis brevicaulis produce significant amounts of trimethylarsine if inorganic arsenic is present. The organic compound arsenobetaine is found in some marine foods such as fish and algae, and also in mushrooms in larger concentrations. The average person's intake is about 10–50 µg/day. Values about 1000 µg are not unusual following consumption of fish or mushrooms, but there is little danger in eating fish because this arsenic compound is nearly non-toxic.

Arsenic Environmental Issues

Arsenic Control Measures Can Affect Finished Water Quality

Public water systems installing arsenic treatment should be informed about possible changes to their finished water that may result from the arsenic treatment they install. For example, systems may need to adjust their finished water quality to address new concerns about corrosion. Changes in water chemistry due to using new sources, blending different source waters, or installing arsenic treatment are some of the factors that can affect distribution system water quality. In some cases, this may cause an increase in arsenic levels in the distribution system or create simultaneous compliance issues with other drinking water regulations.

Occurrence in drinking water

Widespread arsenic contamination of groundwater has led to a massive epidemic of arsenic poisoning in Bangladesh and neighboring countries. It is estimated that approximately 57 million people in the Bengal basin are drinking groundwater with arsenic concentrations elevated above the World Health Organization's standard of 10 parts per billion (ppb). However, a study of cancer rates in Taiwan suggested that significant increases in cancer mortality appear only at levels above 150 ppb.

The arsenic in the groundwater is of natural origin, and is released from the sediment into the groundwater, owing to the anoxic conditions of the subsurface. This groundwater began to be used after local and western NGOs and the Bangladeshi government undertook a massive shallow tube well drinking-water program in the late twentieth century. This program was designed to prevent drinking of bacteria-contaminated surface waters, but failed to test for arsenic in the groundwater. Many other countries and districts in Southeast Asia, such as Vietnam and Cambodia have geological environments conducive to generation of high-arsenic groundwaters. Arsenicosis was reported in Nakhon Si Thammarat, Thailand in 1987, and the dissolved arsenic in the Chao Phraya River is suspected of containing high levels of naturally occurring arsenic, but has not been a public health problem owing to the use of bottled water.

In the United States, arsenic is most commonly found in the ground waters of the southwest. Parts of New England, Michigan, Wisconsin, Minnesota and the Dakotas are also known to have significant concentrations of arsenic in ground water. Increased levels of skin cancer have been associated with arsenic exposure in Wisconsin, even at levels below the 10 part per billion drinking water standard, although this link has not been proven.

According to a recent film funded by the US Superfund, millions of private wells have unknown arsenic levels, and in some areas of the US, over 20% of wells may contain levels that exceed established limits.

Low-level exposure to arsenic at concentrations found commonly in US drinking water compromises the initial immune response to H1N1 or swine flu infection according to NIEHS-supported scientists. The study, conducted in laboratory mice, suggests that people exposed to arsenic in their drinking water may be at increased risk for more serious illness or death in response to infection from the virus.

Some Canadians are drinking water that contains inorganic arsenic. Private dug well waters are most at risk for containing inorganic arsenic. Preliminary well water analyses typically does not test for arsenic. Researchers at the Geological Survey of Canada have modeled relative variation in natural arsenic hazard potential for the province of New Brunswick. This study has important implications for potable water and health concerns relating to inorganic arsenic.

Epidemiological evidence from Chile shows a dose-dependent connection between chronic arsenic exposure and various forms of cancer, in particular when other risk factors, such as cigarette smoking, are present. These effects have been demonstrated to persist below 50 ppb.

Analyzing multiple epidemiological studies on inorganic arsenic exposure suggests a small but measurable risk increase for bladder cancer at 10 ppb. According to Peter Ravenscroft of the Department of Geography at the University of Cambridge, roughly 80 million people worldwide consume between 10 and 50 ppb arsenic in their drinking water. If they all consumed exactly 10 ppb arsenic in their drinking water, the previously cited multiple epidemiological study analysis would predict an additional 2,000 cases of bladder cancer alone. This represents a clear underestimate of the overall impact, since it does not include lung or skin cancer, and explicitly underestimates the exposure. Those exposed to levels of arsenic above the current WHO standard should weigh the costs and benefits of arsenic remediation.

Early (1973) evaluations of the removal of dissolved arsenic by drinking water treatment processes demonstrated that arsenic is very effectively removed by co-precipitation with either iron or aluminum oxides. The use of iron as a coagulant, in particular, was found to remove arsenic with efficiencies exceeding 90%. Several adsorptive media systems have been approved for point-of-service use in a study funded by the United States Environmental Protection Agency (US EPA) and the National Science Foundation (NSF).

A team of European and Indian scientists and engineers have set up six arsenic treatment plants in West Bengal based on in-situ remediation method (SAR Technology). This technology does not use any chemicals and arsenic is left as an insoluble form (+5 state) in the subterranean zone by recharging aerated water into the aquifer and thus developing an oxidation zone to support arsenic oxidizing micro-organisms. This process does not produce any waste stream or sludge and is relatively cheap.

Another effective and inexpensive method to remove arsenic from contaminated well water is to sink wells 500 feet or deeper to reach purer waters. A recent 2011 study funded by the US National Institute of Environmental Health Sciences' Superfund Research Program shows that deep sediments can remove arsenic and take it out of circulation.

Through this process called adsorption in which arsenic sticks to the surfaces of deep sediment articles, arsenic can be naturally removed from well water.

Magnetic separations of arsenic at very low magnetic field gradients have been demonstrated in point-of-use water purification with high-surface-area and monodisperse magnetite (Fe_3O_4) nanocrystals. Using the high specific surface area of Fe_3O_4 nanocrystals the mass of waste associated with arsenic removal from water has been dramatically reduced.

Epidemiological studies have suggested a correlation between chronic consumption of drinking water contaminated with arsenic and the incidence of all leading causes of mortality. The literature provides reason to believe arsenic exposure is causative in the pathogenesis of diabetes.

Hungarian engineer László Schremmer has recently discovered that by the use of chaff-based filters it is possible to reduce the arsenic content of water to 3 µg/L. This is especially important in areas where the potable water is provided by filtering the water extracted from the underground aquifer.

Wood Preservation in the US

As of 2002, US-based industries consumed 19,600 metric tons of arsenic. Ninety percent of this was used for treatment of wood with chromated copper arsenate (CCA). In 2007, 50% of the 5,280 metric tons of consumption was still used for this purpose. In the United States, the use of arsenic in consumer products was discontinued for residential and general consumer construction on December 31, 2003 and alternative chemicals are now used, such as Alkaline Copper Quaternary, borates, copper azole, cyproconazole, and propiconazole.

Although discontinued, this application is also one of the most concerns to the general public. The vast majority of older pressure-treated wood was treated with CCA. CCA lumber is still in widespread use in many countries, and was heavily used during the latter half of the 20th century as a structural and outdoor building material. Although the use of CCA lumber was banned in many areas after studies showed that arsenic could leach out of the wood into the surrounding soil (from playground equipment, for instance), a risk is also presented by the burning of older CCA timber.

The direct or indirect ingestion of wood ash from burnt CCA lumber has caused fatalities in animals and serious poisonings in humans; the lethal human dose is approximately 20 grams of ash. Scrap CCA lumber from construction and demolition sites may be inadvertently used in commercial and domestic fires. Protocols for safe disposal of CCA lumber do not exist evenly throughout the world; there is also concern in some quarters about the widespread landfill disposal of such timber.

Water Purification Solutions

Small-scale water treatment

A review of methods to remove arsenic from groundwater in Pakistan summarizes the most technically viable inexpensive methods. A simpler and less expensive form of arsenic removal is known as the Sono arsenic filter, using three pitchers containing cast iron turnings and sand in the first pitcher and wood activated carbon and sand in the second. Plastic buckets can also be used as filter containers. It is claimed that thousands of these systems are in use and can last for years while avoiding the toxic waste disposal problem inherent to conventional arsenic removal plants. Although novel, this filter has not been certified by any sanitary standards such as NSF, ANSI, WQA and does not avoid toxic waste disposal similar to any other iron removal process.

In the United States small "under the sink" units have been used to remove arsenic from drinking water. This option is called "point of use" treatment. The most common types of domestic treatment use the technologies of adsorption (using media such as Bayoxide E33, GFH, or titanium dioxide) or reverse osmosis. Ion exchange and activated alumina have been considered but not commonly used.

Arsenic Large-scale water treatment

In some places, such as the United States, all the water supplied to residences by utilities must meet primary (health-based) drinking water standards. Regulations may necessitate large-scale treatment systems to remove arsenic from the water supply. The effectiveness of any method depends on the chemical makeup of a particular water supply. The aqueous chemistry of arsenic is complex, and may affect the removal rate that can be achieved by a particular process.

Some large utilities with multiple water supply wells could shut down those wells with high arsenic concentrations, and produce only from wells or surface water sources that meet the arsenic standard. Other utilities, however, especially small utilities with only a few wells, may have no available water supply that meets the arsenic standard.

Coagulation/filtration (also known as flocculation) removes arsenic by coprecipitation and adsorption using iron coagulants. Coagulation/filtration using alum is already used by some utilities to remove suspended solids and may be adjusted to remove arsenic. But the problem of this type of filtration system is that it gets clogged very easily, mostly within two to three months. The toxic arsenic sludge are disposed of by concrete stabilization, but there is no guarantee that they won't leach out in future.

Iron oxide adsorption filters the water through a granular medium containing ferric oxide. Ferric oxide has a high affinity for adsorbing dissolved metals such as arsenic. The iron oxide medium eventually becomes saturated, and must be replaced. The sludge disposal is a problem here too.

Activated alumina is an adsorbent that effectively removes arsenic. Activated alumina columns connected to shallow tube wells in India and Bangladesh have successfully removed both As(III) and As(V) from groundwater for decades. Long-term column performance has been possible through the efforts of community-elected water committees that collect a local water tax for funding operations and maintenance. It has also been used to remove undesirably high concentrations of fluoride.

Ion Exchange has long been used as a water-softening process, although usually on a single-home basis. Traditional anion exchange is effective in removing As(V), but not As (III), or arsenic trioxide, which doesn't have a net charge. Effective long-term ion exchange removal of arsenic requires a trained operator to maintain the column.

Both **Reverse osmosis** and **electrodialysis** (also called *electrodialysis reversal*) can remove arsenic with a net ionic charge. (Note that arsenic oxide, As_2O_3, is a common form of arsenic in groundwater that is soluble, but has no net charge.) Some utilities presently use one of these methods to reduce total dissolved solids and therefore improve taste. A problem with both methods is the production of high-salinity waste water, called brine, or concentrate, which then must be disposed of.

Subterranean Arsenic Removal (SAR) Technology

In subterranean arsenic removal (SAR), aerated groundwater is recharged back into the aquifer to create an oxidation zone which can trap iron and arsenic on the soil particles through adsorption process. The oxidation zone created by aerated water boosts the activity of the arsenic-oxidizing microorganisms which can oxidize arsenic from +3 to +5 state SAR Technology.

No chemicals are used and almost no sludge is produced during operational stage since iron and arsenic compounds are rendered inactive in the aquifer itself. Thus toxic waste disposal and the risk of its future mobilization is prevented. Also, it has very long operational life, similar to the long lasting tube wells drawing water from the shallow aquifers.

Six such SAR plants, funded by the World Bank and constructed by Ramakrishna Vivekananda Mission, Barrackpore & Queen's University Belfast, UK are operating in West Bengal. Each plant has been delivering more than 3,000 liters of arsenic and iron-free water daily to the rural community. The first community water treatment plant based on SAR technology was set up at Kashimpore near Kolkata in 2004 by a team of European and Indian engineers led by Dr. Bhaskar Sen Gupta of Queen's University Belfast for TiPOT.

SAR technology had been awarded Dhirubhai Ambani Award, 2010 from IChemE UK for Chemical Innovation. Again, SAR was the winner of the St. Andrews Award for Environment, 2010. The SAR Project was selected by the Blacksmith Institute - New York & Green Cross- Switzerland as one of the "12 Cases of Cleanup & Success" in the World's Worst Polluted Places Report 2009.

The Hungarian Solution

Hungarian engineer László Schremmer has recently discovered that by the use of chaff-based filters it is possible to reduce the arsenic content of water to 3 microgram/liter. This is especially important in areas where the potable water is provided by filtering the water extracted from the underground aquifer.

Arsenic Can Build Up on and Release in Pipes and Storage Tanks

Water systems may also find deposits of arsenic-rich particles in their storage tanks or at locations in their distribution system with low flows. If the flow is increased or a storage tank is drawn down to a low level, these arsenic-rich particles can get stirred up and transported to consumers' taps.

This situation occurs primarily when iron media used in treatment are released into the distribution system, or when iron particles are not properly filtered out during iron removal treatment. If these treatment technologies are operated correctly, this should not be a problem for most water systems.

Public water systems with arsenic in their raw water may find that scales on pipes and other components in their distribution systems contain relatively high arsenic concentrations. These arsenic-rich scales can become dislodged and suspended in the water, and may be ultimately delivered to consumers.

Arsenic has been shown to attach to iron in distribution system pipes. Because iron is so effective at binding with arsenic, corrosion deposits can have high concentrations of arsenic solids. In a recent study, arsenic levels found in solids that were collected after pipe sections and hydrants were flushed were as high as 13.65 milligrams of arsenic per gram of solid.

Asbestos - Inorganic Contaminant 7 MFL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for asbestos is 7 MFL. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for asbestos, called a maximum contaminant level (MCL), at 7 MFL. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for asbestos, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed asbestos as part of the Six Year Review and determined that the 7 MFL MCLG and 7 MFL MCL for asbestos are still protective of human health.

How does Asbestos get into my Drinking Water?

The major sources of asbestos in drinking water are decay of asbestos cement water mains; and erosion of natural deposits.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Asbestos is in my Drinking Water?

When routine monitoring indicates that asbestos levels are above the MCL, your water supplier must take steps to reduce the amount of asbestos so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

How will Asbestos be removed from my Drinking Water?

The following treatment method(s) have proven to be effective for removing asbestos to below 7 MFL: coagulation/filtration, direct and diatomite filtration, and corrosion control.

Asbestos Cement Pipe (ACP)

Common water distribution pipe, notice that both pipes have been cut with a power saw. You are not allowed to cut this type of pipe with a power saw, because it will spread the Asbestos.

Wetting agents may be applied with garden sprayers or hoses. Garden sprayers are hand-held, portable, and have a one- to five-gallon capacity. Water hoses are usually attached to a faucet tap, fire hydrant or water tank. Generally, the hose has a nozzle attached which spreads the water stream so that a fine mist is created.

Asbestos-Cement Products

Asbestos-cement products (such as transite) are commonly used for duct insulation, pipes, and siding. Being a Category II nonfriable ACM, asbestos-cement products need to be removed prior to demolition if they have a high probability of becoming crumbled, pulverized, or reduced to powder during demolition activities. EPA believes that most demolition activities will subject such Category II nonfriable ACM to the regulation.

Asbestos is an Excellent …

Heat Stability

Asbestos will maintain its structural integrity at temperatures well above 800 F. The melting point is at about 2800 F

Thermal Insulation

The fibers have a relatively large surface area, along with numerous pores, and cracks. This allows for a low heat transfer. This makes it useful as an insulator in homes and machinery. The large surface area also absorbs water making it practical as pipe insulator to prevent sweating.

Chemical Resistance

The amphiboles are resistant to aqueous media and chemical attack. They also show high resistance to acids. This makes this class of asbestos useful for battery packing. Chrysotile is significantly less resistant to chemical destruction.

Sound Absorption
Asbestos have a large internal volume, large surface area, and the fibers are flexible. This makes it ideal for the absorption of sound energy. It is often uses to help acoustics.

Serpent

Asbestos

OSHA requires that employees who may be exposed to dangerous levels of asbestos must be made aware of the hazards and how to protect themselves. Employees must be told where in their workplace they can find copies of all applicable asbestos standards. Employers must provide any employee with the opportunity to review the regulations if they so desire. It is an employee's right to have access to the regulations.

What Is Asbestos?
Asbestos is the name given to a number of naturally occurring fibrous silicate minerals that have been mined for their useful properties such as thermal insulation, chemical and thermal stability, and high tensile strength. The three most common types of asbestos are: a) chrysotile, b) amosite and c) crocidolite. Chrysotile, also known as white asbestos and a member of the Serpentine mineral group is the commonest. Asbestos can only be identified under a microscope. Asbestos differs from other minerals in its crystal development. The crystal formation of asbestos is in the form of long thin fibers. Asbestos is divided into two mineral groups

Serpentine and **Amphibole**. The division between the two types of asbestos is based upon the crystalline structure.

Serpentines have a sheet or layered structure where amphiboles have a chain-like structure. As the only member of the serpentine group, Chrysotile (A, B) is the most common type of asbestos found in buildings. Chrysotile makes up approximately 90%-95% of all asbestos contained in buildings in the United States.

Unlike most minerals, which turn into dust particles when crushed, asbestos breaks up into fine fibers that are too small to be seen by the human eye. Often, individual fibers are mixed with a material that binds them together, producing asbestos-containing material (**ACM**).

Health Effects of Asbestos Exposure

Asbestos is the largest single cause of fatal disease and ill-health caused by work in Great Britain. Although almost all the deaths and ill health related to asbestos today are due to exposures that happened several decades ago, if you work with asbestos, or come into contact with it as a result of repair and maintenance work, you need to be particularly careful. Asbestos can be found in most buildings built between 1950 and 1980, as insulation and lagging. It is still used in some brake pads and clutch linings and can be met in vehicle servicing and repair.

Asbestos-Related Health Problems

Some people exposed to asbestos develop asbestos-related health problems; some do not. Once inhaled, asbestos fibers can easily penetrate body tissues. They may be deposited and retained in the airways and lung tissue. Because asbestos fibers remain in the body, each exposure increases the likelihood of developing an asbestos-related disease.

Asbestos-related diseases may not appear until years after exposure. A medical examination that includes a medical history, breathing capacity test, and chest X ray may detect problems early.

Many substances have a "**safe dose**" or an exposure that is unlikely to cause any harm. Above the safe dose, a health effect is expected. This concept is known as a dose response. As the dose increases, so does the expected severity of the health effect.

However, in the case of asbestos, scientists have not determined a "**safe dose**" or threshold level for exposure to airborne asbestos. Still, the less exposure a person receives over a lifetime, the less likely it is that that person will develop an asbestos-related health problem.

In addition to breathing it, ingesting asbestos may also be harmful to you, but the consequences of this type of exposure have not been clearly documented. People who touch asbestos may get a rash similar to the rash caused by fiberglass. While the effects of skin exposure to asbestos have not been scientifically documented, it is best to minimize all contact with asbestos.

Asbestos was used in approximately 3,000 products. Two-thirds of this total (2,000) was used in construction products. Appendix A includes a short list of products where asbestos may be found.

Common Asbestos Questions

IS ASBESTOS CURRENTLY USED IN ANY NEW PRODUCTS?
Probably not. As you can imagine there has been tremendous liability for any company that manufactured asbestos-containing materials. Manufacturers have found substitutes for asbestos, thus it is not likely that you would encounter new products that contain asbestos. Manufacturers started to phase out the use of asbestos in products during the mid-1970s to early-1980s.

WHAT IS A CARCINOGEN? IS ASBESTOS A CARCINOGEN?
A carcinogen is a substance capable of causing cancer. Asbestos is a recognized carcinogen. If fact, asbestos is one of a few substances recognized as being a "***true***" human carcinogen.

HOW ABOUT DOSE-RESPONSE? WHAT DOES THIS MEAN AND HOW IMPORTANT IS IT?
Understanding the concept of dose-response is extremely important in the role of environmental contaminants. The term "**dose**" applies to a person's exposure to a substance. Dose is a measure of how much of a substance a person's body absorbs. In this case, the number of fibers that are in the air, and how much time is spent breathing these fibers. The term "**response**" refers to a health outcome from the dose and generally refers to disease.

Many people are under the false impression that any exposure to an environmental contaminant can cause harm and should be avoided.

However, it is impossible to live in a world without contaminants. We are exposed to pollutant, allergens, contaminants and toxic materials every day in our lives in the water we drink, the food we eat and the substances we encounter. Generally these contaminants are found in extremely small quantities and do not pose a threat to our health. Even when we are exposed to higher levels there are mechanisms in the body for detoxification of the contaminants.

It is only when we are exposed to high concentrations (**dose**) for long periods of time that health problems (**response**) become likely. The terms "**high**" and "**long**" vary for each particular substance in the environmental. If exposure can't be avoided, an employees' exposure to asbestos should be for a short duration and at very low levels. This will lower their risk of disease. Even a single exposure to high levels of asbestos most likely would not be a problem.

HOW CAN ASBESTOS HURT ME?
Unless the asbestos is disturbed, it does not present a hazard. Generally it is necessary to inhale the asbestos fibers for a prolonged period of time before any damaged occurs.

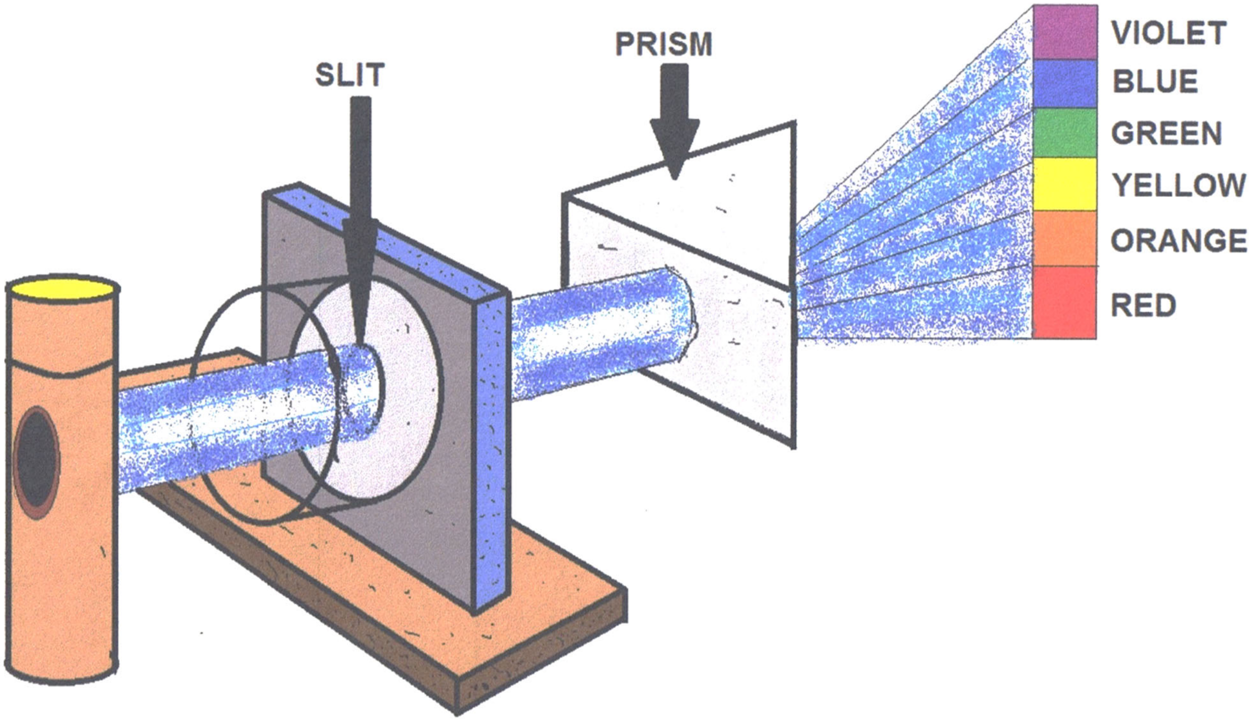
WHAT CAN I DO TO PROTECT MYSELF AGAINST ASBESTOS?
First and foremost it is important to recognize asbestos or the many products that may contain asbestos. Asbestos was often used for insulation purposes. It generally appears as small fibers that break lengthwise and generally not in half. If you encounter asbestos, or a material that you think contains asbestos, contact your supervisor.

At the present time no UT employees are trained to remove or handle asbestos. Since asbestos is primarily a hazard to the lungs, avoid breathing it. If it is impossible to avoid, or if you feel safer, a respirator equipped with HEPA filters is acceptable. Another method of controlling exposure is to use good dust control procedures. Water is frequently used to control dust.

ARE THERE ANY ACUTE SYMPTOMS OF ASBESTOS EXPOSURE?
Generally there are no short-term (**acute**) symptoms of asbestos exposure, until the exposure level is extremely high. Inhalation of extremely high levels of asbestos can result in shortness of breath, chest or abdominal pain and irritation of the skin and mucous membranes.

HOW IS ASBESTOS MEASURED IN THE AIR?
The number of asbestos fibers in the air can be measured by a process known as air sampling or, as it is sometimes called, air monitoring. Basically it is simple. Air is drawn through a small filter where the fibers are trapped. The volume of air sampled is calculated based on the flow rate of the pump and the how long the pump operates. After the sample is collected the filter is sent to a laboratory where the number of fibers are counted.

Note that only fibers are counted. There are other airborne fibers, similar to asbestos that can cause the sample to be artificially high. The laboratory reports the results as the number of fibers per volume of air. Generally the volume of air is expressed as cubic centimeters or cc. Thus, the results are expressed at fibers/cc. There are other lab procedures that can more precisely determine which fibers are asbestos.



Spectroscopy
The emission spectrum of a chemical element or chemical compound is the spectrum of frequencies of electromagnetic radiation emitted due to an atom's electrons making a transition from a high energy state to a lower energy state. The energy of the emitted photon is equal to the energy difference between the two states. There are many possible electron transitions for each atom, and each transition has a specific energy difference. This collection of different transitions, leading to different radiated wavelengths, make up an emission spectrum. Each element's emission spectrum is unique. Therefore, spectroscopy can be used to identify the elements in matter of unknown composition. Similarly, the emission spectra of molecules can be used in chemical analysis of substances.

Barium - Inorganic Contaminant 2 mg/L MCL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for barium is 2 mg/L or 2 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for barium, called a maximum contaminant level (MCL), at 2 mg/L or 2 ppm. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase IIB Rule, the regulation for barium, became effective in 1993. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed barium as part of the Six Year Review and determined that the 2 mg/L or 2 ppm MCLG and 2 mg/L or 2 ppm MCL for barium are still protective of human health.

The major sources of barium in drinking water are discharge of drilling wastes; discharge from metal refineries; and erosion of natural deposits.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

When routine monitoring indicates that barium levels are above the MCL, your water supplier must take steps to reduce the amount of barium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

How will barium be removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing barium to below 2 mg/L or 2 ppm: ion exchange, reverse osmosis, lime softening, and electrodialysis.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Barium Explained

Barium is a chemical element with symbol **Ba** and atomic number 56. It is the fifth element in Group 2, a soft silvery metallic alkaline earth metal. Because of its high chemical reactivity barium is never found in nature as a free element. Its hydroxide was known in pre-modern history as baryta; this substance does not occur as a mineral, but can be prepared by heating barium carbonate.

The most common naturally occurring minerals of barium are barite (barium sulfate, $BaSO_4$) and witherite (barium carbonate, $BaCO_3$), both being insoluble in water. Barium's name originates from the alchemical derivative "baryta", which itself comes from Greek βαρύς (*barys*), meaning "heavy." Barium was identified as a new element in 1774, but not reduced to a metal until 1808, shortly after electrolytic isolation techniques became available.

Barium has only a few industrial applications. The metal has been historically used to scavenge air in vacuum tubes. It is a component of YBCO (high-temperature superconductors) and electroceramics, and is added to steel and cast iron to reduce the size of carbon grains within the microstructure of the metal. Barium compounds are added to fireworks to impart a green color. For instance, barium sulfate is used as an insoluble heavy additive to oil well drilling fluid, and in purer form, as X-ray radiocontrast agents for imaging the human gastrointestinal tract. Soluble barium compounds are poisonous due to release of the soluble barium ion, and therefore have been used as rodenticides.

Physical Properties

Barium is a soft, silvery-white metal, with a slight golden shade when ultrapure. The silvery-white color of barium metal rapidly vanishes upon oxidation in air yielding a dark gray oxide layer. Barium has a medium specific weight and good electrical conductivity. Ultrapure barium is very hard to prepare, and therefore many properties of barium have not been accurately measured yet.

At room temperature and pressure, barium has a body-centered cubic structure, with a barium–barium distance of 503 picometers, expanding with heating at a rate of approximately 1.8×10^{-5}/°C. It is a very soft metal with a Mohs hardness of 1.25. Its melting temperature of 1000 K (727 °C, 1341 °F) is intermediate between those of the lighter strontium (1050 K) and heavier radium (973 K); however, its boiling point of 2170 K (1897 °C, 3447 °F) exceeds that of strontium (1655 K). The density ($3.62\ g\cdot cm^{-3}$) is again intermediate between those of strontium ($2.36\ g\cdot cm^{-3}$) and radium ($\sim 5\ g\cdot cm^{-3}$).

Chemical Reactivity

Barium is chemically similar to magnesium, calcium, and strontium, being even more reactive. It always exhibits the oxidation state of +2. Reactions with chalcogens are highly exothermic (release energy); the reaction with oxygen or air occurs at room temperature, and therefore barium is stored under oil or inert gas atmosphere. Reactions with other nonmetals, such as carbon, nitrogen, phosphorus, silicon, and hydrogen, are generally exothermic and proceed upon heating. Reactions with water and alcohols are also very exothermic and release hydrogen gas:

$$Ba + 2\ ROH \rightarrow Ba(OR)_2 + H_2\uparrow$$ (R is an alkyl or a hydrogen atom)

Additionally, barium reacts with ammonia to form complexes such as $Ba(NH_3)_6$.

The metal is readily attacked by most acids. Sulfuric acid is a notable exception, as passivation stops the reaction by forming the insoluble barium sulfate. Barium combines with several metals, including aluminum, zinc, lead, and tin, forming intermetallic phases and alloys.

Compounds

Selected alkaline earth and zinc salts densities, g·cm^{-3}

	O^{2-}	S^{2-}	F^{-}	Cl^{-}	SO2− 4	CO2− 3	O2− 2	H^{-}
Ca^{2+}[9]	3.34	2.59	3.18	2.15	2.96	2.83	2.9	1.7
Sr^{2+}[10]	5.1	3.7	4.24	3.05	3.96	3.5	4.78	3.26
Ba^{2+}[11]	*5.72*	*4.3*	*2.1*	*1.9*	*4.49*	*4.29*	*4.96*	*4.16*
Zn^{2+}[12]	5.6	4.09	4.9	2.09	3.8	4.4	1.57	—

Barium salts are typically white when solid and colorless when dissolved, as barium ions provide no specific coloring. They are also denser than their strontium or calcium analogs, except for the halides.

Barium hydroxide ("baryta") was known to alchemists who produced it by heating barium carbonate. Unlike calcium hydroxide, it absorbs very little CO_2 in aqueous solutions and is therefore insensitive to atmospheric fluctuations. This property is used in calibrating pH equipment.

Volatile barium compounds burn with a green to pale green flame, which is an efficient test to detect a barium compound. The color results from spectral lines at 455.4, 493.4, 553.6, and 611.1 nm.

Organobarium compounds are a growing class of compounds: for example, dialkylbariums are known, as are alkylhalobariums.

Isotopes of Barium

Barium occurs naturally on Earth as a mixture of seven primordial nuclides, barium-130, 132, and 134 through 138. The first two are thought to be radioactive: barium-130 should decay to xenon-130 via double beta plus decay, and barium-132 should similarly decay to xenon-132. The corresponding half-lives should exceed the age of the Universe by at least thousand times. Their abundances are ~0.1% relative to that of natural barium. Their radioactivity is so weak that they pose no danger to life.

Out of the stable isotopes, barium-138 makes up 71.7% of all barium, and the lighter the isotope, the less it is abundant. In total, barium has about 50 known isotopes, ranging in mass between 114 and 153. The most stable metastable isotope is barium-133, which has a half-life of approximately 10.51 years, and five more isotopes have their half-lives longer than a day. Barium also has 10 meta states, out of which barium-133m1 is the most stable, having a half-live of about 39 hours.

Biological Dangers and Precautions

Because of the high reactivity of the metal toxicological data are available only for compounds. Water-soluble barium compounds are poisonous. At low doses, barium ions act as a muscle stimulant, whereas higher doses affect the nervous system, causing cardiac irregularities, tremors, weakness, anxiety, dyspnea and paralysis. This may be due to the ability of Ba^{2+} to block potassium ion channels, which are critical to the proper function of the nervous system.

Other target organs for water-soluble barium compounds (i.e., barium ions) are eyes, immune system, heart, respiratory system, and skin. They affect the body strongly, causing, for example, blindness and sensitization.

Barium is not carcinogenic, and it does not bioaccumulate. However, inhaled dust containing insoluble barium compounds can accumulate in the lungs, causing a benign condition called baritosis. For comparison to the soluble poisons, the insoluble sulfate is nontoxic and is thus not classified as a dangerous good.

To avoid a potentially vigorous chemical reaction, barium metal is kept under argon or mineral oils. Contact with air is dangerous, as it may cause ignition. Moisture, friction, heat, sparks, flames, shocks, static electricity, reactions with oxidizers and acids should be avoided. Everything that may make contact with barium should be grounded. Those who work with the metal should wear pre-cleaned non-sparking shoes, flame-resistant rubber clothes, rubber gloves, apron, goggles, and a gas mask; they are not allowed to smoke in the working area and must wash themselves after handling barium.

Beryllium - Inorganic Contaminant 0.004 mg/L MCL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for beryllium is 0.004 mg/L or 4 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for beryllium, called a maximum contaminant level (MCL), at 0.004 mg/L or 4 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase V Rule, the regulation for beryllium, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed beryllium as part of the Six Year Review and determined that the 0.004 mg/L or 4 ppb MCLG and 0.004 mg/L or 4 ppb MCL for beryllium are still protective of human health.

How does Beryllium get into my Drinking Water?
Beryllium naturally enters surface water and ground water through the weathering of rocks and soils or from industrial wastewater discharges. The major source of environmental releases from human activities are coal and fuel oil combustion.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Beryllium is in my Drinking Water?
When routine monitoring indicates that beryllium levels are above the MCL, your water supplier must take steps to reduce the amount of beryllium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

Beryllium Explained

Beryllium is the chemical element with the symbol **Be** and atomic number 4. Because any beryllium synthesized in stars is short-lived, it is a relatively rare element in both the universe and in the crust of the Earth. It is a divalent element which occurs naturally only in combination with other elements in minerals. Notable gemstones which contain beryllium include beryl (aquamarine, emerald) and chrysoberyl. As a free element it is a steel-gray, strong, lightweight and brittle alkaline earth metal.

Beryllium increases hardness and resistance to corrosion when alloyed to aluminum, cobalt, copper (notably beryllium copper), iron and nickel. In structural applications, high flexural rigidity, thermal stability, thermal conductivity and low density (1.85 times that of water) make beryllium a quality aerospace material for high-speed aircraft, missiles, space vehicles and communication satellites. Because of its low density and atomic mass, beryllium is relatively transparent to X-rays and other forms of ionizing radiation; therefore, it is the most common window material for X-ray equipment and in particle physics experiments. The high thermal conductivities of beryllium and beryllium oxide have led to their use in heat transport and heat sinking applications.

The commercial use of beryllium metal presents technical challenges due to the toxicity (especially by inhalation) of beryllium-containing dusts. Beryllium is corrosive to tissue, and can cause a chronic life-threatening allergic disease called berylliosis in some people. The element is not known to be necessary or useful for either plant or animal life

Characteristics

Physical Properties

Beryllium is a steel gray and hard metal that is brittle at room temperature and has a close-packed hexagonal crystal structure. It has exceptional flexural rigidity (Young's modulus 287 GPa) and a reasonably high melting point. The modulus of elasticity of beryllium is approximately 50% greater than that of steel. The combination of this modulus and a relatively low density results in an unusually fast sound conduction speed in beryllium – about 12.9 km/s at ambient conditions.

Other significant properties are high specific heat (1925 $J \cdot kg^{-1} \cdot K^{-1}$) and thermal conductivity (216 $W \cdot m^{-1} \cdot K^{-1}$), which make beryllium the metal with the best heat dissipation characteristics per unit weight. In combination with the relatively low coefficient of linear thermal expansion ($11.4 \times 10^{-6}\ K^{-1}$), these characteristics result in a unique stability under conditions of thermal loading.

Nuclear Properties

Natural beryllium, save for slight contamination by cosmogenic radioisotopes, is essentially beryllium-9, which has a nuclear spin of 3/2-. Beryllium has a large scattering cross section for high-energy neutrons, about 6 barns for energies above ~0.01 MeV. Therefore, it works as a neutron reflector and neutron moderator, effectively slowing the neutrons to the thermal energy range of below 0.03 eV, where the total cross section is at least an order of magnitude lower – exact value strongly depends on the purity and size of the crystallites in the material.

The single primordial beryllium isotope ^{9}Be also undergoes a (n,2n) neutron reaction with neutron energies over about 1.9 MeV, to produce ^{8}Be, which almost immediately breaks into two alpha particles. Thus, for high-energy neutrons beryllium is a neutron multiplier, releasing more neutrons than it absorbs.

This nuclear reaction is:

9
4Be + n → 2(4
2He) + 2n
Neutrons are liberated when beryllium nuclei are struck by energetic alpha particles producing the nuclear reaction

9
4Be + 4
2He → 12
6C + n , where 4
2He is an alpha particle and 12
6C is a carbon-12 nucleus.

Beryllium also releases neutrons under bombardment by gamma rays. Thus, natural beryllium bombarded either by alphas or gammas from a suitable radioisotope is a key component of most radioisotope-powered nuclear reaction neutron sources for the laboratory production of free neutrons.

As a metal, beryllium is transparent to most wavelengths of X-rays and gamma rays, making it useful for the output windows of X-ray tubes and other such apparatus.

Isotopes and Nucleosynthesis
Both stable and unstable isotopes of beryllium are created in stars, but these do not last long. It is believed that most of the stable beryllium in the universe was originally created in the interstellar medium when cosmic rays induced fission in heavier elements found in interstellar gas and dust. Primordial beryllium contains only one stable isotope, ^{9}Be, and therefore beryllium is a monoisotopic element.

Plot showing variations in solar activity, including variation in ^{10}Be concentration. Note that the beryllium scale is inverted, so increases on this scale indicate lower ^{10}Be levels

Radioactive cosmogenic ^{10}Be is produced in the atmosphere of the Earth by the cosmic ray spallation of oxygen. ^{10}Be accumulates at the soil surface, where its relatively long half-life (1.36 million years) permits a long residence time before decaying to boron-10. Thus, ^{10}Be and its daughter products are used to examine natural soil erosion, soil formation and the development of lateritic soils, and as a proxy for measurement of the variations in solar activity and the age of ice cores. The production of ^{10}Be is inversely proportional to solar activity, because increased solar wind during periods of high solar activity decreases the flux of galactic cosmic rays that reach the Earth. Nuclear explosions also form ^{10}Be by the reaction of fast neutrons with ^{13}C in the carbon dioxide in air. This is one of the indicators of past activity at nuclear weapon test sites. The isotope ^{7}Be (half-life 53 days) is also cosmogenic, and shows an atmospheric abundance linked to sunspots, much like ^{10}Be.

^{8}Be has a very short half-life of about 7×10^{-17} s that contributes to its significant cosmological role, as elements heavier than beryllium could not have been produced by nuclear fusion in the Big Bang. This is due to the lack of sufficient time during the Big Bang's nucleosynthesis phase to produce carbon by the fusion of ^{4}He nuclei and the very low concentrations of available beryllium-8.

The British astronomer Sir Fred Hoyle first showed that the energy levels of ^{8}Be and ^{12}C allow carbon production by the so-called triple-alpha process in helium-fueled stars where more nucleosynthesis time is available. This process allows carbon to be produced in stars, but not in the Big Bang. Star-created carbon (the basis of carbon-based life) is thus a component in the elements in the gas and dust ejected by AGB stars and supernovae (see also Big Bang nucleosynthesis), as well as the creation of all other elements with atomic numbers larger than that of carbon.

The innermost electrons of beryllium may contribute to chemical bonding. Therefore, when ^{7}Be decays by electron capture, it does so by taking electrons from atomic orbitals that may participate in bonding. This makes its decay rate dependent to a measurable degree upon its electron configuration – a rare occurrence in nuclear decay.

The shortest-lived known isotope of beryllium is ^{13}Be which decays through neutron emission. It has a half-life of 2.7×10^{-21} s. ^{6}Be is also very short-lived with a half-life of 5.0×10^{-21} s. The exotic isotopes ^{11}Be and ^{14}Be are known to exhibit a nuclear halo. This phenomenon can be understood as the nuclei of ^{11}Be and ^{14}Be have, respectively, 1 and 4 neutrons orbiting substantially outside the classical Fermi 'water drop' model of the nucleus.

Occurrence

Beryllium has a concentration of 2 to 6 parts per million (ppm) in the Earth's crust. The Sun has a concentration of 0.1 parts per billion (ppb) of beryllium, similar to that of rhenium. It is most concentrated in the soils, 6 ppm, and is found in 0.2 parts per trillion (ppt) of sea water. Trace amounts of ^{9}Be are found in the Earth's atmosphere. In sea water, beryllium is exceedingly rare, more so than even scandium, comprising only 0.0006 ppb by weight. In stream water, however, beryllium is more abundant with 0.1 ppb by weight.

Beryllium is found in over 100 minerals, but most are uncommon to rare. The more common beryllium containing minerals include: bertrandite ($Be_4Si_2O_7(OH)_2$), beryl ($Al_2Be_3Si_6O_{18}$), chrysoberyl (Al_2BeO_4) and phenakite (Be_2SiO_4). Precious forms of beryl are aquamarine, bixbite and emerald. The green color in gem-quality forms of beryl comes from varying amounts of chromium (about 2% for emerald).

The two main ores of beryllium, beryl and bertrandite, are found in Argentina, Brazil, India, Madagascar, Russia and the United States. Total world reserves of beryllium ore are greater than 400,000 tons.

Production

The extraction of beryllium from its compounds is a difficult process due to its high affinity for oxygen at elevated temperatures, and its ability to reduce water when its oxide film is removed. The United States, China and Kazakhstan are the only three countries involved in the industrial scale extraction of beryllium.

Beryllium is most-commonly extracted from beryl, which is either sintered using an extraction agent or melted into a soluble mixture. The sintering process involves mixing beryl with sodium fluorosilicate and soda at 770°C to form sodium fluoroberyllate, aluminum oxide and silicon dioxide. Beryllium hydroxide is precipitated from a solution of sodium fluoroberyllate and sodium hydroxide in water. Extraction of beryllium using the melt method involves grinding beryl into a powder and heating it to 1650°C. The melt is quickly cooled with water and then reheated 250 to 300°C in concentrated sulfuric acid, mostly yielding beryllium sulfate and aluminum sulfate.

Aqueous ammonia is then used to remove the aluminum and sulfur, leaving beryllium hydroxide.

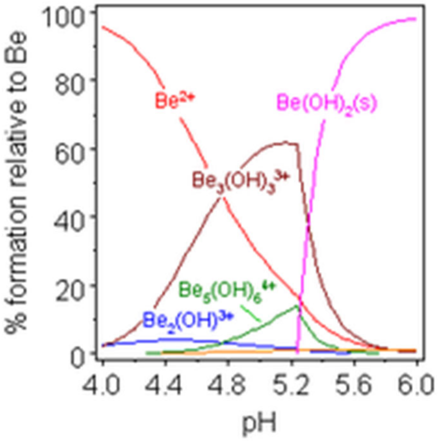
Beryllium hydroxide created using either the sinter or melt method is then converted into beryllium fluoride or beryllium chloride. To form the fluoride, aqueous ammonium hydrogen fluoride is added to beryllium hydroxide to yield a precipitate of ammonium tetrafluoroberyllate, which is heated to 1000°C to form beryllium fluoride.

Heating the fluoride to 900°C with magnesium forms finely divided beryllium and additional heating to 1300°C creates the compact metal. Heating beryllium hydroxide forms the oxide which becomes beryllium chloride when mixed with carbon and chloride. Electrolysis of molten beryllium chloride is then used to obtain the metal.

Chemical Properties

Beryllium's chemical behavior is largely a result of its small atomic and ionic radii. It thus has very high ionization potentials and strong polarization while bonded to other atoms, which is why all of its compounds are covalent. It is more chemically similar to aluminum than its close neighbors in the periodic table due to having a similar charge-to-radius ratio. An oxide layer forms around beryllium that prevents further reactions with air unless heated above 1000°C.

Once ignited, beryllium burns brilliantly forming a mixture of beryllium oxide and beryllium nitride. Beryllium dissolves readily in non-oxidizing acids, such as HCl and diluted H_2SO_4, but not in nitric acid or water as this forms the oxide. This behavior is similar to that of aluminum metal. Beryllium also dissolves in alkali solutions.



Beryllium hydrolysis as a function of pH
Water molecules attached to Be are omitted

The beryllium atom has the electronic configuration [He] $2s^2$. The two valence electrons give beryllium a +2 oxidation state and the thus the ability to form two covalent bonds; the only evidence of lower valence of beryllium is in the solubility of the metal in $BeCl_2$.

Due to the octet rule, atoms tend to seek a valence of 8 in order to resemble a noble gas. Beryllium tries to achieve a coordination number of 4 because its two covalent bonds fill half of this octet. A coordination of 4 allows beryllium compounds, such as the fluoride or chloride, to form polymers.

This characteristic is employed in analytical techniques using EDTA as a ligand. EDTA preferentially forms octahedral complexes – thus absorbing other cations such as Al^{3+} which might interfere – for example, in the solvent extraction of a complex formed between Be^{2+} and acetylacetone. Beryllium(II) readily forms complexes with strong donating ligands such as phosphine oxides and arsine oxides. There have been extensive studies of these complexes which show the stability of the O-Be bond.

Solutions of beryllium salts, e.g. beryllium sulfate and beryllium nitrate, are acidic because of hydrolysis of the $[Be(H_2O)_4]^{2+}$ ion.

$$[Be(H_2O)_4]^{2+} + H_2O \rightleftharpoons [Be(H_2O)_3(OH)]^{+} + H_3O^{+}$$

Other products of hydrolysis include the trimeric ion $[Be_3(OH)_3(H_2O)_6]^{3+}$. Beryllium hydroxide, $Be(OH)_2$, is insoluble even in acidic solutions with pH less than 6, that is at biological pH. It is amphoteric and dissolves in strongly alkaline solutions.

Beryllium forms binary compounds with many non-metals. Anhydrous halides are known for F, Cl, Br and I. BeF_2 has a silica-like structure with corner-shared BeF_4 tetrahedra. $BeCl_2$ and $BeBr_2$ have chain structures with edge-shared tetrahedra. All beryllium halides have a linear monomeric molecular structure in the gas phase.

Beryllium difluoride, BeF_2, is different than the other difluorides. In general, beryllium has a tendency to bond covalently, much more so than the other alkaline earths and its fluoride is partially covalent (although still more ionic than its other halides). BeF_2 has many similarities to SiO_2 (quartz) a mostly covalently bonded network solid. BeF_2 has tetrahedrally coordinated metal and forms glasses (is difficult to crystallize). When crystalline, beryllium fluoride has the same room temperature crystal structure as quartz and shares many higher temperatures structures also. Beryllium difluoride is very soluble in water, unlike the other alkaline earths. (Although they are strongly ionic, they do not dissolve because of the especially strong lattice energy of the fluorite structure.) However, BeF_2 has much lower electrical conductivity when in solution or when molten than would be expected if it were fully ionic.

Beryllium Oxide

Beryllium oxide, BeO, is a white refractory solid, which has the wurtzite crystal structure and a thermal conductivity as high as in some metals. BeO is amphoteric. Salts of beryllium can be produced by treating $Be(OH)_2$ with acid. Beryllium sulfide, selenide and telluride are known, all having the zincblende structure.

Beryllium Nitride

Beryllium nitride, Be_3N_2 is a high-melting-point compound which is readily hydrolyzed. Beryllium azide, BeN_6 is known and beryllium phosphide, Be_3P_2 has a similar structure to Be_3N_2. Basic beryllium nitrate and basic beryllium acetate have similar tetrahedral structures with four beryllium atoms coordinated to a central oxide ion. A number of beryllium borides are known, such as Be_5B, Be_4B, Be_2B, BeB_2, BeB_6 and BeB_{12}. Beryllium carbide, Be_2C, is a refractory brick-red compound that reacts with water to give methane. No beryllium silicide has been identified.

Approximately 35 micrograms of beryllium is found in the human body, but this amount is not considered harmful. Beryllium is chemically similar to magnesium and therefore can displace it from enzymes, which causes them to malfunction.

Chronic berylliosis is a pulmonary and systemic granulomatous disease caused by inhalation of dust or fumes contaminated with beryllium; either large amounts over a short time or small amounts over a long time can lead to this ailment. Symptoms of the disease can take up to 5 years to develop; about a third of patients with it die and the survivors are left disabled. The International Agency for Research on Cancer (IARC) lists beryllium and beryllium compounds as Category 1 carcinogens.

Acute beryllium disease in the form of chemical pneumonitis was first reported in Europe in 1933 and in the United States in 1943. A survey found that about 5% of workers in plants manufacturing fluorescent lamps in 1949 in the United States had beryllium-related lung diseases. Chronic berylliosis resembles sarcoidosis in many respects, and the differential diagnosis is often difficult. It killed some early workers in nuclear weapons design, such as Herbert L. Anderson.

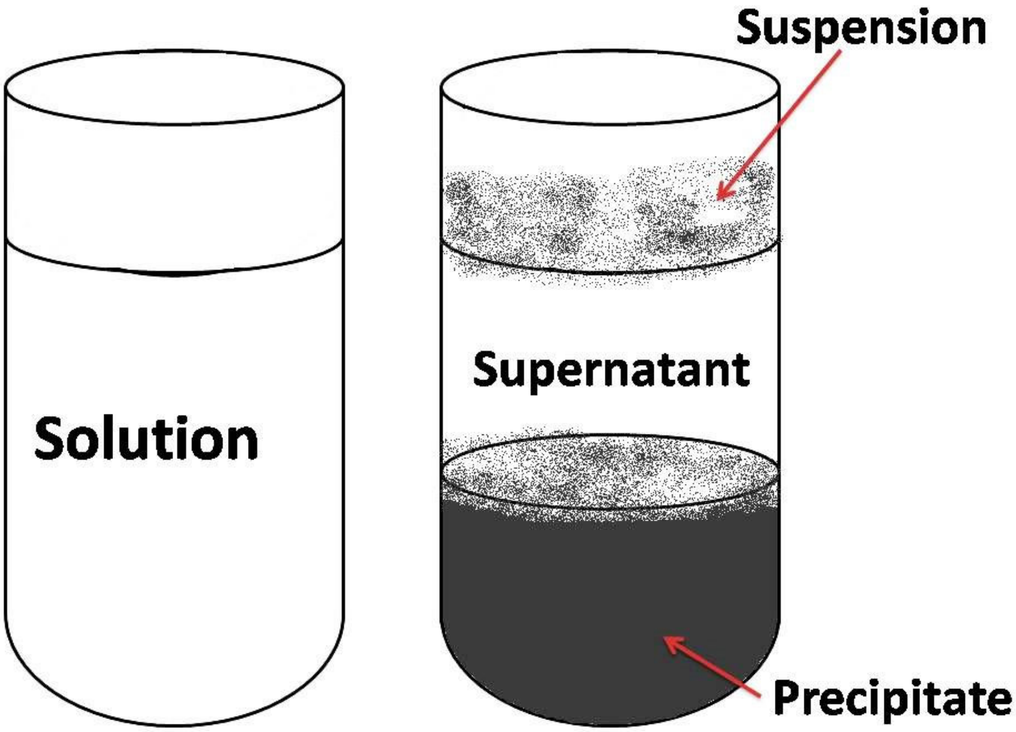
Early researchers tasted beryllium and its various compounds for sweetness in order to verify its presence. Modern diagnostic equipment no longer necessitates this highly risky procedure and no attempt should be made to ingest this highly toxic substance. Beryllium and its compounds should be handled with great care and special precautions must be taken when carrying out any activity which could result in the release of beryllium dust (lung cancer is a possible result of prolonged exposure to beryllium laden dust).

Although the use of beryllium compounds in fluorescent lighting tubes was discontinued in 1949, potential for exposure to beryllium exists in the nuclear and aerospace industries and in the refining of beryllium metal and melting of beryllium-containing alloys, the manufacturing of electronic devices, and the handling of other beryllium-containing material.

A successful test for beryllium in air and on surfaces has been recently developed and published as an international voluntary consensus standard ASTM D7202.

The procedure uses dilute ammonium bifluoride for dissolution and fluorescence detection with beryllium bound to sulfonated hydroxybenzoquinoline, allowing up to 100 times more sensitive detection than the recommended limit for beryllium concentration in the workplace.

Fluorescence increases with increasing beryllium concentration. The new procedure has been successfully tested on a variety of surfaces and is effective for the dissolution and ultratrace detection of refractory beryllium oxide and siliceous beryllium (ASTM D7458).



Precipitation

Precipitation is the formation of a solid in a solution or inside another solid during a chemical reaction or by diffusion in a solid. When the reaction occurs in a liquid, the solid formed is called the precipitate. Without sufficient force of gravity (settling) to bring the solid particles together, the precipitate remains in suspension.

After sedimentation, especially when using a centrifuge to press it into a compact mass, the precipitate may be referred to as a pellet. The precipitate-free liquid remaining above the solid is called the supernate or supernatant. Powders derived from precipitation have also historically been known as flowers.

Precipitation may occur if the concentration of a compound exceeds its solubility (such as when mixing solvents or changing their temperature). Precipitation may occur rapidly from a supersaturated solution.

In solids, precipitation occurs if the concentration of one solid is above the solubility limit in the host solid, due to e.g. rapid quenching or ion implantation, and the temperature is high enough that diffusion can lead to segregation into precipitates. Precipitation in solids is routinely used to synthesize nanoclusters.

An important stage of the precipitation process is the onset of nucleation. The creation of a hypothetical solid particle includes the formation of an interface, which requires some energy based on the relative surface energy of the solid and the solution. If this energy is not available, and no suitable nucleation surface is available, super-saturation occurs.

Cadmium - Inorganic Contaminant 0.005 mg/L MCL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for cadmium is 0.005 mg/L or 5 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for cadmium, called a maximum contaminant level (MCL), at 0.005 mg/L or 5 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for cadmium, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed cadmium as part of the Six Year Review and determined that the 0.005 mg/L or 5 ppb MCLG and 0.005 mg/L or 5 ppb MCL for cadmium are still protective of human health.

How does cadmium get into my drinking water?
The major sources of cadmium in drinking water are corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints. A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if cadmium is in my drinking water?
When routine monitoring indicates that cadmium levels are above the MCL, your water supplier must take steps to reduce the amount of cadmium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will cadmium be removed from my drinking water?
The following treatment method(s) have proven to be effective for removing cadmium to below 0.005 mg/L or 5 ppb: coagulation/filtration, ion exchange, lime softening, and reverse osmosis.

Cadmium Explained

Cadmium is a chemical element with the symbol **Cd** and atomic number 48. This soft, bluish-white metal is chemically similar to the two other stable metals in group 12, zinc and mercury. Like zinc, it prefers oxidation state +2 in most of its compounds and like mercury it shows a low melting point compared to transition metals. Cadmium and its congeners are not always considered transition metals, in that they do not have partly filled d or f electron shells in the elemental or common oxidation states. The average concentration of cadmium in the Earth's crust is between 0.1 and 0.5 parts per million (ppm). It was discovered in 1817 simultaneously by Stromeyer and Hermann, both in Germany, as an impurity in zinc carbonate.

Cadmium occurs as a minor component in most zinc ores and therefore is a byproduct of zinc production. It was used for a long time as a pigment and for corrosion resistant plating on steel while cadmium compounds were used to stabilize plastic. With the exception of its use in nickel–cadmium batteries and cadmium telluride solar panels, the use of cadmium is generally decreasing. These declines have been due to competing technologies, cadmium’s toxicity in certain forms and concentration and resulting regulations. Although cadmium has no known biological function in higher organisms, a cadmium-dependent carbonic anhydrase has been found in marine diatoms.

Characteristics

Physical Properties

Cadmium is a soft, malleable, ductile, bluish-white divalent metal. It is similar in many respects to zinc but forms complex compounds. Unlike other metals, cadmium is resistant to corrosion and as a result it is used as a protective layer when deposited on other metals. As a bulk metal, cadmium is insoluble in water and is not flammable; however, in its powdered form it may burn and release toxic fumes.

Chemical Properties

Although cadmium usually has an oxidation state of +2, it also exists in the +1 state. Cadmium and its congeners are not always considered transition metals, in that they do not have partly filled d or f electron shells in the elemental or common oxidation states.

Cadmium burns in air to form brown amorphous cadmium oxide (CdO); the crystalline form of this compound is a dark red which changes color when heated, similar to zinc oxide. Hydrochloric acid, sulfuric acid and nitric acid dissolve cadmium by forming cadmium chloride ($CdCl_2$), cadmium sulfate ($CdSO_4$), or cadmium nitrate ($Cd(NO_3)_2$). The oxidation state +1 can be reached by dissolving cadmium in a mixture of cadmium chloride and aluminum chloride, forming the Cd_2^{2+} cation, which is similar to the Hg_2^{2+} cation in mercury(I) chloride.

$$\mathbf{Cd + CdCl_2 + 2\ AlCl_3 \rightarrow Cd_2(AlCl_4)_2}$$

Isotopes

Naturally occurring cadmium is composed of 8 isotopes. Two of them are naturally radioactive, and three are expected to decay but have not been experimentally confirmed to do so. The two natural radioactive isotopes are ^{113}Cd (beta decay, half-life is 7.7 × 10^{15} years) and ^{116}Cd (two-neutrino double beta decay, half-life is 2.9 × 10^{19} years). The other three are ^{106}Cd, ^{108}Cd (both double electron capture), and ^{114}Cd (double beta decay); only lower limits on their half-life times have been set. At least three isotopes – ^{110}Cd, ^{111}Cd, and ^{112}Cd – are stable.

Among the isotopes that do not occur naturally, the most long-lived are ^{109}Cd with a half-life of 462.6 days, and ^{115}Cd with a half-life of 53.46 hours. All of the remaining radioactive isotopes have half-lives that are less than 2.5 hours, and the majority of these have half-lives that are less than 5 minutes. Cadmium has 8 known meta states, with the most stable being ^{113m}Cd ($t_{½}$ = 14.1 years), ^{115m}Cd ($t_{½}$ = 44.6 days), and ^{117m}Cd ($t_{½}$ = 3.36 hours).

The known isotopes of cadmium range in atomic mass from 94.950 u (^{95}Cd) to 131.946 u (^{132}Cd). For isotopes lighter than 112 u, the primary decay mode is electron capture and the dominant decay product is element 47 (silver). Heavier isotopes decay mostly through beta emission producing element 49 (indium).

One isotope of cadmium, ^{113}Cd, absorbs neutrons with very high probability if they have an energy below the *cadmium cut-off* and transmits them otherwise. The cadmium cut-off is about 0.5 eV. Neutrons with energy below the cut-off are deemed slow neutrons, distinguishing them from intermediate and fast neutrons.

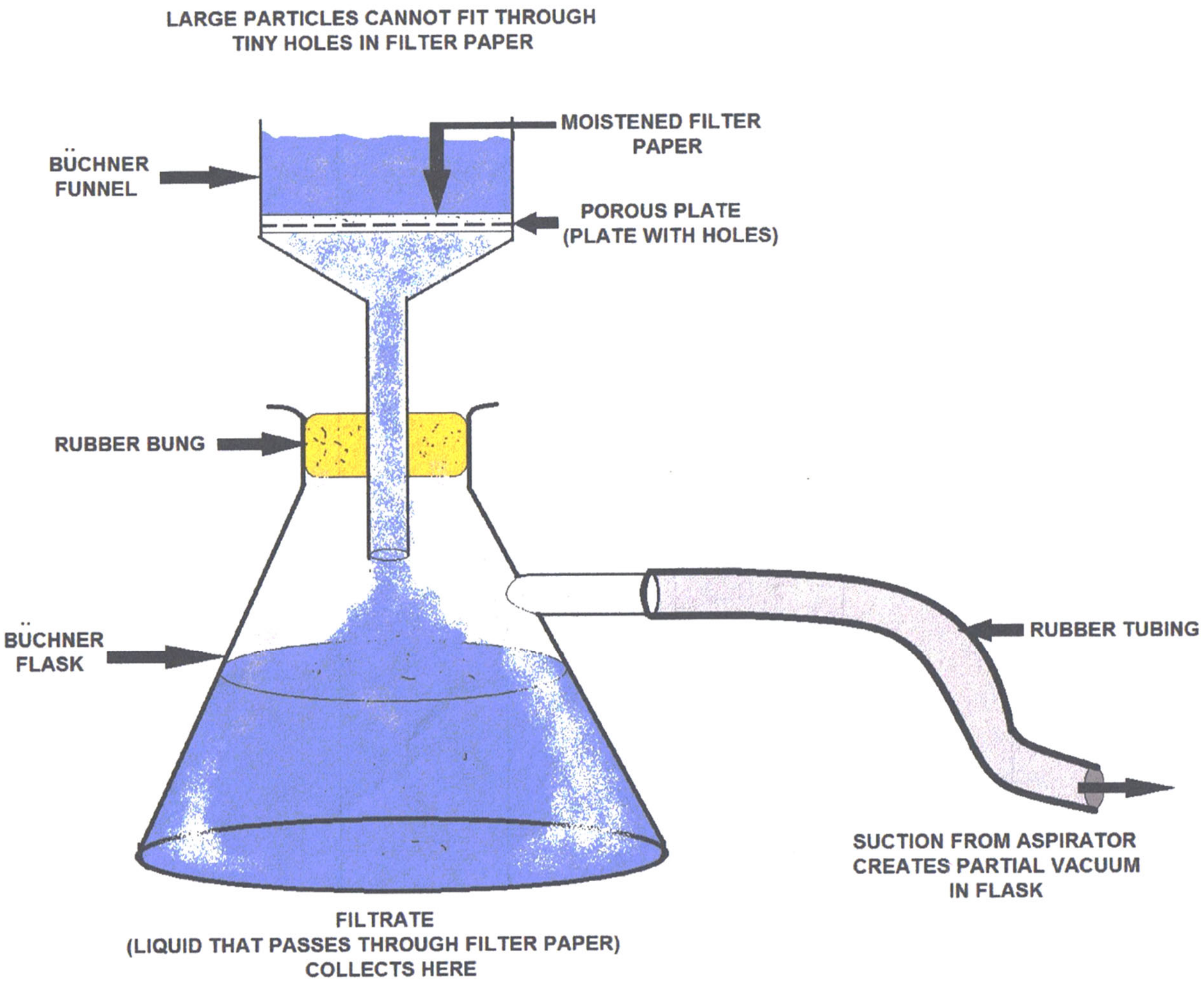
Cadmium is created via the long s-process in low-medium mass stars with masses of 0.6 to 10 solar masses, which lasts thousands of years. It requires a silver atom to capture a neutron and then undergo beta decay.

Cadmium makes up about 0.1 ppm of the Earth's crust. Compared with the more abundant 65 ppm zinc, cadmium is rare. No significant deposits of cadmium-containing ores are known.

Greenockite (CdS), the only cadmium mineral of importance, is nearly always associated with sphalerite (ZnS). This association is caused by the geochemical similarity between zinc and cadmium which makes geological separation unlikely. As a consequence, cadmium is produced mainly as a byproduct from mining, smelting, and refining sulfidic ores of zinc, and, to a lesser degree, lead and copper.

Small amounts of cadmium, about 10% of consumption, are produced from secondary sources, mainly from dust generated by recycling iron and steel scrap. Production in the United States began in 1907, but it was not until after World War I that cadmium came into wide use. One place where metallic cadmium can be found is the Vilyuy River basin in Siberia.

Rocks mined to produce phosphate fertilizers contain varying amounts of cadmium, leading to a cadmium concentration of up to 300 mg/kg in the produced phosphate fertilizers and thus in the high cadmium content in agricultural soils. Coal can contain significant amounts of cadmium, which ends up mostly in the flue dust.



In chemistry and common usage, a **filter** is a device (usually a membrane or layer) that is designed to physically block certain objects or substances while letting others through, depending on their size. Filters are often used to remove solid substances suspended in fluids, for example to remove air pollution, to make water drinkable, and to prepare coffee. Some devices that are called filters may also carry out other processes, such as waste treatment, (e.g. biofilter).

Several types of filters are used in chemistry in order to facilitate separation, thereby purifying a liquid (or gas). Many filters use gravity, or gravity enhanced by vacuum (suction) in order to create this separation, often through a funnel-shaped device.

Filter efficiency can be improved in a number of ways, such as with the use of fluted filter paper. Other types of materials may be used to effect separations based on size, similar to filters, such as molecular sieves.

The process of passing a mixture through a filter is called **filtration**.

The liquid produced after filtering a suspension of a solid in a liquid is called **filtrate**, while the solid remaining in the filter is called **retentate**, **residue**, or **filtrand**.

Chromium- Inorganic Contaminant 0.1 mg/L MCL

The Safe Drinking Water Act requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based on possible health risks from exposure over a lifetime, are called maximum contaminant level goals (MCLG).

EPA sets enforceable standards for drinking water contaminants based on the best available science to prevent potential health problems. In most cases, the enforceable standard is known as a maximum contaminant level (MCL), the maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are set as close to the health goals as possible after considering costs, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

The national primary drinking water regulation that established the MCL for total chromium was promulgated in 1991. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed total chromium as part of the second six-year review that was announced in March 2010. The Agency noted in March 2010 that it had initiated a reassessment of the health risks associated with chromium exposure and that the Agency did not believe it was appropriate to revise the national primary drinking water regulation while that effort was in process. In 2008, EPA began a rigorous and comprehensive review of chromium-6 health effects based on new science. When this human health assessment is finalized EPA will carefully review the conclusions and consider all relevant information to determine if the current chromium standard should be revised

Ensuring safe drinking water for all Americans is a top priority for EPA. EPA has an enforceable drinking water standard of 0.1 milligrams per liter (mg/L) for total chromium, which includes chromium-6 and chromium-3. This standard was established in 1991 and was based on the best available science at the time which indicated that some people who use water containing chromium in excess of the drinking water standard over many years could experience allergic dermatitis (skin reactions).

EPA regularly re-evaluates drinking water standards and, based on new science on chromium-6, had begun a rigorous and comprehensive review of its health effects in 2008. In September 2010, EPA released a draft of that scientific assessment for public comment. When this human health assessment is finalized, EPA will carefully review the conclusions and consider all relevant information to determine if a new drinking water standard for chromium-6 or a revision to the current total chromium standard is warranted.

Chromium is an odorless and tasteless metallic element. Chromium is found naturally in rocks, plants, soil and volcanic dust, humans and animals.

The most common forms of chromium that occur in natural waters in the environment are trivalent chromium (chromium-3), and hexavalent chromium (chromium-6).

Chromium-3 is an essential human dietary element and occurs naturally in many vegetables, fruits, meats, grains and yeast. Chromium-6 occurs naturally in the environment from the erosion of natural chromium deposits but it can also be produced by industrial processes. There are demonstrated instances of chromium being released to the environment by leakage, poor storage, or inadequate industrial waste disposal practices.

What are some uses for Chromium?

Metallic chromium is used mainly for making steel and other alloys. Chromium compounds in either the chromium-3 or chromium-6 forms are used for chrome plating, dyes and pigments, leather and wood preservation.

What are Chromium's Health Effects?

Chromium-3 is a nutritionally essential element in humans and is often added to vitamins as a dietary supplement. Chromium-3 has relatively low toxicity and would be a concern in drinking water only at very high levels of contamination; Chromium-6 is more toxic and poses potential health risks. People who use water containing total chromium in excess of the maximum contaminant level (MCL) over many years could experience allergic dermatitis.

EPA proposed to classify chromium-6 as likely to be carcinogenic to humans when ingested. The Agency continues to work towards completing the human health assessment and making a final determination about the carcinogenicity of chromium-6. When the assessment is completed, EPA will determine whether the drinking water standard for total chromium needs to be revised.

What are EPA's drinking water regulations for Chromium?

The Safe Drinking Water Act requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based on possible health risks from exposure over a lifetime are called maximum contaminant level goals (MCLG).

The MCLG for total chromium is 0.1 mg/L or 100 parts per billion (ppb). EPA has set this level of protection based on the best available science at the time the rule was promulgated. EPA has set an enforceable regulation for total chromium, called a maximum contaminant level (MCL), at 0.1 mg/L or 100 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

States may set more stringent drinking water MCLGs and MCLs for total chromium than EPA.

Why are Chromium-6 and Chromium-3 covered in the same Standard?

Chromium-6 and chromium-3 are covered under the total chromium drinking water standard because these forms of chromium can convert back and forth in water and in the human body, depending on environmental conditions.

Measuring just one form may not capture all of the chromium that is present. In order to ensure that the greatest potential risk is addressed, EPA's regulation assumes that a measurement of total chromium is 100 percent chromium-6, the more toxic form.

How often does the EPA update the Total Chromium Drinking Water Standard?

The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed total chromium as part of the second six-year review that was announced in March 2010 . The Agency noted in March 2010 that it had initiated a reassessment of the health risks associated with chromium exposure and that the Agency did not believe it was appropriate to revise the national primary drinking water regulation while that effort was in process.

In 2008, EPA began a rigorous and comprehensive review of chromium-6 health effects based on new science. When this human health assessment is finalized EPA will carefully review the conclusions and consider all relevant information to determine if the current chromium standard should be revised.

Chromium Explained

Chromium Description

Chromium is a chemical element which has the symbol **Cr** and atomic number 24. It is the first element in Group 6. It is a steely-gray, lustrous, hard metal that takes a high polish and has a high melting point. It is also odorless, tasteless, and malleable. The name of the element is derived from the Greek word "chrōma" (χρώμα), meaning color, because many of its compounds are intensely colored.

Chromium oxide was used by the Chinese in the Qin dynasty over 2,000 years ago to coat metal weapons found with the Terracotta Army. Chromium was discovered as an element after it came to the attention of the western world in the red crystalline mineral crocoite (lead(II) chromate), discovered in 1761 and initially used as a pigment. Louis Nicolas Vauquelin first isolated chromium metal from this mineral in 1797.

Since Vauquelin's first production of metallic chromium, small amounts of native (free) chromium metal have been discovered in rare minerals, but these are not used commercially. Instead, nearly all chromium is commercially extracted from the single commercially viable ore chromite, which is iron chromium oxide ($FeCr_2O_4$). Chromite is also now the chief source of chromium for chromium pigments.

Chromium metal and ferrochromium alloy are commercially produced from chromite by silicothermic or aluminothermic reactions, or by roasting and leaching processes.

Chromium metal has proven of high value due to its high corrosion resistance and hardness. A major development was the discovery that steel could be made highly resistant to corrosion and discoloration by adding metallic chromium to form stainless steel.

This application, along with chrome plating (electroplating with chromium) currently comprise 85% of the commercial use for the element, with applications for chromium compounds forming the remainder.

Trivalent chromium (Cr(III)) ion is possibly required in trace amounts for sugar and lipid metabolism, although the issue remains in debate. In larger amounts and in different forms, chromium can be toxic and carcinogenic. The most prominent example of toxic chromium is hexavalent chromium (Cr(VI)). Abandoned chromium production sites often require environmental cleanup.

Characteristics

Physical

Chromium is remarkable for its magnetic properties: it is the only elemental solid which shows antiferromagnetic ordering at room temperature (and below). Above 38 °C, it transforms into a paramagnetic state.

Passivation

Chromium metal left standing in air is passivated by oxygen, forming a thin protective oxide surface layer. This layer is a spinel structure only a few atoms thick. It is very dense, and prevents the diffusion of oxygen into the underlying material. This barrier is in contrast to iron or plain carbon steels, where the oxygen migrates into the underlying material and causes rusting.

The passivation can be enhanced by short contact with oxidizing acids like nitric acid. Passivated chromium is stable against acids. The opposite effect can be achieved by treatment with a strong reducing agent that destroys the protective oxide layer on the metal. Chromium metal treated in this way readily dissolves in weak acids.

Chromium, unlike metals such as iron and nickel, does not suffer from hydrogen embrittlement. However, it does suffer from nitrogen embrittlement, reacting with nitrogen from air and forming brittle nitrides at the high temperatures necessary to work the metal parts.

Occurrence

Chromium is the 24th most abundant element in Earth's crust with an average concentration of 100 ppm. Chromium compounds are found in the environment, due to erosion of chromium-containing rocks and can be distributed by volcanic eruptions. The concentrations range in soil is between 1 and 3000 mg/kg, in sea water 5 to 800 µg/liter, and in rivers and lakes 26 µg/liter to 5.2 mg/liter. Chromium is mined as chromite ($FeCr_2O_4$) ore. About two-fifths of the chromite ores and concentrates in the world are produced in South Africa, while Kazakhstan, India, Russia, and Turkey are also substantial producers. Untapped chromite deposits are plentiful, but geographically concentrated in Kazakhstan and southern Africa.

Although rare, deposits of native chromium exist. The Udachnaya Pipe in Russia produces samples of the native metal. This mine is a kimberlite pipe, rich in diamonds, and the reducing environment helped produce both elemental chromium and diamond.

The relation between Cr(III) and Cr(VI) strongly depends on pH and oxidative properties of the location, but in most cases, the Cr(III) is the dominating species, although in some areas the ground water can contain up to 39 µg/liter of total chromium of which 30 µg/liter is present as Cr(VI).

Isotopes

Naturally occurring chromium is composed of three stable isotopes; ^{52}Cr, ^{53}Cr and ^{54}Cr with ^{52}Cr being the most abundant (83.789% natural abundance). 19 radioisotopes have been characterized with the most stable being ^{50}Cr with a half-life of (more than) 1.8×10^{17} years, and ^{51}Cr with a half-life of 27.7 days. All of the remaining radioactive isotopes have half-lives that are less than 24 hours and the majority of these have half-lives that are less than 1 minute. This element also has 2 meta states.

^{53}Cr is the radiogenic decay product of ^{53}Mn. Chromium isotopic contents are typically combined with manganese isotopic contents and have found application in isotope geology.

Mn-Cr isotope ratios reinforce the evidence from ^{26}Al and ^{107}Pd for the early history of the solar system. Variations in $^{53}Cr/^{52}Cr$ and Mn/Cr ratios from several meteorites indicate an initial $^{53}Mn/^{55}Mn$ ratio that suggests Mn-Cr isotopic composition must result from in-situ decay of ^{53}Mn in differentiated planetary bodies. Hence ^{53}Cr provides additional evidence for nucleosynthetic processes immediately before coalescence of the solar system.

The isotopes of chromium range in atomic mass from 43 u (^{43}Cr) to 67 u (^{67}Cr). The primary decay mode before the most abundant stable isotope, ^{52}Cr, is electron capture and the primary mode after is beta decay. ^{53}Cr has been posited as a proxy for atmospheric oxygen concentration

Chromium(III)

A large number of chromium(III) compounds are known. Chromium(III) can be obtained by dissolving elemental chromium in acids like hydrochloric acid or sulfuric acid. The Cr^{3+} ion has a similar radius (63 pm) to the Al^{3+} ion (radius 50 pm), so they can replace each other in some compounds, such as in chrome alum and alum. When a trace amount of Cr^{3+} replaces Al^{3+} in corundum (aluminum oxide, Al_2O_3), the red-colored ruby is formed.

Chromium(III) ions tend to form octahedral complexes. The colors of these complexes is determined by the ligands attached to the Cr center. The commercially available chromium(III) chloride hydrate is the dark green complex $[CrCl_2(H_2O)_4]Cl$. Closely related compounds have different colors: pale green $[CrCl(H_2O)_5]Cl_2$ and the violet $[Cr(H_2O)_6]Cl_3$.

If water-free green chromium(III) chloride is dissolved in water then the green solution turns violet after some time, due to the substitution of water by chloride in the inner coordination sphere. This kind of reaction is also observed with solutions of chrome alum and other water-soluble chromium(III) salts.

Chromium(III) hydroxide ($Cr(OH)_3$) is amphoteric, dissolving in acidic solutions to form $[Cr(H_2O)_6]^{3+}$, and in basic solutions to form $[Cr(OH)_6]^{3-}$. It is dehydrated by heating to form the green chromium(III) oxide (Cr_2O_3), which is the stable oxide with a crystal structure identical to that of corundum.

Chromium(VI)

Chromium(VI) compounds are powerful oxidants at low or neutral pH. Most important are chromate anion ($CrO2-4$) and dichromate ($Cr_2O_7^{2-}$) anions, which exist in equilibrium:

$$2\ [CrO_4]^{2-} + 2\ H^+ \rightleftarrows [Cr_2O_7]^{2-} + H_2O$$

Chromium(VI) halides are known also and include the hexafluoride CrF_6 and chromyl chloride (CrO_2Cl_2).

Sodium chromate is produced industrially by the oxidative roasting of chromite ore with calcium or sodium carbonate. The dominant species is therefore, by the law of mass action, determined by the pH of the solution. The change in equilibrium is visible by a change from yellow (chromate) to orange (dichromate), such as when an acid is added to a neutral solution of potassium chromate. At yet lower pH values, further condensation to more complex oxyanions of chromium is possible.

Both the chromate and dichromate anions are strong oxidizing reagents at low pH:
Sodium chromate (Na_2CrO_4)

$$Cr_2O2-\ 7 + 14\ H_3O^+ + 6\ e^- \rightarrow 2\ Cr^{3+} + 21\ H_2O\ (\varepsilon_0 = 1.33\ V)$$

They are, however, only moderately oxidizing at high pH:

$$CrO2-4 + 4 H_2O + 3 e^- \rightarrow Cr(OH)_3 + 5 OH^- (\varepsilon_0 = -0.13 \text{ V})$$

Chromium(VI) compounds in solution can be detected by adding an acidic hydrogen peroxide solution. The unstable dark blue chromium(VI) peroxide (CrO_5) is formed, which can be stabilized as an ether adduct $CrO_5 \cdot OR_2$.

Chromic acid has the hypothetical formula H_2CrO_4. It is a vaguely described chemical, despite many well-defined chromates and dichromates are known. The dark red chromium(VI) oxide CrO_3, the acid anhydride of chromic acid, is sold industrially as "chromic acid". It can be produced by mixing sulfuric acid with dichromate, and is a strong oxidizing agent.

Chromium(V) and chromium(IV)

The oxidation state +5 is only realized in few compounds but are intermediates in many reactions involving oxidations by chromate. The only binary compound is the volatile chromium(V) fluoride (CrF_5). This red solid has a melting point of 30 °C and a boiling point of 117 °C. It can be synthesized by treating chromium metal with fluorine at 400 °C and 200 bar pressure. The peroxochromate(V) is another example of the +5 oxidation state. Potassium peroxochromate ($K_3[Cr(O_2)_4]$) is made by reacting potassium chromate with hydrogen peroxide at low temperatures. This red brown compound is stable at room temperature but decomposes spontaneously at 150–170 °C.

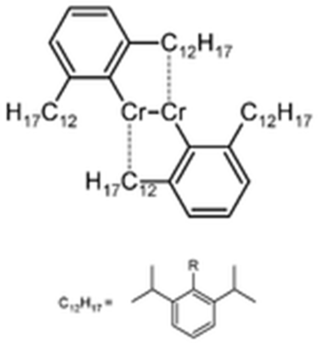
Compounds of chromium(IV) (in the +4 oxidation state) are slightly more common than those of chromium(V). The tetrahalides, CrF_4, $CrCl_4$, and $CrBr_4$, can be produced by treating the trihalides (CrX_3) with the corresponding halogen at elevated temperatures. Such compounds are susceptible to disproportionation reactions and are not stable in water.

Chromium(II)

Many chromium(II) compounds are known, including the water-stable chromium(II) chloride, $CrCl_2$, which can be made by reduction of chromium(III) chloride with zinc. The resulting bright blue solution is only stable at neutral pH. Many chromous carboxylates are also known, most famously, the red chromous acetate ($Cr_2(O_2CCH_3)_4$), which features a quadruple bond.

Chromium(I)

Most Cr(I) compounds are obtained by oxidation of electron-rich, octahedral Cr(0) complexes. Other Cr(I) complexes contain cyclopentadienyl ligands. As verified by X-ray diffraction, a Cr-Cr quintuple bond (length 183.51(4) pm) has also been described. Extremely bulky monodentate ligands stabilize this compound by shielding the quintuple bond from further reactions.



Chromium compound determined experimentally to contain a Cr-Cr quintuple bond

Chromium(0)
Many chromium(0) compounds are known. Most are derivatives of chromium hexacarbonyl or bis(benzene)chromium.

What are EPA's Drinking Water Regulations for Chromium (total)?

EPA has a drinking water standard of 0.1 milligrams per liter (mg/L) or 100 parts per billion (ppb) for total chromium, which includes all forms of chromium including chromium-6. Water systems are required to test for total chromium. The current standard is based on potential adverse dermatological effects over many years, such as allergic dermatitis (skin reactions). EPA regularly re-evaluates drinking water standards and, based on new science on chromium-6, began a rigorous and comprehensive review of its health effects in 2008.

Is Total Chromium or Chromium-6 in Drinking Water a Health Concern?

The current federal drinking water standard for total chromium is 0.1 mg/L or 100 ppb. Chromium-6 and chromium-3 are covered under the total chromium drinking water standard because these forms of chromium can convert back and forth in water and in the human body, depending on environmental conditions. Measuring just one form may not capture all of the chromium that is present. In order to ensure that the greatest potential risk is addressed, EPA's regulation assumes that a measurement of total chromium is 100 percent chromium-6, the more toxic form. If tap water from a public water system exceeds this federal standard, consumers will be notified.

The MCL for total chromium was established in 1991 and is based on the best available science at the time which indicated that continued exposure to chromium-6 could result in allergic dermatitis (skin reactions). EPA is now reviewing data from a 2008 long-term animal study by the Department of Health and Human Service's National Toxicology Program, which suggested that chromium-6 may be a human carcinogen if ingested. When the review is completed, EPA will consider this and other information to determine whether the drinking water standard for total chromium needs to be revised.

If EPA decides to revise the Regulation that includes Chromium-6 in Drinking Water, what is the process the agency will follow?

Prior to EPA making any decisions about revising the chromium drinking water regulation, EPA must issue its final human health assessment for chromium-6. EPA will carefully review the final assessment and consider all other relevant information to determine if a new drinking water regulation for chromium-6 or a revision to the current total chromium standard is warranted.

How does Chromium get into my Drinking Water?

The most common forms of chromium that occur in natural waters in the environment are chromium-3 and chromium-6. Chromium-3 and chromium-6 occur naturally in the environment, and are present in water from the erosion of chromium deposits found in rocks and soils. Chromium-6 is also produced by industrial processes and manufacturing activities including discharges from steel and pulp mills among others. At many locations, chromium compounds have been released to the environment via leakage, poor storage, or improper disposal practices. Chromium compounds are very persistent in water as sediments.

A federal law called the Emergency Planning and Community Right to Know Act requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the community right-to-know hotline at (800) 424-9346.

How will I know if there is Chromium in my Drinking Water?
Your public water system's annual water quality report will provide information if total chromium is detected in the drinking water it delivers. The water quality report is sent to customers by July 1 of each year and may also be found on your public water system's website. Some water utilities have conducted monitoring specifically for chromium-6. Contact your public water system to find out if this information is available.

Consumers served by private wells can have their water tested by a state certified laboratory. You can find information on how to sample for chromium-6 and where to send samples by contacting your state water laboratory certification officer.

What should I do if I am concerned about the Presence of Chromium-6 in my Drinking Water while EPA is reviewing the Science and the Regulation?
If you remain concerned after finding out more about the chromium-6 levels in your drinking water, you may consider taking additional steps.

Can home treatment devices remove chromium-6?
Some home treatment devices are certified by organizations to remove chromium-6. Two certification organizations are: NSF International and the Water Quality Association.

These certification programs are based on current drinking water standards and home treatment devices are only certified to remove chromium-6 to either 50 or 100 parts per billion. Contact the device's manufacturer for specific information about how effective the product is, given your water and treatment goal. Your public water system's water quality report and your water system's staff can help you understand the characteristics of your water.

If you choose to use a home treatment device, it is very important to follow the manufacturer's operation and maintenance instructions carefully in order to make sure the device works properly.

Consumers should be aware that the current EPA drinking water standard for chromium requires that public water systems provide drinking water that does not exceed a total chromium concentration of 100 ppb.

Can I avoid exposure to chromium-6 if I only Drink Bottled Water? (Is there Chromium-6 in bottled water?)
The Food and Drug Administration (FDA) establishes standards for bottled water and has adopted EPA's total chromium standard of 100 ppb. Contact bottled water manufacturers for specific information about levels of chromium-6 in their products.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to provide safe drinking water. Your water bill or telephone book's government listings are a good starting point for local information. Check your water system provider's website or contact your water provider. EPA requires all community water systems to prepare and deliver an annual consumer confidence report, sometimes called a water quality report, to their customers by July 1 of each year.

Copper - Inorganic Contaminant 1.3 mg/L MCLG

What are Copper's Health Effects?

Some people who drink water containing copper in excess of the action level may, with short term exposure, experience gastrointestinal distress, and with long-term exposure may experience liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level.

This health effects language is not intended to catalog all possible health effects for copper. Rather, it is intended to inform consumers of some of the possible health effects associated with copper in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Copper?

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for copper is 1.3 mg/L or 1.3 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems.

For most contaminants, EPA sets an enforceable regulation called a maximum contaminant level (MCL) based on the MCLG. MCLs are set as close to the MCLGs as feasible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

However, because copper contamination of drinking water often results from corrosion of the plumbing materials belonging to water system customers, EPA established a treatment technique rather than an MCL for copper.

A treatment technique is an enforceable procedure or level of technological performance which water systems must follow to ensure control of a contaminant. The treatment technique regulation for copper (referred to as the Lead and Copper rule) requires water systems to control the corrosivity of the water. The regulation also requires systems to collect tap samples from sites served by the system that are more likely to have plumbing materials containing lead. If more than 10 percent of tap water samples exceed the copper action level of 1.3 milligrams per Liter (mg/L), water systems must take additional steps to reduce corrosiveness.

EPA promulgated the Lead and Copper Rule in 1991, and revised the regulation in 2000 and in 2007. States may set a more stringent regulation for copper in drinking water than EPA.

How does Copper get into my Drinking Water?

The major sources of copper in drinking water are corrosion of household plumbing systems; and erosion of natural deposits. Copper enters the water ("leaches") through contact with the plumbing. Copper leaches into water through corrosion – a dissolving or wearing away of metal caused by a chemical reaction between water and your plumbing. Copper can leach into water primarily from pipes, but fixtures and faucets (brass), and fittings can also be a source. The amount of copper in your water also depends on the types and amounts of minerals in the water, how long the water stays in the pipes, the amount of wear in the pipes, the water's acidity and its temperature.

How will I know if Copper is in my Drinking Water?

If you are concerned about copper in your drinking water, have the water tested for copper by a certified laboratory. (Lists are available from your state or local drinking water authority.) Since you cannot see, taste, or smell copper dissolved in water, testing is the only sure way of telling whether there are harmful quantities of lead in your drinking water. You should be particularly suspicious if your home has copper pipes. if you see signs of corrosion (frequent leaks, rust-colored water, stained dishes or laundry, or if your non-plastic plumbing is less than five years old. Your water supplier may have useful information, including whether the service connector used in your home or area is made of copper. Testing is especially important in high-rise buildings where flushing might not work.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Copper be removed from my Drinking Water?

The following treatment method(s) have proven to be effective for removing copper to below the action level of 1.3 mg/L or 1.3 ppm: corrosion control.

How do I learn more about my Drinking Water?

EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Copper Explained

Copper is a chemical element with the symbol **Cu** (from Latin: *cuprum*) and atomic number 29. It is a ductile metal with very high thermal and electrical conductivity. Pure copper is soft and malleable; a freshly exposed surface has a reddish-orange color. It is used as a conductor of heat and electricity, a building material, and a constituent of various metal alloys.

The metal and its alloys have been used for thousands of years. In the Roman era, copper was principally mined on Cyprus, hence the origin of the name of the metal as *cyprium* (metal of Cyprus), later shortened to *cuprum*.

Its compounds are commonly encountered as copper(II) salts, which often impart blue or green colors to minerals such as turquoise and have been widely used historically as pigments.

Architectural structures built with copper corrode to give green verdigris (or patina). Decorative art prominently features copper, both by itself and as part of pigments.

Copper(II) ions are water-soluble, where they function at low concentration as bacteriostatic substances, fungicides, and wood preservatives. In sufficient amounts, they are poisonous to higher organisms; at lower concentrations it is an essential trace nutrient to all higher plant and animal life. The main areas where copper is found in animals are liver, muscle and bone.

Characteristics

Physical

Copper, silver and gold are in group 11 of the periodic table, and they share certain attributes: they have one s-orbital electron on top of a filled d-electron shell and are characterized by high ductility and electrical conductivity. The filled d-shells in these elements do not contribute much to the interatomic interactions, which are dominated by the s-electrons through metallic bonds. Contrary to metals with incomplete d-shells, metallic bonds in copper are lacking a covalent character and are relatively weak. This explains the low hardness and high ductility of single crystals of copper. At the macroscopic scale, introduction of extended defects to the crystal lattice, such as grain boundaries, hinders flow of the material under applied stress thereby increasing its hardness. For this reason, copper is usually supplied in a fine-grained polycrystalline form, which has greater strength than monocrystalline forms.

The low hardness of copper partly explains its high electrical (59.6×10^6 S/m) and thus also high thermal conductivity, which are the second highest among pure metals at room temperature. This is because the resistivity to electron transport in metals at room temperature mostly originates from scattering of electrons on thermal vibrations of the lattice, which are relatively weak for a soft metal. The maximum permissible current density of copper in open air is approximately 3.1×10^6 A/m^2 of cross-sectional area, above which it begins to heat excessively. As with other metals, if copper is placed against another metal, galvanic corrosion will occur.

Together with cesium and gold (both yellow), copper is one of only three elemental metals with a natural color other than gray or silver. Pure copper is orange-red and acquires a reddish tarnish when exposed to air. The characteristic color of copper results from the electronic transitions between the filled 3d and half-empty 4s atomic shells – the energy difference between these shells is such that it corresponds to orange light. The same mechanism accounts for the yellow color of gold and cesium.

Chemical

Copper forms a rich variety of compounds with oxidation states +1 and +2, which are often called *cuprous* and *cupric*, respectively. It does not react with water, but it slowly reacts with atmospheric oxygen forming a layer of brown-black copper oxide. In contrast to the oxidation of iron by wet air, this oxide layer stops the further, bulk corrosion. A green layer of verdigris (copper carbonate) can often be seen on old copper constructions, such as the Statue of Liberty, the largest copper statue in the world built using repoussé and chasing. Hydrogen sulfides and sulfides react with copper to form various copper sulfides on the surface. In the latter case, the copper corrodes, as is seen when copper is exposed to air containing sulfur compounds.

Oxygen-containing ammonia solutions give water-soluble complexes with copper, as do oxygen and hydrochloric acid to form copper chlorides and acidified hydrogen peroxide to form copper(II) salts. Copper(II) chloride and copper comproportionate to form copper(I) chloride.

Isotopes

There are 29 isotopes of copper. ^{63}Cu and ^{65}Cu are stable, with ^{63}Cu comprising approximately 69% of naturally occurring copper; they both have a spin of 3/2. The other isotopes are radioactive, with the most stable being ^{67}Cu with a half-life of 61.83 hours. Seven metastable isotopes have been characterized, with ^{68m}Cu the longest-lived with a half-life of 3.8 minutes. Isotopes with a mass number above 64 decay by β^-, whereas those with a mass number below 64 decay by β^+. ^{64}Cu, which has a half-life of 12.7 hours, decays both ways.

^{62}Cu and ^{64}Cu have significant applications. ^{64}Cu is a radiocontrast for X-ray imaging, and complexed with a chelate can be used for treating cancer. ^{62}Cu is used in ^{62}Cu-PTSM that is a radioactive tracer for positron emission tomography.

Occurrence

Copper can be found as either native copper or as part of minerals. Native copper is a polycrystal, with the largest described single crystal measuring 4.4×3.2×3.2 cm. The largest mass of elemental copper weighed 420 tons and was found in 1857 on the Keweenaw Peninsula in Michigan, US. There are many examples of copper-containing minerals: chalcopyrite and chalcocite are copper sulfides, azurite and malachite are copper carbonates and cuprite is a copper oxide. Copper is present in the Earth's crust at a concentration of about 50 parts per million (ppm), and is also synthesized in massive stars.

Compounds

Binary Compounds

As for other elements, the simplest compounds of copper are binary compounds, i.e. those containing only two elements. The principal ones are the oxides, sulfides and halides. Both cuprous and cupric oxides are known. Among the numerous copper sulfides, important examples include copper(I) sulfide and copper(II) sulfide.

The cuprous halides with chlorine, bromine, and iodine are known, as are the cupric halides with fluorine, chlorine, and bromine. Attempts to prepare copper(II) iodide give cuprous iodide and iodine.

$$2\ Cu^{2+} + 4\ I^- \rightarrow 2\ CuI + I_2$$

Coordination Chemistry

Copper, like all metals, forms coordination complexes with ligands. In aqueous solution, copper(II) exists as $[Cu(H_2O)_6]^{2+}$. This complex exhibits the fastest water exchange rate (speed of water ligands attaching and detaching) for any transition metal aquo complex. Adding aqueous sodium hydroxide causes the precipitation of light blue solid copper(II) hydroxide. A simplified equation is:

$$Cu^{2+} + 2\ OH^- \rightarrow Cu(OH)_2$$

Aqueous ammonia results in the same precipitate. Upon adding excess ammonia, the precipitate dissolves, forming tetraamminecopper(II):

$$Cu(H_2O)_4(OH)_2 + 4\ NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 2\ H_2O + 2\ OH^-$$

Many other oxyanions form complexes; these include copper(II) acetate, copper(II) nitrate, and copper(II) carbonate. Copper(II) sulfate forms a blue crystalline pentahydrate, which is the most familiar copper compound in the laboratory. It is used in a fungicide called the Bordeaux mixture.

Polyols, compounds containing more than one alcohol functional group, generally interact with cupric salts.

For example, copper salts are used to test for reducing sugars. Specifically, using Benedict's reagent and Fehling's solution the presence of the sugar is signaled by a color change from blue Cu(II) to reddish copper(I) oxide. Schweizer's reagent and related complexes with ethylenediamine and other amines dissolve cellulose. Amino acids form very stable chelate complexes with copper(II). Many wet-chemical tests for copper ions exist, one involving potassium ferrocyanide, which gives a brown precipitate with copper(II) salts.

Organocopper Chemistry

Compounds that contain a carbon-copper bond are known as organocopper compounds. They are very reactive towards oxygen to form copper(I) oxide and have many uses in chemistry. They are synthesized by treating copper(I) compounds with Grignard reagents, terminal alkynes or organolithium reagents; in particular, the last reaction described produces a Gilman reagent. These can undergo substitution with alkyl halides to form coupling products; as such, they are important in the field of organic synthesis.

Copper(I) acetylide is highly shock-sensitive but is an intermediate in reactions such as the Cadiot-Chodkiewicz coupling and the Sonogashira coupling. Conjugate addition to enones and carbocupration of alkynes can also be achieved with organocopper compounds. Copper(I) forms a variety of weak complexes with alkenes and carbon monoxide, especially in the presence of amine ligands.

Copper (III) and Copper (IV)

Copper(III) is most characteristically found in oxides. A simple example is potassium cuprate, $KCuO_2$, a blue-black solid. The best studied copper(III) compounds are the cuprate superconductors. Yttrium barium copper oxide ($YBa_2Cu_3O_7$) consists of both Cu(II) and Cu(III) centers. Like oxide, fluoride is a highly basic anion and is known to stabilize metal ions in high oxidation states. Indeed, both copper(III) and even copper(IV) fluorides are known, K_3CuF_6 and Cs_2CuF_6, respectively.

Some copper proteins form oxo complexes, which also feature copper(III). With di- and tripeptides, purple-colored copper(III) complexes are stabilized by the deprotonated amide ligands.

Complexes of copper(III) are also observed as intermediates in reactions of organocopper compounds.

Biological Role

Rich sources of copper include oysters, beef and lamb liver, Brazil nuts, blackstrap molasses, cocoa, and black pepper. Good sources include lobster, nuts and sunflower seeds, green olives, avocados, and wheat bran.

Copper proteins have diverse roles in biological electron transport and oxygen transportation, processes that exploit the easy interconversion of Cu(I) and Cu(II). The biological role for copper commenced with the appearance of oxygen in earth's atmosphere. The protein hemocyanin is the oxygen carrier in most mollusks and some arthropods such as the horseshoe crab (*Limulus polyphemus*). Because hemocyanin is blue, these organisms have blue blood, not the red blood found in organisms that rely on hemoglobin for this purpose. Structurally related to hemocyanin are the laccases and tyrosinases. Instead of reversibly binding oxygen, these proteins hydroxylate substrates, illustrated by their role in the formation of lacquers.

Copper is also a component of other proteins associated with the processing of oxygen. In cytochrome c oxidase, which is required for aerobic respiration, copper and iron cooperate in the reduction of oxygen.

Copper is also found in many superoxide dismutases, proteins that catalyze the decomposition of superoxides, by converting it (by disproportionation) to oxygen and hydrogen peroxide:

$$2\ HO_2 \rightarrow H_2O_2 + O_2$$

Several copper proteins, such as the "blue copper proteins", do not interact directly with substrates, hence they are not enzymes. These proteins relay electrons by the process called electron transfer.

Photosynthesis functions by an elaborate electron transport chain within the thylakoid membrane. A central "link" in this chain is plastocyanin, a blue copper protein.

Dietary Needs

Copper is an essential trace element in plants and animals, but not some microorganisms. The human body contains copper at a level of about 1.4 to 2.1 mg per kg of body mass. Stated differently, the RDA for copper in normal healthy adults is quoted as 0.97 mg/day and as 3.0 mg/day. Copper is absorbed in the gut, then transported to the liver bound to albumin. After processing in the liver, copper is distributed to other tissues in a second phase.

Copper transport here involves the protein ceruloplasmin, which carries the majority of copper in blood. Ceruloplasmin also carries copper that is excreted in milk, and is particularly well-absorbed as a copper source. Copper in the body normally undergoes enterohepatic circulation (about 5 mg a day, vs. about 1 mg per day absorbed in the diet and excreted from the body), and the body is able to excrete some excess copper, if needed, via bile, which carries some copper out of the liver that is not then reabsorbed by the intestine.

Copper-based Disorders

Because of its role in facilitating iron uptake, copper deficiency can produce anemia-like symptoms, neutropenia, bone abnormalities, hypopigmentation, impaired growth, increased incidence of infections, osteoporosis, hyperthyroidism, and abnormalities in glucose and cholesterol metabolism. Conversely, Wilson's disease causes an accumulation of copper in body tissues.

Severe deficiency can be found by testing for low plasma or serum copper levels, low ceruloplasmin, and low red blood cell superoxide dismutase levels; these are not sensitive to marginal copper status. The "cytochrome c oxidase activity of leucocytes and platelets" has been stated as another factor in deficiency, but the results have not been confirmed by replication.

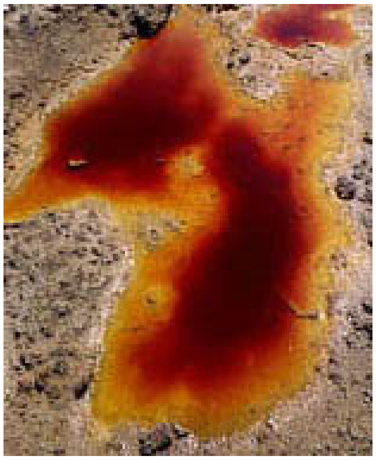
Copper Toxicity

Gram quantities of various copper salts have been taken in suicide attempts and produced acute copper toxicity in humans, possibly due to redox cycling and the generation of reactive oxygen species that damage DNA. Corresponding amounts of copper salts (30 mg/kg) are toxic in animals. A minimum dietary value for healthy growth in rabbits has been reported to be at least 3 ppm in the diet. However, higher concentrations of copper (100 ppm, 200 ppm, or 500 ppm) in the diet of rabbits may favorably influence feed conversion efficiency, growth rates, and carcass dressing percentages.

Chronic copper toxicity does not normally occur in humans because of transport systems that regulate absorption and excretion. Autosomal recessive mutations in copper transport proteins can disable these systems, leading to Wilson's disease with copper accumulation and cirrhosis of the liver in persons who have inherited two defective genes.

Cyanide - Inorganic Contaminant 0.2 mg/L MCL

Cyanide is a carbon-nitrogen chemical unit which combines with many organic and inorganic compounds.



Uses for Cyanide.
The most commonly used form, hydrogen cyanide, is mainly used to make compounds and other synthetic fibers and resins.

What are Cyanide's Health Effects?
Some people who drink water containing cyanide well in excess of the maximum contaminant level (MCL) for many years could experience nerve damage or problems with their thyroid.
This health effects language is not intended to catalog all possible health effects for cyanide. Rather, it is intended to inform consumers of some of the possible health effects associated with cyanide in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Cyanide?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for cyanide is 0.2 mg/L or 200 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for cyanide, called a maximum contaminant level (MCL), at 0.2 mg/L or 200 ppb.

MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase V Rule, the regulation for cyanide, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed cyanide as part of the Six Year Review and determined that the 0.2 mg/L or 200 ppb MCLG and 0.2 mg/L or 200 ppb MCL for cyanide are still protective of human health.

States may set more stringent drinking water MCLGs and MCLs for cyanide than EPA.

How does Cyanide get into my Drinking Water?
The major source of cyanide in drinking water is discharge from industrial chemical factories.
A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Cyanide is in my Drinking Water?

When routine monitoring indicates that cyanide levels are above the MCL, your water supplier must take steps to reduce the amount of cyanide so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Cyanide be Removed from my Drinking Water?

The following treatment method(s) have proven to be effective for removing cyanide to below 0.2 mg/L or 200 ppb: granular activated carbon in combination with packed tower aeration.

How do I learn more about my Drinking Water?

EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Cyanide Explained

A **cyanide** is a chemical compound that contains the **cyano group**, -C≡N, which consists of a carbon atom triple-bonded to a nitrogen atom. Cyanides most commonly refer to salts of the anion CN^-, which is isoelectronic with carbon monoxide and with molecular nitrogen. Most cyanides are highly toxic.

Nomenclature and Etymology

In IUPAC nomenclature, organic compounds that have a –C≡N functional group are called nitriles. Thus, nitriles are organic compounds. An example of a nitrile is CH_3CN, acetonitrile, also known as methyl cyanide. Nitriles usually do not release cyanide ions. A functional group with a hydroxyl and cyanide bonded to the same carbon is called cyanohydrin. Unlike nitriles, cyanohydridins do release hydrogen cyanide. In inorganic chemistry, salts containing the $C{\equiv}N^-$ ion are referred to as **cyanides**.

Occurrence and Reactions

Cyanides are produced by certain bacteria, fungi, and algae and are found in a number of plants. Cyanides are found, although in small amounts, in certain seeds and fruit stones, e.g., those of apple, mango, peach, and bitter almonds. In plants, cyanides are usually bound to sugar molecules in the form of cyanogenic glycosides and defend the plant against herbivores. Cassava roots (also called manioc), an important potato-like food grown in tropical countries (and the base from which tapioca is made), also contain cyanogenic glycosides.

Interstellar Medium

The cyanide radical $CN\cdot$ has been identified in interstellar space. The cyanide radical (called cyanogen) is used to measure the temperature of interstellar gas clouds.

Pyrolysis and Combustion Product

Hydrogen cyanide is produced by the combustion or pyrolysis of certain materials under oxygen-deficient conditions. For example, it can be detected in the exhaust of internal combustion engines and tobacco smoke. Certain plastics, especially those derived from acrylonitrile, release hydrogen cyanide when heated or burnt.

Coordination Chemistry

The cyanide anion is a ligand for many transition metals. The high affinities of metals for this anion can be attributed to its negative charge, compactness, and ability to engage in π-bonding.

Well-known complexes include:

- hexacyanides $[M(CN)_6]^{3-}$ (M = Ti, V, Cr, Mn, Fe, Co), which are octahedral in shape;
- the tetracyanides, $[M(CN)_4]^{2-}$ (M = Ni, Pd, Pt), which are square planar in their geometry;
- the dicyanides $[M(CN)_2]^-$ (M = Cu, Ag, Au), which are linear in geometry.

The dye Prussian blue was first accidentally made around 1706, by heating substances containing iron and carbon and nitrogen. Prussian blue consists of an iron-containing compound called "ferrocyanide" ($\{Fe(CN)_6]^{4-}$) meaning "blue substance with iron", from Latin *ferrum* = "iron" and Greek *kyanos* = "(dark) blue". Prussian blue is the deep-blue pigment used in the making of blueprints.

The enzymes called hydrogenases contain cyanide ligands attached to iron in their active sites. The biosynthesis of cyanide in the [NiFe]-hydrogenases proceeds from carbamoylphosphate, which converts to cysteinyl thiocyanate, the CN^- donor.

Organic Derivatives

Because of the cyanide anion's high nucleophilicity, cyano groups are readily introduced into organic molecules by displacement of a halide group (e.g., the chloride on methyl chloride). In general, organic cyanides are called nitriles. Thus, CH_3CN can be called methyl cyanide but more commonly is referred to as acetonitrile. In organic synthesis, cyanide is a C-1 synthon; i.e., it can be used to lengthen a carbon chain by one, while retaining the ability to be functionalized.

$RX + CN^- \rightarrow RCN + X^-$ (nucleophilic substitution) followed by

1. $RCN + 2\ H_2O \rightarrow RCOOH + NH_3$ (hydrolysis under reflux with mineral acid catalyst), or
2. $2\ RCN + LiAlH_4 +$ (second step) $4\ H_2O \rightarrow 2\ RCH_2NH_2 + LiAl(OH)_4$ (under reflux in dry ether, followed by addition of H_2O)

Manufacture

The principal process used to manufacture cyanides is the Andrussow process in which gaseous hydrogen cyanide is produced from methane and ammonia in the presence of oxygen and a platinum catalyst.

$$2\ CH_4 + 2\ NH_3 + 3\ O_2 \rightarrow 2\ HCN + 6\ H_2O$$

Gaseous hydrogen cyanide may be dissolved in aqueous sodium hydroxide solution to produce sodium cyanide.

Toxicity

Many cyanides are highly toxic. The cyanide anion is an inhibitor of the enzyme cytochrome c oxidase (also known as aa_3) in the fourth complex of the electron transport chain (found in the membrane of the mitochondria of eukaryotic cells). It attaches to the iron within this protein. The binding of cyanide to this cytochrome prevents transport of electrons from cytochrome c oxidase to oxygen. As a result, the electron transport chain is disrupted, meaning that the cell can no longer aerobically produce ATP for energy. Tissues that depend highly on aerobic respiration, such as the central nervous system and the heart, are particularly affected. This is an example of histotoxic hypoxia.

The most hazardous compound is hydrogen cyanide, which is a gas at ambient temperatures and pressure and can therefore be inhaled. For this reason, an air respirator supplied by an external oxygen source must be worn when working with hydrogen cyanide. Hydrogen cyanide is produced when a solution containing a labile cyanide is made acidic, because HCN is a weak acid. Alkaline solutions are safer to use because they do not evolve hydrogen cyanide gas. Hydrogen cyanide may be produced in the combustion of polyurethanes; for this reason, polyurethanes are not recommended for use in domestic and aircraft furniture. Oral ingestion of a small quantity of solid cyanide or a cyanide solution as little as 200 mg, or to airborne cyanide of 270 ppm is sufficient to cause death within minutes.

Organic nitriles do not readily release cyanide ions, and so have low toxicities. By contrast, compounds such as trimethylsilyl cyanide $(CH_3)_3SiCN$ readily release HCN or the cyanide ion upon contact with water.

Antidote

Hydroxocobalamin reacts with cyanide to form cyanocobalamin, which can be safely eliminated by the kidneys. This method has the advantage of avoiding the formation of methemoglobin.

An older cyanide antidote kit included administration of three substances: amyl nitrite pearls (administered by inhalation), sodium nitrite, and sodium thiosulfate (administered by infusion). The goal of the antidote was to generate a large pool of ferric iron (Fe^{3+}) to compete with cyanide cytochrome a_3 (so that cyanide will bind to the antidote rather that the enzyme). The nitrites oxidize hemoglobin to methemoglobin, which competes with cytochrome oxidase for the cyanide ion. Cyanmethemoglobin is formed and the cytochrome oxidase enzyme is restored. The major mechanism to remove the cyanide from the body is by enzymatic conversion to thiocyanate by the mitochondrial enzyme rhodanese.

Thiocyanate is a relatively non-toxic molecule and is excreted by the kidneys. To accelerate this detoxification, sodium thiosulfate is administered to provide a sulfur donor for rhodanese, needed in order to produce thiocyanate.

Sensitivity

Minimum risk levels (MRLs) may not protect for delayed health effects or health effects acquired following repeated sublethal exposure, such as hypersensitivity, asthma, or bronchitis. MRLs may be revised after sufficient data accumulates (Toxicological Profile for Cyanide, U.S. Department of Health and Human Services, 2006).

Chemical Tests for Cyanide

Prussian Blue

Iron (II) sulfate is added to a solution suspected of containing cyanide, such as the filtrate from the sodium fusion test. The resulting mixture is acidified with mineral acid. The formation of Prussian blue is a positive result for cyanide.

Para-Benzoquinone in DMSO

A solution of *para*-benzoquinone in DMSO reacts with inorganic cyanide to form a cyanophenol, which is fluorescent. Illumination with a UV light gives a green/blue glow if the test is positive.

Copper and an Aromatic Amine

As used by fumigators to detect hydrogen cyanide, copper (II) salt and an aromatic amine such as benzidine is added to the sample; as an alternative to benzidine an alternative amine di-(4,4-*bis*-dimethylaminophenyl) methane can be used. A positive test gives a blue color. Copper (I) cyanide is poorly soluble. By sequestering the copper(I) the copper(II) is rendered a stronger oxidant. The copper, in a cyanide facilitated oxidation, converts the amine into a colored compound. The Nernst equation explains this process. Another good example of such chemistry is the way in which the saturated calomel reference electrode (SCE) works. The copper, in a cyanide-facilitated oxidation, converts the amine into a colored compound.

Pyridine-Barbituric Acid Colorimetry

A sample containing inorganic cyanide is purged with air from a boiling acid solution into a basic absorber solution. The cyanide salt absorbed in the basic solution is buffered at pH 4.5 and then reacted with chlorine to form cyanogen chloride. The cyanogen chloride formed couples pyridine with barbituric acid to form a strongly colored red dye that is proportional to the cyanide concentration.

This colorimetric method following distillation is the basis for most regulatory methods (for instance EPA 335.4) used to analyze cyanide in water, wastewater, and contaminated soils.

Distillation followed by colorimetric methods, however, have been found to be prone to interferences from thiocyanate, nitrate, thiosulfate, sulfite, and sulfide that can result in both positive and negative bias. It has been recommended by the USEPA (MUR March 12, 2007) that samples containing these compounds be analyzed by Gas-Diffusion Flow Injection Analysis — Amperometry.

Gas Diffusion Flow Injection Analysis — Amperometry

Instead of distilling, the sample is injected into an acidic stream where the HCN formed is passed under a hydrophobic gas diffusion membrane that selectively allows only HCN to pass through. The HCN that passes through the membrane is absorbed into a basic carrier solution that transports the CN to an amperometric detector that accurately measures cyanide concentration with high sensitivity.

Sample pretreatment determined by acid reagents, ligands, or preliminary UV irradiation allow cyanide speciation of free cyanide, available cyanide, and total cyanide respectively. The relative simplicity of these flow injection analysis methods limit the interference experienced by the high heat of distillation and also prove to be cost effective since time consuming distillations are not required.

Fluoride

Many communities add fluoride to their drinking water to promote dental health. Each community makes its own decision about whether or not to add fluoride. The EPA has set an enforceable drinking water standard for fluoride of 4 mg/L (some people who drink water containing fluoride in excess of this level over many years could develop bone disease, including pain and tenderness of the bones). The EPA has also set a secondary fluoride standard of 2 mg/L to protect against dental fluorosis.

Fluoride - Inorganic Contaminant 4.0 mg/L MCL

Fluoride compounds are salts that form when the element, fluorine, combines with minerals in soil or rocks.

Uses for Fluoride.
Many communities add fluoride to their drinking water to promote dental health.

What are Fluoride's Health Effects?
Exposure to excessive consumption of fluoride over a lifetime may lead to increased likelihood of bone fractures in adults, and may result in effects on bone leading to pain and tenderness. Children aged 8 years and younger exposed to excessive amounts of fluoride have an increased chance of developing pits in the tooth enamel, along with a range of cosmetic effects to teeth.

This health effects language is not intended to catalog all possible health effects for fluoride. Rather, it is intended to inform consumers of some of the possible health effects associated with fluoride in drinking water.

What are EPA's Drinking Water Regulations for Fluoride?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for fluoride is 4.0 mg/L or 4.0 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for fluoride, called a maximum contaminant level (MCL), at 4.0 mg/L or 4.0 ppm.

MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

EPA has also set a secondary standard (SMCL) for fluoride at 2.0 mg/L or 2.0 ppm. Secondary standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

Tooth discoloration and/or pitting is caused by excess fluoride exposures during the formative period prior to eruption of the teeth in children. The secondary standard of 2.0 mg/L is intended as a guideline for an upper bound level in areas which have high levels of naturally occurring fluoride. The level of the SMCL was set based upon a balancing of the beneficial effects of protection from tooth decay and the undesirable effects of excessive exposures leading to discoloration.

Fluoride is voluntarily added to some drinking water systems as a public health measure for reducing the incidence of cavities among the treated population.

The decision to fluoridate a water supply is made by the State or local municipality, and is not mandated by EPA or any other Federal entity. The Centers for Disease Control and Prevention (CDC) provides recommendations about the optimal levels of fluoride in drinking water in order to prevent tooth decay. Information about CDC's recommendations can be found at: http://www.cdc.gov/fluoridation/

States may set more stringent drinking water MCLGs and MCLs for fluoride than EPA.

The drinking water standards are currently under review. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. In 2003 and as part of the first Six Year Review, EPA reviewed the drinking water standard for fluoride and found that new health and exposure data were available on orally ingested fluoride.

EPA requested that the National Research Council (NRC) of the National Academies of Science (NAS) conduct a review of this data and in 2006, the NRC published their evaluation in a report entitled, Fluoride in Drinking Water: A Scientific Review of EPA's Standards. The NRC recommended that EPA update its fluoride risk assessment to include new data on health risks and better estimates of total exposure.

In March 2010 and as part of the second Six Year Review, the Agency indicated that the Office of Water was in the process of developing its health and exposure assessments to address the NRC's recommendations. The Agency finalized the risk and exposure assessments for fluoride in January 2011 and announced its intent to review the drinking water regulations for fluoride to determine whether revisions are appropriate.

How does Fluoride get into my Drinking Water?

Some fluoride compounds, such as sodium fluoride and fluorosilicates, dissolve easily into ground water as it moves through gaps and pore spaces between rocks. Most water supplies contain some naturally occurring fluoride. Fluoride also enters drinking water in discharge from fertilizer or aluminum factories. Also, many communities add fluoride to their drinking water to promote dental health.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Fluoride is in my Drinking Water?

When routine monitoring indicates that fluoride levels are above the MCL, your water supplier must take steps to reduce the amount of fluoride so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household or private well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Fluoride be removed from my Drinking Water?

The following treatment method(s) have proven to be effective for removing fluoride to below 4.0 mg/L or 4.0 ppm: distillation or reverse osmosis.

How do I learn more about my Drinking Water?

EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Fluoride Explained

Fluoride is the anion F^-, the reduced form of fluorine when as an ion and when bonded to another element. Inorganic fluorine containing compounds are called fluorides. Fluoride, like other halides, is a monovalent ion (−1 charge). Its compounds often have properties that are distinct relative to other halides. Structurally, and to some extent chemically, the fluoride ion resembles the hydroxide ion.

Occurrence

Solutions of inorganic fluorides in water contain F^- and bifluoride HF−2. Few inorganic fluorides are soluble in water without undergoing significant hydrolysis. In terms of its reactivity, fluoride differs significantly from chloride and other halides, and is more strongly solvated due to its smaller radius/charge ratio. Its closest chemical relative is hydroxide. When relatively unsolvated, fluoride anions are called "naked". Naked fluoride is a very strong lewis base. The presence of fluoride and its compounds can be detected by F NMR spectroscopy.

Natural Occurrence

Many fluoride minerals are known, but of paramount commercial importance are fluorite and fluorapatite.

Fluoride is usually found naturally in low concentration in drinking water and foods. The concentration in seawater averages 1.3 parts per million (ppm). Fresh water supplies generally contain between 0.01–0.3 ppm, whereas the ocean contains between 1.2 and 1.5 ppm. In some locations, the fresh water contains dangerously high levels of fluoride, leading to serious health problems.

Applications

Fluorides are pervasive in modern technology. Hydrofluoric acid is the fluoride synthesized on the largest scale. It is produced by treating fluoride minerals with sulfuric acid. Hydrofluoric acid and its anhydrous form hydrogen fluoride are used in the production of fluorocarbons and aluminum fluorides. Hydrofluoric acid has a variety of specialized applications, including its ability to dissolve glass.

Inorganic Chemicals

Fluoride salts are used in the manufacture of many inorganic chemicals, many of which contain fluoride covalently bonded to the metal or nonmetal in question. Some examples of these are:

- Cryolite (Na_3AlF_6) is a pesticide that can leave fluoride on agricultural commodities. Cryolite was originally utilized in the preparation of aluminum.
- Sulfuryl fluoride (SO_2F_2) is used as a pesticide and fumigant on agricultural crops. In 2010, the United States Environmental Protection Agency proposed to withdraw the use of sulfuryl fluoride on food. Sulfuryl fluoride releases fluoride when metabolized.
- Sulfur hexafluoride is an inert, nontoxic insulator gas that is used in electrical transformers and as a tracer gas in indoor air quality investigations.
- Uranium hexafluoride, although not ionic, is prepared from fluoride reagents. It is utilized in the separation of isotopes of uranium between the fissile isotope U-235 and the non-fissile isotope U-238 in preparation of nuclear reactor fuel and atomic bombs. This is due to the volatility of fluorides of uranium.

Organic Chemicals

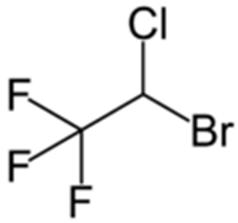
Fluoride reagents are significant in synthetic organic chemistry. Organofluorine chemistry has produced many useful compounds over the last 50 years. Included in this area are polytetrafluorethylene (Teflon), polychlorotrifluoroethylene (moisture barriers), efavirenz (pharmaceutical used for treatment of HIV), fluoxetine (an antidepressant), 5-fluorouracil (an anticancer drug), hydrochlorofluorocarbons and hydrofluorcarbons (refrigerants, blowing agents and propellants).

Due to the affinity of silicon for fluoride, and the ability of silicon to expand its coordination number, silyl ether protecting groups can be easily removed by the fluoride sources such as sodium fluoride and tetra-n-butylammonium fluoride (TBAF). This is quite useful for organic synthesis and the production of fine chemicals. The Si-F linkage is one of the strongest single bonds. In contrast, other silyl halides are easily hydrolyzed.

Cavity Prevention

Fluoride-containing compounds are used in topical and systemic fluoride therapy for preventing tooth decay. They are used for water fluoridation and in many products associated with oral hygiene. Originally, sodium fluoride was used to fluoridate water; hexafluorosilicic acid (H_2SiF_6) and its salt sodium hexafluorosilicate (Na_2SiF_6) are more commonly used additives, especially in the United States.

The fluoridation of water is known to prevent tooth decay and is considered by the U.S. Centers for Disease Control and Prevention as "one of 10 great public health achievements of the 20th century". In some countries where large, centralized water systems are uncommon, fluoride is delivered to the populace by fluoridating table salt. Fluoridation of water has its critics (see Water fluoridation controversy).



Structure of halothane.

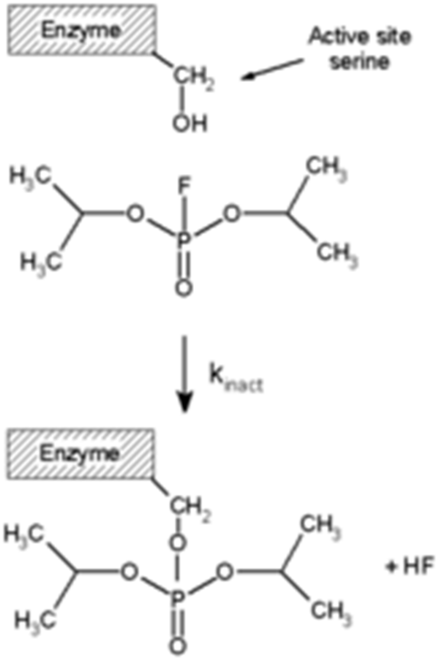
Biomedical Applications

Positron emission tomography is commonly carried out using fluoride-containing pharmaceuticals such as fluorodeoxyglucose, which is labeled with the radioactive isotope fluorine-18, which emits positrons when it decays into ^{18}O.

Numerous drugs contain fluorine including antipsychotics such as fluphenazine, HIV protease inhibitors such as tipranavir, antibiotics such as ofloxacin and trovafloxacin, and anesthetics such as halothane. Fluorine is incorporated in the drug structures to reduce drug metabolism, as the strong C-F bond resists deactivation in the liver by cytochrome P450 oxidases.

Fluoride salts are commonly used to inhibit the activity of phosphatases, such as serine/threonine phosphatases. Fluoride mimics the nucleophilic hydroxyl ion in these enzymes' active sites. Beryllium fluoride and aluminum fluoride are also used as phosphatase inhibitors, since these compounds are structural mimics of the phosphate group and can act as analogues of the transition state of the reaction.

Toxicology



Reaction of the irreversible inhibitor diisopropylfluorophosphate with a serine protease.

Fluoride-containing compounds are so diverse that it is not possible to generalize on their toxicity, which depends on their reactivity and structure, and in the case of salts, their solubility and ability to release fluoride ions.

Soluble fluoride salts, of which sodium fluoride is the most common, are mildly toxic but have resulted in both accidental and suicidal deaths from acute poisoning. While the minimum fatal dose in humans is not known, the lethal dose for most adult humans is estimated at 5 to 10 g (which is equivalent to 32 to 64 mg/kg elemental fluoride/kg body weight). However, a case of a fatal poisoning of an adult with 4 grams of sodium fluoride is documented, while a dose of 120 g sodium fluoride has been survived.

A toxic dose that may lead to adverse health effects is estimated at 3 to 5 mg/kg of elemental fluoride. For Sodium fluorosilicate (Na_2SiF_6), the median lethal dose (LD_{50}) orally in rats is 0.125 g/kg, corresponding to 12.5 g for a 100 kg adult. The fatal period ranges from 5 min to 12 hours.

The mechanism of toxicity involves the combination of the fluoride anion with the calcium ions in the blood to form insoluble calcium fluoride, resulting in hypocalcemia; calcium is indispensable for the function of the nervous system, and the condition can be fatal.

Treatment may involve oral administration of dilute calcium hydroxide or calcium chloride to prevent further absorption, and injection of calcium gluconate to increase the calcium levels in the blood.

Hydrogen fluoride is more dangerous than salts such as NaF because it is corrosive and volatile, and can result in fatal exposure through inhalation or upon contact with the skin; calcium gluconate gel is the usual antidote.

In the higher doses used to treat osteoporosis, sodium fluoride can cause pain in the legs and incomplete stress fractures when the doses are too high; it also irritates the stomach, sometimes so severely as to cause ulcers. Slow-release and enteric-coated versions of sodium fluoride do not have gastric side effects in any significant way, and have milder and less frequent complications in the bones. In the lower doses used for water fluoridation, the only clear adverse effect is dental fluorosis, which can alter the appearance of children's teeth during tooth development; this is mostly mild and is unlikely to represent any real effect on aesthetic appearance or on public health.

Lead- Inorganic Contaminant 0.015 Action Level

The United States Environmental Protection Agency (EPA) regulates lead in drinking water to protect public health. Lead may cause health problems if present in public or private water supplies in amounts greater than the drinking water standard set by EPA.

What is Lead?

Lead is a toxic metal that was used for many years in products found in and around homes. Even at low levels, lead may cause a range of health effects including behavioral problems and learning disabilities. Children six years old and under are most at risk because this is when the brain is developing. The primary source of lead exposure for most children is lead-based paint in older homes. Lead in drinking water can add to that exposure.

Uses for Lead.

Lead is sometimes used in household plumbing materials or in water service lines used to bring water from the main to the home. A prohibition on lead in plumbing materials has been in effect since 1986. The lead ban, which was included in the 1986 Amendments of the Safe Drinking Water Act, states that only "lead free" pipe, solder, or flux may be used in the installation or repair of (1) public water systems, or (2) any plumbing in a residential or non-residential facility providing water for human consumption, which is connected to a public water system. But even "lead free" plumbing may contain traces of lead. The term "lead free" means that solders and flux may not contain more than 0.2 percent lead, and that pipes and pipe fittings may not contain more than 8.0 percent lead. Faucets and other end use devices must be tested and certified against the ANSI – NSF Standard 61 to be considered lead free.

What are Lead's Health Effects?

Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

This health effects language is not intended to catalog all possible health effects for lead. Rather, it is intended to inform consumers of the most significant and probable health effects, associated with lead in drinking water.

What are EPA's Drinking Water Regulations for Lead?

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur with an adequate margin of safety. These non-enforceable health goals, based solely on possible health risks are called maximum contaminant level goals (MCLG) The MCLG for lead is zero.

EPA has set this level based on the best available science which shows there is no safe level of exposure to lead.

For most contaminants, EPA sets an enforceable regulation called a maximum contaminant level (MCL) based on the MCLG. MCLs are set as close to the MCLGs as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. However, because lead contamination of drinking water often results from corrosion of the plumbing materials belonging to water system customers, EPA established a treatment technique rather than an MCL for lead.

A treatment technique is an enforceable procedure or level of technological performance which water systems must follow to ensure control of a contaminant. The treatment technique regulation for lead (referred to as the Lead and Copper rule) requires water systems to control the corrosivity of the water. The regulation also requires systems to collect tap samples from sites served by the system that are more likely to have plumbing materials containing lead.

If more than 10% of tap water samples exceed the lead action level of 15 parts per billion, then water systems are required to take additional actions including:

- Taking further steps optimize their corrosion control treatment (for water systems serving 50,000 people that have not fully optimized their corrosion control) .
- Educating the public about lead in drinking water and actions consumers can take to reduce their exposure to lead.
- Replacing the portions of lead service lines (lines that connect distribution mains to customers) under the water system's control.

EPA promulgated the Lead and Copper Rule in 1991 and revised the regulation in 2000 and 2007. States may set more stringent drinking water regulations than EPA.

How does Lead get into my Drinking Water?

The major sources of lead in drinking water are corrosion of household plumbing systems; and erosion of natural deposits. Lead enters the water ("leaches") through contact with the plumbing. Lead leaches into water through corrosion – a dissolving or wearing away of metal caused by a chemical reaction between water and your plumbing. Lead can leach into water from pipes, solder, fixtures and faucets (brass), and fittings. The amount of lead in your water also depends on the types and amounts of minerals in the water, how long the water stays in the pipes, the amount of wear in the pipes, the water's acidity and its temperature.

Although the main sources of exposure to lead are ingesting paint chips and inhaling dust, EPA estimates that 10 to 20 percent of human exposure to lead may come from lead in drinking water. Infants who consume mostly mixed formula can receive 40 to 60 percent of their exposure to lead from drinking water.

How will I know if Lead is in my Drinking Water?

Have your water tested for lead? A list of certified laboratory of labs are available from your state or local drinking water authority. Testing costs between $20 and $100. Since you cannot see, taste, or smell lead dissolved in water, testing is the only sure way of telling whether there are harmful quantities of lead in your drinking water. You should be particularly suspicious if your home has lead pipes (lead is a dull gray metal that is soft enough to be easily scratched with a house key) or if you see signs of corrosion (frequent leaks, rust-colored water). Your water supplier may have useful information, including whether the service connector used in your home or area is made of lead. Testing is especially important in high-rise buildings where flushing might not work.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How can I Reduce Lead in Drinking Water at Home?

Flush your pipes before drinking, and only use cold water for consumption. The more time water has been sitting in your home's pipes, the more lead it may contain. Anytime the water in a particular faucet has not been used for six hours or longer, "flush" your cold-water pipes by running the water until it becomes as cold as it will get.

This could take as little as five to thirty seconds if there has been recent heavy water use such as showering or toilet flushing. Otherwise, it could take two minutes or longer. Your water utility will inform you if longer flushing times are needed to respond to local conditions.

Use only water from the cold-water tap for drinking, cooking, and especially for making baby formula. Hot water is likely to contain higher levels of lead. The two actions recommended above are very important to the health of your family. They will probably be effective in reducing lead levels because most of the lead in household water usually comes from the plumbing in your house, not from the local water supply.

Should I be concerned about Lead in Drinking water in my child's school or child care facility?

Children spend a significant part of their days at school or in a child care facility. The faucets that provide water used for consumption, including drinking, cooking lunch, and preparing juice and infant formula, should be tested.

How do I learn more about my Drinking Water?

EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect and upgrade the supply of safe drinking water. Your water bill or telephone book’s government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Lead Explained

Lead is a chemical element in the carbon group with symbol **Pb** (from Latin: *plumbum*) and atomic number 82. Lead is a soft, malleable poor metal. It is also counted as one of the heavy metals. Metallic lead has a bluish-white color after being freshly cut, but it soon tarnishes to a dull grayish color when exposed to air. Lead has a shiny chrome-silver luster when it is melted into a liquid.

Lead is used in building construction, lead-acid batteries, bullets and shot, weights, as part of solders, pewters, fusible alloys, and as a radiation shield. Lead has the highest atomic number of all of the stable elements, although the next higher element, bismuth, has a half-life that is so long (much longer than the age of the universe) that it can be considered stable. Its four stable isotopes have 82 protons, a magic number in the nuclear shell model of atomic nuclei.

Lead, at certain contact degrees, is a poisonous substance to animals, including humans. It damages the nervous system and causes brain disorders. Excessive lead also causes blood disorders in mammals. Like the element mercury, another heavy metal, lead is a neurotoxin that accumulates both in soft tissues and the bones. Lead poisoning has been documented from ancient Rome, ancient Greece, and ancient China.

Characteristics

Lead is a bright and silvery metal with a very slight shade of blue in a dry atmosphere. Upon contact with air, it begins to tarnish by forming a complex mixture of compounds depending on the conditions. The color of the compounds can vary. The tarnish layer can contain significant amounts of carbonates and hydroxycarbonates. It has a few characteristic properties: high density, softness, ductility and malleability, poor electrical conductivity compared to other metals, high resistance to corrosion, and ability to react with organic chemicals.

Various traces of other metals change its properties significantly: the addition of small amounts of antimony or copper increases hardness and improves the corrosion reflection from sulfuric acid for lead. A few other metals also improve only hardness and fight metal fatigue, such as cadmium, tin, or tellurium; metals like sodium or calcium also have this ability, but they weaken the chemical stability. Finally, zinc and bismuth simply impair the corrosion resistance (0.1% bismuth content is the industrial usage threshold). In return, lead impurities mostly worsen the quality of industrial materials, although there are exceptions: for example, small amounts of lead improve the ductility of steel.

Lead has only one common allotrope, which is face-centered cubic, with the lead–lead distance being 349 pm. At 327.5 °C (621.5 °F), lead melts; the melting point is above that of tin (232 °C, 449.5 °F), but significantly below that of germanium (938 °C, 1721 °F).[6] The boiling point of lead is 1749 °C (3180 °F), which is below those of both tin (2602 °C, 4716 °F) and germanium (2833 °C, 5131 °F). Densities increase down the group: the Ge and Sn values (5.23 and 7.29 $g \cdot cm^{-3}$, respectively) are significantly below that of lead: 11.32 $g \cdot cm^{-3}$.

A lead atom has 82 electrons, having an electronic configuration of $[Xe]4f^{14}5d^{10}6s^{2}6p^{2}$. In its compounds, lead (unlike the other group 14 elements) most commonly loses its two and not four outermost electrons, becoming lead(II) ions, Pb^{2+}. Such unusual behavior is rationalized by considering the inert pair effect, which occurs because of the stabilization of the 6s-orbital due to relativistic effects, which are stronger closer to the bottom of the periodic table. Tin shows a weaker such effect: tin(II) is still a reducer.

The figures for electrode potential show that lead is only slightly easier to oxidize than hydrogen. Lead thus can dissolve in acids, but this is often impossible due to specific problems (such as the formation of insoluble salts). Powdered lead burns with a bluish-white flame. As with many metals, finely divided powdered lead exhibits pyrophoricity. Toxic fumes are released when lead is burned.

Isotopes

Lead occurs naturally on Earth exclusively in the form of four isotopes: lead-204, -206, -207, and -208. All four can be radioactive as the hypothetical alpha decay of any would be exothermic, but the lower half-life limit has been put only for lead-204: over 1.4×10^{17} years. This effect is, however, so weak that natural lead poses no radiation hazard. Three isotopes are also found in three of the four major decay chains: lead-206, -207 and -208 are final decay products of uranium-238, uranium-235, and thorium-232, respectively.

Since the amounts of them in nature depend also on other elements' presence, the isotopic composition of natural lead varies by sample: in particular, the relative amount of lead-206 varies between 20.84% and 27.78%.

Aside from the stable ones, thirty-four radioisotopes have been synthesized: they have mass numbers of 178–215. Lead-205 is the most stable radioisotope of lead, with a half-life of over 10^{7} years. 47 nuclear isomers (long-lived excited nuclear states), corresponding to 24 lead isotopes, have been characterized. The most long-lived isomer is lead-204m2 (half-life of about 1.1 hours).

Chemical Reactivity

Lead is classified as a post-transition metal and is also a member of the carbon group. Lead only forms a protective oxide layer although finely powdered highly purified lead can ignite in air. Melted lead is oxidized in air to lead monoxide. All chalcogens oxidize lead upon heating.

Fluorine does not oxidize cold lead. Hot lead can be oxidized, but the formation of a protective halide layer lowers the intensity of the reaction above 100 °C (210 °F). The reaction with chlorine is similar: thanks to the chloride layer, lead persistence against chlorine surpasses those of copper or steel up to 300 °C (570 °F).

Water in the presence of oxygen attacks lead to start an accelerating reaction. The presence of carbonates or sulfates results in the formation of insoluble lead salts, which protect the metal from corrosion. So does carbon dioxide, as the insoluble lead carbonate is formed; however, an excess of the gas leads to the formation of the soluble bicarbonate; this makes the use of lead pipes dangerous. Lead dissolves in organic acids (in the presence of oxygen) and concentrated (≥80%) sulfuric acid thanks to complexation; however, it is only weakly affected by hydrochloric acid and is stable against hydrofluoric acid, as the corresponding halides are weakly soluble. Lead also dissolves in quite concentrated alkalis (≥10%) because of the amphoteric character and solubility of plumbites.

Compounds

Lead compounds exist mainly in two main oxidation states, +2 and +4. The former is more common. Inorganic lead(IV) compounds are typically strong oxidants or exist only in highly acidic solutions.

Oxides and Sulfides

Three oxides are known: lead(II) oxide or lead monoxide (PbO), lead tetroxide (Pb_3O_4) (sometimes called "minimum"), and lead dioxide (PbO_2). The monoxide exists as two allotropes: α-PbO and β-PbO, both with layer structure and tetracoordinated lead. The alpha polymorph is red-colored and has the Pb–O distance of 230 pm; the beta polymorph is yellow-colored and has the Pb–O distance of 221 and 249 pm (due to asymmetry). Both polymorphs can exist under standard conditions (beta with small (10^{-5} relative) impurities, such as Si, Ge, Mo, etc.). PbO reacts with acids to form salts, and with alkalis to give plumbites, $[Pb(OH)_3]^-$ or $[Pb(OH)_4]^{2-}$.The monoxide oxidizes in air to trilead tetroxide, which at 550 °C (1020 °F) degrades back into PbO.

The dioxide may be prepared by, for example, halogenization of lead(II) salts. Regardless the polymorph, it has a black-brown color. The alpha allotrope is rhombohedral, and the beta allotrope is tetragonal. Both allotropes are black-brown in color and always contain some water, which cannot be removed, as heating also causes decomposition (to PbO and Pb_3O_4).

The dioxide is a powerful oxidizer: it can oxidize hydrochloric and sulfuric acids. It does not react with alkaline solution, but reacts with solid alkalis to give hydroxyplumbates, or with basic oxides to give plumbates.

Reaction of lead salts with hydrogen sulfide yields lead monosulfide. The solid has the rocksalt-like simple cubic structure, which it keeps up to the melting point, 1114 °C (2037 °F). When heated in air, it oxidizes to the sulfate and then the monoxide. Lead monosulfide is almost insoluble in water, weak acids, and $(NH_4)_2S/(NH_4)_2S_2$ solution is the key for separation of lead from analytical groups I to III ions, tin, arsenic, and antimony. However, it dissolves in nitric and hydrochloric acids, to give elemental sulfur and hydrogen sulfide, respectively. Upon heating under high pressures with sulfur, it gives the disulfide. In the compound, the lead atoms are linked octahedrally with the sulfur atoms. It is also a semiconductor. A mixture of the monoxide and the monosulfide when heated forms the metal.

$$2\ PbO + PbS \rightarrow 3\ Pb + SO_2$$

Halides and Other Salts

Heating lead carbonate with hydrogen fluoride yields the hydrofluoride, which decomposes to the difluoride when it melts. This white crystalline powder is more soluble than the diiodide, but less than the dibromide and the dichloride. The tetrafluoride, a yellow crystalline powder, is unstable.

Other dihalides are obtained upon heating lead(II) salts with the halides of other metals; lead dihalides precipitate to give white orthorhombic crystals (diiodide forms yellow hexagonal crystals). They can also be obtained by direct reaction of their constituent elements at temperature exceeding melting points of dihalides. Their solubility increases with temperature; adding more halides first decreases the solubility, but then increases due to complexation, with the maximum coordination number being 6.

The complexation depends on halide ion numbers, atomic number of the alkali metal, the halide of which is added, temperature and solution ionic strength. The tetrachloride is obtained upon dissolving the dioxide in hydrochloric acid; to prevent the exothermic decomposition, it is kept under concentrated sulfuric acid. The tetrabromide may not, and the tetraiodide definitely does not exist. The diastatide has also been prepared.

The metal is not attacked by sulfuric or hydrochloric acids. It dissolves in nitric acid with the evolution of nitric oxide gas to form dissolved $Pb(NO_3)_2$. It is a well-soluble solid in water; it is thus a key to receive the precipitates of halides, sulfate, chromate, carbonate, and basic carbonate $Pb_3(OH)_2(CO_3)_2$ salts of lead.

Organolead

The best-known compounds are the two simplest plumbane derivatives: tetramethyllead (TML) and tetraethyllead (TEL). The homologs of these, as well as hexaethyldilead (HEDL), are of lesser stability. The tetralkyl derivatives contain lead(IV), where the Pb–C bonds are covalent. They thus resemble typical organic compounds.

Lead readily forms an equimolar alloy with sodium metal that reacts with alkyl halides to form organometallic compounds of lead such as tetraethyllead. The Pb–C bond energies in TML and TEL are only 167 and 145 kJ/mol; the compounds thus decompose upon heating, with first signs of TEL composition seen at 100 °C (210 °F).

The pyrolysis yields of elemental lead and alkyl radicals; their interreaction causes the synthesis of HEDL. TML and TEL also decompose upon sunlight or UV light. In presence of chlorine, the alkyls begin to be replaced with chlorides; the R_2PbCl_2 in the presence of HCl (a by-product of the previous reaction) leads to the complete mineralization to give $PbCl_2$. Reaction with bromine follows the same principle.

Applications

Elemental Form

Contrary to popular belief, pencil leads in wooden pencils have never been made from lead. The term comes from the Roman stylus, called the *penicillus*, a small brush used for painting. When the pencil originated as a wrapped graphite writing tool, the particular type of graphite being used was named *plumbago* (lit. *act for lead*, or *lead mockup*).

Lead is used in applications where its low melting point, ductility and high density are advantageous. The low melting point makes casting of lead easy, and therefore small arms ammunition and shotgun pellets can be cast with minimal technical equipment. It is also inexpensive and denser than other common metals.

Because of its high density and resistance from corrosion, lead is used for the ballast keel of sailboats. Its high density allows it to counterbalance the heeling effect of wind on the sails while at the same time occupying a small volume and thus offering the least underwater resistance.

For the same reason it is used in scuba diving weight belts to counteract the diver's natural buoyancy and that of his equipment. It does not have the weight-to-volume ratio of many heavy metals, but its low cost increases its use in these and other applications.

More than half of the US lead production (at least 1.15 million tons in 2000) is used for automobiles, mostly as electrodes in the lead–acid battery, used extensively as a car battery.

Cathode (Reduction)

$PbO_2 + 4\ H^+ + SO2-$
$4 + 2e^- \rightarrow PbSO_4 + 2\ H_2O$

Anode (Oxidation)

$Pb + SO2-$
$4 \rightarrow PbSO_4 + 2e^-$

Lead is used as electrodes in the process of electrolysis. It is used in solder for electronics, although this usage is being phased out by some countries to reduce the amount of environmentally hazardous waste, and in high voltage power cables as sheathing material to prevent water diffusion into insulation. Lead is one of three metals used in the Oddy test for museum materials, helping detect organic acids, aldehydes, and acidic gases. It is also used as shielding from radiation (e.g., in X-ray rooms). Molten lead is used as a coolant (e.g., for lead cooled fast reactors).

Lead is added to brass to reduce machine tool wear. In the form of strips, or tape, lead is used for the customization of tennis rackets. Tennis rackets of the past sometimes had lead added to them by the manufacturer to increase weight. It is also used to form glazing bars for stained glass or other multi-lit windows. The practice has become less common, not for danger but for stylistic reasons.

Lead, or *sheet-lead*, is used as a sound deadening layer in some areas in wall, floor and ceiling design in sound studios where levels of airborne and mechanically produced sound are targeted for reduction or virtual elimination. It is the traditional base metal of organ pipes, mixed with varying amounts of tin to control the tone of the pipe.

Compounds

Lead compounds are used as a coloring element in ceramic glazes, notably in the colors red and yellow. Lead is frequently used in polyvinyl chloride (PVC) plastic, which coats electrical cords.

Lead is used in some candles to treat the wick to ensure a longer, more even burn. Because of the dangers, European and North American manufacturers use more expensive alternatives such as zinc. Lead glass is composed of 12–28% lead oxide. It changes the optical characteristics of the glass and reduces the transmission of radiation.

Some artists using oil-based paints continue to use lead carbonate white, citing its properties in comparison with the alternatives. Tetra-ethyl lead is used as an anti-knock additive for aviation fuel in piston-driven aircraft. Lead-based semiconductors, such as lead telluride, lead selenide and lead antimonide are finding applications in photovoltaic (solar energy) cells and infrared detectors.

Former Applications

Lead pigments were used in lead paint for white as well as yellow, orange, and red. Most uses have been discontinued due of the dangers of lead poisoning. Beginning April 22, 2010, US federal law requires that contractors performing renovation, repair, and painting projects that disturb more than six square feet of paint in homes, child care facilities, and schools built before 1978 must be certified and trained to follow specific work practices to prevent lead contamination.

Lead chromate is still in industrial use. Lead carbonate (white) is the traditional pigment for the priming medium for oil painting, but it has been largely displaced by the zinc and titanium oxide pigments. It was also quickly replaced in water-based painting mediums. Lead carbonate white was used by the Japanese geisha and in the West for face-whitening make-up, which was detrimental to health.

Lead is the hot metal that was used in hot metal typesetting. It was used for plumbing (hence the name) as well as a preservative for food and drink in Ancient Rome. Until the early 1970s, lead was used for joining cast iron water pipes and used as a material for small diameter water pipes.

Tetraethyllead was used in leaded fuels to reduce engine knocking, but this practice has been phased out across many countries of the world in efforts to reduce toxic pollution that affected humans and the environment.

Lead was used to make bullets for slings. Lead was used for shotgun pellets in the US until about 1992 when it was outlawed (for waterfowl hunting only) and replaced by non-toxic shot, primarily steel pellets. In the Netherlands, the use of lead shot for hunting and sport shooting was banned in 1993, which caused a large drop in lead emission, from 230 tons in 1990 to 47.5 tons in 1995, two years after the ban.

Lead was a component of the paint used on children's toys – now restricted in the United States and across Europe (ROHS Directive). Lead was used in car body filler, which was used in many custom cars in the 1940s–60s. Hence the term Leadsled. Lead is a superconductor with a transition temperature of 7.2 K, and therefore IBM tried to make a Josephson effect computer out of a lead alloy.

Lead was also used in pesticides before the 1950s, when fruit orchards were treated especially against the codling moth. A lead cylinder attached to a long line was used by sailors for the vital navigational task of determining water depth by *heaving the lead* at regular intervals. A soft tallow insert at its base allowed the nature of the sea bed to be determined, further aiding position finding.

Health Effects

Lead is a highly poisonous metal (regardless if inhaled or swallowed), affecting almost every organ and system in the body. The main target for lead toxicity is the nervous system, both in adults and children. Long-term exposure of adults can result in decreased performance in some tests that measure functions of the nervous system. Long-term exposure to lead or its salts (especially soluble salts or the strong oxidant PbO_2) can cause nephropathy, and colic-like abdominal pains. It may also cause weakness in fingers, wrists, or ankles. Lead exposure also causes small increases in blood pressure, particularly in middle-aged and older people and can cause anemia. Exposure to high lead levels can severely damage the brain and kidneys in adults or children and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage.

Chronic, high-level exposure have shown to reduce fertility in males. Lead also damages nervous connections (especially in young children) and cause blood and brain disorders. Lead poisoning typically results from ingestion of food or water contaminated with lead; but may also occur after accidental ingestion of contaminated soil, dust, or lead-based paint. It is rapidly absorbed into the bloodstream and is believed to have adverse effects on the central nervous system, the cardiovascular system, kidneys, and the immune system. The component limit of lead (1.0 µg/g) is a test benchmark for pharmaceuticals, representing the maximum daily intake an individual should have. However, even at this low level, a prolonged intake can be hazardous to human beings. The treatment for lead poisoning consists of dimercaprol and succimer.

The concern about lead's role in cognitive deficits in children has brought about widespread reduction in its use (lead exposure has been linked to learning disabilities). Most cases of adult elevated blood lead levels are workplace-related. High blood levels are associated with delayed puberty in girls. Lead has been shown many times to permanently reduce the cognitive capacity of children at extremely low levels of exposure.

During the 20th century, the use of lead in paint pigments was sharply reduced because of the danger of lead poisoning, especially to children. By the mid-1980s, a significant shift in lead end-use patterns had taken place. Much of this shift was a result of the U.S. lead consumers' compliance with environmental regulations that significantly reduced or eliminated the use of lead in non-battery products, including gasoline, paints, solders, and water systems. Lead use is being further curtailed by the European Union's RoHS directive.

Lead may still be found in harmful quantities in stoneware, vinyl (such as that used for tubing and the insulation of electrical cords), and Chinese brass. Older houses may still contain substantial amounts of lead paint. White lead paint has been withdrawn from sale in industrialized countries, but the yellow lead chromate is still in use. Old paint should not be stripped by sanding, as this produces inhalable dust.

Lead salts used in pottery glazes have on occasion caused poisoning, when acidic drinks, such as fruit juices, have leached lead ions out of the glaze. It has been suggested that what was known as "Devon colic" arose from the use of lead-lined presses to extract apple juice in the manufacture of cider. Lead is considered to be particularly harmful for women's ability to reproduce. Lead(II) acetate (also known as *sugar of lead*) was used in the Roman Empire as a sweetener for wine, and some consider this to be the cause of the dementia that affected many of the Roman Emperors and even be a partial reason for the Roman Empire's fall.

Biochemistry of Poisoning

In the human body, lead inhibits porphobilinogen synthase and ferrochelatase, preventing both porphobilinogen formation and the incorporation of iron into protoporphyrin IX, the final step in heme synthesis. This causes ineffective heme synthesis and subsequent microcytic anemia. At lower levels, it acts as a calcium analog, interfering with ion channels during nerve conduction. This is one of the mechanisms by which it interferes with cognition. Acute lead poisoning is treated using disodium calcium edetate: the calcium chelate of the disodium salt of ethylene-diamine-tetracetic acid (EDTA). This chelating agent has a greater affinity for lead than for calcium and so the lead chelate is formed by exchange.

This is then excreted in the urine leaving behind harmless calcium. According to the Agency for Toxic Substance and Disease Registry, a small amount of ingested lead (1%) will store itself in bones, and the rest will be excreted by an adult through urine and feces within a few weeks of exposure. However, only about 32% of lead will be excreted by a child.

Exposure

Exposure to lead and lead chemicals can occur through inhalation, ingestion and dermal contact. Most exposure occurs through ingestion or inhalation; in the U.S. the skin exposure is unlikely as leaded gasoline additives are no longer used. Lead exposure is a global issue as lead mining and lead smelting are common in many countries. Most countries have stopped using lead-containing gasoline by 2007. Lead exposure mostly occurs through ingestion. Lead paint is the major source of lead exposure for children. As lead paint deteriorates, it peels, is pulverized into dust and then enters the body through hand-to-mouth contact or through contaminated food, water or alcohol. Ingesting certain home remedy medicines may also expose people to lead or lead compounds. Lead can be ingested through fruits and vegetables contaminated by high levels of lead in the soils they were grown in.

Soil is contaminated through particulate accumulation from lead in pipes, lead paint and residual emissions from leaded gasoline that was used before the Environment Protection Agency issue the regulation around 1980. The use of lead for water pipes is problematic in areas with soft or (and) acidic water. Hard water forms insoluble layers in the pipes while soft and acidic water dissolves the lead pipes.

Inhalation is the second major pathway of exposure, especially for workers in lead-related occupations. Almost all inhaled lead is absorbed into the body, the rate is 20–70% for ingested lead; children absorb more than adults. Dermal exposure may be significant for a narrow category of people working with organic lead compounds, but is of little concern for general population. The rate of skin absorption is also low for inorganic lead.

Mercury - Inorganic Contaminant 0.002 mg/L MCL

EPA regulates mercury in drinking water to protect public health. Mercury may cause health problems if present in public or private water supplies in amounts greater than the drinking water standard set by EPA.

What is Mercury?
Mercury is a liquid metal found in natural deposits such as ores containing other elements.

Uses for Mercury.
Electrical products such as dry-cell batteries, fluorescent light bulbs, switches, and other control equipment account for 50 percent of mercury used.

What are Mercury's Health Effects?
Some people who drink water containing mercury well in excess of the maximum contaminant level (MCL) for many years could experience kidney damage.

This health effects language is not intended to catalog all possible health effects for mercury. Rather, it is intended to inform consumers of some of the possible health effects associated with mercury in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Mercury?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for mercury is 0.002 mg/L or 2 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for mercury, called a maximum contaminant level (MCL), at 0.002 mg/L or 2 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for mercury, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed mercury as part of the Six Year Review and determined that the 0.002 mg/L or 2 ppb MCLG and 0.002 mg/L or 2 ppb MCL for mercury are still protective of human health.

States may set more stringent drinking water MCLGs and MCLs for mercury than EPA.

How does Mercury get into my Drinking Water?
The major sources of mercury in drinking water are erosion of natural deposits; discharge from refineries and factories; runoff from landfills; and runoff from croplands.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Mercury is in my Drinking Water?

When routine monitoring indicates that mercury levels are above the MCL, your water supplier must take steps to reduce the amount of mercury so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Mercury be removed from my Drinking Water?

The following treatment method(s) have proven to be effective for removing mercury to below 0.002 mg/L or 2 ppb: coagulation/filtration, granular activated carbon, lime softening, and reverse osmosis.

How do I learn more about my Drinking Water?

EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Mercury Explained

Mercury is a chemical element with the symbol **Hg** and atomic number 80. It is also known as **quicksilver** or **hydrargyrum** (< Greek "hydr-" *water* and "argyros" *silver*). A heavy, silvery d-block element, mercury is the only metal that is liquid at standard conditions for temperature and pressure; the only other element that is liquid under these conditions is bromine, though metals such as cesium, gallium, and rubidium melt just above room temperature. With a freezing point of −38.83 °C and boiling point of 356.73 °C, mercury has one of the narrowest ranges of its liquid state of any metal.

Mercury occurs in deposits throughout the world mostly as cinnabar (mercuric sulfide). The red pigment vermilion is mostly obtained by reduction from cinnabar. Cinnabar is highly toxic by ingestion or inhalation of the dust. Mercury poisoning can also result from exposure to water-soluble forms of mercury (such as mercuric chloride or methylmercury), inhalation of mercury vapor, or eating seafood contaminated with mercury.

Mercury is used in thermometers, barometers, manometers, sphygmomanometers, float valves, mercury switches, and other devices though concerns about the element's toxicity have led to mercury thermometers and sphygmomanometers being largely phased out in clinical environments in favor of alcohol-filled, galinstan-filled, digital, or thermistor-based instruments.

It remains in use in scientific research applications and in amalgam material for dental restoration. It is used in lighting: electricity passed through mercury vapor in a phosphor tube produces short-wave ultraviolet light which then causes the phosphor to fluoresce, making visible light.

Physical Properties

Mercury is a heavy, silvery-white metal. As compared to other metals, it is a poor conductor of heat, but a fair conductor of electricity. Mercury has an exceptionally low melting temperature for a d-block metal. A complete explanation of this delves deep into the realm of quantum physics, but it can be summarized as follows: mercury has a unique electronic configuration where electrons fill up all the available 1s, 2s, 2p, 3s, 3p, 3d, 4s, 4p, 4d, 4f, 5s, 5p, 5d and 6s subshells. As such configuration strongly resists removal of an electron, mercury behaves similarly to noble gas elements, which form weak bonds and thus easily melting solids. The stability of the 6s shell is due to the presence of a filled 4f shell. An f shell poorly screens the nuclear charge that increases the attractive Coulomb interaction of the 6s shell and the nucleus (see lanthanide contraction).

The absence of a filled inner *f* shell is the reason for the somewhat higher melting temperature of cadmium and zinc, although both these metals still melt easily and, in addition, have unusually low boiling points. On the other hand, gold, which is one space to the left of mercury on the periodic table, has atoms with one less 6s electron than mercury. Those electrons are more easily removed and are shared between the gold atoms forming relatively strong metallic bonds.

Chemical Properties

Mercury does not react with most acids, such as dilute sulfuric acid, although oxidizing acids such as concentrated sulfuric acid and nitric acid or aqua regia dissolve it to give sulfate, nitrate, and chloride salts. Like silver, mercury reacts with atmospheric hydrogen sulfide. Mercury even reacts with solid sulfur flakes, which are used in mercury spill kits to absorb mercury vapors (spill kits also use activated carbon and powdered zinc).

Amalgams

Mercury dissolves to form amalgams with gold, zinc and many other metals. Because iron is an exception, iron flasks have been traditionally used to trade mercury. Other metals that do not form amalgams with mercury include tantalum, tungsten and platinum. Sodium amalgam is a common reducing agent in organic synthesis, and is also used in high-pressure sodium lamps.

Mercury readily combines with aluminum to form a mercury-aluminum amalgam when the two pure metals come into contact. Since the amalgam destroys the aluminum oxide layer which protects metallic aluminum from oxidizing in-depth (as in iron rusting), even small amounts of mercury can seriously corrode aluminum. For this reason, mercury is not allowed aboard an aircraft under most circumstances because of the risk of it forming an amalgam with exposed aluminum parts in the aircraft.

Isotopes

There are seven stable isotopes of mercury with ^{202}Hg being the most abundant (29.86%). The longest-lived radioisotopes are ^{194}Hg with a half-life of 444 years, and ^{203}Hg with a half-life of 46.612 days. Most of the remaining radioisotopes have half-lives that are less than a day. ^{199}Hg and ^{201}Hg are the most often studied NMR-active nuclei, having spins of ½ and $\frac{3}{2}$ respectively.

History

The symbol for the planet Mercury (☿) has been used since ancient times to represent the element.

In China and Tibet, mercury use was thought to prolong life, heal fractures, and maintain generally good health, although it is now known that exposure to mercury leads to serious adverse health effects. The first emperor of China, Qín Shǐ Huáng Dì — allegedly buried in a tomb that contained rivers of flowing mercury on a model of the land he ruled, representative of the rivers of China — was killed by drinking a mercury and powdered jade mixture formulated by Qin alchemists (causing liver failure, mercury poisoning, and brain death) who intended to give him eternal life.

The ancient Greeks used mercury in ointments; the ancient Egyptians and the Romans used it in cosmetics which sometimes deformed the face. In Lamanai, once a major city of the Maya civilization, a pool of mercury was found under a marker in a Mesoamerican ballcourt. By 500 BC mercury was used to make amalgams (Medieval Latin amalgama, "alloy of mercury") with other metals.

Alchemists thought of mercury as the First Matter from which all metals were formed. They believed that different metals could be produced by varying the quality and quantity of sulfur contained within the mercury. The purest of these was gold, and mercury was called for in attempts at the transmutation of base (or impure) metals into gold, which was the goal of many alchemists.

Hg is the modern chemical symbol for mercury. It comes from *hydrargyrum*, a Latinized form of the Greek word ΄Υδραργυρος (*hydrargyros*), which is a compound word meaning "water-silver" (hydr- = water, argyros = silver) — since it is liquid like water and shiny like silver. The element was named after the Roman god Mercury, known for speed and mobility. It is associated with the planet Mercury; the astrological symbol for the planet is also one of the alchemical symbols for the metal; the Sanskrit word for alchemy is *Rasavātam* which means "the way of mercury". Mercury is the only metal for which the alchemical planetary name became the common name.

The mines in Almadén (Spain), Monte Amiata (Italy), and Idrija (now Slovenia) dominated mercury production from the opening of the mine in Almadén 2500 years ago, until new deposits were found at the end of the 19th century.

Chemistry

Mercury exists in two main oxidation states, I and II. Higher oxidation states are unimportant, but have been detected, e.g., mercury(IV) fluoride (HgF_4) but only under extraordinary conditions.

Compounds of Mercury (I)

Different from its lighter neighbors, cadmium and zinc, mercury forms simple stable compounds with metal-metal bonds. The mercury(I) compounds are diamagnetic and feature the dimeric cation, Hg2+2.

Stable derivatives include the chloride and nitrate. Treatment of Hg(I) compounds complexation with strong ligands such as sulfide, cyanide, etc. induces disproportionation to Hg^{2+} and elemental mercury. Mercury(I) chloride, a colorless solid also known as calomel, is really the compound with the formula Hg_2Cl_2, with the connectivity Cl-Hg-Hg-Cl. It is a standard in electrochemistry. It reacts with chlorine to give mercuric chloride, which resists further oxidation.

Indicative of its tendency to bond to itself, mercury forms mercury polycations, which consist of linear chains of mercury centers, capped with a positive charge. One example is Hg2+ 3(AsF−6)2.

Compounds of Mercury (II)

Mercury(II) is the most common oxidation state and is the main one in nature as well. All four mercuric halides are known. The form tetrahedral complexes with other ligands but the halides adopt linear coordination geometry, somewhat like Ag^+ does. Best known is mercury(II) chloride, an easily sublimating white solid. $HgCl_2$ forms coordination complexes that are typically tetrahedral, e.g. HgCl2−4.

Mercury(II) oxide, the main oxide of mercury, arises when the metal is exposed to air for long periods at elevated temperatures. It reverts to the elements upon heating near 400 °C, as was demonstrated by Priestly in an early synthesis of pure oxygen. Hydroxides of mercury are poorly characterized, as they are for its neighbors gold and silver.

Being a soft metal, mercury forms very stable derivatives with the heavier chalcogens. Preeminent is mercury(II) sulfide, HgS, which occurs in nature as the ore cinnabar and is the brilliant pigment vermillion. Like ZnS, HgS crystallizes in two forms, the reddish cubic form and the black zinc blende form. Mercury(II) selenide (HgSe) and mercury(II) telluride (HgTe) are also known, these as well as various derivatives, e.g. mercury cadmium telluride and mercury zinc telluride being semiconductors useful as infrared detector materials.

Mercury(II) salts form a variety of complex derivatives with ammonia. These include Millon's base (Hg_2N^+), the one-dimensional polymer (salts of HgNH+2) n), and "fusible white precipitate" or $[Hg(NH_3)_2]Cl_2$. Known as Nessler's reagent, potassium tetraiodomercurate(II) (HgI2−4) is still occasionally used to test for ammonia owing to its tendency to form the deeply colored iodide salt of Millon's base.

Higher Oxidation States

Oxidation states above +2 in a non-charged species are extremely rare, although a cyclic mercurinium(IV) cation, with three substituents, is an intermediate in oxymercuration reactions. In 2007, a report of synthesis of a mercury(IV) compound, mercury(IV) fluoride, was published. In the 1970s, there was a claim on synthesis of a mercury(III) compound, but it is now thought to be false.

Organomercury Compounds

Organic mercury compounds are historically important but are of little industrial value in the western world. Mercury(II) salts are a rare examples of simple metal complexes that react directly with aromatic rings. Organomercury compounds are always divalent and usually two-coordinate and linear geometry. Unlike organocadmium and organozinc compounds, organomercury, . compounds do not react with water. They usually have the formula HgR_2, which are often volatile, or HgRX, which are often solids, where R is aryl or alkyl and X is usually halide or acetate. Methylmercury, a generic term for compounds with the formula CH_3HgX, is a dangerous family of compounds that are often found in polluted water. They arise by a process known as biomethylation.

Applications
Mercury is used primarily for the manufacture of industrial chemicals or for electrical and electronic applications. It is used in some thermometers, especially ones which are used to measure high temperatures. A still increasing amount is used as gaseous mercury in fluorescent lamps, while most of the other applications are slowly phased out due to health and safety regulations and is in some applications replaced with less toxic but considerably more expensive Galinstan alloy.

Medicine
Mercury and its compounds have been used in medicine, although they are much less common today than they once were, now that the toxic effects of mercury and its compounds are more widely understood. The element mercury is an ingredient in dental amalgams. Thiomersal (called *Thimerosal* in the United States) is an organic compound used as a preservative in vaccines, though this use is in decline. Another mercury compound Merbromin (Mercurochrome) is a topical antiseptic used for minor cuts and scrapes is still in use in some countries.

Since the 1930s some vaccines have contained the preservative thiomersal, which is metabolized or degraded to ethyl mercury. Although it was widely speculated that this mercury-based preservative can cause or trigger autism in children, scientific studies showed no evidence supporting any such link. Nevertheless thiomersal has been removed from or reduced to trace amounts in all U.S. vaccines recommended for children 6 years of age and under, with the exception of inactivated influenza vaccine.

Mercury in the form of one of its common ores, cinnabar, is used in various traditional medicines, especially in traditional Chinese medicine. Review of its safety has found cinnabar can lead to significant mercury intoxication when heated, consumed in overdose or taken long term, and can have adverse effects at therapeutic doses, though this is typically reversible at therapeutic doses. Although this form of mercury appears less toxic than others, its use in traditional Chinese medicine has not yet been justified as the therapeutic basis for the use of cinnabar is not clear.

Today, the use of mercury in medicine has greatly declined in all respects, especially in developed countries. Thermometers and sphygmomanometers containing mercury were invented in the early 18th and late 19th centuries, respectively. In the early 21st century, their use is declining and has been banned in some countries, states and medical institutions. In 2002, the U.S. Senate passed legislation to phase out the sale of non-prescription mercury thermometers. In 2003, Washington and Maine became the first states to ban mercury blood pressure devices. Mercury compounds are found in some over-the-counter drugs, including topical antiseptics, stimulant laxatives, diaper-rash ointment, eye drops, and nasal sprays.

The FDA has "inadequate data to establish general recognition of the safety and effectiveness", of the mercury ingredients in these products. Mercury is still used in some diuretics, although substitutes now exist for most therapeutic uses.

Production of Chlorine and Caustic Soda
Chlorine is produced from sodium chloride (common salt, NaCl) using electrolysis to separate the metallic sodium from the chlorine gas. Usually the salt is dissolved in water to produce a brine. By-products of any such chloralkali process are hydrogen (H_2) and sodium hydroxide (NaOH), which is commonly called caustic soda or lye. By far the largest use of mercury in the late 20th century was in the mercury cell process (also called the Castner-Kellner process) where metallic sodium is formed as an amalgam at a cathode made from mercury; this sodium is then reacted with water to produce sodium hydroxide. Many of the industrial mercury releases of the 20th century came from this process, although modern plants claimed to be safe in this regard.

After about 1985, all new chloralkali production facilities that were built in the United States used either membrane cell or diaphragm cell technologies to produce chlorine.

Laboratory Uses

Some medical thermometers, especially those for high temperatures, are filled with mercury; however, they are gradually disappearing. In the United States, non-prescription sale of mercury fever thermometers has been banned since 2003.

Liquid mercury is a part of popular secondary reference electrode (called the calomel electrode) in electrochemistry as an alternative to the standard hydrogen electrode. The calomel electrode is used to work out the electrode potential of half cells. Last, but not least, the triple point of mercury, −38.8344 °C, is a fixed point used as a temperature standard for the International Temperature Scale (ITS-90).

Toxicity and Safety

Mercury and most of its compounds are extremely toxic and must be handled with care; in cases of spills involving mercury (such as from certain thermometers or fluorescent light bulbs), specific cleaning procedures are used to avoid exposure and contain the spill. Protocols call for physically merging smaller droplets on hard surfaces, combining them into a single larger pool for easier removal with an eyedropper, or for gently pushing the spill into a disposable container. Vacuum cleaners and brooms cause greater dispersal of the mercury and should not be used.

Afterwards, fine sulfur, zinc, or some other powder that readily forms an amalgam (alloy) with mercury at ordinary temperatures is sprinkled over the area before itself being collected and properly disposed of. Cleaning porous surfaces and clothing is not effective at removing all traces of mercury and it is therefore advised to discard these kinds of items should they be exposed to a mercury spill.

Mercury can be absorbed through the skin and mucous membranes and mercury vapors can be inhaled, so containers of mercury are securely sealed to avoid spills and evaporation. Heating of mercury, or of compounds of mercury that may decompose when heated, is always carried out with adequate ventilation in order to avoid exposure to mercury vapor. The most toxic forms of mercury are its organic compounds, such as dimethylmercury and methylmercury. Inorganic compounds, such as cinnabar are also highly toxic by ingestion or inhalation. Mercury can cause both chronic and acute poisoning.

Releases in the Environment

Amount of atmospheric mercury deposited at Wyoming's Upper Fremont Glacier over the last 270 years

Preindustrial deposition rates of mercury from the atmosphere may be about 4 ng /(1 L of ice deposit). Although that can be considered a natural level of exposure, regional or global sources have significant effects. Volcanic eruptions can increase the atmospheric source by 4–6 times.
Natural sources, such as volcanoes, are responsible for approximately half of atmospheric mercury emissions.

The human-generated half can be divided into the following estimated percentages:

- 65% from stationary combustion, of which coal-fired power plants are the largest aggregate source (40% of U.S. mercury emissions in 1999). This includes power plants fueled with gas where the mercury has not been removed. Emissions from coal combustion are between one and two orders of magnitude higher than emissions from oil combustion, depending on the country.

- 11% from gold production. The three largest point sources for mercury emissions in the U.S. are the three largest gold mines. Hydrogeochemical release of mercury from gold-mine tailings has been accounted as a significant source of atmospheric mercury in eastern Canada.
- 6.8% from non-ferrous metal production, typically smelters.
- 6.4% from cement production.
- 3.0% from waste disposal, including municipal and hazardous waste, crematoria, and sewage sludge incineration.
- 3.0% from caustic soda production.
- 1.4% from pig iron and steel production.
- 1.1% from mercury production, mainly for batteries.
- 2.0% from other sources.

The above percentages are estimates of the global human-caused mercury emissions in 2000, excluding biomass burning, an important source in some regions.

Mercury also enters into the environment through the improper disposal (e.g., land filling, incineration) of certain products. Products containing mercury include: auto parts, batteries, fluorescent bulbs, medical products, thermometers, and thermostats. Due to health concerns (see below), toxics use reduction efforts are cutting back or eliminating mercury in such products. For example, the amount of mercury sold in thermostats in the United States decreased from 14.5 tons in 2004 to 3.9 tons in 2007.

Most thermometers now use pigmented alcohol instead of mercury, and galinstan alloy thermometers are also an option. Mercury thermometers are still occasionally used in the medical field because they are more accurate than alcohol thermometers, though both are commonly being replaced by electronic thermometers and less commonly by galinstan thermometers. Mercury thermometers are still widely used for certain scientific applications because of their greater accuracy and working range.

The United States Clean Air Act, passed in 1990, put mercury on a list of toxic pollutants that need to be controlled to the greatest possible extent. Thus, industries that release high concentrations of mercury into the environment agreed to install maximum achievable control technologies (MACT). In March 2005 EPA rule added power plants to the list of sources that should be controlled and a national cap and trade rule was issued.

States were given until November 2006 to impose stricter controls, and several States are doing so. The rule was being subjected to legal challenges from several States in 2005 and decision was made in 2008. The Clean Air Mercury Rule was struck down by a Federal Appeals Court on February 8, 2008. The rule was deemed not sufficient to protect the health of persons living near coal-fired power plants. The court opinion cited the negative impact on human health from coal-fired power plants' mercury emissions documented in the EPA Study Report to Congress of 1998.

The EPA announced new rules for coal-fired power plants on December 22, 2011. Cement kilns that burn hazardous waste are held to a looser standard than are standard hazardous waste incinerators in the United States, and as a result are a disproportionate source of mercury pollution.

Historically, one of the largest releases was from the Colex plant, a lithium-isotope separation plant at Oak Ridge. The plant operated in the 1950s and 1960s. Records are incomplete and unclear, but government commissions have estimated that some two million pounds of mercury are unaccounted for.

A serious industrial disaster was the dumping of mercury compounds into Minamata Bay, Japan. It is estimated that over 3,000 people suffered various deformities, severe mercury poisoning symptoms or death from what became known as Minamata disease.

Occupational Exposure

Due to the health effects of mercury exposure, industrial and commercial uses are regulated in many countries. The World Health Organization, OSHA, and NIOSH all treat mercury as an occupational hazard, and have established specific occupational exposure limits. Environmental releases and disposal of mercury are regulated in the U.S. primarily by the United States Environmental Protection Agency.

Case control studies have shown effects such as tremors, impaired cognitive skills, and sleep disturbance in workers with chronic exposure to mercury vapor even at low concentrations in the range 0.7–42 $\mu g/m^3$. A study has shown that acute exposure (4 – 8 hours) to calculated elemental mercury levels of 1.1 to 44 mg/m^3 resulted in chest pain, dyspnea, cough, hemoptysis, impairment of pulmonary function, and evidence of interstitial pneumonitis. Acute exposure to mercury vapor has been shown to result in profound central nervous system effects, including psychotic reactions characterized by delirium, hallucinations, and suicidal tendency.

Occupational exposure has resulted in broad-ranging functional disturbance, including erethism, irritability, excitability, excessive shyness, and insomnia. With continuing exposure, a fine tremor develops and may escalate to violent muscular spasms. Tremor initially involves the hands and later spreads to the eyelids, lips, and tongue. Long-term, low-level exposure has been associated with more subtle symptoms of erethism, including fatigue, irritability, loss of memory, vivid dreams and depression.

Treatment

Research on the treatment of mercury poisoning is limited. Currently available drugs for acute mercurial poisoning include chelators N-acetyl-D, L-penicillamine (NAP), British Anti-Lewisite (BAL), 2,3-dimercapto-1-propanesulfonic acid (DMPS), and dimercaptosuccinic acid (DMSA). In one small study including 11 construction workers exposed to elemental mercury, patients were treated with DMSA and NAP. Chelation therapy with both drugs resulted in the mobilization of a small fraction of the total estimated body mercury. DMSA was able to increase the excretion of mercury to a greater extent than NAP.

Fish

Fish and shellfish have a natural tendency to concentrate mercury in their bodies, often in the form of methylmercury, a highly toxic organic compound of mercury. Species of fish that are high on the food chain, such as shark, swordfish, king mackerel, bluefin tuna, albacore tuna, and tilefish contain higher concentrations of mercury than others. As mercury and methylmercury are fat soluble, they primarily accumulate in the viscera, although they are also found throughout the muscle tissue. When this fish is consumed by a predator, the mercury level is accumulated.

Since fish are less efficient at depurating than accumulating methylmercury, fish-tissue concentrations increase over time. Thus species that are high on the food chain amass body burdens of mercury that can be ten times higher than the species they consume. This process is called biomagnification. Mercury poisoning happened this way in Minamata, Japan, now called Minamata disease.

Regulations

United States

In the United States, the Environmental Protection Agency is charged with regulating and managing mercury contamination. Several laws give the EPA this authority, including the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act, and the Safe Drinking Water Act. Additionally, the Mercury-Containing and Rechargeable Battery Management Act, passed in 1996, phases out the use of mercury in batteries, and provides for the efficient and cost-effective disposal of many types of used batteries. North America contributed approximately 11% of the total global anthropogenic mercury emissions in 1995.

Nitrate (Measured as Nitrogen) - Inorganic Contaminant 10 mg/L MCL

EPA regulates nitrate in drinking water to protect public health. Nitrate may cause health problems if present in public or private water supplies in amounts greater than the drinking water standard set by EPA.

What is Nitrate?
Nitrates and nitrites are nitrogen-oxygen chemical units which combine with various organic and inorganic compounds.

Uses for Nitrate.
The greatest use of nitrates is as a fertilizer. Once taken into the body, nitrates are converted to nitrites.

What are Nitrate's Health Effects?
Infants below six months who drink water containing nitrate in excess of the maximum contaminant level (MCL) could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue baby syndrome.

This health effects language is not intended to catalog all possible health effects for nitrate. Rather, it is intended to inform consumers of some of the possible health effects associated with nitrate in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Nitrate?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for nitrate is 10 mg/L or 10 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for nitrate, called a maximum contaminant level (MCL), at 10 mg/L or 10 ppm. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule , the regulation for nitrate, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed nitrate as part of the Six Year Review and determined that the 10 mg/L or 10 ppm MCLG and 10 mg/L or 10 ppm MCL for nitrate are still protective of human health.

States may set more stringent drinking water MCLGs and MCLs for nitrate than EPA.

How does Nitrate get into my Drinking Water?

The major sources of nitrates in drinking water are runoff from fertilizer use; leaking from septic tanks, sewage; and erosion of natural deposits.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Nitrate is in my Drinking Water?

When routine monitoring indicates that nitrate levels are above the MCL, your water supplier must take steps to reduce the amount of nitrate so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 24 hours after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will nitrate be Removed from my Drinking Water?

The following treatment method(s) have proven to be effective for removing nitrate to below 10 mg/L or 10 ppm: ion exchange, reverse osmosis, electrodialysis.

How do I learn more about my Drinking Water?

EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

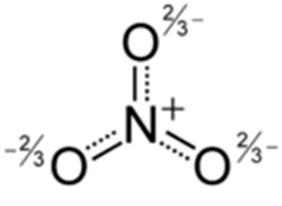
Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Nitrate Explained

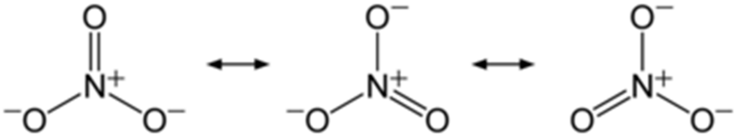
The **nitrate ion** is a polyatomic ion with the molecular formula NO_3^- and a molecular mass of 62.0049 g/mol.

Structure

It is the conjugate base of nitric acid, consisting of one central nitrogen atom surrounded by three identically bonded oxygen atoms in a trigonal planar arrangement. The nitrate ion carries a formal charge of -1. This results from a combination formal charge in which each of the three oxygens carries a $-\frac{2}{3}$ charge, whereas the nitrogen carries a +1 charge, all these adding up to formal charge of the polyatomic nitrate ion.



The nitrate ion. The net charge of the whole ion is 1^-.
This arrangement is commonly used as an example of resonance. Like the isoelectronic carbonate ion, the nitrate ion can be represented by resonance structures:



Properties
Almost all inorganic nitrate salts are soluble in water at standard temperature and pressure. A common example of an inorganic nitrate salt is potassium nitrate (saltpeter).

In organic chemistry a nitrate (not to be confused with Nitro or Nitrite) is a relatively rare functional group with general chemical formula $RONO_2$ where R stands for any organic residue. They are the esters of nitric acid and alcohols formed by **nitroxylation**. Examples are **methyl nitrate** formed by reaction of methanol and nitric acid, the nitrate of tartaric acid, and the inaccurately named nitroglycerin (which is actually an organic *nitrate* compound, not a *nitro* compound).

Like organic nitro compounds (see below) both organic and inorganic nitrates can be used as propellants and explosives. In these uses, the thermal decomposition of the nitrate yields molecular nitrogen N_2 gas plus considerable chemical energy, due to the high strength of the bond in molecular nitrogen. Especially in inorganic nitrate reactions, oxidation from the nitrate oxygens is also an important energy-releasing process.

Occurrence
Nitrate compounds are found naturally on earth as large deposits, particularly of Chile saltpeter a major source of sodium nitrate.

Nitrites are produced by a number of species of nitrifying bacteria, and the nitrate compounds for gunpowder (see this topic for more) were historically produced, in the absence of mineral nitrate sources, by means of various fermentation processes using urine and dung.

Uses
Nitrates are mainly produced for use as fertilizers in agriculture because of their high solubility and biodegradability. The main nitrates are ammonium, sodium, potassium, and calcium salts. Several million kilograms are produced annually for this purpose.

Other Uses
The second major application of nitrates as oxidizing agents, most notably in explosives where the rapid oxidation of carbon compounds liberates large volumes of gases (see Gunpowder for an example). Sodium nitrate is used to remove air bubbles from molten glass and some ceramics. Mixtures of the molten salt are used to harden some metals.

Detection
Free nitrate ions in solution can be detected by a nitrate ion selective electrode. Such electroders analogously to the pH selective electrode. This response is partially described by the Nernst equation.

Toxicity/Toxicosis

Nitrate toxicosis can occur through enterohepatic metabolism of nitrate to nitrite being an intermediate. Nitrites oxidize the iron atoms in hemoglobin from ferrous iron (2+) to ferric iron (3+), rendering it unable to carry oxygen. This process can lead to generalized lack of oxygen in organ tissue and a dangerous condition called methemoglobinemia. Although nitrite converts to ammonia, if there is more nitrite than can be converted, the animal slowly suffers from a lack of oxygen.

Human Health Effects

Humans are subject to nitrate toxicity, with infants being especially vulnerable to methemoglobinemia due to nitrate metabolizing triglycerides present at higher concentrations than at other stages of development. Methemoglobinemia in infants is known as blue baby syndrome. Although nitrates in drinking water were once thought to be a contributing factor, there are now significant scientific doubts as to whether there is a causal link.

Blue baby syndrome is now thought to be the product of a number of factors, which can include any factor which causes gastric upset, such as diarrheal infection, protein intolerance, heavy metal toxicity etc., with nitrates playing a minor role. Nitrates, if a factor in a specific case, would most often be ingested by infants in high nitrate drinking water. However, nitrate exposure may also occur if eating, for instance, vegetables containing high levels of nitrate. Lettuce may contain elevated nitrate under growth conditions such as reduced sunlight, undersupply of the essential micronutrients molybdenum (Mo) and iron (Fe), or high concentrations of nitrate due to reduced assimilation of nitrate in the plant. High levels of nitrate fertilization also contribute to elevated levels of nitrate in the harvested plant.

Nitrate Overview

HNO_3																	He
$LiNO_3$	$Be(NO_3)_2$											B	C	N	O	F	Ne
$NaNO_3$	$Mg(NO_3)_2$											$Al(NO_3)_3$	Si	P	S	$ClONO_2$	Ar
KNO_3	$Ca(NO_3)_2$	$Sc(NO_3)_3$	Ti	V	$Cr(NO_3)_3$	$Mn(NO_3)_2$	$Fe(NO_3)_3$	$Co(NO_3)_2$	$Ni(NO_3)_2$	$Cu(NO_3)_2$	$Zn(NO_3)_2$	Ga	Ge	As	Se	Br	Kr
$RbNO_3$	$Sr(NO_3)_2$	Y	Zr	Nb	Mo	Tc	Ru	Rh	$Pd(NO_3)_2$	$AgNO_3$	$Cd(NO_3)_2$	In	Sn	Sb	Te	Cl	Xe
$CsNO_3$	$Ba(NO_3)_2$		Hf	Ta	W	Re	Os	Ir	Pt	Au	$Hg(NO_3)_2$	Tl	$Pb(NO_3)_2$	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo

↓

La	Ce	Pr	Nd	Pm	Sm	Eu	$Gd(NO_3)_3$	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	$UO_2(NO_3)_2$	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Nitrite (Measured as Nitrogen) - Inorganic Contaminant 1 mg/L MCL

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The following treatment method(s) have proven to be effective for removing nitrite to below 1 mg/L or 1 ppm: ion exchange, reverse osmosis.

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Nitrite Explained

The **nitrite** ion, which has the chemical formula NO_2^-, is a symmetric anion with equal N-O bond lengths and a O-N-O bond angle of approximately 120°. Upon protonation, the unstable weak acid nitrous acid is produced. Nitrite can be oxidized or reduced, with the product somewhat dependent on the oxidizing/reducing agent and its strength.

The nitrite ion is an ambidentate ligand, and is known to bond to metal centers in at least five different ways. Nitrite is also important in biochemistry as a source of the potent vasodilator nitric oxide. In organic chemistry the NO_2 group is present in nitrous acid esters and nitro compounds. Nitrites are also used in the food production industry for curing meat.

The Nitrite Ion
Nitrite Salts
Sodium nitrite is made industrially by passing "nitrous fumes" into aqueous sodium hydroxide or sodium carbonate solution:

$$\mathbf{NO + NO_2 + 2NaOH\ (or\ Na_2CO_3) \rightarrow 2NaNO_2 + H_2O\ (\ or\ CO_2)}$$

The product is purified by recrystallization. Alkali metal nitrites are thermally stable up to and beyond their melting point (441 °C for KNO_2). Ammonium nitrite can be made from dinitrogen trioxide, N_2O_3, which is formally the anhydride of nitrous acid:

$$\mathbf{2NH_3 + H_2O + N_2O_3 \rightarrow 2NH_4NO_2}$$

This compound may decompose explosively on heating. In organic chemistry nitrites are used in diazotization reactions.

Structure
The nitrite ion has a symmetrical structure (C_{2v} symmetry), with both N-O bonds having equal length. In valence bond theory, it is described as a resonance hybrid with equal contributions from two canonical forms that are mirror images of each other. In molecular orbital theory, there is a sigma bond between each oxygen atom and the nitrogen atom, and a delocalized pi bond made from the p orbitals on nitrogen and oxygen atoms which is perpendicular to the plane of the molecule. The negative charge of the ion is equally distributed on the two oxygen atoms. Both nitrogen and oxygen atoms carry a lone pair of electrons. Therefore, the nitrite ion is a Lewis base. Moreover, it can act as an ambidentate ligand towards a metal ion, donating a pair of electrons from either nitrogen or oxygen atoms.

Acid-base Properties
In aqueous solution, nitrous acid is a weak acid:

$$\mathbf{HNO_2 \rightleftharpoons H^+ + NO_2^-;\ pK_a = ca.\ 3.3\ at\ 18\ ^\circ C}$$

Nitrous acid is also highly volatile - in the gas phase it exists predominantly as a *trans*-planar molecule. In solution, it is unstable with respect to the disproportionation reaction:

$$\mathbf{3HNO_2\ (aq) \rightleftharpoons H_3O^+ + NO_3^- + 2NO}$$

This reaction is slow at 0 °C. Addition of acid to a solution of a nitrite in the presence of a reducing agent, such as iron (II), is a way to make nitric oxide (NO) in the laboratory.

Oxidation and reduction
The formal oxidation state of the nitrogen atom in a nitrite is +3. This means that it is can be either oxidized to oxidation states +4 and +5, or reduced to oxidation states as low as -3. Standard reduction potentials for reactions directly involving nitrous acid are shown in the table below:

Half-reaction	**E^0/V**
$NO_3^- + 3H^+ + 2e^- \rightleftharpoons HNO_2 + H_2O$	+0.94
$2HNO_2 + 4H^+ + 4e^- \rightleftharpoons H_2N_2O_2 + 2H_2O$	+0.86
$N_2O_4 + 2H^+ + 2e^- \rightleftharpoons 2HNO_2$	+1.065
$2HNO_2 + 4H^+ + 4e^- \rightleftharpoons N_2O + 3H_2O$	+1.29

The data can be extended to include products in lower oxidation states. For example:

$$H_2N_2O_2 + 2H^+ + 2e^- \rightleftharpoons N_2 + 2H_2O;\ E^0 = 2.65V$$

Oxidation reactions usually result in the formation of the nitrate ion, with nitrogen in oxidation state +5. For example, oxidation with permanganate ion can be used for quantitative analysis of nitrite (by titration):

$$5NO_2^- + 2MnO_4^- + 6H^+ \rightarrow 5NO_3^- + 2Mn^{2+} + 3H_2O$$

The product of reduction reactions with nitrite ion are varied, depending on the reducing agent used and its strength. With sulfur dioxide, the products are NO and N_2O; with tin (II), Sn^{2+}, the product is hyponitrous acid, $H_2N_2O_2$; reduction all the way to ammonia ($NH_{3)}$ occurs with hydrogen sulfide. With the hydrazinium cation, $N_2H_5^+$, hydrogen azide, HN_3, an explosive compound, is produced:

$$HNO_2 + N_2H_5^+ \rightarrow HN_3 + H_2O + H_3O^+$$

which can also further react with nitrite:

$$HNO_2 + HN_3 \rightarrow N_2O + N_2 + H_2O$$

This reaction is unusual in that it involves compounds with nitrogen in four different oxidation states.

Coordination Complexes

The nitrite ion is known to form coordination complexes in at least five different ways.

1. When donation is from nitrogen to a metal center, the complex is known as a *nitro-* complex.
2. When donation is from one oxygen to a metal center, the complex is known as a *nitrito-* complex.
3. Both oxygen atoms may donate to a metal center, forming a chelate complex.
4. A nitrite ion can form an unsymmetrical bridge between two metal centers, donating through nitrogen to one metal, and through oxygen to the other.
5. A single oxygen atom can bridge to two metal centers.

Alfred Werner studied the nitro-nitrito isomerism (1 and 2) extensively. The red isomer of cobalt pentamine with nitrite is now known to be a nitrito complex, $[Co(NH_3)_5(ONO)]^{2+}$; it is metastable and isomerizes to the yellow nitro complex $[Co(NH_3)_5(NO_2)]^{2+}$.

An example of chelating nitrite (3) was found in $[Cu(bipy)_2(O_2N)]NO_3$ - "bipy" is the bidentate ligand 2,2'bypyridyl, with the two bipy ligands occupying four coordination sites on the copper ion, so that the nitrite is forced to occupy two sites in order to achieve an octahedral environment around the copper ion.

Nitrite in Biochemistry

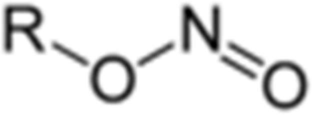
Sodium nitrite is used for the curing of meat because it prevents bacterial growth and, in a reaction with the meat's myoglobin, gives the product a desirable dark red color. Because of the relatively high toxicity of nitrite (the lethal dose in humans is about 22 milligrams per kilogram of body weight), the maximum allowed nitrite concentration in meat products is 200 ppm.

Under certain conditions - especially during cooking - nitrites in meat can react with degradation products of amino acids, forming nitrosamines, which are known carcinogens.

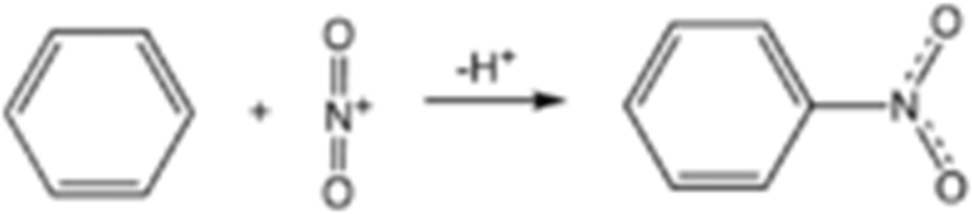
Nitrite is detected and analyzed by the Griess Reaction, involving the formation of a deep red-colored azo dye upon treatment of a NO_2^--containing sample with sulfanilic acid and naphthyl-1-amine in the presence of acid. Nitrite can be reduced to nitric oxide or ammonia by many species of bacteria.

Under hypoxic conditions, nitrite may release nitric oxide, which causes potent vasodilation. Several mechanisms for nitrite conversion to NO have been described, including enzymatic reduction by xanthine oxidoreductase, nitrite reductase, and NO synthase (NOS), as well as nonenzymatic acidic disproportionation reactions.

Organic Nitrites and Nitro Compounds



A Nitrite Ester



Aromatic Nitration

In organic chemistry, nitrites are esters of nitrous acid and contain the nitrosoxy functional group. Nitro compounds contain the $C\text{-}NO_2$ group. Nitrites have the general formula RONO, where R is an aryl or alkyl group. Nitrobenzene is a simple example of a nitro compound. In aromatic nitration reactions a C-H bond is broken, leaving the two electrons on the carbon atom. These two electrons are added to the nitronium ion, reducing it to nitrite.

Here is a wastewater Inspector is utilizing the auto sampler's manual to help adjust the time and adjust for the correct flow for a composite sample. You can see that she is pouring off the pickle jar. This inspector is also the course author.

Selenium- Inorganic Contaminant 0.05 mg/L MCL

Selenium (Se) is an essential element for human nutrition, with the majority of our intake coming from foods such as nuts, cereals, meat, fish, and eggs. The concentration of Selenium in drinking water is usually low, and comes from natural minerals. In soils, selenium often occurs in soluble forms such as selenate, which are leached into rivers very easily by runoff increasing the amount of selenium in groundwater. Selenium in water is also a by-product of copper mining / smelting. Selenium is also used in photoelectric devises because its electrical conductivity varies with light.

Naturally occurring selenium compounds have not been shown to be carcinogenic in animals. However, acute toxicity caused by high levels of selenium in water or other sources of intake has been observed in laboratory animals and in animals grazing in areas where high selenium levels exist in the soil. The US EPA has established the MCL for selenium in water at 0.05 mg/l.

What are selenium's health effects?
Some people who drink water containing selenium well in excess of the maximum contaminant level (MCL) for many years could experience hair or fingernail losses, numbness in fingers or toes, or problems with their circulation.

This health effects language is not intended to catalog all possible health effects for selenium. Rather, it is intended to inform consumers of some of the possible health effects associated with selenium in drinking water when the rule was finalized.

What are EPA's drinking water regulations for selenium?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for selenium is 0.05 mg/L or 50 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for selenium, called a maximum contaminant level (MCL), at 0.05 mg/L or 50 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for selenium, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed selenium as part of the Six Year Review and determined that the 0.05 mg/L or 50 ppb MCLG and 0.05 mg/L or 50 ppb MCL for selenium are still protective of human health.

Selenium Water Treatment

Selenium contamination of water systems may result whenever new agricultural runoff courses through normally dry undeveloped lands. If you have high levels of selenium in your water the following are recommended selenium water treatment options. Anion exchange can reduce the amount of selenium in drinking water by 60 - 95%. Reverse Osmosis Systems are excellent at removing selenium in drinking water.

Selenium shows borderline metalloid or nonmetal behavior. Its most stable form, the grey trigonal allotrope, is sometimes called 'metallic' selenium. This is because its electrical conductivity is several orders of magnitude greater than that of the red monoclinic form.

The metallic character of selenium is further shown by the following properties:

- Its luster.
- Its crystalline structure, which is thought to include weakly 'metallic' interchain bonding.
- Its capacity, when molten, to be drawn into thin threads.
- Its reluctance to acquire 'the high positive oxidation numbers characteristic of nonmetals'.
- Its capacity to form cyclic polycations (such as Se2+ 8) when dissolved in oleums (an attribute it shares with sulfur and tellurium).
- The existence of a hydrolyzed cationic salt in the form of trihydroxoselenium (IV) perchlorate $[Se(OH)_3]^+$.ClO– 4.

The Non-metallic Character of Selenium is shown by:

- Its brittleness.
- Its electronic band structure, which is that of a semiconductor.
- The low electrical conductivity ($\sim 10^{-9}$ to 10^{-12} S·cm^{-1}) of its highly purified form. This is comparable to or less than that of bromine (7.95×10^{-12} S·cm^{-1}), a nonmetal.
- Its relatively high electronegativity (2.55 revised Pauling scale).
- The retention of its semiconducting properties in liquid form.
- Its reaction chemistry, which is mainly that of its nonmetallic anionic forms Se^{2-}, SeO2− 3 and SeO2− 4.

Selenium Explained

Selenium is a chemical element with symbol **Se** and atomic number 34. It is a nonmetal with properties that are intermediate between those of its periodic table column-adjacent chalcogen elements sulfur and tellurium. It rarely occurs in its elemental state in nature, or as pure ore compounds. Selenium (Greek σελήνη *selene* meaning "Moon") was discovered in 1817 by Jöns Jakob Berzelius, who noted the similarity of the new element to the previously-known tellurium (named for the Earth).

Selenium is found impurely in metal sulfide ores, where it partially replaces the sulfur. Commercially, selenium is produced as a byproduct in the refining of these ores, most often during copper production.

Minerals that are pure selenide or selenate compounds are known, but are rare. The chief commercial uses for selenium today are in glassmaking and in pigments. Selenium is a semiconductor and is used in photocells. Uses in electronics, once important, have been mostly supplanted by silicon semiconductor devices. Selenium continues to be used in a few types of DC power surge protectors and one type of fluorescent quantum dot.

Selenium salts are toxic in large amounts, but trace amounts are necessary for cellular function in many organisms, including all animals. Selenium is a component of the antioxidant enzymes glutathione peroxidase and thioredoxin reductase (which indirectly reduce certain oxidized molecules in animals and some plants). It is also found in three deiodinase enzymes, which convert one thyroid hormone to another. Selenium requirements in plants differ by species, with some plants requiring relatively large amounts, and others apparently requiring none.

Characteristics

Physical Properties

Selenium exists in several allotropes that interconvert upon heating and cooling carried out at different temperatures and rates. As prepared in chemical reactions, selenium is usually amorphous, brick-red powder. When rapidly melted, it forms the black, vitreous form, which is usually sold industrially as beads. The structure of black selenium is irregular and complex and consists of polymeric rings with up to 1000 atoms per ring. Black Se is a brittle, lustrous solid that is slightly soluble in CS_2. Upon heating, it softens at 50 °C and converts to gray selenium at 180 °C; the transformation temperature is reduced by presence of halogens and amines.

The red-colored α, β and γ forms are produced from solutions of black selenium by varying evaporation rates of the solvent (usually CS_2). They all have relatively low, monoclinic crystal symmetries and contain nearly identical puckered Se_8 rings arranged in different fashions, as in sulfur. The packing is most dense in the α form. In the Se_8 rings, the Se-Se distance is 233.5 pm and Se-Se-Se angle is 105.7 degrees. Other selenium allotropes may contain Se_6 or Se_7 rings.

The most stable and dense form of selenium has a gray color and hexagonal crystal lattice consisting of helical polymeric chains, wherein the Se-Se distance is 237.3 pm and Se-Se-Se angle is 130.1 degrees. The minimum distance between chains is 343.6 pm. Gray Se is formed by mild heating of other allotropes, by slow cooling of molten Se, or by condensing Se vapors just below the melting point. Whereas other Se forms are insulators, gray Se is a semiconductor showing appreciable photoconductivity. Contrary to other allotropes, it is unsoluble in CS_2. It resists oxidation by air and is not attacked by non-oxidizing acids. With strong reducing agents, it forms polyselenides. Selenium does not exhibit the unusual changes in viscosity that sulfur undergoes when gradually heated.

Isotopes

Selenium has six naturally occurring isotopes, five of which are stable: ^{74}Se, ^{76}Se, ^{77}Se, ^{78}Se, and ^{80}Se. The last three also occur as fission products, along with ^{79}Se, which has a half-life of 327,000 years. The final naturally occurring isotope, ^{82}Se, has a very long half-life (~10^{20} yr, decaying via double beta decay to ^{82}Kr), which, for practical purposes, can be considered to be stable. Twenty-three other unstable isotopes have been characterized.

See also Selenium-79 for more information on recent changes in the measured half-life of this long-lived fission product, important for the dose calculations performed in the frame of the geological disposal of long-lived radioactive waste.

Chemical Compounds

Selenium compounds commonly exist in the oxidation states −2, +2, +4, and +6.

Chalcogen Compounds

Selenium forms two oxides: selenium dioxide (SeO_2) and selenium trioxide (SeO_3). Selenium dioxide is formed by the reaction of elemental selenium with oxygen:

$$\mathbf{Se_8 + 8\ O_2 \rightarrow 8\ SeO_2}$$

It is a polymeric solid that forms monomeric SeO_2 molecules in the gas phase. It dissolves in water to form selenous acid, H_2SeO_3. Selenous acid can also be made directly by oxidizing elemental selenium with nitric acid:

$$\mathbf{3\ Se + 4\ HNO_3 + H_2O \rightarrow 3\ H_2SeO_3 + 4\ NO}$$

Unlike sulfur, which forms a stable trioxide, selenium trioxide is thermodynamically unstable and decomposes to the dioxide above 185 °C:

$$\mathbf{2\ SeO_3 \rightarrow 2\ SeO_2 + O_2\ (\Delta H = -54\ kJ/mol)}$$

Selenium trioxide is produced in the laboratory by the reaction of anhydrous potassium selenate (K_2SeO_4) and sulfur trioxide (SO_3).

Salts of selenous acid are called *selenites*. These include silver selenite (Ag_2SeO_3) and sodium selenite (Na_2SeO_3).

Hydrogen sulfide reacts with aqueous selenous acid to produce selenium disulfide:

$$\mathbf{H_2SeO_3 + 2\ H_2S \rightarrow SeS_2 + 3\ H_2O}$$

Selenium disulfide consists of 8-membered rings of a nearly statistical distribution of sulfur and selenium atoms. It has an approximate composition of SeS_2, with individual rings varying in composition, such as Se_4S_4 and Se_2S_6. Selenium disulfide has been use in shampoo as an anti-dandruff agent, an inhibitor in polymer chemistry, a glass dye, and a reducing agent in fireworks.
Selenium trioxide may be synthesized by dehydrating selenic acid, H_2SeO_4, which is itself produced by the oxidation of selenium dioxide with hydrogen peroxide:

$$\mathbf{SeO_2 + H_2O_2 \rightarrow H_2SeO_4}$$

Hot, concentrated selenic acid is capable of dissolving gold, forming gold(III) selenate.

Halogen Compounds

Iodides of selenium are not well known. The only stable chloride is selenium monochloride (Se_2Cl_2), which might be better known as selenium(I) chloride; the corresponding bromide is also known. These species are structurally analogous to the corresponding disulfur dichloride. Selenium dichloride is an important reagent in the preparation of selenium compounds (e.g. the preparation of Se_7). It is prepared by treating selenium with sulfuryl chloride (SO_2Cl_2). Selenium reacts with fluorine to form selenium hexafluoride:

$$\mathbf{Se_8 + 24\ F_2 \rightarrow 8\ SeF_6}$$

In comparison with its sulfur counterpart (sulfur hexafluoride), selenium hexafluoride (SeF_6) is more reactive and is a toxic pulmonary irritant. Some of the selenium oxyhalides, such as selenium oxyfluoride ($SeOF_2$) and selenium oxychloride ($SeOCl_2$) have been used as specialty solvents.

Selenides

Analogous to the behavior of other chalcogens, selenium forms a dihydride H_2Se. It is a strongly odiferous, toxic, and colorless gas. It is more acidic than H_2S. In solution it ionizes to HSe^-. The selenide dianion Se^{2-} forms a variety of compounds, including the minerals from which selenium is obtained commercially. Illustrative selenides include mercury selenide (HgSe), lead selenide (PbSe), zinc selenide (ZnSe), and copper indium gallium diselenide ($Cu(Ga, In)Se_2$). These materials are semiconductors. With highly electropositive metals, such as aluminum, these selenides are prone to hydrolysis:

$$\mathbf{Al_2Se_3 + 6\ H_2O \rightarrow Al_2O_3 + 6\ H_2Se}$$

Alkali metal selenides react with selenium to form polyselenides, Se2−x, which exist as chains.

Other Compounds

Tetraselenium tetranitride, Se_4N_4, is an explosive orange compound analogous to tetrasulfur tetranitride (S_4N_4). It can be synthesized by the reaction of selenium tetrachloride ($SeCl_4$) with $[((CH_3)_3Si)_2N]_2Se$.

Selenium reacts with cyanides to yield selenocyanates:

$$\mathbf{8\ KCN + Se_8 \rightarrow 8\ KSeCN}$$

Organoselenium Compounds

Selenium, especially in the II oxidation state, forms stable bonds to carbon, which are structurally analogous to the corresponding organosulfur compounds. Especially common are selenides (R_2Se, analogues of thioethers), diselenides (R_2Se_2, analogues of disulfides), and selenols (RSeH, analogues of thiols). Representatives of selenides, diselenides, and selenols include respectively selenomethionine, diphenyldiselenide, and benzeneselenol. The sulfoxide in sulfur chemistry is represented in selenium chemistry by the selenoxides (formula RSe(O)R), which are intermediates in organic synthesis, as illustrated by the selenoxide elimination reaction. Consistent with trends indicated by the double bond rule, selenoketones, R(C=Se)R, and selenaldehydes, R(C=Se)H, are rarely observed.

History

Selenium (Greek σελήνη *selene* meaning "Moon") was discovered in 1817 by Jöns Jakob Berzelius and Johan Gottlieb Gahn. Both chemists owned a chemistry plant near Gripsholm, Sweden producing sulfuric acid by the lead chamber process. The pyrite from the Falun mine created a red precipitate in the lead chambers which was presumed to be an arsenic compound, and so the pyrite's use to make acid was discontinued. Berzelius and Gahn wanted to use the pyrite and they also observed that the red precipitate gave off a smell like horseradish when burned. This smell was not typical of arsenic, but a similar odor was known from tellurium compounds. Hence, Berzelius's first letter to Alexander Marcet stated that this was a tellurium compound. However, the lack of tellurium compounds in the Falun mine minerals eventually led Berzelius to reanalyze the red precipitate, and in 1818 he wrote a second letter to Marcet describing a newly found element similar to sulfur and tellurium. Because of its similarity to tellurium, named for the Earth, Berzelius named the new element after the Moon.

In 1873, Willoughby Smith found that the electrical resistance of grey selenium was dependent on the ambient light. This led to its use as a cell for sensing light. The first of commercial products using selenium were developed by Werner Siemens in the mid-1870s. The selenium cell was used in the photophone developed by Alexander Graham Bell in 1879. Selenium transmits an electric current proportional to the amount of light falling on its surface. This phenomenon was used in the design of light meters and similar devices. Selenium's semiconductor properties found numerous other applications in electronics. The development of selenium rectifiers began during the early 1930s, and these replaced copper oxide rectifiers because of their superior efficiencies. These lasted in commercial applications until the 1970s, following which they were replaced with less expensive and even more efficient silicon rectifiers. Selenium came to medical notice later because of its toxicity to human beings working in industries.

Selenium was also recognized as an important veterinary toxin, which is seen in animals that have eaten high-selenium plants. In 1954, the first hints of specific biological functions of selenium were discovered in microorganisms. Its essentiality for mammalian life was discovered in 1957. In the 1970s, it was shown to be present in two independent sets of enzymes. This was followed by the discovery of selenocysteine in proteins.

Occurrence

Native (i.e., elemental) selenium is a rare mineral, which does not usually form good crystals, but, when it does, they are steep rhombohedra or tiny acicular (hair-like) crystals. Isolation of selenium is often complicated by the presence of other compounds and elements.

Selenium occurs naturally in a number of inorganic forms, including selenide-, selenate-, and selenite-containing minerals, but these minerals are rare. The common mineral selenite is *not* a selenium mineral, and contains no selenite ion, but is rather a type of gypsum (calcium sulfate hydrate) named like selenium for the moon well before the discovery of selenium. Selenium is most commonly found quite impurely, replacing a small part of the sulfur in sulfide ores of many metals.

In living systems, selenium is found in the amino acids selenomethionine, selenocysteine, and methylselenocysteine. In these compounds, selenium plays a role analogous to that of sulfur. Another naturally occurring organoselenium compound is dimethyl selenide.

Certain solids are selenium-rich, and selenium can be bioconcentrated by certain plants. In soils, selenium most often occurs in soluble forms such as selenate (analogous to sulfate), which are leached into rivers very easily by runoff. Ocean water contains significant amounts of selenium.
Anthropogenic sources of selenium include coal burning and the mining and smelting of sulfide ores.

Production

Selenium is most commonly produced from selenide in many sulfide ores, such as those of copper, silver, or lead. Electrolytic metal refining is particularly conducive to producing selenium as a byproduct, and it is obtained from the anode mud of copper refineries. Another source was the mud from the lead chambers of sulfuric acid plants but this method to produce sulfuric acid is no longer used.

These muds can be processed by a number of means to obtain selenium. However, most elemental selenium comes as a byproduct of refining copper or producing sulfuric acid.

Since the invention of solvent extraction and electrowinning (SX/EW) for the production of copper this method takes an increasing share of the world wide copper production. This changes the availability of selenium because only a comparably small part of the selenium in the ore is leached together with the copper.

Industrial production of selenium usually involves the extraction of selenium dioxide from residues obtained during the purification of copper. Common production from the residue then begins by oxidation with sodium carbonate to produce selenium dioxide. The selenium dioxide is then mixed with water and the solution is acidified to form selenous acid (oxidation step). Selenous acid is bubbled with sulfur dioxide (reduction step) to give elemental selenium.

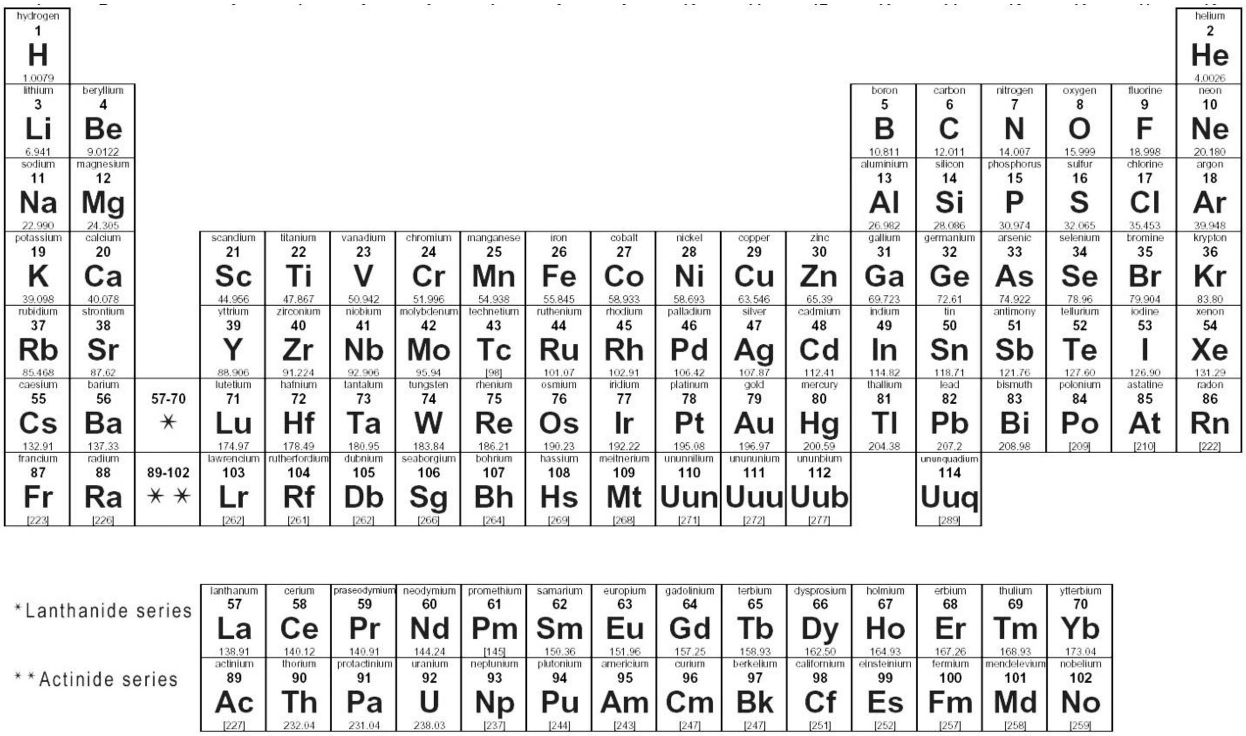
Toxicity

Although selenium is an essential trace element, it is toxic if taken in excess. Exceeding the Tolerable Upper Intake Level of 400 micrograms per day can lead to selenosis. This 400 microgram (µg) Tolerable Upper Intake Level is based primarily on a 1986 study of five Chinese patients who exhibited overt signs of selenosis and a follow up study on the same five people in 1992.

The 1992 study actually found the maximum safe dietary Se intake to be approximately 800 micrograms per day (15 micrograms per kilogram body weight), but suggested 400 micrograms per day to not only avoid toxicity, but also to avoid creating an imbalance of nutrients in the diet and to account for data from other countries. In China, people who ingested corn grown in extremely selenium-rich stony coal (carbonaceous shale) have suffered from selenium toxicity. This coal was shown to have selenium content as high as 9.1%, the highest concentration in coal ever recorded in literature.

Symptoms of selenosis include a garlic odor on the breath, gastrointestinal disorders, hair loss, sloughing of nails, fatigue, irritability, and neurological damage. Extreme cases of selenosis can result in cirrhosis of the liver, pulmonary edema, and death. Elemental selenium and most metallic selenides have relatively low toxicities because of their low bioavailability. By contrast, selenates and selenites are very toxic, having an oxidant mode of action similar to that of arsenic trioxide. The chronic toxic dose of selenite for humans is about 2400 to 3000 micrograms of selenium per day for a long time. Hydrogen selenide is an extremely toxic, corrosive gas. Selenium also occurs in organic compounds, such as dimethyl selenide, selenomethionine, selenocysteine and methylselenocysteine, all of which have high bioavailability and are toxic in large doses.

In fish and other wildlife, low levels of selenium cause deficiency while high levels cause toxicity. For example, in salmon, the optimal concentration of selenium in the fish tissue (whole body) is about 1 microgram selenium per gram of tissue (dry weight). At levels much below that concentration, young salmon die from selenium deficiency; much above that level they die from toxic excess.



hydrogen 1 **H** 1.0079																	helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122											boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305											aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	**57-70** *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	**89-102** * *	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
* *Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Thallium- Inorganic Contaminant 0.002 mg/L MCL

Thallium is a metal found in natural deposits such as ores containing other elements.

Uses for Thallium.

The greatest use of thallium is in specialized electronic research equipment.

What are Thallium's Health Effects?

Some people who drink water containing thallium well in excess of the maximum contaminant level (MCL) for many years could experience hair loss, changes in their blood, or problems with their kidneys, intestines, or liver problems.

This health effects language is not intended to catalog all possible health effects for thallium. Rather, it is intended to inform consumers of some of the possible health effects associated with thallium in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Thallium?

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for thallium is 0.0005 mg/L or 0.5 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for thallium, called a maximum contaminant level (MCL), at 0.002 mg/L or 2 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

The Phase V Rule, the regulation for thallium, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed thallium as part of the Six Year Review and determined that the 0.0005 mg/L or 0.5 ppb MCLG and 0.002 mg/L or 2 ppb MCL for thallium are still protective of human health. States may set more stringent drinking water MCLGs and MCLs for thallium than EPA.

How does Thallium get into my Drinking Water?

The major sources of thallium in drinking water are leaching from ore-processing sites; and discharge from electronics, glass, and drug factories.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals.

For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Thallium is in my Drinking Water?
When routine monitoring indicates that thallium levels are above the MCL, your water supplier must take steps to reduce the amount of thallium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

How will Thallium be Removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing thallium to below 0.002 mg/L or 2 ppb: activated alumina; ion exchange.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Thallium Explained

Thallium is a chemical element with symbol **Tl** and atomic number 81. This soft gray poor metal is not found free in nature. When isolated, it resembles tin, but discolors when exposed to air. Chemists William Crookes and Claude-Auguste Lamy discovered thallium independently in 1861, in residues of sulfuric acid production. Both used the newly developed method of flame spectroscopy, in which thallium produces a notable green spectral line. Thallium, from Greek *θαλλός*, *thallos*, meaning "a green shoot or twig," was named by Crookes. It was isolated by electrolysis a year later, by Lamy.

Thallium tends to oxidize to the +3 and +1 oxidation states as ionic salts. The +3 state resembles that of the other elements in thallium's group (boron, aluminum, gallium, indium). However, the +1 state, which is far more prominent in thallium than the elements above it, recalls the chemistry of alkali metals, and thallium(I) ions are found geologically mostly in potassium-based ores, and (when ingested) are handled in many ways like potassium ions (K^+) by ion pumps in living cells.

Commercially, however, thallium is produced not from potassium ores, but as a byproduct from refining of heavy metal sulfide ores. Approximately 60–70% of thallium production is used in the electronics industry, and the remainder is used in the pharmaceutical industry and in glass manufacturing. It is also used in infrared detectors.

The radioisotope thallium-201 (as the soluble chloride TlCl) is used in small, nontoxic amounts as an agent in a nuclear medicine scan, during one type of nuclear cardiac stress test.

Soluble thallium salts (many of which are nearly tasteless) are highly toxic in quantity, and were historically used in rat poisons and insecticides. Use of these compounds has been restricted or banned in many countries, because of their nonselective toxicity. Thallium poisoning notably results in hair loss. Because of its historic popularity as a murder weapon, thallium has gained notoriety as "the poisoner's poison" and "inheritance powder" (alongside arsenic).

Characteristics

Thallium is extremely soft, malleable and sectile enough to be cut with a knife at room temperature. It has a metallic luster that, when exposed to air, quickly tarnishes to a bluish-gray tinge, resembling lead. It may be preserved by immersion in oil. A heavy layer of oxide builds up on thallium if left in air. In the presence of water, thallium hydroxide is formed. Sulfuric and nitric acid dissolve thallium rapidly to make the sulfate and nitrate salts, while hydrochloric acid forms an insoluble thallium(I) chloride layer. Its standard electrode potential is −0.34, slightly higher than the potential for iron (at −0.44).

Isotopes

Thallium has 25 isotopes which have atomic masses that range from 184 to 210. ^{203}Tl and ^{205}Tl are the only stable isotopes, and ^{204}Tl is the most stable radioisotope, with a half-life of 3.78 years.

^{202}Tl (half-life 12.23 days) can be made in a cyclotron, while ^{204}Tl is made by the neutron activation of stable thallium in a nuclear reactor.

^{201}Tl (half-life 73 hrs), decays by electron capture, emitting Hg X-rays (~70–80 keV), and photons of 135 and 167 keV in 10% total abundance; therefore it has good imaging characteristics without excessive patient radiation dose. It is the most popular isotope used for thallium nuclear cardiac stress tests.

^{208}Tl (half-life 3.05 minutes) is generated in the naturally-occurring thorium decay chain. Its prominent 2615 keV gamma ray is the dominant high-energy feature observed in natural background radiation.

Chemistry

The two main oxidation states of thallium are +1 and +3. In the oxidation state +1 most compounds closely resemble the corresponding potassium or silver compounds (the ionic radius of thallium(I) is 1.47 Å while that of potassium is 1.33 Å and that of silver is 1.26 Å), which was the reason why thallium was sometimes considered to be an alkali metal in Europe (but not in England) in the years immediately following its discovery.[:126]

For example, the water-soluble and very basic thallium(I) hydroxide reacts with carbon dioxide forming water-soluble thallium carbonate. This carbonate is the only water soluble heavy metal carbonate. The similarity with silver compounds is observed with the halide, oxide, and sulfide compounds. Thallium(I) bromide is a photosensitive yellow compound very similar to the silver bromide, while the black thallium(I) oxide and thallium(I) sulfide are very similar to the silver oxide and silver sulfide.

The compounds with oxidation state +3 resemble the corresponding aluminum (III) compounds. They are moderately strong oxidizing agents, as illustrated by the reduction potential of +0.72 volts for $Tl^{3+} + 3\ e^{-} \rightarrow Tl(s)$. The thallium(III) oxide is a black solid which decomposes above 800 °C, forming the thallium(I) oxide and oxygen.

History

Thallium (Greek *θαλλός*, *thallos*, meaning "a green shoot or twig") was discovered by flame spectroscopy in 1861. The name comes from thallium's bright green spectral emission lines.

After the publication of the improved method of flame spectroscopy by Robert Bunsen and Gustav Kirchhoff and the discovery of caesium and rubidium in the years 1859 to 1860, flame spectroscopy became an approved method to determine the composition of minerals and chemical products.

William Crookes and Claude-Auguste Lamy both started to use the new method. William Crookes used it to make spectroscopic determinations for tellurium on selenium compounds deposited in the lead chamber of a sulfuric acid production plant near Tilkerode in the Harz mountains. He had obtained the samples for his research on selenium cyanide from August Hofmann years earlier. By 1862, Crookes was able to isolate small quantities of the new element and determine the properties of a few compounds. Claude-Auguste Lamy used a spectrometer that was similar to Crookes' to determine the composition of a selenium-containing substance which was deposited during the production of sulfuric acid from pyrite. He also noticed the new green line in the spectra and concluded that a new element was present. Lamy had received this material from the sulfuric acid plant of his friend Fréd Kuhlmann and this by-product was available in large quantities. Lamy started to isolate the new element from that source.

The fact that Lamy was able to work ample quantities of thallium enabled him to determine the properties of several compounds and in addition he prepared a small ingot of metallic thallium which he prepared by remelting thallium he had obtained by electrolysis of thallium salts.

As both scientists discovered thallium independently and a large part of the work, especially the isolation of the metallic thallium was done by Lamy, Crookes tried to secure his priority on the work. Lamy was awarded a medal at the International Exhibition in London 1862: *For the discovery of a new and abundant source of thallium* and after heavy protest Crookes also received a medal: *thallium, for the discovery of the new element.* The controversy between both scientists continued through 1862 and 1863. Most of the discussion ended after Crookes was elected Fellow of the Royal Society in June 1863.

The dominant use of thallium was the use as poison for rodents. After several accidents the use as poison was banned in the United States by the Presidential Executive Order 11643 in February 1972. In the subsequent years several other countries also banned the use.

Occurrence and Production

Although thallium is a modestly abundant element in the Earth's crust, with a concentration estimated to be about 0.7 mg/kg, mostly in association with potassium-based minerals in clays, soils, and granites, thallium is not generally economically recoverable from these sources. The major source of thallium for practical purposes is the trace amount that is found in copper, lead, zinc, and other heavy-metal-sulfide ores.

Thallium is found in the minerals crookesite $TlCu_7Se_4$, hutchinsonite $TlPbAs_5S_9$, and lorandite $TlAsS_2$. Thallium also occurs as a trace element in iron pyrite, and thallium is extracted as a by-product of roasting this mineral for the production of sulfuric acid.

Thallium can also be obtained from the smelting of lead and zinc ores. Manganese nodules found on the ocean floor also contain some thallium, but the collection of these nodules has been and continues to be prohibitively expensive.

There is also the potential for damaging the environment of the oceans. In addition, several other thallium minerals, containing 16% to 60% thallium, occur in nature as complexes of sulfides or selenides that primarily contain antimony, arsenic, copper, lead, and/or silver. However, these minerals are rare, and they have had no commercial importance as sources of thallium. The Allchar deposit in southern Macedonia was the only area where thallium was ever actively mined. This deposit still contains a loosely estimated 500 tons of thallium, and it is a source for several rare thallium minerals, for example lorandite.

The United States Geological Survey (USGS) estimates that the annual worldwide production of thallium is about 10 metric tons as a by-product from the smelting of copper, zinc, and lead ores. Thallium is either extracted from the dusts from the smelter flues or from residues such as slag that are collected at the end of the smelting process.

The raw materials used for thallium production contain large amounts of other materials and therefore a purification is the first step.

The thallium is leached either by the use of a base or sulfuric acid from the material. The thallium is several times precipitated from the solution and to remove further impurities. At the end it is converted to thallium sulfate and the thallium is extracted by electrolysis on platinum or stainless steel plates. The production of thallium decreased by about 33% in the period from 1995 to 2009 – from about 15 metric tons to about 10 tons.

Since there are several small deposits or ores with relatively high thallium content, it would be possible to increase the production of it if a new application, such as a hypothetical thallium-containing high-temperature superconductor, becomes practical for widespread use outside of the laboratory.

Applications

Historic Uses

The odorless and tasteless thallium sulfate was once widely used as rat poison and ant killer. Since 1972 this use has been prohibited in the United States due to safety concerns. Many other countries followed this example in the following years. Thallium salts were used in the treatment of ringworm, other skin infections and to reduce the night sweating of tuberculosis patients. However this use has been limited due to their narrow therapeutic index, and the development of more-advanced medicines for these conditions.

Optics

Thallium(I) bromide and thallium(I) iodide crystals have been used as infrared optical materials, because they are harder than other common infrared optics, and because they have transmission at significantly longer wavelengths. The trade name KRS-5 refers to this material.

Thallium(I) oxide has been used to manufacture glasses that have a high index of refraction. Combined with sulfur or selenium and arsenic, thallium has been used in the production of high-density glasses that have low melting points in the range of 125 and 150 °C. These glasses have room temperature properties that are similar to ordinary glasses and are durable, insoluble in water and have unique refractive indices.

Electronics

Thallium(I) sulfide's electrical conductivity changes with exposure to infrared light therefore making this compound useful in photoresistors. Thallium selenide has been used in a bolometer for infrared detection. Doping selenium semiconductors with thallium improves their performance, and therefore it is used in trace amounts in selenium rectifiers. Another application of thallium doping is the sodium iodide crystals in gamma radiation detection devices.

In these, the sodium iodide crystals are doped with a small amount of thallium to improve their efficiency as scintillation generators. Some of the electrodes in dissolved oxygen analyzers contain thallium.

High-Temperature Superconductivity

Research activity with thallium is ongoing to develop high-temperature superconducting materials for such applications as magnetic resonance imaging, storage of magnetic energy, magnetic propulsion, and electric power generation and transmission. The research in applications started after the discovery of the first thallium barium calcium copper oxide superconductor in 1988.

Other Uses

A mercury-thallium alloy, which forms a eutectic at 8.5% thallium, is reported to freeze at −60 °C, some 20 °C below the freezing point of mercury. This alloy is used in thermometers and low-temperature switches. In organic synthesis thallium(III) salts, as thallium trinitrate or triacetate, are useful reagents performing different transformations in aromatics, ketones, olefins, among others. Thallium is a constituent of the alloy in the anode plates in magnesium seawater batteries. Soluble thallium salts are added to gold plating baths to increase the speed of plating and to reduce grain size within the gold layer.

The saturated solution of equal parts of thallium(I) formate ($Tl(CHO_2)$) and thallium(I) malonate ($Tl(C_3H_3O_4)$) in water is known as Clerici solution. It is a mobile odorless liquid whose color changes from yellowish to clear upon reducing the concentration of the thallium salts. With the density of 4.25 g/cm^3 at 20 °C, Clerici solution is one of the heaviest aqueous solutions known. It was used in the 20th century for measuring density of minerals by the flotation method, but the use is discontinued due to the high toxicity and corrosiveness of the solution.

Thallium iodide is used as an additive to metal halide lamps, often together with one-two halides of other metals. It allows to optimize the lamp temperature and color rendering, and shift the spectral output to the green region, which is useful for underwater lighting.

Toxicity

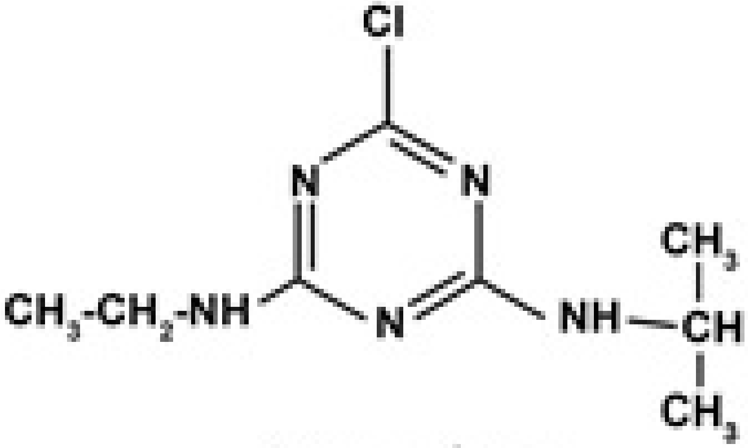
Thallium and its compounds are extremely toxic, and should be handled with great care. There are numerous recorded cases of fatal thallium poisoning. Contact with skin is dangerous, and adequate ventilation should be provided when melting this metal. Thallium(I) compounds have a high aqueous solubility and are readily absorbed through the skin. Exposure to them should not exceed 0.1 mg per m^2 of skin in an 8-hour time-weighted average (40-hour work week).

Thallium is a suspected human carcinogen. For a long time thallium compounds were easily available as rat poison. This fact and that it is water soluble and nearly tasteless led to frequent intoxications caused by accident or criminal intent.

Treatment and Internal Decontamination
One of the main methods of removing thallium (both radioactive and normal) from humans is to use Prussian blue, which is a material which absorbs thallium. Up to 20 g per day of Prussian blue is fed by mouth to the person, and it passes through their digestive system and comes out in the stool. Hemodialysis and hemoperfusion are also used to remove thallium from the blood serum. At later stage of the treatment additional potassium is used to mobilize thallium from the tissue.

Thallium Pollution
According to the United States Environmental Protection Agency (EPA), man-made sources of thallium pollution include gaseous emission of cement factories, coal burning power plants, and metal sewers. The main source of elevated thallium concentrations in water is the leaching of thallium from ore processing operations.

Organic chemicals that are regulated in drinking water are a group of human-made chemical compounds and are components of a variety of pesticides and industrial and commercial products, including degreasers, paints, and petroleum distillates.



Atrazine

More on Drinking Water Standards

The US Environmental Protection Agency is responsible for establishing maximum contaminant levels for drinking water. These standards are expressed as MCL (Maximum Contaminant Level). In most cases, this measurement is expressed as milligrams per liter of water (mg/l) or as parts per million (ppm).

In general terms, inorganic compounds are those materials that do not contain carbon. These compounds are often able to be dissolved in water. For example, dissolved gases such as nitrogen, oxygen, radon, and methane can be classified as inorganic compounds.

In addition to dissolved gases, some metals may be present in water as well. Some of these metals can be hazardous to human health, and may be introduced into water either naturally or through man-made activities.

Some of the more common metals include arsenic and aluminum which the EPA has established a MCL of no more than.05. Lead with a MCL of.015. Mercury MCL of.002. In addition, zinc, calcium, sodium, magnesium, potassium, and copper, all with a 1.3 MCL.

Lead, mercury, and arsenic can be dangerous to human health even at low concentrations, and as mentioned above can be introduced to our water from a variety of sources, including old pipes and lead solder.

Conversely, some of the other inorganic compounds such as sodium, potassium, calcium, and magnesium are important to our overall health and well-being.

Another class of inorganic compounds are known as negative ions. These include substances such as fluoride: MCL 4.0 PPM (parts per million). Chloride and nitrate: MCL 10.0 ppm. Nitrite MCL 1.0. Sulfate, phosphate, carbonate, and cyanide: MCL 0.2

Inorganic Chemistry

Inorganic chemistry is the study of the synthesis and behavior of inorganic and organometallic compounds. This field covers all chemical compounds except the myriad organic compounds (carbon based compounds, usually containing C-H bonds), which are the subjects of organic chemistry.

The distinction between the two disciplines is far from absolute, and there is much overlap, most importantly in the sub-discipline of organometallic chemistry. It has applications in every aspect of the chemical industry–including catalysis, materials science, pigments, surfactants, coatings, medicine, fuel, and agriculture.

Subdivisions of Inorganic Chemistry

Many inorganic compounds are ionic compounds, consisting of cations and anions joined by ionic bonding. Examples of salts (which are ionic compounds) are magnesium chloride $MgCl_2$, which consists of magnesium cations Mg^{2+} and chloride anions Cl^-; or sodium oxide Na_2O, which consists of sodium cations Na^+ and oxide anions O^{2-}.

In any salt, the proportions of the ions are such that the electric charges cancel out, so that the bulk compound is electrically neutral. The ions are described by their oxidation state and their ease of formation can be inferred from the ionization potential (for cations) or from the electron affinity (anions) of the parent elements.

Important classes of inorganic salts are the oxides, the carbonates, the sulfates and the halides. Many inorganic compounds are characterized by high melting points. Inorganic salts typically are poor conductors in the solid state. Another important feature is their solubility in water, e.g., and ease of crystallization. Where some salts (e.g., NaCl) are very soluble in water, others (e.g., SiO_2) are not.

The simplest inorganic reaction is double displacement when in mixing of two salts the ions are swapped without a change in oxidation state. In redox reactions one reactant, the *oxidant*, lowers its oxidation state and another reactant, the *reductant*, has its oxidation state increased. The net result is an exchange of electrons.

Electron exchange can occur indirectly as well, e.g., in batteries, a key concept in electrochemistry.

When one reactant contains hydrogen atoms, a reaction can take place by exchanging protons in acid-base chemistry. In a more general definition, an acid can be any chemical species capable of binding to electron pairs is called a Lewis acid; conversely any molecule that tends to donate an electron pair is referred to as a Lewis base. As a refinement of acid-base interactions, the HSAB theory takes into account polarizability and size of ions.

Inorganic compounds are found in nature as minerals. Soil may contain iron sulfide as pyrite or calcium sulfate as gypsum. Inorganic compounds are also found multitasking as biomolecules: as electrolytes (sodium chloride), in energy storage (ATP) or in construction (the polyphosphate backbone in DNA).

The first important man-made inorganic compound was ammonium nitrate for soil fertilization through the Haber process. Inorganic compounds are synthesized for use as catalysts such as vanadium(V) oxide and titanium(III) chloride, or as reagents in organic chemistry such as lithium aluminum hydride.

Subdivisions of inorganic chemistry are organometallic chemistry, cluster chemistry and bioinorganic chemistry. These fields are active areas of research in inorganic chemistry, aimed toward new catalysts, superconductors, and therapies.

Industrial Inorganic Chemistry

Inorganic chemistry is a highly practical area of science. Traditionally, the scale of a nation's economy could be evaluated by their productivity of sulfuric acid. The top 20 inorganic chemicals manufactured in Canada, China, Europe, India, Japan, and the US (2005 data): aluminum sulfate, ammonia, ammonium nitrate, ammonium sulfate, carbon black, chlorine, hydrochloric acid, hydrogen, hydrogen peroxide, nitric acid, nitrogen, oxygen, phosphoric acid, sodium carbonate, sodium chlorate, sodium hydroxide, sodium silicate, sodium sulfate, sulfuric acid, and titanium dioxide. The manufacturing of fertilizers is another practical application of industrial inorganic chemistry.

Descriptive Inorganic Chemistry

Descriptive inorganic chemistry focuses on the classification of compounds based on their properties. Partly the classification focuses on the position in the periodic table of the heaviest element (the element with the highest atomic weight) in the compound, partly by grouping compounds by their structural similarities. When studying inorganic compounds, one often encounters parts of the different classes of inorganic chemistry (an organometallic compound is characterized by its coordination chemistry, and may show interesting solid state properties).
Different classifications are:

Coordination Compounds

Classical coordination compounds feature metals bound to "lone pairs" of electrons residing on the main group atoms of ligands such as H_2O, NH_3, Cl^-, and CN^-. In modern coordination compounds almost all organic and inorganic compounds can be used as ligands.

The "metal" usually is a metal from the groups 3-13, as well as the *trans*-lanthanides and *trans*-actinides, but from a certain perspective, all chemical compounds can be described as coordination complexes.

The stereochemistry of coordination complexes can be quite rich, as hinted at by Werner's separation of two enantiomers of $[Co((OH)_2Co(NH_3)_4)_3]^{6+}$, an early demonstration that chirality is not inherent to organic compounds. A topical theme within this specialization is supramolecular coordination chemistry.

- **Examples:** $[Co(EDTA)]^-$, $[Co(NH_3)_6]^{3+}$, $TiCl_4(THF)_2$.

Main Group Compounds

These species feature elements from groups 1, 2 and 13-18 (excluding hydrogen) of the periodic table. Due to their often similar reactivity, the elements in group 3 (Sc, Y, and La) and group 12 (Zn, Cd, and Hg) are also generally included.

Main group compounds have been known since the beginnings of chemistry, e.g., elemental sulfur and the distillable white phosphorus. Experiments on oxygen, O_2, by Lavoisier and Priestley not only identified an important diatomic gas, but opened the way for describing compounds and reactions according to stoichiometric ratios.

The discovery of a practical synthesis of ammonia using iron catalysts by Carl Bosch and Fritz Haber in the early 1900s deeply impacted mankind, demonstrating the significance of inorganic chemical synthesis.

Typical main group compounds are SiO_2, $SnCl_4$, and N_2O. Many main group compounds can also be classed as "organometallic", as they contain organic groups, e.g., $B(CH_3)_3$). Main group compounds also occur in nature, e.g., phosphate in DNA, and therefore may be classed as bioinorganic. Conversely, organic compounds lacking (many) hydrogen ligands can be classed as "inorganic", such as the fullerenes, buckytubes and binary carbon oxides.

- **Examples:** tetrasulfur tetranitride S_4N_4, diborane B_2H_6, silicones, buckminsterfullerene C_{60}.

Transition Metal Compounds
Compounds containing metals from group 4 to 11 are considered transition metal compounds. Compounds with a metal from group 3 or 12 are sometimes also incorporated into this group, but also often classified as main group compounds.

Transition metal compounds show a rich coordination chemistry, varying from tetrahedral for titanium (e.g., $TiCl_4$) to square planar for some nickel complexes to octahedral for coordination complexes of cobalt. A range of transition metals can be found in biologically important compounds; such as iron in hemoglobin.

- **Examples:** iron pentacarbonyl, titanium tetrachloride, cisplatin

Organometallic Compounds
Usually, organometallic compounds are considered to contain the M-C-H group. The metal (M) in these species can either be a main group element or a transition metal. Operationally, the definition of an organometallic compound is more relaxed to include also highly lipophilic complexes such as metal carbonyls and even metal alkoxides.

Organometallic compounds are mainly considered a special category because organic ligands are often sensitive to hydrolysis or oxidation, necessitating that organometallic chemistry employs more specialized preparative methods than was traditional in Werner-type complexes.

Synthetic methodology, especially the ability to manipulate complexes in solvents of low coordinating power, enabled the exploration of very weakly coordinating ligands such as hydrocarbons, H_2, and N_2.

Because the ligands are petrochemicals in some sense, the area of organometallic chemistry has greatly benefited from its relevance to industry.

- **Examples:** Cyclopentadienyliron dicarbonyl dimer $(C_5H_5)Fe(CO)_2CH_3$, Ferrocene $Fe(C_5H_5)_2$, Molybdenum hexacarbonyl $Mo(CO)_6$, Diborane B_2H_6, Tetrakis(triphenylphosphine)palladium(0) $Pd[P(C_6H_5)_3]_4$

Cluster Compounds
Clusters can be found in all classes of chemical compounds. According to the commonly accepted definition, a cluster consists minimally of a triangular set of atoms that are directly bonded to each other. But metal-metal bonded dimetallic complexes are highly relevant to the area. Clusters occur in "pure" inorganic systems, organometallic chemistry, main group chemistry, and bioinorganic chemistry. The distinction between very large clusters and bulk solids is increasingly blurred. This interface is the chemical basis of nanoscience or nanotechnology and specifically arise from the study of quantum size effects in cadmium selenide clusters. Thus, large clusters can be described as an array of bound atoms intermediate in character between a molecule and a solid.

- **Examples:** $Fe_3(CO)_{12}$, $B_{10}H_{14}$, $[Mo_6Cl_{14}]^{2-}$, 4Fe-4S

Bioinorganic Compounds

By definition, these compounds occur in nature, but the subfield includes anthropogenic species, such as pollutants (e.g., methylmercury) and drugs (e.g., Cisplatin). The field, which incorporates many aspects of biochemistry, includes many kinds of compounds, e.g., the phosphates in DNA, and also metal complexes containing ligands that range from biological macromolecules, commonly peptides, to ill-defined species such as humic acid, and to water (e.g., coordinated to gadolinium complexes employed for MRI). Traditionally bioinorganic chemistry focuses on electron- and energy-transfer in proteins relevant to respiration. Medicinal inorganic chemistry includes the study of both non-essential and essential elements with applications to diagnosis and therapies.

- **Examples**: hemoglobin, methylmercury, carboxypeptidase

Solid State Compounds

This important area focuses on structure, bonding, and the physical properties of materials. In practice, solid state inorganic chemistry uses techniques such as crystallography to gain an understanding of the properties that result from collective interactions between the subunits of the solid. Included in solid state chemistry are metals and their alloys or intermetallic derivatives. Related fields are condensed matter physics, mineralogy, and materials science.

- **Examples:** silicon chips, zeolites, $YBa_2Cu_3O_7$

Theoretical Inorganic Chemistry

An alternative perspective on the area of inorganic chemistry begins with the Bohr model of the atom and, using the tools and models of theoretical chemistry and computational chemistry, expands into bonding in simple and then more complex molecules.

Precise quantum mechanical descriptions for multielectron species, the province of inorganic chemistry, is difficult. This challenge has spawned many semi-quantitative or semi-empirical approaches including molecular orbital theory and ligand field theory, In parallel with these theoretical descriptions, approximate methodologies are employed, including density functional theory.

Exceptions to theories, qualitative and quantitative, are extremely important in the development of the field. For example, $Cu^{II}_2(OAc)_4(H_2O)_2$ is almost diamagnetic below room temperature whereas Crystal Field Theory predicts that the molecule would have two unpaired electrons. The disagreement between qualitative theory (paramagnetic) and observation (diamagnetic) led to the development of models for "magnetic coupling."

These improved models led to the development of new magnetic materials and new technologies.

Qualitative Theories

Inorganic chemistry has greatly benefited from qualitative theories. Such theories are easier to learn as they require little background in quantum theory. Within main group compounds, VSEPR theory powerfully predicts, or at least rationalizes, the structures of main group compounds, such as an explanation for why NH_3 is pyramidal whereas ClF_3 is T-shaped.

For the transition metals, crystal field theory allows one to understand the magnetism of many simple complexes, such as why $[Fe^{III}(CN)_6]^{3-}$ has only one unpaired electron, whereas $[Fe^{III}(H_2O)_6]^{3+}$ has five. A particularly powerful qualitative approach to assessing the structure and reactivity begins with classifying molecules according to electron counting, focusing on the numbers of valence electrons, usually at the central atom in a molecule.

Inorganic Chemical Summary

What are Inorganic Compounds?

Inorganic compounds are of inanimate, not biological origin. Inorganic compounds lack carbon and hydrogen atoms and are synthesized by the agency of geological systems. In contrast, the synthesis of organic compounds in biological systems incorporates carbohydrates into the molecular structure.

Organic chemists traditionally refer to any molecule containing carbon as an organic compound and by default this means that inorganic chemistry deals with molecules lacking carbon. However, biologists may distinguish organic from inorganic compounds in a different way that does not hinge on the presence of a carbon atom.

Pools of organic matter, for example, that have been metabolically incorporated into living tissues persist in decomposing tissues, but as molecules become oxidized into the open environment, such as atmospheric CO_2, this creates a separate pool of inorganic compounds.

The distinction between inorganic and organic compounds is not always clear when dealing with open and closed systems, because everything is ultimately connected to everything else on the planet.

Some scientists, for example, view the open environment (i.e., the ecosphere) as an extension of life and from this perspective may consider atmospheric CO_2 as an organic compound. IUPAC, an agency widely recognized for defining chemical terms, does not offer definitions of inorganic or organic.

Inorganic compounds are rather simple chemicals present in ground water. These chemicals are generally described as mineral in nature and usually exist as ions (chemical substances with a positive or negative charge) when dissolved in water.

Typical examples include sodium, iron, calcium, magnesium, manganese, nitrate, chloride, sulfate, and zinc. Many of these chemicals are naturally occurring minerals that are dissolved from the rock/soil which make up the aquifer or water-bearing rock formations below the soil surface.

However, some of these compounds may be introduced into ground water by human activities. Nitrate (an agricultural fertilizer) and sodium chloride (road salt) are two examples.

Water purveyors need to test for 30 different inorganic compounds including all arsenic, barium, cadmium, lead, mercury, selenium, and thallium

- ✓ **Organic compounds** - these are once living, or are living and can bring life to cells. These contain carbon, and their electrons spin clockwise, just like those of the human body. Additionally, these cells can form an ionic bond with the body and can easily break down into materials to help with bodily function, such as tissue repair.
- ✓ **Inorganic compounds**- these were never living, without carbon and cannot bring life to cells. The body treats these metals like toxins and are tightly held together; they cannot be easily broken down. And, their electrons spin counterclockwise, out of sync with the rest of the body.

Molecular Symmetry Group Theory

A central construct in inorganic chemistry is the theory of molecular symmetry. Mathematical group theory provides the language to describe the shapes of molecules according to their point group symmetry. Group theory also enables factoring and simplification of theoretical calculations.

Spectroscopic features are analyzed and described with respect to the symmetry properties of the, *inter alia*, vibrational or electronic states. Knowledge of the symmetry properties of the ground and excited states allows one to predict the numbers and intensities of absorptions in vibrational and electronic spectra. A classic application of group theory is the prediction of the number of C-O vibrations in substituted metal carbonyl complexes. The most common applications of symmetry to spectroscopy involve vibrational and electronic spectra.

As an instructional tool, group theory highlights commonalities and differences in the bonding of otherwise disparate species, such as WF_6 and $Mo(CO)_6$ or CO_2 and NO_2.

Thermodynamics and Inorganic Chemistry

An alternative quantitative approach to inorganic chemistry focuses on energies of reactions. This approach is highly traditional and empirical, but it is also useful. Broad concepts that are couched in thermodynamic terms include redox potential, acidity, phase changes.

A classic concept in inorganic thermodynamics is the Born-Haber cycle, which is used for assessing the energies of elementary processes such as electron affinity, some of which cannot be observed directly.

Mechanistic Inorganic Chemistry

An important and increasingly popular aspect of inorganic chemistry focuses on reaction pathways. The mechanisms of reactions are discussed differently for different classes of compounds.

Main Group Elements and Lanthanides

The mechanisms of main group compounds of groups 13-18 are usually discussed in the context of organic chemistry (organic compounds are main group compounds, after all). Elements heavier than C, N, O, and F often form compounds with more electrons than predicted by the octet rule, as explained in the article on hypervalent molecules. The mechanisms of their reactions differ from organic compounds for this reason.

Elements lighter than carbon (B, Be, Li) as well as Al and Mg often form electron-deficient structures that are electronically akin to carbocations. Such electron-deficient species tend to react via associative pathways. The chemistry of the lanthanides mirrors many aspects of chemistry seen for aluminum.

Transition Metal Complexes

Mechanisms for the reactions of transition metals are discussed differently from main group compounds. The important role of d-orbitals in bonding strongly influences the pathways and rates of ligand substitution and dissociation. These themes are covered in articles on coordination chemistry and ligand. Both associative and dissociative pathways are observed.

An overarching aspect of mechanistic transition metal chemistry is the kinetic lability of the complex illustrated by the exchange of free and bound water in the prototypical complexes $[M(H_2O)_6]^{n+}$:

$$[M(H_2O)_6]^{n+} + 6\ H_2O^* \rightarrow [M(H_2O^*)_6]^{n+} + 6\ H_2O$$

where H_2O^* denotes isotopically enriched water, e.g., $H_2{}^{17}O$

The rates of water exchange varies by 20 orders of magnitude across the periodic table, with lanthanide complexes at one extreme and Ir(III) species being the slowest.

Redox Reactions

Redox reactions are prevalent for the transition elements. Two classes of redox reaction are considered: atom-transfer reactions, such as oxidative addition/reductive elimination, and electron-transfer. A fundamental redox reaction is "self-exchange", which involves the degenerate reaction between an oxidant and a reductant. For example, permanganate and its one-electron reduced relative manganate exchange one electron:

$$[MnO_4]^- + [Mn^*O_4]^{2-} \rightarrow [MnO_4]^{2-} + [Mn^*O_4]^-$$

Reactions at Ligands

Coordinated ligands display reactivity distinct from the free ligands. For example, the acidity of the ammonia ligands in $[Co(NH_3)_6]^{3+}$ is elevated relative to NH_3 itself. Alkenes bound to metal cations are reactive toward nucleophiles whereas alkenes normally are not. The large and industrially important area of catalysis hinges on the ability of metals to modify the reactivity of organic ligands.

Homogeneous catalysis occurs in solution and heterogeneous catalysis occurs when gaseous or dissolved substrates interact with surfaces of solids.

Traditionally homogeneous catalysis is considered part of organometallic chemistry and heterogeneous catalysis is discussed in the context of surface science, a subfield of solid state chemistry. But the basic inorganic chemical principles are the same.

Transition metals, almost uniquely, react with small molecules such as CO, H_2, O_2, and C_2H_4. The industrial significance of these feedstocks drives the active area of catalysis. Ligands can also undergo ligand transfer reactions such as transmetalation.

SOC Section

Common water sampling bottles.

SOC/VOC bottles are the smaller, thin bottles with the septum tops. Be careful not to get any air bubbles in the SOC/VOC bottles and this may take a few weeks to learn to collect a proper sample.

SOC Introduction

Synthetic Organic Chemicals (SOCs) are organic (carbon based) chemicals that are less volatile than Volatile Organic Compounds (VOCs). SOCs are used as pesticides, defoliants, fuel additives and as ingredients for other organic compounds. They are all man made and do not naturally occur in the environment. Some of the more well-known SOCs are Atrazine, 2,4-D, Dioxin and Polychlorinated Biphenyls (PCBs).

SOCs most often enter the natural environment through application of pesticide (including runoff from areas where they are applied), as part of a legally discharged waste stream, improper or illegal waste disposal, accidental releases or as a byproduct of incineration. Some SOCs are very persistent in the environment, whether in soil or water.

SOCs are generally toxic and can have substantial health impacts from both acute (short-term) and chronic (long-term) exposure. Many are known carcinogens (cancer causing). EPA has set Maximum Contaminant Levels (MCL) for 30 SOCs under the Safe Drinking Water Act.

The Safe Drinking Water Act requires that all water sources of all public water systems be periodically monitored for regulated SOCs. The monitoring frequency can be adjusted through a waiver if SOCs are not detected.

EPA established Maximum Contaminant Levels (MCL), Maximum Contaminant Level Goals (MCLG), monitoring requirements and best available technologies for removal for 65 chemical contaminants over a five year period as EPA gathered and analyzed occurrence and health effects data. This series of rules are known as the Chemical Phase Rules and they define regulations for three contaminant groups:

- Inorganic Chemicals (IOC),
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- Volatile Organic Chemicals (VOC).

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- cancer;
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- circulatory,
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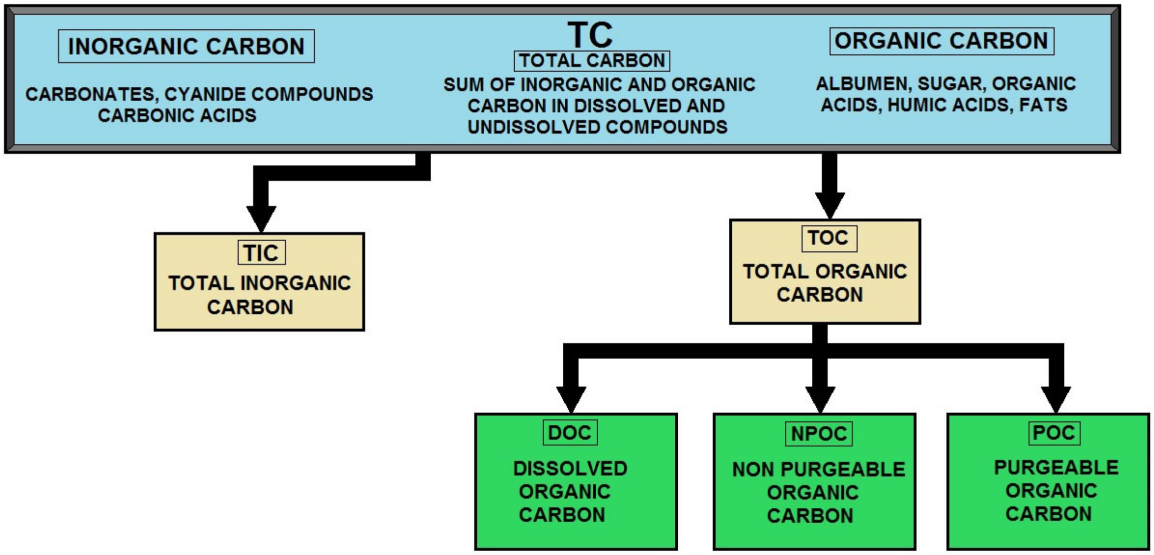
They also help to reduce the occurrence of Methemoglobinemia or "blue baby syndrome" from ingestion of elevated levels of nitrate or nitrite. All public water systems must monitor for Nitrate and Nitrite. Community water systems and Non-transient non-community water systems must also monitor for IOCs, SOCs, and VOCs. This is a list of the organic chemicals—which include pesticides, industrial chemicals, and disinfection by-products—that are tested for in public water systems (those that provide water to the public), along with the maximum standard for the contaminant, and a brief description of the potential health effects associated with long-term consumption of elevated levels of the contaminants.

The federal standard for most contaminants is listed as a Maximum Contaminant Level (MCL), the lowest concentration at which that particular contaminant is believed to represent a potential health concern. Unless otherwise noted, the MCL is expressed as parts per billion (ppb). Also, because of technological limitations or other factors, it is not possible to test for some contaminants in a reliable fashion. Instead, public water systems are required to use specific Treatment Techniques (TT) that are designed to remove these particular contaminants from the water.

In addition to the chemicals listed, monitoring is done for approximately 60 organic chemicals for which MCLs have not been established. If unacceptable levels are found of these “unregulated” contaminants—based on established state health standards and an assessment of the risks they pose—the response is the same as if an MCL has been exceeded: the public water system must notify those served by the system.

Synthetic Organic Chemicals	MCL (ppb)	Potential Health Effects
Acrylamide	TT	Cancer, nervous system effects
Alachlor	2	Cancer
Aldicarb	3	Nervous system effects
Aldicarb sulfoxide	4	Nervous system effects
Aldicarb sulfone	2	Nervous system effects
Atrazine	3	Liver, kidney, lung, cardiovascular effects; possible carcinogen
Benzo(a)pyrene (PAHs)	0.2	Liver, kidney effects, possible carcinogen
Carbofuran	40	Nervous system, reproductive system effects
Chlordane	2	Cancer
2,4-D	70	Liver, kidney effects
Di(2-ethylhexyl) adipate	400	Reproductive effects
Di(2-ethylhexyl) phthalate	6	Cancer
Dibromochloro-propane (DBCP)	0.2	Cancer
Dinoseb	7	Thyroid, reproductive effects
Diquat	20	Ocular, liver, kidney effects
Endothall	100	Liver, kidney, gastrointestinal effects
Endrin	2	Liver, kidney effects
Epichlorohydrin	TT	Cancer
Ethylene dibromide (EDB)	0.05	Cancer
Glyphosate	700	Liver, kidney effects
Heptachlor	0.4	Cancer
Heptachlor epoxide	0.2	Cancer
Hexachlorobenzene	1	Cancer
Hexachlorocyclopentadiene (HEX)	50	Kidney, stomach effects

Lindane	0.2	Liver, kidney, nervous system, immune system, circulatory system effects
Methoxychlor	40	Developmental, liver, kidney, nervous system effects
Oxamyl (Vydate)	200	Kidney effects
Pentachlorophenol	1	Cancer
Picloram	500	Kidney, liver effects
Polychlorinated biphenyls (PCBs)	0.5	Cancer
Simazine	4	Body weight and blood effects, possible carcinogen
2,3,7,8-TCDD (Dioxin)	0.00003	Cancer
Toxaphene	3	Cancer
2,4,5-TP (Silvex)	50	Liver, kidney effects



TOTAL ORGANIC COMPOUNDS (CARBON)

Volatile Organic Compounds (VOCs)

Definitions
Volatile Organic Compounds (VOCs) – "VOCs are ground-water contaminants of concern because of very large environmental releases, human toxicity, and a tendency for some compounds to persist in and migrate with ground-water to drinking-water supply well … In general, VOCs have high vapor pressures, low-to-medium water solubilities, and low molecular weights. Some VOCs may occur naturally in the environment, other compounds occur only as a result of manmade activities, and some compounds have both origins." - Zogorski and others, 2006

Volatile Organic Compounds (VOCs) – "Volatile organic compounds released into the atmosphere by anthropogenic and natural emissions which are important because of their involvement in photochemical pollution." - Lincoln and others, 1998

Volatile Organic Compounds (VOCs) – "Hydrocarbon compounds that have low boiling points, usually less than 100ºC, and therefore evaporate readily. Some are gases at room temperature. Propane, benzene, and other components of gasoline are all volatile organic compounds." - Art, 1993

Volatile Organic Compounds (VOCs) – "VOCs are organic compounds that can be isolated from the water phase of a sample by purging the water sample with inert gas, such as helium, and, subsequently, analyzed by gas chromatography. Many VOCs are human-made chemicals that are used and produced in the manufacture of paints, adhesives, petroleum products, pharmaceuticals, and refrigerants. They often are compounds of fuels, solvents, hydraulic fluids, paint thinners, and dry-cleaning agents commonly used in urban settings. VOC contamination of drinking water supplies is a human-health concern because many are toxic and are known or suspected human carcinogens." - U.S. Geological Survey, 2005

VOCs Explained

Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary, room-temperature conditions. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air. An example is formaldehyde, with a boiling point of –19 °C (–2 °F), slowly exiting paint and getting into the air.

VOCs are numerous, varied, and ubiquitous. They include both human-made and naturally occurring chemical compounds. Most scents or odors are of VOCs. VOCs play an important role in communication between plants. Some VOCs are dangerous to human health or cause harm to the environment.

Anthropogenic VOCs are regulated by law, especially indoors, where concentrations are the highest. Harmful VOCs are typically not acutely toxic, but instead have compounding long-term health effects. Because the concentrations are usually low and the symptoms slow to develop, research into VOCs and their effects is difficult.

Specific Components

Paints and Coatings

A major source of man-made VOCs are coatings, especially paints and protective coatings. Solvents are required to spread a protective or decorative film. Approximately 12 billion liters of paints are produced annually. Typical solvents are aliphatic hydrocarbons, ethyl acetate, glycol ethers, and acetone. Motivated by cost, environmental concerns, and regulation, the paint and coating industries are increasingly shifting toward aqueous solvents.

Chlorofluorocarbons and Chlorocarbons

Chlorofluorocarbons, which are banned or highly regulated, were widely used cleaning products and refrigerants. Tetrachloroethene is used widely in dry cleaning and by industry. Industrial use of fossil fuels produces VOCs either directly as products (e.g., gasoline) or indirectly as byproducts (e.g., automobile exhaust).

Benzene

One VOC that is a known human carcinogen is benzene, which is a chemical found in environmental tobacco smoke, stored fuels, and exhaust from cars in an attached garage. Benzene also has natural sources such as volcanoes and forest fires. It is frequently used to make other chemicals in the production of plastics, resins, and synthetic fibers.

Benzene evaporates into the air quickly and the vapor of benzene is heavier than air allowing the compound to sink into low-lying areas. Benzene has also been known to contaminate food and water and if digested can lead to vomiting, dizziness, sleepiness, rapid heartbeat, and at high levels, even death may occur.

Methylene Chloride

Methylene chloride is another VOC that is highly dangerous to human health. It can be found in adhesive removers and aerosol spray paints and the chemical has been proven to cause cancer in animals. In the human body, methylene chloride is converted to carbon monoxide and a person will suffer the same symptoms as exposure to carbon monoxide. If a product that contains methylene chloride needs to be used the best way to protect human health is to use the product outdoors. If it must be used indoors, proper ventilation is essential to keeping exposure levels down.

Perchloroethylene

Perchloroethylene is a volatile organic compound that has been linked to causing cancer in animals. It is also suspected to cause many of the breathing related symptoms of exposure to VOC's. Perchloroethylene is used mostly in dry cleaning. Studies show that people breathe in low levels of this VOC in homes where dry-cleaned clothes are stored and while wearing dry-cleaned clothing. While dry cleaners attempt to recapture perchlorothylene in the dry cleaning process to reuse it in an effort to save money, they can't recapture it all. To avoid exposure to perchlorothylene, if a strong chemical odor is coming from clothing when picked up from the dry cleaner, do not accept them and request that less of the chemical be used as well as a complete drying of the garments

MTBE

MTBE was banned in the US around 2004 in order to limit further contamination of drinking water aquifers primarily from leaking underground gasoline storage tanks where MTBE was used as an octane booster and oxygenated-additive.

Formaldehyde

Many building materials such as paints, adhesives, wall boards, and ceiling tiles slowly emit formaldehyde, which irritates the mucous membranes and can make a person irritated and uncomfortable. Formaldehyde emissions from wood are in the range of 0.02 – 0.04 ppm. Relative humidity within an indoor environment can also affect the emissions of formaldehyde. High relative humidity and high temperatures allow more vaporization of formaldehyde from wood-materials.

Health Risks

Respiratory, allergic, or immune effects in infants or children are associated with man-made VOCs and other indoor or outdoor air pollutants. Some VOCs, such as styrene and limonene, can react with nitrogen oxides or with ozone to produce new oxidation products and secondary aerosols, which can cause sensory irritation symptoms. Unspecified VOCs are important in the creation of smog.

Health effects include:

> Eye, nose, and throat irritation; headaches, loss of coordination, nausea; damage to liver, kidney, and central nervous system. Some organics can cause cancer in animals; some are suspected or known to cause cancer in humans. Key signs or symptoms associated with exposure to VOCs include conjunctival irritation, nose and throat discomfort, headache, allergic skin reaction, dyspnea, declines in serum cholinesterase levels, nausea, emesis, epistaxis, fatigue, dizziness.

The ability of organic chemicals to cause health effects varies greatly from those that are highly toxic, to those with no known health effects. As with other pollutants, the extent and nature of the health effect will depend on many factors including level of exposure and length of time exposed. Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to some organics.

At present, not much is known about what health effects occur from the levels of organics usually found in homes. Many organic compounds are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans.

Reducing Exposure

To reduce exposure to these toxins, one should buy products that contain Low-VOC's or No VOC's. Only the quantity which will soon be needed should be purchased, eliminating stockpiling of these chemicals. Use products with VOC's in well ventilated areas. When designing homes and buildings, design teams can implement the best possible ventilation plans, call for the best mechanical systems available, and design assemblies to reduce the amount of infiltration into the building. These methods will help improve indoor air quality, but by themselves they cannot keep a building from becoming an unhealthy place to breathe. While proper building ventilation is a key component to improving indoor air quality, it cannot do the job on its own.

As stated earlier, awareness is the key component to improving air quality, when choosing building materials, furnishings, and decorations. When architects and engineers implement best practices in ventilation and mechanical systems, the owner must maintain good air quality levels thereafter.

Limit Values for VOC Emissions

Limit values for VOC emissions into indoor air are published by e.g. AgBB, AFSSET, California Department of Public Health, and others.

Chemical Fingerprinting

The exhaled human breath contains a few hundred volatile organic compounds and is used in breath analysis to serve as a VOC biomarker to test for diseases such as lung cancer. One study has shown that "volatile organic compounds ... are mainly blood borne and therefore enable monitoring of different processes in the body." And it appears that VOC compounds in the body "may be either produced by metabolic processes or inhaled/absorbed from exogenous sources" such as environmental tobacco smoke. Research is still in the process to determine whether VOCs in the body are contributed by cellular processes or by the cancerous tumors in the lung or other organs.

Volatile Organic Chemicals	MCL (ppb)	Potential Health Effects
Benzene	5	Cancer
Carbon tetrachloride	5	Liver effects, cancer
Chlorobenzene	100	Liver, kidney, nervous system effects
o-Dichlorobenzene	600	Liver, kidney, blood cell effects
para-Dichlorobenzene	175	Kidney effects, possible carcinogen
1,2-Dichloroethane	5	Cancer
1,1-Dichloroethylene	7	Liver, kidney effects, possible carcinogen
cis-1,2-Dichloroethylene	70	Liver, kidney, nervous system, circulatory system effects
trans-1,2-Dichloroethylene	100	Liver, kidney, nervous system, circulatory system effects
1,2-Dichloropropane	5	Cancer
Ethylbenzene	700	Liver, kidney, nervous system effects
Methylene chloride	5	Cancer
Styrene	100	Liver, nervous systems effects, possible carcinogen
Tetrachloroethylene (PCE)	5	Cancer
Toluene	1,000	Liver, kidney, nervous system, circulatory system effects
Total trihalomethanes Chloroform Bromoform Bromodichloromethane Chlorodibromomethane	100	Cancer
1,2,4-Trichlorobenzene	70	Liver, kidney effects
1,1,1-Trichloroethane	200	Liver, nervous system effects
1,1,2-Trichloroethane	5	Kidney, liver effects, possible carcinogen
Trichloroethylene (TCE)	5	Cancer

Vinyl chloride	2	Nervous system, liver effects, cancer
Xylenes (total)	10,000	Liver, kidney, nervous system effects

Disinfection By-products	MCL (ppb)	Potential Health Effects
Bromate	10	Cancer
Chlorate	1,000	Anemia, nervous system effects
Haloacetic Acids (HAA5)*	60	Cancer
Total trihalomethanes (TTHMs)**	100	Cancer

*Haloacetic acids consist of monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid.

**Total trihalomethanes consist of chloroform, bromoform, bromodichloromethane, and chlorodibromomethane.

Regulated Chemical Contaminants

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For more information on each of these contaminants, see specialized sections.

Phased Rules	VOC	SOC	IOC
Phase I, July 7, 1987 (52 FR 25690) Effective: 1989	benzene carbon tetrachloride p-dichlorobenzene trichloroethylene vinyl chloride 1,1,1-trichloroethane 1,1-dichloroethylene 1,2-dichloroethane		
Phase II, January 1991[1] (56 FR 3526) Effective: 1992	cis-1,2-dichloroethylene ethylbenzene monochlorobenzene (chlorobenzene) o-dichlorobenzene styrene tetrachloroethylene toluene trans-1,2-dichloroethylene xylenes 1,2-dichloropropane	alachlor atrazine carbofuran chlordane EDB (ethylene dibromide) DBCP (1,2-dibromo-3-chloropropane) heptachlor heptachlor epoxide lindane methoxychlor toxaphene PCBs 2,4-D 2,4,5-TP	asbestos cadmium chromium fluoride mercury nitrate nitrite selenium

Phased Rules	VOC	SOC	IOC
Phase IIB, July 1991 (56 FR 30266) Effective: 1993		pentachlorophenol	barium
Phase V, July 1992 (57 FR 31776) Effective: 1994	dichloromethane 1,1,2-trichloroethane 1,2,4-trichlorobenzene	benzo(a)pyrene dalapon di(ethylhexyl)-adipate di(ethylhexyl)-phthalate dinoseb diquat endothall endrin glyphosate hexachlorobenzene hexachlorocyclopentadiene oxymal picloram simazine 2,3,7,8-TCDD (dioxin)	antimony beryllium cyanide nickel (remanded 1995) thallium

[1] Aldicarb, aldicarb sulfone, and aldicarb sulfoxide are considered regulated chemicals although their MCLs are stayed. Therefore PWS are not required to meet an MCL.

For each contaminant, EPA set a health goal, or Maximum Contaminant Level Goal (MCLG). This is the level at which a person could drink two liters of water containing the contaminant every day for 70 years without suffering any ill effects. This goal is not a legal limit with which water systems must comply; it is based solely on human health. For known cancer-causing agents (carcinogens), EPA set the health goal at zero, under the assumption that any exposure to the chemical could present a cancer risk.

The rules also set a legal limit, or Maximum Contaminant Level (MCL), for each contaminant. EPA sets legal limits as close to the health goal as possible, keeping in mind the technical and financial barriers that exist. Except for contaminants regulated as carcinogens, most legal limits and health goals are the same. Even when they are less strict than the health goals, the legal limits provide substantial public health protection.

The Standardized Monitoring Framework

The Standardized Monitoring Framework (SMF), promulgated in the Phase II rule on January 30, 1991 and revised under Phases IIB and V, includes contaminants regulated under Phases I, II, IIB, V, the revised Arsenic Rule and the Radionuclides Rule Monitoring under the SMF began in 1993. The goal of the Standardized Monitoring Framework is to standardize, simplify, and consolidate drinking water monitoring requirements across contaminant groups. In order to do this, EPA has established nine-year compliance cycles. Each nine-year compliance cycle is divided into 3 three-year compliance periods, which may be further subdivided into annual and quarterly periods. Compliance periods run on a calendar year basis, from January 1 through December 31. Compliance cycle 1 began January 1, 1993 and ended December 31, 2001; the second compliance cycle began January 1, 2002 and ends December 31, 2010; the third compliance cycle begins January

1, 2011 and ends December 31, 2019. Monitoring schedules and sample requirements are standardized for each compliance cycle for each contaminant group.

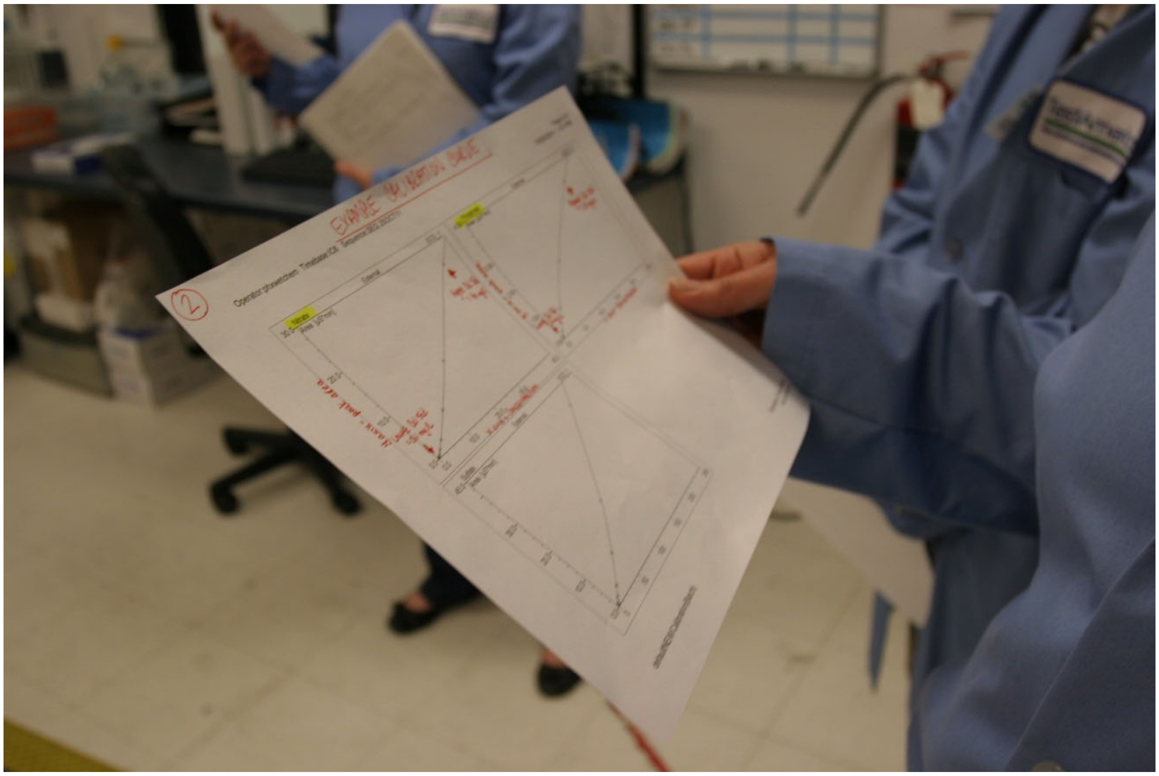
Standardized Monitoring Framework – Compliance Cycles and Period

2nd Compliance Cycle			3rd Compliance Cycle		
1st Period	2nd Period	3rd Period	1st Period	2nd Period	3rd Period
2002	2005	2008	2011	2014	2017
2003	2006	2009	2012	2015	2018
2004	2007	2010	2013	2016	2019

Monitoring Waivers

The SMF allows States to grant waivers to water systems to reduce the sampling frequencies to once every 3, 6 or 9 years for inorganic compounds, synthetic organic compounds, and volatile organic compound.

Waivers of sampling requirements are granted for specified contaminants based on both a vulnerability assessment and the analytical results of previous sampling. The vulnerability assessment may be based on a determination that either the contaminant has not been used in the area or that the system is not susceptible to contamination.



Analytical Method

An analytical method is a procedure that determines the concentration of a contaminant in a water sample.

Analytical methods generally describe:

- How to collect, preserve, and store the sample.
- Procedures to concentrate, separate, identify, and quantify contaminants present in the sample.
- Quality control criteria the analytical data must meet.
- How to report the results of the analysis.

In general, an analytical method:

- Is applicable to routine analyses of samples.
- Is suitable for measuring the drinking water contaminant in the concentration range of interest.
- Provides data with the necessary accuracy and precision to demonstrate compliance or meet monitoring objectives in a wide variety of drinking water matrices.
- Includes instructions for all aspects of the analysis from sample collection to data reporting.
- Incorporates appropriate quality control criteria so that acceptable method performance is demonstrated during the analysis of samples.

Drinking Water Analysis Chart

ANALYSIS	METHOD	HOLDING TIME
Inorganic Compounds (IOC) Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Selenium, Silver, Sodium, Thallium, Zinc, Hardness, Conductivity, Turbidity, Color, Chloride, Cyanide, Fluoride, Nitrate, Nitrite, Sulfate, and Total Dissolved Solids.	**(various)**	**48 hours**
Primary Pollutants (Short IOC) Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver, Sodium, Thallium, Turbidity, Fluoride, Cyanide, Nitrate, and Nitrite.	**(various)**	**48 hours**
Municipal Testing		
Lead and Copper	**EPA 200.9 for Pb** **EPA 200.7 for Cu**	**14 days**
Public or Individual Water Source Testing		
Nitrate	**SM-4500 NO3 D**	**48 hours**
Total Coliform & E. Coli	**SM-9223 B**	**30 Hours**
Metals Analysis on Drinking Water (per element)		
GFAA **(As, Pb, Sb, Se, Tl)**	**EPA 200.9**	**6 months**
ICP (Ag, Al, B, Ba, Be, Cd, Cr, Cu, Fe, Mn, Mo, Na, Ni, Zn)	**EPA 200.7**	**6 months**
CVAA (Hg)	**EPA 245.1**	**6 months**
Primary Pollutant Metals	**GFAA/ICP/CVAA**	**6 months**

Drinking Water Analysis		
PH	**EPA 150.1**	
Acidity	**SM-2310 B (4b)**	**14 days**
Alkalinity (Bicarbonate & Carbonate)	**SM-2320 B (4a)**	**14 days**
BOD	**SM-5210 B**	**48 hours**
Calcium	**EPA 200.7**	**6 months**
Chloride	**SM-4500 Cl**	**8 days**
Chlorine, total	**SM-4500 Cl**	**5 hours**
Color	**SM-2120 B**	**8 hours**
COD	**EPA 410.4 (7.3)**	**28 days**
Cyanide	**EPA 335.2 (8.7)**	**28 days**
Dissolved Oxygen	**SM-4500 O C**	**8 hours**
Fluoride	**SM-4500 F C**	**28 days**
Hardness	**SM-2340 B**	**6 months**
Magnesium	**EPA 200.7**	**6 months**
Nitrogen, ammonia	**SM-4500 NH3 E** **SM-4500 NH3 H**	**28 days**
Nitrogen, nitrate	**SM-4500 NO3 D**	**48 hours**
Nitrogen, nitrite	**SM-4500 NO2**	**48 hours**
Nitrate + Nitrite	**SM-4500 NO3 E**	**48 hours**
Nitrogen, TKN	**EPA 351.4**	**28 days**
Odor	**SM-2150**	**6 days**
Phosphorous, ortho	**EPA 200.7**	**48 hours**
Phosphorous, total	**SM-4500 P**	**28 days**
Solids, settle able	**SM-2540**	**7 days**
Solids, suspended	**SM-2540 D**	**7 days**

Drinking Water Analysis		
Solids, total	**SM-2540 B**	**7 days**
Solids, volatile	**SM-2540 E**	**7 days**
Specific Conductance	**SM-2510 B**	**28 days**
Sulfate	**SM-4500 SO-4 E**	**28 days**
Sulfide	**SM-4500 S-2 D**	**28 days**
Sulfite	**EPA 377.1**	**28 days**
Silica	**SM-4500 SI E**	**28 days**
Total Organic Carbon	**EPA 415.1**	**28 days**
Turbidity	**SM- 2130 B**	**48 hours**

This course contains EPA's federal rule requirements. Please be aware that each state implements drinking water regulations that may be more stringent than EPA's regulations. Check with your state environmental agency for more information.

ORGANICS		
Semi-volatile Organics in Water (SOC)*	**(various)**	**7 days**
Volatile Organics in Water*	**(various)**	**7 days**
Trihalomethanes*	**EPA 501.1**	**7 days**
Gross Alpha & Bata (Radionuclides)*	**(various)**	**7 days**
BOD	**SM-5210 B**	**48 hours**
COD	**EPA 410.4(7.3)**	**28 days**
Oil and Grease	**EPA 413.1(1.2)**	**28 days**
Hardness W/digestion	**SM-2340 B**	**6 months**
Nitrogen, TKN	**EPA 351.4**	**28 days**
Nitrogen, ammonia	**SM-4500 NH3 F**	**28 days**
Nitrogen, Total Organic	**SM-4500 NorgNH3**	**28 days**
Nitrogen, nitrate	**SM-4500 NO3 D**	**48 hours**
Nitrogen, nitrite	**SM-4500 NO2 B**	**48 hours**
Phosphorous, ortho	**SM-4500 P E**	**48 hours**
Sulfate	**SM-4500 SO4 E**	**28 days**
Solids, dissolved	**SM-2540**	**7 days**
Solids, settle able	**SM-2540 F**	**7 days**

Solids, suspended	**SM-2540 D**	**7 days**
Solids, total	**SM-2540 B**	**7 days**
Solids, volatile	**SM-2540 E**	**7 days**
Total Organic Carbon	**EPA 415.1**	**28 days**
PH	**EPA 150.1**	
Metals (per element)		
ICP **(Ag, Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Sb,**	**EPA 200.7**	**6 months**
GFAA **(As, Pb, Ba, Se, Tl)**	**EPA 200.9**	**6 months**
CVAA (Hg)	**EPA 245.1**	**6 months**

Definitions:

Action level - the concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

Maximum Contaminant Level - the “Maximum Allowed” (MCL) is the highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

Maximum Contaminant Level Goal - the “Goal” (MCLG) is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

Non-Detects (ND) - laboratory analysis indicates that the constituent is not present.

Parts per million (ppm) or Milligrams per liter (mg/L) - one part per million corresponds to one minute in two years or a single penny in $10,000.

Parts per billion (ppb) or Micrograms per liter (ug/L) - one part per billion corresponds to one minute in 2,000 years, or a single penny in $10,000,000.

Picocuries per liter (pCi/L) - picocuries per liter is a measure of the radioactivity in water.

SAMPLE CONTAINERS and PRESERVATION

Methods used by the laboratory usually specify what type of container and how much sample is required to run an analysis. The following table provides a summary of the sample handling and preservation requirements for some of the most common tests.

Parameter	Bottle Type	Minimum Sample Size	Maximum Holding Time	Storage & Preservation
Acidity	P or G^B	100ml	24 hrs/14 days	refrigerate
Alkalinity	P or G	200ml	24 hrs/14 days	refrigerate
BOD (5 day)	P or G	1L	6 hrs/48 hrs	refrigerate
Boron	P	100ml	28 days/6 months	
Chloride	P or G	250ml	28 days	
Chlorine, residual	P or G	500ml	0.5 hr/stat	analyze on site ASAP
COD	P or G	500ml	28 days/28 days	analyze on site ASAP
Color	P or G	500ml	48 hrs/48 hrs	refrigerate
Coliform, Total	P or G	125ml	30 hrs	refrigerate
Conductivity	P or G	500ml	48 hrs/48 hrs	refrigerate
Cyanide, Total	P or G	500ml	28 days/28 days	add NaOH to pH>12
				refrigerate in dark
Fluoride	P	300ml	28days/ 28 days	
Hardness	P or G	100ml	6 months/6 months	add HNO_3 to pH<2
Metals, general	P^A or G^A	250ml	6 months/6 months	add HNO_3 to pH<2
Furnace	P^A or G^A	250ml	6 months/6 months	
Flame	P^A or G^A	250ml	6 months/6 months	
Mercury	P^A or G^A	500ml	28 days/28 days	add HNO_3 to pH<2
Nitrogen *Ammonia*	P or G	500ml	7 days/ 28 days	ASAP or add H_2SO_4 to pH<2 & refrigerate

Nitrate	P or G	100ml	48 hrs/48 hrs	ASAP & refrigerate
Nitrate + Nitrite	P or G	200ml	48 hrs/28 days	ASAP & refrigerate
Nitrite	P or G	100ml	none/48 hrs	ASAP & refrigerate
TKN	P or G	500ml	7 days/28 days	add H_2SO_4 to pH<2
Oxygen, dissolved	G (BOD)	300ml		
Electrode			0.5 hrs/stat	ASAP on site
Winkler			8hrs/8 hrs	ASAP on site
pH	P or G	50ml	2 hrs/stat	ASAP on site
Phosphate,	G^A			
Ortho		100ml	48hrs	filter ASAP refrigerate
Total		100ml	28 days/28 days	refrigerate
Solids,	P or G			
Dissolved		250ml	7 days	refrigerate
Settleable		1L	48 hrs	refrigerate
Suspended		250ml	7 days	refrigerate
Total		250ml	7 days	refrigerate
Volatile		250ml	7 days	refrigerate
Silica	P	200ml	28 days/28 days	refrigerate
Sulfate	P or G	100ml	28 days/28 days	refrigerate
Turbidity	P or G	100ml	24 hrs/48 hrs	ASAP/refrigerate, store in dark up to 24 hrs

Refrigerate = storage at 4 degrees C, in the dark. P = plastic (polyethylene or equivalent); G = glass, G^A or P^A = rinsed with 1:1 HNO_3; G^B = glass, borosilicate, G^S = glass rinsed with organic solvents; NS = not stated in cited reference; stat = no storage allowed; analyze immediately.

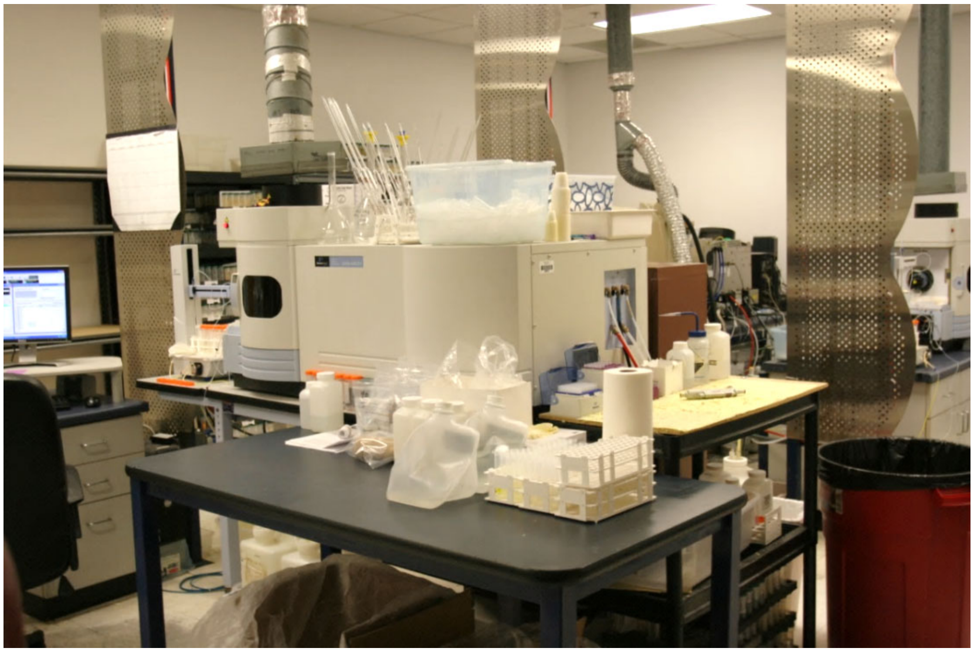
This course contains EPA's federal rule requirements. Please be aware that each state implements drinking water regulations that may be more stringent than EPA's regulations. Check with your state environmental agency for more information.

Laboratory Sample Procedure Photographs

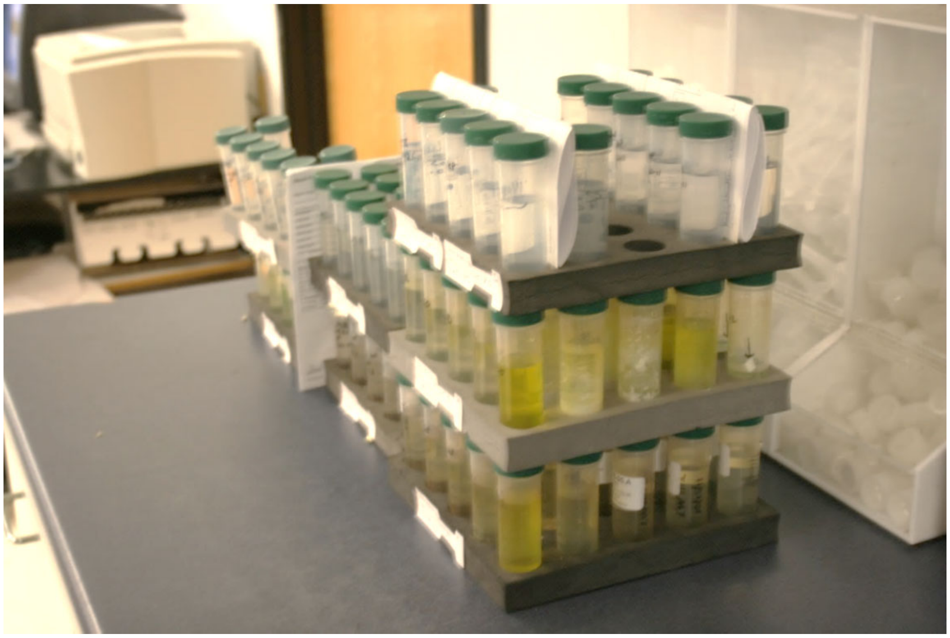
This lab equipment is used for testing parameters in water such as Metals, Pesticides and Hydrocarbons. Often geotechnical water testing that is performed to support characterization regarding the fate and transport of contaminants in soils and sediments. Information such as the grain size distribution provides insight into the absorption, accumulation and movement of contaminants as it may relate to various particle sizes.

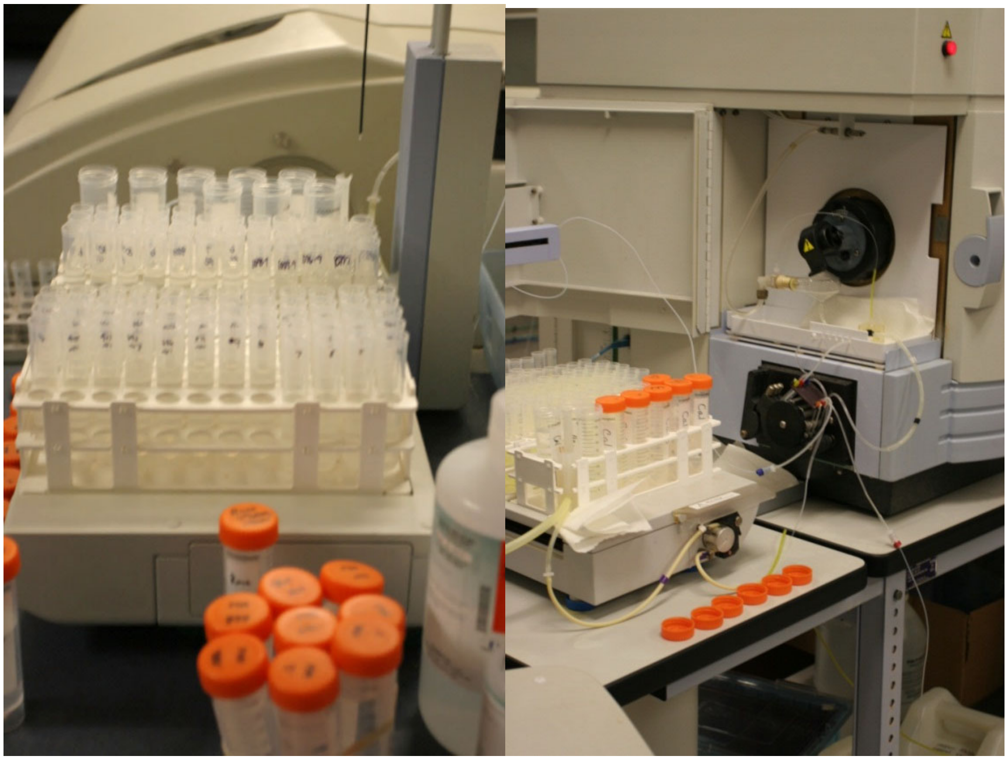
Top Photo: Extraction is a process used to concentrate trace levels of materials, in this case metals. Some metals are able to be complexed with an organic chelating agent. The organic chelating agent, Ammonium pyrrolidine dithiocarbamate (APDC), chemically binds the metals in the water. APDC is easily dissolved in the nonpolar organic solvent, methyl isobutyl ketone (MIBK). Because MIBK is nonpolar, it will not dissolve in water and will separate from the water like oil and water.

Bottom Photo: Atomic absorption requires the presence of ground state metal atoms (Me^o). The initial process which takes place in an atomic absorption spectrophotometer is to create a population of ground state atoms. This is accomplished in a variety of ways, usually classified as flame and non-flame. The simplest and most common method uses a flame to produce these atoms.



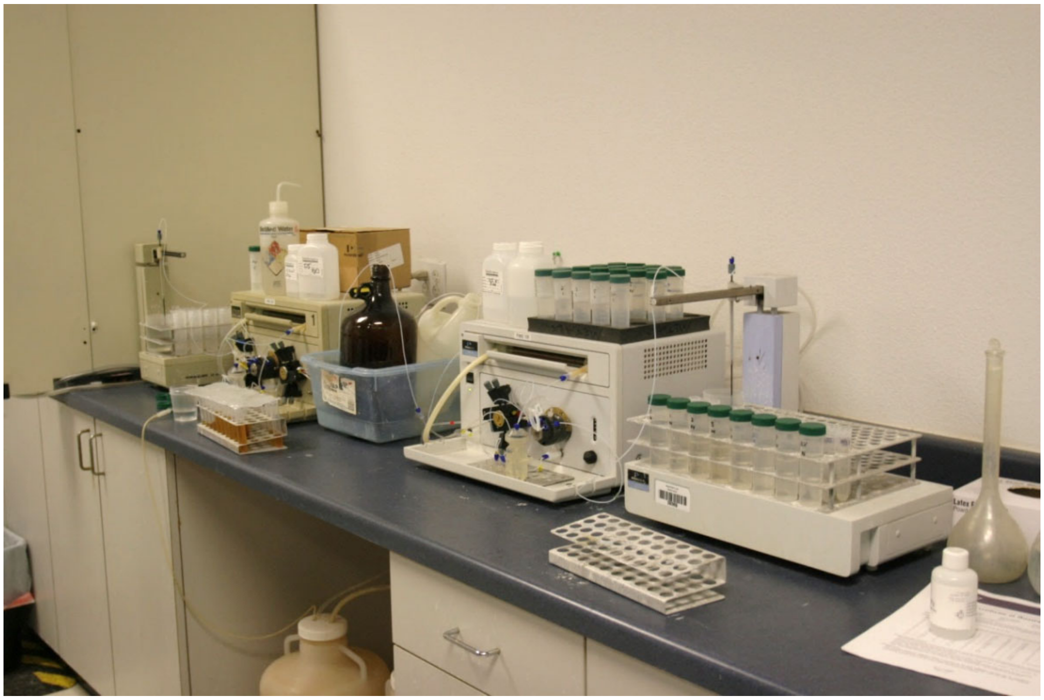
Vapor atomic fluorescence spectroscopy (CVAFS) analytical techniques were designed by the EPA for the analysis of Mercury at low and sub parts per trillion (ppt) concentrations. Low detection limits were developed to support risk assessment, Mercury bioaccumulation in fish is a heightened concern. Thirty-nine states have issued fish consumption advisories due to mercury contamination. Mercury is a toxic pollutant across most regulatory programs (air, water, hazardous waste & pollution prevention). It is persistent and harmful to human health and the environment at relatively low levels.

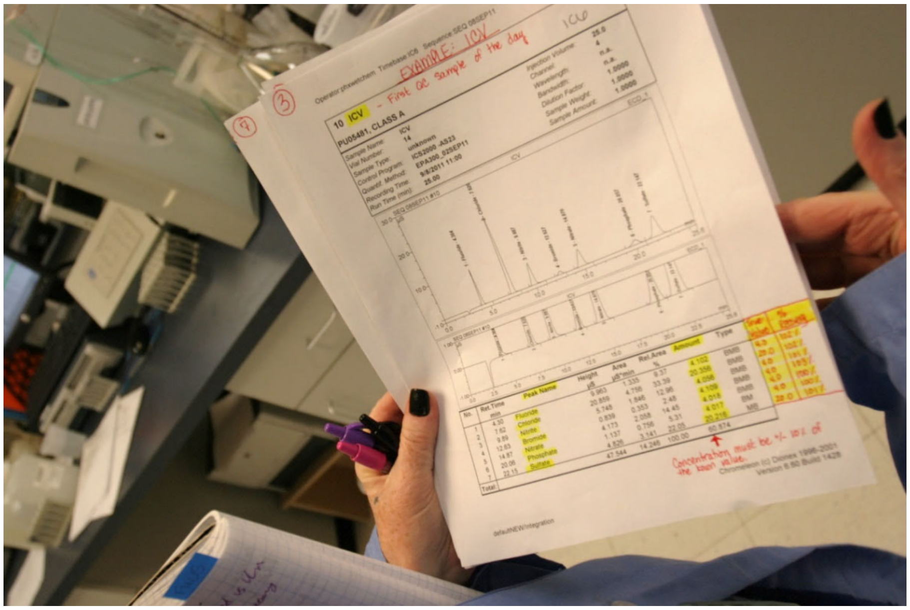




This lab’s Quality Assurance Quality Control (QAQC) methods includes spikes, performance samples, replicates, detection limits and blanks.

Prepared samples stored for metal analysis.





Operator:phxwetchem Timebase:IC6 Sequence:SEQ 08SEP11

EXAMPLE: ICV - First QC Sample of the day

10 ICV

PU05481, CLASS A

Sample Name:	ICV	Injection Volume:	25.0
Vial Number:	14	Channel:	4
Sample Type:	unknown	Wavelength:	n.a.
Control Program:	ICS2000 -AS23	Bandwidth:	n.a.
Quantif. Method:	EPA300_02SEP11	Dilution Factor:	1.0000
Recording Time:	9/8/2011 11:00	Sample Weight:	1.0000
Run Time (min):	25.00	Sample Amount:	1.0000

No.	Ret.Time min	Peak Name	Height µS	Area µS*min	Rel.Area %	Amount	Type	True value	% Recovery
1	4.30	Fluoride	9.963	1.335	9.37	4.102	BMB	4.0	102%
2	7.62	Chloride	20.859	4.756	33.39	20.356	BMB	20.0	102%
3	9.89	Nitrite	5.748	1.846	12.96	4.056	BMB	4.0	101%
4	12.63	Bromide	0.839	0.353	2.48	4.109	BMB	4.0	103%
5	14.87	Nitrate	4.173	2.058	14.45	4.018	BMB	4.0	100%
6	20.06	Phosphate	1.137	0.756	5.31	4.017	BM	4.0	100%
7	22.15	Sulfate	4.826	3.141	22.05	20.216	MB	20.0	101%
Total:			47.544	14.246	100.00	60.874			

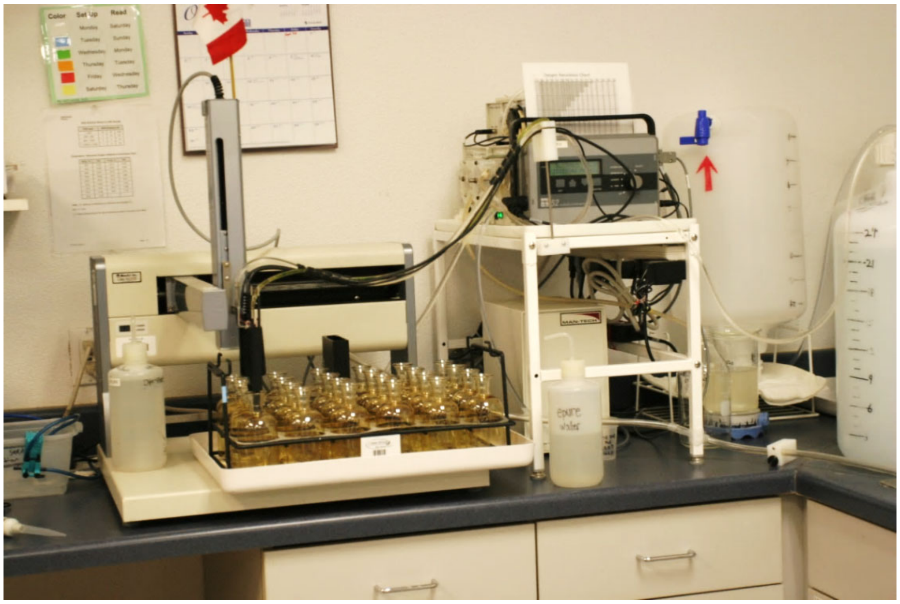
Concentration must be +/- 10% of the known value.

Chromeleon (c) Dionex 1996-2001
Version 6.60 Build 1428

defaultNEW/integration

Top Photo: This form shows a typical ion chromatography run will have a standard curve consisting of 4 or 5 points for each ion of interest. A combined ion stock standard is used. The correlation coefficient of the standard curve for each ion should be >.998. The coefficient is calculated by plotting the peak area against the standard concentration using a linear fit.

Bottom Photo: Some labs have the luxury of automatic filling dilution water for BOD bottles. If the BOD bottle is filled too rapidly, excessive agitation and bubbling may result in supersaturated water. This device also has the capability of measuring the oxygen level.



Collection of Surface Water Samples

Representative samples may be collected from rivers, streams and lakes if certain rules are followed:

1. Watch out for flash floods! If a flooding event is likely and samples must be obtained, always go in two-person teams for safety. Look for an easy route of escape.

2. Select a sampling location at or near a gauging station, so that stream discharge can be related to water-quality loading. If no gauging station exists, then measure the flow rate at the time of sampling, using the streamflow method described below.

3. Locate a straight and uniform channel for sampling.

4. Unless specified in the sampling plan, avoid sampling locations next to confluences or point sources of contamination.

5. Use bridges or boats for deep rivers and lakes where wading is dangerous or impractical.

6. Do not collect samples along a bank, as they may not be representative of the surface water body as a whole.

7. Use appropriate gloves when collecting the sample.

Streamflow Measurement

Before collecting water quality samples, record the stream's flow rate at the selected station. The flow rate measurement is important for estimating contaminant loading and other impacts.

The first step in streamflow measurement is selecting a cross-section. Select a straight reach where the stream bed is uniform and relatively free of boulders and aquatic growth. Be certain that the flow is uniform and free of eddies, slack water and excessive turbulence.

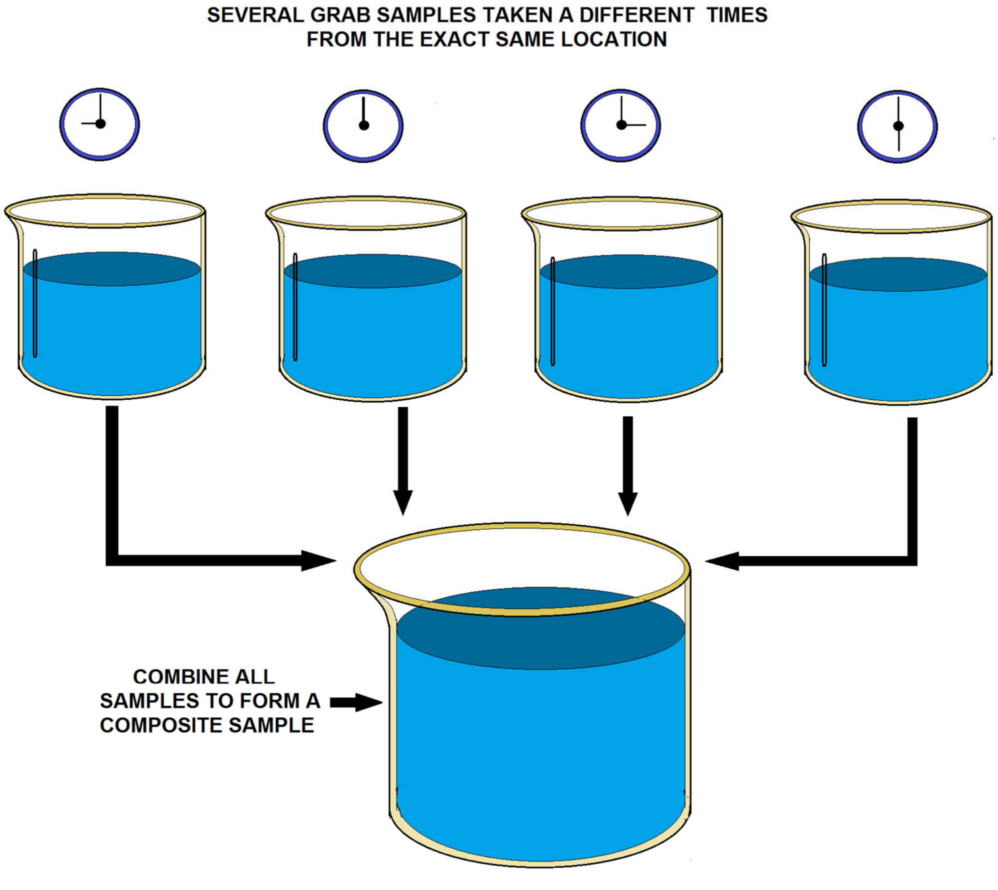
After the cross-section has been selected, determine the width of the stream by stringing a measuring tape from bank-to-bank at right angles to the direction of flow. Next, determine the spacing of the verticals. Space the verticals so that no partial section has more than 5 per cent of the total discharge within it.

At the first vertical, face upstream and lower the velocity meter to the channel bottom, record its depth, then raise the meter to 0.8 and 0.2 of the distance from the stream surface, measure the water velocities at each level, and average them. Move to the next vertical and repeat the procedure until you reach the opposite bank. Once the velocity, depth and distance of the cross-section have been determined, the mid-section method can be used for determining discharge. Calculate the discharge in each increment by multiplying the averaged velocity in each increment by the increment width and averaged depth.

(Note that the first and last stations are located at the edge of the waterway and have a depth and velocity of zero.) Add up the discharges for each increment to calculate total stream discharge. Record the flow in liters (or cubic feet) per second in your field book.

Composite Sampling

Composite sampling is intended to produce a water quality sample representative of the total stream discharge at the sampling station. If your sampling plan calls for composite sampling, use an automatic type sampler.



Chain of Custody Procedures

Because a sample is physical evidence, chain of custody procedures are used to maintain and document sample possession from the time the sample is collected until it is introduced as evidence. Chain of custody requirements will vary from agency to agency.

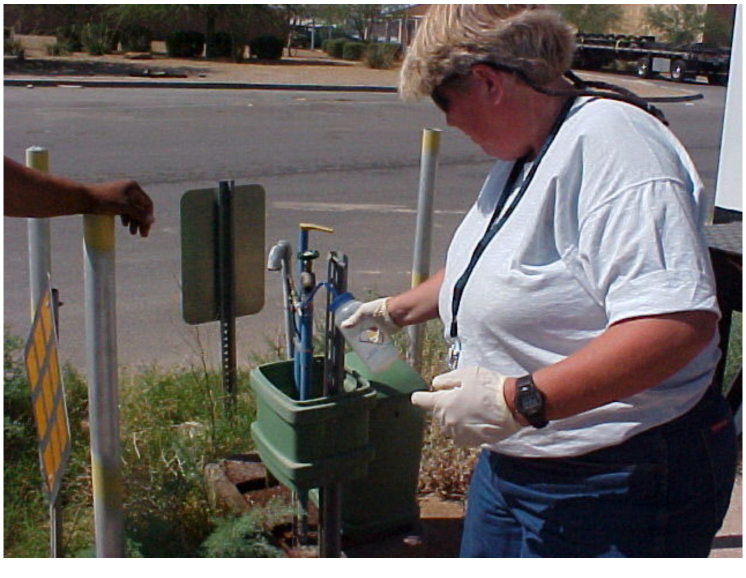
However, these procedures are similar and the chain of custody outlined in this manual is only a guideline. Consult your project manager for specific requirements.

If you have physical possession of a sample, have it in view, or have physically secured it to prevent tampering then it is defined as being in ***"custody*."** A chain of custody record, therefore, begins when the sample containers are obtained from the laboratory. From this point on, a chain of custody record will accompany the sample containers.

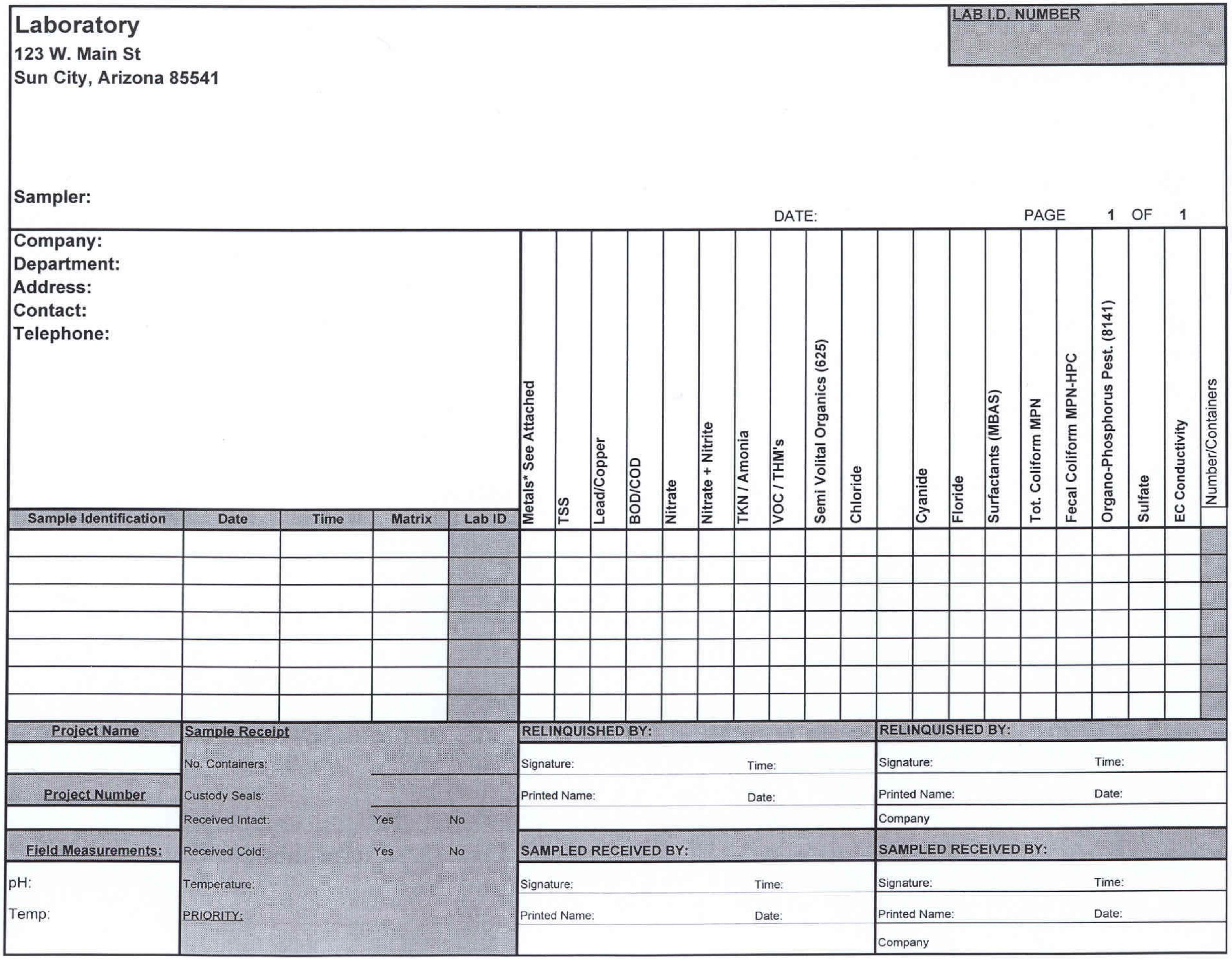
Handle the samples as little as possible in the field. Each custody sample requires a chain of custody record and may require a seal. If you do not seal individual samples, then seal the containers in which the samples are shipped.

When the samples transfer possession, both parties involved in the transfer must sign, date and note the time on the chain of custody record. If a shipper refuses to sign the chain-of-custody you must seal the samples and chain of custody documents inside a box or cooler with bottle seals or evidence tape.

The recipient will then attach the shipping invoices showing the transfer dates and times to the custody sheets. If the samples are split and sent to more than one laboratory, prepare a separate chain of custody record for each sample. If the samples are delivered to after-hours night drop-off boxes, the custody record should note such a transfer and be locked with the sealed samples inside sealed boxes.



Using alcohol to disinfect a special sample tap before obtaining a sample.



Laboratory
123 W. Main St
Sun City, Arizona 85541

LAB I.D. NUMBER

Sampler:

DATE:

PAGE **1** OF **1**

Company:
Department:
Address:
Contact:
Telephone:

Sample Identification	Date	Time	Matrix	Lab ID	Metals* See Attached	TSS	Lead/Copper	BOD/COD	Nitrate	Nitrate + Nitrite	TKN / Amonia	VOC / THM's	Semi Volital Organics (625)	Chloride		Cyanide	Floride	Surfactants (MBAS)	Tot. Coliform MPN	Fecal Coliform MPN-HPC	Organo-Phosphorus Pest. (8141)	Sulfate	EC Conductivity	Number/Containers

Project Name

Project Number

Field Measurements:
pH:
Temp:

Sample Receipt
No. Containers:
Custody Seals:
Received Intact: Yes No
Received Cold: Yes No
Temperature:
PRIORITY:

RELINQUISHED BY:
Signature: Time:
Printed Name: Date:

SAMPLED RECEIVED BY:
Signature: Time:
Printed Name: Date:

RELINQUISHED BY:
Signature: Time:
Printed Name: Date:
Company

SAMPLED RECEIVED BY:
Signature: Time:
Printed Name: Date:
Company

Chain of Custody Example.

EPA Rules Section 8 Post Quiz

Drinking Water Standards

1. The ___________________is responsible for establishing maximum contaminant levels for drinking water. These standards are expressed as MCL (Maximum Contaminant Level). In most cases, this measurement is expressed as milligrams per liter of water (mg/l) or as parts per million (ppm).

A. MCLG
B. MCLs
C. Group USA
D. Emergency Planning and Community Right to Know Act (EPCRA)
E. US Environmental Protection Agency
F. None of the Above

2. In general terms, inorganic compounds are those materials that do not contain carbon. These compounds are often able to be dissolved in water. For example, dissolved gases such as nitrogen, oxygen, radon, and methane can be classified as _________________.

A. Myriad organic compounds
B. Inorganic compounds
C. Some metals
D. Ionic compounds
E. Electron affinity (anions)
F. None of the Above

3. In addition to dissolved gases, some metals may be present in water as well. Some of these metals can be hazardous to human health, and may be introduced into water either naturally or through___________________________.

A. Myriad organic compounds
B. Inorganic compounds
C. Some metals
D. Ionic compounds
E. Electron affinity (anions)
F. None of the Above

4. Some of the more common metals include arsenic and aluminum which the EPA has established a MCL of no more than____________________.

A. 4.0
B. .002
C. 1.3
D. .015
E. 10.0
F. None of the Above

5. Lead with a MCL of____________________.

A. 4.0
B. .002
C. 1.3
D. .015
E. 10.0
F. None of the Above

6. Mercury MCL of_______________

A. 4.0
B. .002
C. 1.3
D. .015
E. 10.0
F. None of the Above

7. In addition, zinc, calcium, sodium, magnesium, potassium, and copper, all with a _______ MCL.

A. 4.0
B. .002.
C. 1.3
D. .015
E. 10.0
F. None of the Above

8. ______________ can be dangerous to human health even at low concentrations, and as mentioned above can be introduced to our water from a variety of sources, including old pipes and lead solder.

A. Crystallization compounds	D. Organometallic compounds
B. Inorganic salts	E. Lead, mercury, and arsenic
C. Compounds	F. None of the Above

9. Some of the ________________such as sodium, potassium, calcium, and magnesium are important to our overall health and well-being.

A. Myriad organic compounds	D. Ionic compounds
B. Other inorganic compounds	E. Other organic compounds
C. Metals	F. None of the Above

10. Another class of inorganic compounds are known as negative ions. These include substances such as fluoride: MCL _______ PPM (parts per million).

A. 4.0	D. .015
B. .002	E. 10.0
C. 1.3	F. None of the Above

Glossary

A

Absolute Pressure: The pressure above zone absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury. (mmHg).

Aerodynamics: The study of the flow of gases. The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.

Aeronautics: The mathematics and mechanics of flying objects, in particular airplanes.

Air Break: A physical separation which may be a low inlet into the indirect waste receptor from the fixture, or device that is indirectly connected. You will most likely find an air break on waste fixtures or on non-potable lines. You should never allow an air break on an ice machine.

Air Gap Separation: A physical separation space that is present between the discharge vessel and the receiving vessel, for an example, a kitchen faucet.

Altitude-Control Valve: If an overflow occurs on a storage tank, the operator should first check the altitude-control valve. Altitude-Control Valve is designed to, 1. Prevent overflows from the storage tank or reservoir, or 2. Maintain a constant water level as long as water pressure in the distribution system is adequate.

Angular Motion Formulas: Angular velocity can be expressed as (angular velocity = constant):

$\omega = \theta / t$ (2a)

where
ω= angular velocity (rad/s)
θ = angular displacement (rad)
t = time (s)

Angular velocity can be expressed as (angular acceleration = constant):
$\omega = \omega_o + \alpha t$ (2b)

where
ω_o = angular velocity at time zero (rad/s)
α = angular acceleration (rad/s^2)

Angular displacement can be expressed as (angular acceleration = constant):
$\theta = \omega_o t + 1/2 \alpha t^2$ (2c)

Combining 2a and 2c:
$\omega = (\omega_o^2 + 2 \alpha \theta)^{1/2}$

Angular acceleration can be expressed as:
$\alpha = d\omega / dt = d^2\theta / dt^2$ (2d)

where
$d\theta$ = change of angular displacement (rad)
dt = change in time (s)

Atmospheric Pressure: Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

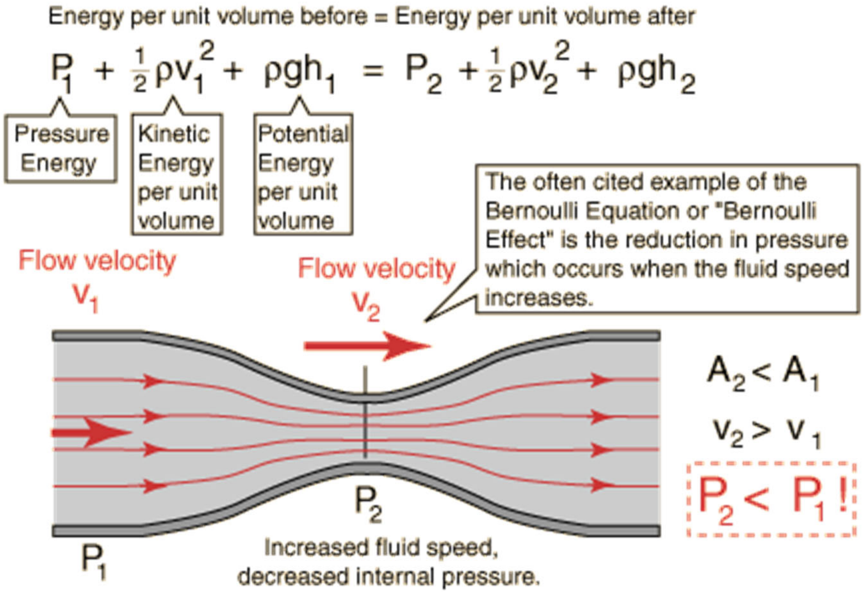
B

Backflow Prevention: To stop or prevent the occurrence of, the unnatural act of reversing the normal direction of the flow of liquid, gases, or solid substances back in to the public potable (drinking) water supply. See Cross-connection control.

Backflow: To reverse the natural and normal directional flow of a liquid, gases, or solid substances back in to the public potable (drinking) water supply. This is normally an undesirable effect.

Backsiphonage: A liquid substance that is carried over a higher point. It is the method by which the liquid substance may be forced by excess pressure over or into a higher point. Is a condition in which the pressure in the distribution system is less than atmospheric pressure. In other words, something is “sucked” into the system because the main is under a vacuum.

Bernoulli's Equation: Describes the behavior of moving fluids along a streamline. The Bernoulli Equation can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids. The qualitative behavior that is usually labeled with the term "***Bernoulli effect***" is the lowering of fluid pressure in regions where the flow velocity is increased. This lowering of pressure in a constriction of a flow path may seem counterintuitive, but seems less so when you consider pressure to be energy density. In the high velocity flow through the constriction, kinetic energy must increase at the expense of pressure energy.



A special form of the Euler’s equation derived along a fluid flow streamline is often called the **Bernoulli Equation.**

$$\frac{\partial}{\partial s}\left(\frac{v^2}{2}+\frac{p}{\rho}+g\cdot h\right)=0 \qquad (1)$$

where
v = flow speed
p = pressure
ρ = density
g = gravity
h = height

$$\frac{v^2}{2}+\frac{p}{\rho}+g\cdot h=\text{Constant} \qquad (2)$$

$$\frac{v^2}{2\cdot g}+\frac{p}{\gamma}+h=\text{Constant} \qquad (3)$$

where
$\gamma=\rho\cdot g$

$$\frac{\rho\cdot v^2}{2}+p=\text{Constant} \qquad (4)$$

$$\frac{\rho\cdot v^2}{2}=p_d \qquad (5)$$

$$\frac{\rho\cdot v_1^2}{2}+p_1=\frac{\rho\cdot v_2^2}{2}+p_2=\text{Constant} \qquad (6)$$

For steady state incompressible flow the Euler equation becomes (1). If we integrate (1) along the streamline it becomes (2). (2) can further be modified to (3) by dividing by gravity.

Head of Flow: Equation (3) is often referred to as the **head** because all elements have the unit of length.

Bernoulli's Equation Continued:

Dynamic Pressure

(2) and (3) are two forms of the Bernoulli Equation for steady state incompressible flow. If we assume that the gravitational body force is negligible, (3) can be written as (4).

Both elements in the equation have the unit of pressure and it's common to refer the flow velocity component as the **dynamic pressure** of the fluid flow (5).

Since energy is conserved along the streamline, (4) can be expressed as (6). Using the equation we see that increasing the velocity of the flow will reduce the pressure, decreasing the velocity will increase the pressure.

This phenomena can be observed in a **venturi meter** where the pressure is reduced in the constriction area and regained after. It can also be observed in a **pitot tube** where the **stagnation** pressure is measured. The stagnation pressure is where the velocity component is zero.

Bernoulli's Equation Continued:

Pressurized Tank

If the tanks are pressurized so that product of gravity and height (g h) is much less than the pressure difference divided by the density, (e4) can be transformed to (e6).
The velocity out from the tanks depends mostly on the pressure difference.

Example - outlet velocity from a pressurized tank

The outlet velocity of a pressurized tank where

$p_1 = 0.2\ MN/m^2,\ p_2 = 0.1\ MN/m^2\ A_2/A_1 = 0.01,\ h = 10\ m$

can be calculated as

$V_2 = [(2/(1-(0.01)^2)\ (\ (0.2 - 0.1)x10^6\ /1x10^3 + 9.81\ x\ 10)]^{1/2} = \underline{19.9\ m/s}$

Coefficient of Discharge - Friction Coefficient

Due to friction the real velocity will be somewhat lower than this theoretical example. If we introduce a **friction coefficient** *c* (coefficient of discharge), (e5) can be expressed as (e5b). The coefficient of discharge can be determined experimentally. For a sharp edged opening it may be as low as 0.6. For smooth orifices it may be between 0.95 and 1.

Bingham Plastic Fluids: Bingham Plastic Fluids have a yield value which must be exceeded before it will start to flow like a fluid. From that point the viscosity will decrease with increase of agitation. Toothpaste, mayonnaise and tomato catsup are examples of such products.

Boundary Layer: The layer of fluid in the immediate vicinity of a bounding surface.

Bulk Modulus and Fluid Elasticity: An introduction to and a definition of the Bulk Modulus Elasticity commonly used to characterize the compressibility of fluids.

The Bulk Modulus Elasticity can be expressed as

$E = - dp / (dV / V)\ (1)$

where
E = *bulk modulus elasticity*
dp = *differential change in pressure on the object*
dV = *differential change in volume of the object*
V = *initial volume of the object*

The Bulk Modulus Elasticity can be alternatively expressed as

$E = - dp / (d\rho / \rho)\ (2)$

where
$d\rho$ = *differential change in density of the object*
ρ = *initial density of the object*

An increase in the pressure will decrease the volume (1). A decrease in the volume will increase the density (2).

- The SI unit of the bulk modulus elasticity is N/m^2 (Pa)
- The imperial (BG) unit is lb_f/in^2 (psi)
- 1 lb_f/in^2 (psi) = $6.894\ 10^3\ N/m^2$ (Pa)

A large Bulk Modulus indicates a relatively incompressible fluid.

Bulk Modulus for some common fluids can be found in the table below:

Bulk Modulus - *E*	Imperial Units - BG (psi, lb_f/in^2) x 10^5	SI Units (Pa, N/m^2) x 10^9
Carbon Tetrachloride	1.91	1.31
Ethyl Alcohol	1.54	1.06
Gasoline	1.9	1.3
Glycerin	6.56	4.52
Mercury	4.14	2.85
SAE 30 Oil	2.2	1.5
Seawater	3.39	2.35
Water	3.12	2.15

C

Capillarity: (or capillary action) The ability of a narrow tube to draw a liquid upwards against the force of gravity.

The height of liquid in a tube due to capillarity can be expressed as

$h = 2 \sigma \cos\theta / (\rho g r)$ *(1)*

where

h = *height of liquid (ft, m)*

σ = *surface tension (lb/ft, N/m)*

θ = *contact angle*

ρ = *density of liquid* (lb/ft^3, kg/m^3)

g = *acceleration due to gravity* ($32.174\ ft/s^2$, $9.81\ m/s^2$)

r = *radius of tube (ft, m)*

Cauchy Number: A dimensionless value useful for analyzing fluid flow dynamics problems where compressibility is a significant factor.
The Cauchy Number is the ratio between inertial and the compressibility force in a flow and can be expressed as

$C = \rho v^2 / E$ *(1)*

where

ρ = *density* (kg/m^3)

v = *flow velocity (m/s)*

E = *bulk modulus elasticity* (N/m^2)

The bulk modulus elasticity has the dimension pressure and is commonly used to characterize the compressibility of a fluid.

The Cauchy Number is the square root of the Mach Number

$M^2 = Ca$ (3)

where

C = Mach Number

Cavitation: Under the wrong condition, cavitation will reduce the components life time dramatically. Cavitation may occur when the local static pressure in a fluid reach a level below the vapor pressure of the liquid at the actual temperature. According to the Bernoulli Equation this may happen when the fluid accelerates in a control valve or around a pump impeller. The vaporization itself does not cause the damage - the damage happens when the vapor almost immediately collapses after evaporation when the velocity is decreased and pressure increased.

Cavitation means that cavities are forming in the liquid that we are pumping. When these cavities form at the suction of the pump several things happen all at once: We experience a loss in capacity. We can no longer build the same head (pressure). The efficiency drops. The cavities or bubbles will collapse when they pass into the higher regions of pressure causing noise, vibration, and damage to many of the components. The cavities form for five basic reasons and it is common practice to lump all of them into the general classification of cavitation.

This is an error because we will learn that to correct each of these conditions we must understand why they occur and how to fix them. Here they are in no particular order: Vaporization, Air ingestion, Internal recirculation, Flow turbulence and finally the Vane Passing Syndrome.

Avoiding Cavitation

Cavitation can in general be avoided by:

- increasing the distance between the actual local static pressure in the fluid - and the vapor pressure of the fluid at the actual temperature

This can be done by:

- reengineering components initiating high speed velocities and low static pressures
- increasing the total or local static pressure in the system
- reducing the temperature of the fluid

Reengineering of Components Initiating High Speed Velocity and Low Static Pressure

Cavitation and damage can be avoided by using special components designed for the actual rough conditions.

- Conditions such as huge pressure drops can - with limitations - be handled by Multi Stage Control Valves
- Difficult pumping conditions - with fluid temperatures close to the vaporization temperature - can be handled with a special pump - working after another principle than the centrifugal pump.

Cavitation Continued: Increasing the Total or Local Pressure in the System
By increasing the total or local pressure in the system, the distance between the static pressure and the vaporization pressure is increased and vaporization and cavitation may be avoided.

The ratio between static pressure and the vaporization pressure, an indication of the possibility of vaporization, is often expressed by the Cavitation Number. Unfortunately it may not always be possible to increase the total static pressure due to system classifications or other limitations. Local static pressure in the component may then be increased by lowering the component in the system. Control valves and pumps should in general be positioned in the lowest part of the system to maximize the static head. This is common for boiler feeding pumps receiving hot condensate (water close to 100 °C) from a condensate receiver.

Cavitation Continued: Reducing the Temperature of the Fluid
The vaporization pressure is highly dependent on the fluid temperature. Water, our most common fluid, is an example:

Temperature (°C)	Vapor Pressure (kN/m^2)
0	0.6
5	0.9
10	1.2
15	1.7
20	2.3
25	3.2
30	4.3
35	5.6
40	7.7
45	9.6
50	12.5
55	15.7
60	20
65	25
70	32.1
75	38.6
80	47.5
85	57.8
90	70
95	84.5
100	101.33

As we can see - the possibility of evaporation and cavitation increases dramatically with the water temperature.

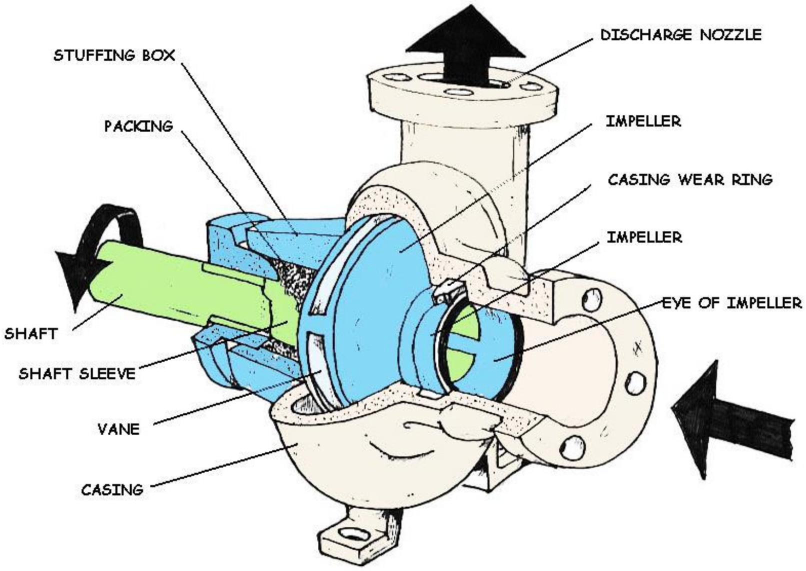
Cavitation can be avoided by locating the components in the coldest part of the system. For example, it is common to locate the pumps in heating systems at the "cold" return lines. The situation is the same for control valves. Where it is possible they should be located on the cold side of heat exchangers.

Cavitations Number: A "special edition" of the dimensionless Euler Number.

The Cavitations Number is useful for analyzing fluid flow dynamics problems where cavitations may occur. The Cavitations Number can be expressed as

$$Ca = (p_r - p_v) / 1/2\ \rho\ v^2 \quad (1)$$

where
Ca = *Cavitations number*
p_r = *reference pressure (Pa)*
p_v = *vapor pressure of the fluid (Pa)*
ρ = *density of the fluid (kg/m*^{3}*)*
v = *velocity of fluid (m/s)*



Centrifugal Pump: A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

Chezy Formula: Conduits flow and mean velocity. The Chezy formula can be used to calculate mean flow velocity in conduits and is expressed as

$$v = c\ (R\ S)^{1/2} \quad (1)$$

where
v = *mean velocity (m/s, ft/s)*
c = *the Chezy roughness and conduit coefficient*
R = *hydraulic radius of the conduit (m, ft)*
S = *slope of the conduit (m/m, ft/ft)*

In general the Chezy coefficient - *c* - is a function of the flow Reynolds Number - Re - and the relative roughness - *ε/R* - of the channel.
ε is the characteristic height of the roughness elements on the channel boundary.

Coanda Effect: The tendency of a stream of fluid to stay attached to a convex surface, rather than follow a straight line in its original direction.

Colebrook Equation: The friction coefficients used to calculate pressure loss (or major loss) in ducts, tubes and pipes can be calculated with the Colebrook equation.

$$1 / \lambda^{1/2} = -2 \log ((2.51 / (Re\ \lambda^{1/2})) + ((k / d_h) / 3.72))\ (1)$$

where
λ = *D'Arcy-Weisbach friction coefficient*
Re = Reynolds Number
k = roughness of duct, pipe or tube surface (m, ft)
d_h = *hydraulic diameter (m, ft)*

The Colebrook equation is only valid at turbulent flow conditions.
Note that the friction coefficient is involved on both sides of the equation and that the equation must be solved by iteration.

The Colebrook equation is generic and can be used to calculate the friction coefficients in different kinds of fluid flows - air ventilation ducts, pipes and tubes with water or oil, compressed air and much more.

Common Pressure Measuring Devices: The Strain Gauge is a common measuring device used for a variety of changes such as head. As the pressure in the system changes, the diaphragm expands which changes the length of the wire attached. This change of length of the wire changes the Resistance of the wire, which is then converted to head. Float mechanisms, diaphragm elements, bubbler tubes, and direct electronic sensors are common types of level sensors.

Compressible Flow: We know that fluids are classified as Incompressible and Compressible fluids. Incompressible fluids do not undergo significant changes in density as they flow. In general, liquids are incompressible; water being an excellent example. In contrast compressible fluids do undergo density changes.

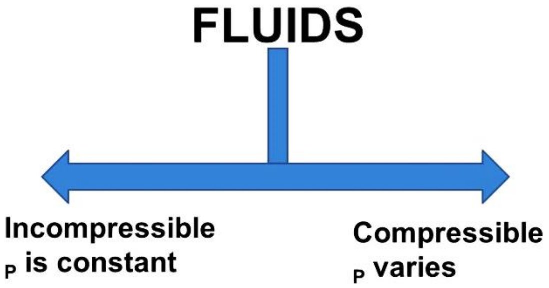
Gases are generally compressible; air being the most common compressible fluid we can find. Compressibility of gases leads to many interesting features such as shocks, which are absent for incompressible fluids. Gas dynamics is the discipline that studies the flow of compressible fluids and forms an important branch of Fluid Mechanics. In this book we give a broad introduction to the basics of compressible fluid flow.

In a compressible flow the compressibility of the fluid must be taken into account. The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of **Gas Mixtures** - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and **Universal Gas Constant** - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Compression and Expansion of Gases: If the compression or expansion takes place under constant temperature conditions - the process is called **isothermal.** The isothermal process can on the basis of the Ideal Gas Law be expressed as:

$$p / \rho = \text{constant} \quad (1)$$

where
p = *absolute pressure*
ρ = *density*



Confined Space Entry: Entry into a confined space requires that all entrants wear a harness and safety line. If an operator is working inside a storage tank and suddenly faints or has a serious problem, there should be two people outside standing by to remove the injured operator.

Conservation Laws: The conservation laws states that particular measurable properties of an isolated physical system does not change as the system evolves: Conservation of energy (including mass). Fluid Mechanics and Conservation of Mass - The law of conservation of mass states that mass can neither be created or destroyed.

Contaminant: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known or anticipated to occur in public water systems.

Contamination: To make something bad; to pollute or infect something. To reduce the quality of the potable (drinking) water and create an actual hazard to the water supply by poisoning or through spread of diseases.

Corrosion: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.

Cross-Contamination: The mixing of two unlike qualities of water. For example, the mixing of good water with a polluting substance like a chemical.

D

Darcy-Weisbach Equation: The **pressure loss** (or major loss) in a pipe, tube or duct can be expressed with the D'Arcy-Weisbach equation:

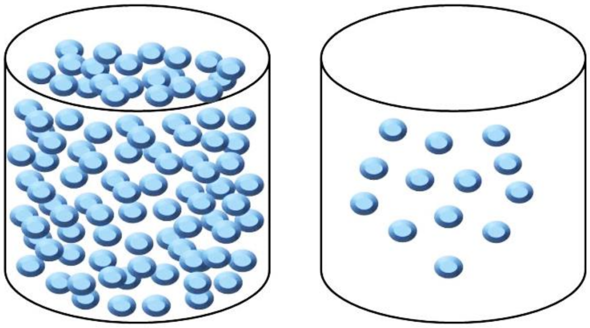
$\Delta p = \lambda \, (l / d_h) \, (\rho \, v^2 / 2)$ *(1)*

where
Δp = *pressure loss* (Pa, N/m^2, lb$_f$/ft^2)
λ = *D'Arcy-Weisbach friction coefficient*
l = *length of duct or pipe* (m, ft)
d_h = *hydraulic diameter* (m, ft)
ρ = *density* (kg/m^3, lb/ft^3)

Note! Be aware that there are two alternative friction coefficients present in the literature. One is 1/4 of the other and (1) must be multiplied with four to achieve the correct result. This is important to verify when selecting friction coefficients from Moody diagrams.

Density: Is a physical property of matter, as each element and compound has a unique density associated with it.

Density defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume. For example: A rock is obviously more dense than a crumpled piece of paper of the same size. A Styrofoam cup is less dense than a ceramic cup. Density may also refer to how closely "packed" or "crowded" the material appears to be - again refer to the Styrofoam vs. ceramic cup. Take a look at the two boxes below.



Each box has the same volume. ***If each ball has the same mass, which box would weigh more? Why?***

The box that has more balls has more mass per unit of volume. This property of matter is called density. The density of a material helps to distinguish it from other materials. Since mass is usually expressed in grams and volume in cubic centimeters, density is expressed in grams/cubic centimeter. We can calculate density using the formula:

Density= Mass/Volume

The density can be expressed as

$\rho = m / V = 1 / v_g$ *(1)*
where
ρ = *density* (kg/m^3)

m = mass (kg)
V = volume (m^3)
v_g = specific volume (m^3/kg)

The SI units for density are kg/m^3. The imperial (BG) units are lb/ft^3 (slugs/ft^3). While people often use pounds per cubic foot as a measure of density in the U.S., pounds are really a measure of force, not mass. Slugs are the correct measure of mass. You can multiply slugs by 32.2 for a rough value in pounds. The higher the density, the tighter the particles are packed inside the substance. Density is a physical property constant at a given temperature and density can help to identify a substance.

Example - Use the Density to Identify the Material:
An unknown liquid substance has a mass of 18.5 g and occupies a volume of 23.4 ml. (milliliter).

The density can be calculated as

$$\begin{aligned}\rho &= [18.5\ (g) / 1000\ (g/kg)] / [23.4\ (ml) / 1000\ (ml/l)\ 1000\ (l/m^3)\ ] \\ &= 18.5\ 10^{-3}\ (kg) / 23.4\ 10^{-6}\ (m^3) \\ &= \underline{790}\ kg/m^3\end{aligned}$$

If we look up densities of some common substances, we can find that ethyl alcohol, or ethanol, has a density of 790 kg/m^3. Our unknown liquid may likely be ethyl alcohol!

Example - Use Density to Calculate the Mass of a Volume
The density of titanium is 4507 kg/m^3 . Calculate the mass of 0.17 m^3 titanium!

$$\begin{aligned}m &= 0.17\ (m^3)\ 4507\ (kg/m^3) \\ &= \underline{766.2}\ kg\end{aligned}$$

Dilatant Fluids: Shear Thickening Fluids or Dilatant Fluids increase their viscosity with agitation. Some of these liquids can become almost solid within a pump or pipe line. With agitation, cream becomes butter and Candy compounds, clay slurries and similar heavily filled liquids do the same thing.

Disinfect: To kill and inhibit growth of harmful bacterial and viruses in drinking water.

Disinfection: The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

Distribution System Water Quality: Can be adversely affected by improperly constructed or poorly located blowoffs of vacuum/air relief valves. Air relief valves in the distribution system lines must be placed in locations that cannot be flooded. This is to prevent water contamination. The common customer complaint of Milky Water or Entrained Air is sometimes solved by the installation of air relief valves.

The venting of air is not a major concern when checking water levels in a storage tank. If the vent line on a ground level storage tank is closed or clogged up, a vacuum will develop in the tank may happen to the tank when the water level begins to lower.

Drag Coefficient: Used to express the drag of an object in moving fluid. Any object moving through a fluid will experience a drag - the net force in direction of flow due to the pressure and shear stress forces on the surface of the object.

The drag force can be expressed as:

$F_d = c_d\ 1/2\ \rho\ v^2\ A$ (1)

where
F_d = *drag force (N)*
c_d = *drag coefficient*
ρ = *density of fluid*
v = *flow velocity*
A = *characteristic frontal area of the body*

The drag coefficient is a function of several parameters as shape of the body, Reynolds Number for the flow, Froude number, Mach Number and Roughness of the Surface.
The characteristic frontal area - *A* - depends on the body.

Dynamic or Absolute Viscosity: The viscosity of a fluid is an important property in the analysis of liquid behavior and fluid motion near solid boundaries. The viscosity of a fluid is its resistance to shear or flow and is a measure of the adhesive/cohesive or frictional properties of a fluid. The resistance is caused by intermolecular friction exerted when layers of fluids attempts to slide by another.

Dynamic Pressure: Dynamic pressure is the component of fluid pressure that represents a fluids kinetic energy. The dynamic pressure is a defined property of a moving flow of gas or liquid and can be expressed as

$p_d = 1/2\ \rho\ v^2$ (1)

where
p_d = *dynamic pressure (Pa)*
ρ = *density of fluid* (kg/m^3)
v = *velocity (m/s)*

Dynamic, Absolute and Kinematic Viscosity: The viscosity of a fluid is an important property in the analysis of liquid behavior and fluid motion near solid boundaries. The viscosity is the fluid resistance to shear or flow and is a measure of the adhesive/cohesive or frictional fluid property. The resistance is caused by intermolecular friction exerted when layers of fluids attempts to slide by another.

Viscosity is a measure of a fluid's resistance to flow.

The knowledge of viscosity is needed for proper design of required temperatures for storage, pumping or injection of fluids.

Common used units for viscosity are
- CentiPoises (cp) = CentiStokes (cSt) × Density
- SSU[1] = Centistokes (cSt) × 4.55
- Degree Engler[1] × 7.45 = Centistokes (cSt)
- Seconds Redwood[1] × 0.2469 = Centistokes (cSt)

[1]centistokes greater than 50

There are two related measures of fluid viscosity - known as **dynamic** (**or absolute**) and **kinematic** viscosity.

Dynamic (absolute) Viscosity: The tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid. The shearing stress between the layers of non-turbulent fluid moving in straight parallel lines can be defined for a Newtonian fluid as:

The dynamic or absolute viscosity can be expressed like

$\tau = \mu\, dc/dy \quad (1)$

where
τ = *shearing stress*
μ = *dynamic viscosity*

Equation (1) is known as the **Newton's Law of Friction**.

In the SI system the dynamic viscosity units are **N s/m²**, **Pa s** or **kg/m s** where

- *1 Pa s = 1 N s/m² = 1 kg/m s*

The dynamic viscosity is also often expressed in the metric CGS (centimeter-gram-second) system as **g/cm.s**, **dyne.s/cm²** or **poise (p)** where

- *1 poise = dyne s/cm² = g/cm s = 1/10 Pa s*

For practical use the Poise is to large and its usual divided by 100 into the smaller unit called the **centiPoise (cP)** where

- *1 p = 100 cP*

Water at 68.4°F (20.2°C) has an absolute viscosity of one - 1 - centiPoise.

E

E. Coli, *Escherichia coli*: A bacterium commonly found in the human intestine. For water quality analyses purposes, it is considered an indicator organism. These are considered evidence of water contamination. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves.

Elevation Head: The energy possessed per unit weight of a fluid because of its elevation. 1 foot of water will produce .433 pounds of pressure head.

Energy: The ability to do work. Energy can exist in one of several forms, such as heat, light, mechanical, electrical, or chemical. Energy can be transferred to different forms. It also can exist in one of two states, either potential or kinetic.

Energy and Hydraulic Grade Line: The hydraulic grade and the energy line are graphical forms of the Bernoulli equation. For steady, in viscid, incompressible flow the total energy remains constant along a stream line as expressed through the Bernoulli

Equation:

$p + 1/2\ \rho\ v^2 + \gamma\ h$ = constant along a streamline (1)

where

p = static pressure (relative to the moving fluid)

ρ = density

γ = specific weight

v = flow velocity

g = acceleration of gravity

h = elevation height

Each term of this equation has the dimension *force per unit area* - psi, lb/ft^2 or N/m^2.

The Head

By dividing each term with the specific weight - $\gamma = \rho\ g$ - (1) can be transformed to express the "head":

$p / \gamma + v^2 / 2\ g + h$ = constant along a streamline = H (2)

where

H = the total head

Each term of this equation has the dimension length - ft, m.

The Total Head

(2) states that the sum of **pressure head** - p / γ -, **velocity head** - $v^2 / 2\ g$ - and **elevation head** - h - is constant along the stream line. This constant can be called **the total head** - H -.

The total head in a flow can be measured by the stagnation pressure using a pitot tube.

Energy and Hydraulic Grade Line Continued:

The Piezometric Head

The sum of pressure head - p / γ - and elevation head - h - is called **the piezometric head**. The piezometric head in a flow can be measured through an flat opening parallel to the flow.

Energy and Hydraulic Grade Line Continued:

The Energy Line

The Energy Line is a line that represents the total head available to the fluid and can be expressed as:

$EL = H = p / \gamma + v^2 / 2\ g + h$ = constant along a streamline (3)

where

EL = Energy Line

For a fluid flow without any losses due to friction (major losses) or components (minor losses) the energy line would be at a constant level. In the practical world the energy line decreases along the flow due to the losses.

A turbine in the flow will reduce the energy line and a pump or fan will increase the energy line.

The Hydraulic Grade Line

The Hydraulic Grade Line is a line that represent the total head available to the fluid minus the velocity head and can be expressed as:

$HGL = p / \gamma + h$ (4)

where
HGL = *Hydraulic Grade Line*

The hydraulic grade line lies one velocity head below the energy line.

Entrance Length and Developed Flow: Fluids need some length to develop the velocity profile after entering the pipe or after passing through components such as bends, valves, pumps, and turbines or similar.

The Entrance Length: The entrance length can be expressed with the dimensionless **Entrance Length Number:**

$El = l_e / d$ (1)

where
El = *Entrance Length Number*
l_e = *length to fully developed velocity profile*
d = *tube or duct diameter*

The Entrance Length Number for Laminar Flow

The Entrance length number correlation with the Reynolds Number for laminar flow can be expressed as:

$El_{laminar} = 0.06\ Re$ (2)

where
Re = *Reynolds Number*

The Entrance Length Number for Turbulent Flow

The Entrance length number correlation with the Reynolds Number for turbulent flow can be expressed as:

$El_{turbulent} = 4.4\ Re^{1/6}$ (3)

Entropy in Compressible Gas Flow: Calculating entropy in compressible gas flow
Entropy change in compressible gas flow can be expressed as

$ds = c_v \ln(T_2 / T_1) + R \ln(\rho_1 / \rho_2)$ (1)
or
$ds = c_p \ln(T_2 / T_1) - R \ln(p_2 / p_1)$ (2)

where
ds = *entropy change*
c_v = *specific heat capacity at a constant volume process*
c_p = *specific heat capacity at a constant pressure process*
T = *absolute temperature*

R = individual gas constant
ρ = density of gas
p = absolute pressure

Equation of Continuity: The Law of Conservation of Mass states that mass can be neither created nor destroyed. Using the Mass Conservation Law on a **steady flow** process - flow where the flow rate doesn't change over time - through a control volume where the stored mass in the control volume doesn't change - implements that inflow equals outflow. This statement is called **the Equation of Continuity.** Common application where **the Equation of Continuity** can be used are pipes, tubes and ducts with flowing fluids and gases, rivers, overall processes as power plants, diaries, logistics in general, roads, computer networks and semiconductor technology and more.

The Equation of Continuity and can be expressed as:

$$m = \rho_{i1} v_{i1} A_{i1} + \rho_{i2} v_{i2} A_{i2} +..+ \rho_{in} v_{in} A_{im}$$
$$= \rho_{o1} v_{o1} A_{o1} + \rho_{o2} v_{o2} A_{o2} +..+ \rho_{om} v_{om} A_{om} \quad (1)$$

where
m = mass flow rate (kg/s)
ρ = density (kg/m^3)
v = speed (m/s)
A = area (m^2)
With uniform density equation (1) can be modified to

$$q = v_{i1} A_{i1} + v_{i2} A_{i2} +..+ v_{in} A_{im}$$
$$= v_{o1} A_{o1} + v_{o2} A_{o2} +..+ v_{om} A_{om} \quad (2)$$

where
q = flow rate (m^3/s)
$\rho_{i1} = \rho_{i2} = . . = \rho_{in} = \rho_{o1} = \rho_{o2} = . .= \rho_{om}$

Example - Equation of Continuity
10 m^3/h of water flows through a pipe of 100 mm inside diameter. The pipe is reduced to an inside dimension of 80 mm. Using equation (2) the velocity in the 100 mm pipe can be calculated as

$$(10\ m^3/h)(1 / 3600\ h/s) = v_{100}\ (3.14 \times 0.1\ (m) \times 0.1\ (m) / 4)$$
or
$$v_{100} = (10\ m^3/h)(1 / 3600\ h/s) / (3.14 \times 0.1\ (m) \times 0.1\ (m) / 4)$$
$$= \underline{0.35}\ m/s$$

Using equation (2) the velocity in the 80 mm pipe can be calculated

$$(10\ m^3/h)(1 / 3600\ h/s) = v_{80}\ (3.14 \times 0.08\ (m) \times 0.08\ (m) / 4)$$
or
$$v_{100} = (10\ m^3/h)(1 / 3600\ h/s) / (3.14 \times 0.08\ (m) \times 0.08\ (m) / 4)$$
$$= \underline{0.55}\ m/s$$

Equation of Mechanical Energy: The Energy Equation is a statement of the first law of thermodynamics. The energy equation involves energy, heat transfer and work. With certain limitations the mechanical energy equation can be compared to the Bernoulli Equation and transferred to the Mechanical Energy Equation in Terms of Energy per Unit Mass.

The mechanical energy equation for a **pump or a fan** can be written in terms of **energy per unit mass**:

$$p_{in} / \rho + v_{in}^2 / 2 + g\ h_{in} + w_{shaft} = p_{out} / \rho + v_{out}^2 / 2 + g\ h_{out} + w_{loss} \quad (1)$$

where
p = *static pressure*
ρ = *density*
v = *flow velocity*
g = *acceleration of gravity*
h = *elevation height*
w_{shaft} = *net shaft energy inn per unit mass for a pump, fan or similar*
w_{loss} = *loss due to friction*

The energy equation is often used for incompressible flow problems and is called **the Mechanical Energy Equation** or **the Extended Bernoulli Equation**.

The mechanical energy equation for a **turbine** can be written as:

$$p_{in} / \rho + v_{in}^2 / 2 + g\, h_{in} = p_{out} / \rho + v_{out}^2 / 2 + g\, h_{out} + w_{shaft} + w_{loss} \quad (2)$$

where
w_{shaft} = *net shaft energy out per unit mass for a turbine or similar*

Equation (1) and (2) dimensions are
energy per unit mass (ft^2/s^2 = ft lb/slug or m^2/s^2 = N m/kg)

Efficiency
According to (1) a larger amount of loss - w_{loss} - result in more shaft work required for the same rise of output energy. The efficiency of a **pump or fan process** can be expressed as:

$$\eta = (w_{shaft} - w_{loss}) / w_{shaft} \quad (3)$$

The efficiency of a **turbine process** can be expressed as:

$$\eta = w_{shaft} / (w_{shaft} + w_{loss}) \quad (4)$$

The Mechanical Energy Equation in Terms of Energy per Unit Volume
The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit volume** by multiplying (1) with fluid density - ρ:

$$p_{in} + \rho\, v_{in}^2 / 2 + \gamma\, h_{in} + \rho\, w_{shaft} = p_{out} + \rho\, v_{out}^2 / 2 + \gamma\, h_{out} + w_{loss} \quad (5)$$

where
$\gamma = \rho\, g$ = *specific weight*

The dimensions of equation (5) are
energy per unit volume ($ft.lb/ft^3 = lb/ft^2$ or $N.m/m^3 = N/m^2$)

The Mechanical Energy Equation in Terms of Energy per Unit Weight involves Heads

The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit weight** by dividing with gravity - *g*:

$p_{in} / \gamma + v_{in}^2 / 2 g + h_{in} + h_{shaft} = p_{out} / \gamma + v_{out}^2 / 2 g + h_{out} + h_{loss}$ *(6)*

where
$\gamma = \rho g$ = *specific weight*
$h_{shaft} = w_{shaft} / g$ = *net shaft energy head inn per unit mass for a pump, fan or similar*
$h_{loss} = w_{loss} / g$ = *loss head due to friction*

The dimensions of equation (6) are

energy per unit weight (ft.lb/lb = ft or N.m/N = m)

Head is the energy per unit weight.

h_{shaft} can also be expressed as:
$h_{shaft} = w_{shaft} / g = W_{shaft} / m g = W_{shaft} / \gamma Q$ *(7)*

where
W_{shaft} = *shaft power*
m = mass flow rate
Q = volume flow rate

Example - Pumping Water

Water is pumped from an open tank at level zero to an open tank at level 10 ft. The pump adds four horsepowers to the water when pumping 2 ft^3/s.

Since $v_{in} = v_{out} = 0$, $p_{in} = p_{out} = 0$ and $h_{in} = 0$ - equation (6) can be modified to:

$h_{shaft} = h_{out} + h_{loss}$
or
$h_{loss} = h_{shaft} - h_{out}$ (8)

Equation (7) gives:

$h_{shaft} = W_{shaft} / \gamma Q = (4 \text{ hp})(550 \text{ ft.lb/s/hp}) / (62.4 \text{ lb/ft}^3)(2 \text{ ft}^3/s) = 17.6 \text{ ft}$

- specific weight of water 62.4 lb/ft^3
- 1 hp (English horse power) = 550 ft. lb/s

Combined with (8):
$h_{loss} = (17.6 \text{ ft}) - (10 \text{ ft}) = 7.6 \text{ ft}$

The pump efficiency can be calculated from (3) modified for head:
$\eta = ((17.6 \text{ ft}) - (7.6 \text{ ft})) / (17.6 \text{ ft}) = 0.58$

Equations in Fluid Mechanics: Common fluid mechanics equations - Bernoulli, conservation of energy, conservation of mass, pressure, Navier-Stokes, ideal gas law, Euler equations, Laplace equations, Darcy-Weisbach Equation and the following:

The Bernoulli Equation

- The Bernoulli Equation - A statement of the conservation of energy in a form useful for solving problems involving fluids. For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point.

Conservation laws

- The conservation laws states that particular measurable properties of an isolated physical system does not change as the system evolves.
- Conservation of energy (including mass)
- Fluid Mechanics and Conservation of Mass - The law of conservation of mass states that mass can neither be created nor destroyed.
- The Continuity Equation - The Continuity Equation is a statement that mass is conserved.

Darcy-Weisbach Equation

- Pressure Loss and Head Loss due to Friction in Ducts and Tubes - Major loss - head loss or pressure loss - due to friction in pipes and ducts.

Euler Equations

- In fluid dynamics, the Euler equations govern the motion of a compressible, inviscid fluid. They correspond to the Navier-Stokes equations with zero viscosity, although they are usually written in the form shown here because this emphasizes the fact that they directly represent conservation of mass, momentum, and energy.

Laplace's Equation

- The Laplace Equation describes the behavior of gravitational, electric, and fluid potentials.

Ideal Gas Law

- The Ideal Gas Law - For a perfect or ideal gas, the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.
- Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density.
- The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Navier-Stokes Equations

- The motion of a non-turbulent, Newtonian fluid is governed by the Navier-Stokes equations. The equation can be used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

Mechanical Energy Equation

- The Mechanical Energy Equation - The mechanical energy equation in Terms of Energy per Unit Mass, in Terms of Energy per Unit Volume and in Terms of Energy per Unit Weight involves Heads.

Pressure

- Static Pressure and Pressure Head in a Fluid - Pressure and pressure head in a static fluid.

Euler Equations: In fluid dynamics, the Euler equations govern the motion of a compressible, inviscid fluid. They correspond to the Navier-Stokes equations with zero viscosity, although they are usually written in the form shown here because this emphasizes the fact that they directly represent conservation of mass, momentum, and energy.

Euler Number: The Euler numbers, also called the secant numbers or zig numbers, are defined for $|x| < \pi/2$ by

$$\operatorname{sech} x - 1 \equiv -\frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} - \frac{E_3^* x^6}{6!} + \ldots$$

$$\sec x - 1 \equiv \frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} + \frac{E_3^* x^6}{6!} + \ldots,$$

where $\operatorname{sech}(z)$ the hyperbolic secant and sec is the secant. Euler numbers give the number of odd alternating permutations and are related to Genocchi numbers. The base *e* of the natural logarithm is sometimes known as Euler's number. A different sort of Euler number, the Euler number of a finite complex K, is defined by

$$\chi(K) = \sum (-1)^p \operatorname{rank}(C_p(K)).$$

This Euler number is a topological invariant. To confuse matters further, the Euler characteristic is sometimes also called the "Euler number," and numbers produced by the prime-generating polynomial $n^2 - n + 41$ are sometimes called "Euler numbers" (Flannery and Flannery 2000, p. 47).

F

Fecal Coliform: A group of bacteria that may indicate the presence of human or animal fecal matter in water.

Filtration: A series of processes that physically remove particles from water.

Flood Rim: The point of an object where the water would run over the edge of something and begin to cause a flood. See Air Break.

Fluids: A fluid is defined as a substance that continually deforms (flows) under an applied shear stress regardless of the magnitude of the applied stress. It is a subset of the phases of matter and includes liquids, gases, plasmas and, to some extent, plastic solids. Fluids are also divided into liquids and gases. Liquids form a free surface (that is, a surface not created by their container) while gases do not.

The distinction between solids and fluids is not so obvious. The distinction is made by evaluating the viscosity of the matter: for example silly putty can be considered either a solid or a fluid, depending on the time period over which it is observed. Fluids share the properties of not resisting deformation and the ability to flow (also described as their ability to take on the shape of their containers).

These properties are typically a function of their inability to support a shear stress in static equilibrium. While in a solid, stress is a function of strain, in a fluid, stress is a function of rate of strain. A consequence of this behavior is Pascal's law which entails the important role of pressure in characterizing a fluid's state.

Based on how the stress depends on the rate of strain and its derivatives, fluids can be characterized as: Newtonian fluids: where stress is directly proportional to rate of strain, and Non-Newtonian fluids : where stress is proportional to rate of strain, its higher powers and derivatives (basically everything other than Newtonian fluid).

The behavior of fluids can be described by a set of partial differential equations, which are based on the conservation of mass, linear and angular momentum (Navier-Stokes equations) and energy. The study of fluids is fluid mechanics, which is subdivided into fluid dynamics and fluid statics depending on whether the fluid is in motion or not. Fluid **Related Information**: The Bernoulli Equation - A statement of the conservation of energy in a form useful for solving problems involving fluids. For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point. Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.

Friction Head: The head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion. It varies with flow, size, type and conditions of conductors and fittings, and the fluid characteristics.

G

Gas: A gas is one of the four major phases of matter (after solid and liquid, and followed by plasma) that subsequently appear as solid material when they are subjected to increasingly higher temperatures. Thus, as energy in the form of heat is added, a solid (e.g., ice) will first melt to become a liquid (e.g., water), which will then boil or evaporate to become a gas (e.g., water vapor). In some circumstances, a solid (e.g., "dry ice") can directly turn into a gas: this is called sublimation. If the gas is further heated, its atoms or molecules can become (wholly or partially) ionized, turning the gas into a plasma.

Relater Gas Information: The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Gauge Pressure: Pressure differential above or below ambient atmospheric pressure.

H

Hazardous Atmosphere: An atmosphere which by reason of being explosive, flammable, poisonous, corrosive, oxidizing, irritating, oxygen deficient, toxic, or otherwise harmful, may cause death, illness, or injury.

Hazen-Williams Factor: Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes.

Hazen-Williams Equation - Calculating Friction Head Loss in Water Pipes

Friction head loss (ft H2O per 100 ft pipe) in water pipes can be obtained by using the empirical Hazen-Williams equation. The Darcy-Weisbach equation with the Moody diagram are considered to be the most accurate model for estimating frictional head loss in steady pipe flow. Since the approach requires a not so efficient trial and error solution, an alternative empirical head loss calculation that does not require the trial and error solutions, as the Hazen-Williams equation, may be preferred:

$$f = 0.2083\ (100/c)^{1.852}\ q^{1.852} / d_h^{4.8655}\ (1)$$

where
f = *friction head loss in feet of water per 100 feet of pipe* (ft_{h20}/100 ft pipe)
c = *Hazen-Williams roughness constant*
q = *volume flow (gal/min)*
d_h = *inside hydraulic diameter (inches)*

Note that the Hazen-Williams formula is empirical and lacks physical basis. Be aware that the roughness constants are based on "normal" condition with approximately 1 m/s (3 ft/sec).

The Hazen-Williams formula is not the only empirical formula available. Manning's formula is common for gravity driven flows in open channels.

The flow velocity may be calculated as:

$$v = 0.4087\ q / d_h^2$$

where
v = *flow velocity (ft/s)*

The Hazen-Williams formula can be assumed to be relatively accurate for piping systems where the Reynolds Number is above 10^5 (turbulent flow).

- 1 ft (foot) = 0.3048 m
- 1 in (inch) = 25.4 mm
- 1 gal (US)/min =6.30888×10^{-5} m^3/s = 0.0227 m^3/h = 0.0631 dm^3(liter)/s = 2.228×10^{-3} ft^3/s = 0.1337 ft^3/min = 0.8327 Imperial gal (UK)/min

Note! The Hazen-Williams formula gives accurate head loss due to friction for fluids with kinematic viscosity of approximately 1.1 cSt. More about fluids and kinematic viscosity.

The results for the formula are acceptable for cold water at 60° F (15.6° C) with kinematic viscosity 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130° F (54.4° C)) the error will be significant. Since the Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 to 75° F, the Darcy Weisbach method should be used for other liquids or gases.

Head: The height of a column or body of fluid above a given point expressed in linear units. Head if often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid. The measure of the pressure of water expressed in feet of height of water. 1 psi = 2.31 feet of water. There are various types of heads of water depending upon what is being measured. Static (water at rest) and Residual (water at flow conditions).

Hydraulics: Hydraulics is a branch of science and engineering concerned with the use of liquids to perform mechanical tasks.

Hydrodynamics: Hydrodynamics is the fluid dynamics applied to liquids, such as water, alcohol, and oil.

I

Ideal Gas: The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Isentropic Compression/Expansion Process: If the compression or expansion takes place under constant volume conditions - the process is called **isentropic.** The isentropic process on the basis of the Ideal Gas Law can be expressed as:

$p / \rho^k = constant$ *(2)*

where
$k = c_p / c_v$ *- the ratio of specific heats - the ratio of specific heat at constant pressure -* c_p *- to the specific heat at constant volume -* c_v

Irrigation: Water that is especially furnished to help provide and sustain the life of growing plants. It comes from ditches. It is sometimes treated with herbicides and pesticides to prevent the growth of weeds and the development of bugs in a lawn and a garden.

K

Kinematic Viscosity: The ratio of absolute or dynamic viscosity to density - a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with its mass density as

$v = \mu / \rho$ *(2)*

where
v *= kinematic viscosity*
μ *= absolute or dynamic viscosity*
ρ *= density*

In the SI-system the theoretical unit is m^2/s or commonly used **Stoke (St)** where

- $1\ St = 10^{-4}\ m^2/s$

Since the Stoke is an unpractical large unit, it is usual divided by 100 to give the unit called **Centistokes (cSt)** where
$1\ St = 100\ cSt$
$1\ cSt = 10^{-6}\ m^2/s$

Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

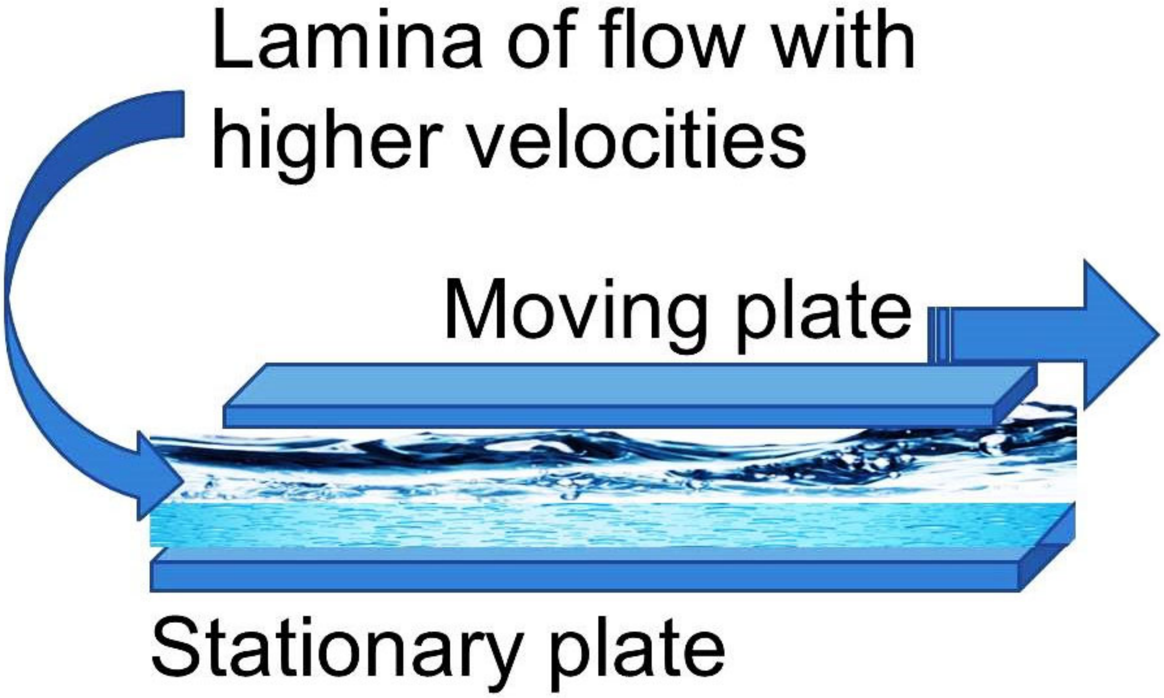
Kinetic Energy: The ability of an object to do work by virtue of its motion. The energy terms that are used to describe the operation of a pump are pressure and head.

Knudsen Number: Used by modelers who wish to express a non-dimensionless speed.

L

Laminar Flow: The resistance to flow in a liquid can be characterized in terms of the viscosity of the fluid if the flow is smooth. In the case of a moving plate in a liquid, it is found that there is a layer or lamina which moves with the plate, and a layer which is essentially stationary if it is next to a stationary plate.

There is a gradient of velocity as you move from the stationary to the moving plate, and the liquid tends to move in layers with successively higher speed. This is called laminar flow, or sometimes "streamlined" flow. Viscous resistance to flow can be modeled for laminar flow, but if the lamina break up into turbulence, it is very difficult to characterize the fluid flow.



The common application of laminar flow would be in the smooth flow of a viscous liquid through a tube or pipe. In that case, the velocity of flow varies from zero at the walls to a maximum along the centerline of the vessel. The flow profile of laminar flow in a tube can be calculated by dividing the flow into thin cylindrical elements and applying the viscous force to them. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.

Laplace's Equation: Describes the behavior of gravitational, electric, and fluid potentials.

The scalar form of Laplace's equation is the partial differential equation

$$\nabla^2 \psi = 0, \qquad (1)$$

where ∇^2 is the Laplacian.

Note that the operator ∇^2 is commonly written as Δ by mathematicians (Krantz 1999, p. 16). Laplace's equation is a special case of the Helmholtz differential equation

$$\nabla^2 \psi + k^2 \psi = 0 \qquad (2)$$

with $k = 0$, or Poisson's equation

$$\nabla^2 \psi = -4 \pi \rho \qquad (3)$$

with $\rho = 0$.

The vector Laplace's equation is given by

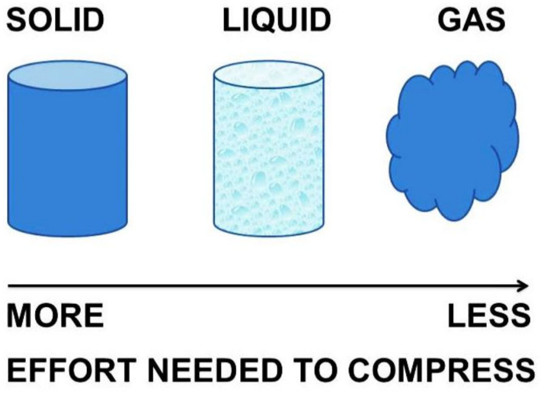
$$\nabla^2 \mathbf{F} = \mathbf{0}. \qquad (4)$$

A function ψ which satisfies Laplace's equation is said to be harmonic. A solution to Laplace's equation has the property that the average value over a spherical surface is equal to the value at the center of the sphere (Gauss's harmonic function theorem). Solutions have no local maxima or minima. Because Laplace's equation is linear, the superposition of any two solutions is also a solution.

Lift (Force): Lift consists of the sum of all the aerodynamic forces normal to the direction of the external airflow.

Liquids: An in-between state of matter. They can be found in between the solid and gas states. They don't have to be made up of the same compounds. If you have a variety of materials in a liquid, it is called a solution. One characteristic of a liquid is that it will fill up the shape of a container. If you pour some water in a cup, it will fill up the bottom of the cup first and then fill the rest. The water will also take the shape of the cup. It fills the bottom first because of **gravity**. The top part of a liquid will usually have a flat surface. That flat surface is because of gravity too. Putting an ice cube (solid) into a cup will leave you with a cube in the middle of the cup; the shape won't change until the ice becomes a liquid.

Another trait of liquids is that they are difficult to compress.



When you compress something, you take a certain amount and force it into a smaller space. Solids are very difficult to compress and gases are very easy. Liquids are in the middle but tend to be difficult. When you compress something, you force the atoms closer together. When pressure go up, substances are compressed. Liquids already have their atoms close together, so they are hard to compress. Many shock absorbers in cars compress liquids in tubes.

A special force keeps liquids together. Solids are stuck together and you have to force them apart. Gases bounce everywhere and they try to spread themselves out. Liquids actually want to stick together. There will always be the occasional evaporation where extra energy gets a molecule excited and the molecule leaves the system. Overall, liquids have **cohesive** (sticky) forces at work that hold the molecules together. Related Liquid Information: Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure.

M

Mach Number: When an object travels through a medium, then its Mach number is the ratio of the object's speed to the speed of sound in that medium.

Magnetic Flow Meter: Inspection of magnetic flow meter instrumentation should include checking for corrosion or insulation deterioration.

Manning Formula for Gravity Flow: Manning's equation can be used to calculate cross-sectional average velocity flow in open channels

$v = k_n/n\ R^{2/3}\ S^{1/2}\ (1)$

where
v = *cross-sectional average velocity (ft/s, m/s)*
$k_n = 1.486$ *for English units and* $k_n = 1.0$ *for SI units*
A = *cross sectional area of flow* (ft^2, $m^{2)}$
n = *Manning coefficient of roughness*
R = *hydraulic radius (ft, m)*
S = *slope of pipe (ft/ft, m/m)*

The volume flow in the channel can be calculated as
$q = A\ v = A\ k_n/n\ R^{2/3}\ S^{1/2}\ (2)$

where
q = *volume flow* (ft^3/s, m^3/s)
A = *cross-sectional area of flow* (ft^2, $m^{2)}$

Maximum Contamination Levels or (MCLs): The maximum allowable level of a contaminant that federal or state regulations allow in a public water system. If the MCL is exceeded, the water system must treat the water so that it meets the MCL. Or provide adequate backflow protection.

Mechanical Seal: A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such tolerances as to prevent the passage of water between them.

Mg/L: milligrams per liter

Microbial Contaminants: Microscopic organisms present in untreated water that can cause waterborne diseases.

ML: milliliter

N

Navier-Stokes Equations: The motion of a non-turbulent, Newtonian fluid is governed by the Navier-Stokes equation. The equation can be used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

Newtonian Fluid: Newtonian fluid (named for Isaac Newton) is a fluid that flows like water—its shear stress is linearly proportional to the velocity gradient in the direction perpendicular to the plane of shear. The constant of proportionality is known as the viscosity. Water is Newtonian, because it continues to exemplify fluid properties no matter how fast it is stirred or mixed.

Contrast this with a non-Newtonian fluid, in which stirring can leave a "hole" behind (that gradually fills up over time - this behavior is seen in materials such as pudding, or to a less rigorous extent, sand), or cause the fluid to become thinner, the drop in viscosity causing it to flow more (this is seen in non-drip paints).

For a Newtonian fluid, the viscosity, by definition, depends only on temperature and pressure (and also the chemical composition of the fluid if the fluid is not a pure substance), not on the forces acting upon it. If the fluid is incompressible and viscosity is constant across the fluid, the equation governing the shear stress.

Related Newtonian Information: A Fluid is Newtonian if viscosity is constant applied to shear force. Dynamic, Absolute and Kinematic Viscosity - An introduction to dynamic, absolute and kinematic viscosity and how to convert between CentiStokes (cSt), CentiPoises (cP), Saybolt Universal Seconds (SSU) and degree Engler.

Newton's Third Law: Newton's third law describes the forces acting on objects interacting with each other. Newton's third law can be expressed as

- *"If one object exerts a force **F** on another object, then the second object exerts an equal but opposite force **F** on the first object"*

Force is a convenient abstraction to represent mentally the pushing and pulling interaction between objects.

It is common to express forces as vectors with magnitude, direction and point of application. The net effect of two or more forces acting on the same point is the vector sum of the forces.

Non-Newtonian Fluid: Non-Newtonian fluid viscosity changes with the applied shear force.

O

Oxidizing: The process of breaking down organic wastes into simpler elemental forms or by products. Also used to separate combined chlorine and convert it into free chlorine.

P

Pascal's Law: A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

Pathogens: Disease-causing pathogens; waterborne pathogens. A pathogen is a bacterium, virus or parasite that causes or is capable of causing disease. Pathogens may contaminate water and cause waterborne disease.

pCi/L- ***picocuries per liter:*** A curie is the amount of radiation released by a set amount of a certain compound. A picocurie is one quadrillionth of a curie.

pH: A measure of the acidity of water. The pH scale runs from 0 to 14 with 7 being the mid-point or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity. pH (Power of Hydroxyl Ion Activity).

Pipeline Appurtenances: Pressure reducers, bends, valves, regulators (which are a type of valve), etc.

Peak Demand: The maximum momentary load placed on a water treatment plant, pumping station or distribution system is the Peak Demand.

Pipe Velocities: For calculating fluid pipe velocity.

Imperial units

A fluids flow velocity in pipes can be calculated with Imperial or American units as

$v = 0.4085\, q / d^2 \quad (1)$

where

v = velocity (ft/s)

q = volume flow (US gal. /min)

d = pipe inside diameter (inches)

SI units

A fluids flow velocity in pipes can be calculated with SI units as

$v = 1.274\, q / d^2 \quad (2)$

where

v = velocity (m/s)

q = volume flow (m^3/s)

d = pipe inside diameter (m)

Pollution: To make something unclean or impure. Some states will have a definition of pollution that relates to non-health related water problems, like taste and odors. See Contaminated.

Positive Flow Report-back Signal: When a pump receives a signal to start, a light will typically be illuminated on the control panel indicating that the pump is running. In order to be sure that the pump is actually pumping water, a Positive flow report-back signal should be installed on the control panel.

Potable: Good water which is safe for drinking or cooking purposes. Non-Potable: A liquid or water that is not approved for drinking.

Potential Energy: The energy that a body has by virtue of its position or state enabling it to do work.

PPM: Abbreviation for parts per million.

Prandtl Number: The Prandtl Number is a dimensionless number approximating the ratio of momentum diffusivity and thermal diffusivity and can be expressed as

$Pr = v / \alpha$ (1)
where
Pr = *Prandtl's number*
v = *kinematic viscosity (Pa s)*
α = *thermal diffusivity (W/m K)*

The Prandtl number can alternatively be expressed as

$Pr = \mu c_p / k$ (2)

where
μ = *absolute or dynamic viscosity (kg/m s, cP)*
c_p = *specific heat capacity (J/kg K, Btu/(lb ^{o}F))*
k = *thermal conductivity (W/m K, Btu/(h ft^2 ^{o}F/ft))*

The Prandtl Number is often used in heat transfer and free and forced convection calculations.

Pressure: An introduction to pressure - the definition and presentation of common units as psi and Pa and the relationship between them.

The pressure in a fluid is defined as
"the normal force per unit area exerted on an imaginary or real plane surface in a fluid or a gas"

The equation for pressure can expressed as:
$p = F / A$ (1)

where
p = *pressure [lb/in^2 (psi) or lb/ft^2 (psf), N/m^2 or kg/ms^2 (Pa)]*
F = *force [$^{1)}$, N]*
A = *area [in^2 or ft^2, m^2]*

$^{1)}$ In the English Engineering System special care must be taken for the force unit. The basic unit for mass is the pound mass (lb_m) and the unit for the force is the pound (lb) or pound force (lb_f).

Absolute Pressure

The **absolute pressure** - p_a - is measured relative to the *absolute zero pressure* - the pressure that would occur at absolute vacuum.

Gauge Pressure

A **gauge** is often used to measure the pressure difference between a system and the surrounding atmosphere. This pressure is often called the **gauge pressure** and can be expressed as

$p_g = p_a - p_o$ (2)

where

p_g = *gauge pressure*

p_o = *atmospheric pressure*

Atmospheric Pressure

The atmospheric pressure is the pressure in the surrounding air. It varies with temperature and altitude above sea level.

Standard Atmospheric Pressure

The **Standard Atmospheric Pressure** (atm) is used as a reference for gas densities and volumes. The Standard Atmospheric Pressure is defined at sea-level at 273°K (0°C) and is **1.01325 bar** or 101325 Pa (absolute). The temperature of 293°K (20°C) is also used.

In imperial units the Standard Atmospheric Pressure is 14.696 psi.

- *1 atm = 1.01325 bar = 101.3 kPa = 14.696 psi* (lb_f/in^2)*= 760 mmHg =10.33* mH_2O *= 760 torr = 29.92 in Hg = 1013 mbar = 1.0332* kg_f/cm^2 *= 33.90* ftH_2O

Pressure Head: The height to which liquid can be raised by a given pressure.

Pressure Regulation Valves: Control water pressure and operate by restricting flows. They are used to deliver water from a high pressure to a low-pressure system. The pressure downstream from the valve regulates the amount of flow. Usually, these valves are of the globe design and have a spring-loaded diaphragm that sets the size of the opening.

Pressure Units: Since 1 Pa is a small pressure unit, the unit hectopascal (hPa) is widely used, especially in meteorology. The unit kilopascal (kPa) is commonly used designing technical applications like HVAC systems, piping systems and similar.

- *1 hectopascal = 100 pascal = 1 millibar*
- *1 kilopascal = 1000 pascal*

Some Pressure Levels

- 10 Pa - The pressure at a depth of 1 mm of water
- 1 kPa - Approximately the pressure exerted by a 10 g mass on a 1 cm^2 area
- 10 kPa - The pressure at a depth of 1 m of water, or
  the drop in air pressure when going from sea level to 1000 m elevation
- 10 MPa - A "high pressure" washer forces the water out of the nozzles at this pressure
- 10 GPa - This pressure forms diamonds

Some Alternative Units of Pressure

- *1 bar - 100,000 Pa*
- *1 millibar - 100 Pa*
- *1 atmosphere - 101,325 Pa*
- *1 mm Hg - 133 Pa*
- *1 inch Hg - 3,386 Pa*

A **torr** (torr) is named after Torricelli and is the pressure produced by a column of mercury 1 mm high equals to 1/760th of an atmosphere. 1 atm = 760 torr = 14.696 psi

Pounds per square inch (psi) was common in U.K. but has now been replaced in almost every country except in the U.S. by the SI units. The Normal atmospheric pressure is 14.696 psi, meaning that a column of air on one square inch in area rising from the Earth's atmosphere to space weighs 14.696 pounds.

The **bar** (bar) is common in the industry. One bar is 100,000 Pa, and for most practical purposes can be approximated to one atmosphere even if

1 Bar = 0.9869 atm

There are 1,000 **millibar** (mbar) in one bar, a unit common in meteorology.

1 millibar = 0.001 bar = 0.750 torr = 100 Pa

R

Residual Disinfection/Protection: A required level of disinfectant that remains in treated water to ensure disinfection protection and prevent recontamination throughout the distribution system (i.e., pipes).

Reynolds Number: The Reynolds number is used to determine whether a flow is laminar or turbulent. The Reynolds Number is a non-dimensional parameter defined by the ratio of dynamic pressure (ρu^2) and shearing stress ($\mu u / L$) - and can be expressed as

$$Re = (\rho u^2) / (\mu u / L)$$
$$= \rho u L / \mu$$
$$= u L / v \quad (1)$$

where

Re = Reynolds Number (non-dimensional)

ρ = density (kg/m^3, lb$_m$/ft^3)

u = velocity (m/s, ft/s)

μ = dynamic viscosity (Ns/m^2, lb$_m$/s ft)

L = characteristic length (m, ft)

v = kinematic viscosity (m^2/s, ft^2/s)

Richardson Number: A dimensionless number that expresses the ratio of potential to kinetic energy.

S

Sanitizer: A chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.

Saybolt Universal Seconds (or SUS, SSU): Saybolt Universal Seconds (or SUS) is used to measure viscosity. The efflux time is Saybolt Universal Seconds (SUS) required for 60 milliliters of a petroleum product to flow through the calibrated orifice of a Saybolt Universal viscometer, under carefully controlled temperature and as prescribed by test method ASTM D 88. This method has largely been replaced by the kinematic viscosity method. Saybolt Universal Seconds is also called the SSU number (Seconds Saybolt Universal) or SSF number (Saybolt Seconds Furol).

Kinematic viscosity versus dynamic or absolute viscosity can be expressed as

$v = 4.63\ \mu / SG$ *(3)*
where
v *= kinematic viscosity (SSU)*
μ *= dynamic or absolute viscosity (cP)*

Scale: Crust of calcium carbonate, the result of unbalanced pool water. Hard insoluble minerals deposited (usually calcium bicarbonate) which forms on pool and spa surfaces and clog filters, heaters and pumps. Scale is caused by high calcium hardness and/or high pH. You will often find major scale deposits inside a backflow prevention assembly.

Shock: Also known as superchlorination or break point chlorination. Ridding a pool of organic waste through oxidization by the addition of significant quantities of a halogen.

Shock Wave: A shock wave is a strong pressure wave produced by explosions or other phenomena that create violent changes in pressure.

Solder: A fusible alloy used to join metallic parts. Solder for potable water pipes shall be lead-free.

Sound Barrier: The sound barrier is the apparent physical boundary stopping large objects from becoming supersonic.

Specific Gravity: The Specific Gravity - *SG* - is a dimensionless unit defined as the ratio of density of the material to the density of water at a specified temperature. Specific Gravity can be expressed as

$SG = = \rho / \rho_{H2O}$ *(3)*

where
SG *= specific gravity*
ρ *= density of fluid or substance* (kg/m^3)
ρ_{H2O} *= density of water* (kg/m^3)

It is common to use the density of water at 4° C (39°F) as a reference - at this point the density of water is at the highest. Since Specific Weight is dimensionless it has the same value in the metric SI system as in the imperial English system (BG). At the reference point the Specific Gravity has same numerically value as density.

Example - Specific Gravity

If the density of iron is 7850 kg/m^3, 7.85 grams per cubic millimeter, 7.85 kilograms per liter, or 7.85 metric tons per cubic meter - the specific gravity of iron is:

$SG = 7850\ kg/m^3 / 1000\ kg/m^3$

$= \underline{7.85}$

(the density of water is 1000 kg/m^3)

Specific Weight: Specific Weight is defined as weight per unit volume. Weight is a **force**.

- Mass and Weight - the difference! - What is weight and what is mass? An explanation of the difference between weight and mass.

Specific Weight can be expressed as

$\gamma = \rho g$ (2)

where

γ = specific weight (kN/m^3)

g = acceleration of gravity (m/s^2)

The SI-units of specific weight are kN/m^3. The imperial units are lb/ft^3. The local acceleration *g* is under normal conditions 9.807 m/s^2 in SI-units and 32.174 ft/s^2 in imperial units.

Example - Specific Weight Water

Specific weight for water at 60 ^{o}F is 62.4 lb/ft^3 in imperial units and 9.80 kN/m^3 in SI-units.

Example - Specific Weight Some other Materials

Product	Specific Weight - *γ*	
	Imperial Units (lb/ft^3)	SI Units (kN/m^3)
Ethyl Alcohol	49.3	7.74
Gasoline	42.5	6.67
Glycerin	78.6	12.4
Mercury	847	133
SAE 20 Oil	57	8.95
Seawater	64	10.1
Water	62.4	9.80

Static Head: The height of a column or body of fluid above a given point

Static Pressure: The pressure in a fluid at rest.

Static Pressure and Pressure Head in Fluids: The pressure indicates the normal force per unit area at a given point acting on a given plane. Since there is no shearing stresses present in a fluid at rest - the pressure in a fluid is independent of direction.

For fluids - liquids or gases - at rest the pressure gradient in the vertical direction depends only on the specific weight of the fluid.

How pressure changes with elevation can be expressed as

$dp = - \gamma\, dz$ *(1)*

where
dp *= change in pressure*
dz *= change in height*
γ *= specific weight*

The pressure gradient in vertical direction is negative - the pressure decrease upwards.

Specific Weight: Specific Weight can be expressed as:

$\gamma = \rho\, g$ *(2)*

where
γ *= specific weight*
g *= acceleration of gravity*

In general the specific weight - *γ* - is constant for fluids. For gases the specific weight - *γ* - varies with the elevation.

Static Pressure in a Fluid: For an incompressible fluid - as a liquid - the pressure difference between two elevations can be expressed as:

$p_2 - p_1 = - \gamma (z_2 - z_1)$ *(3)*

where
p_2 *= pressure at level 2*
p_1 *= pressure at level 1*
z_2 *= level 2*
z_1 *= level 1*

(3) can be transformed to:

$p_1 - p_2 = \gamma (z_2 - z_1)$ *(4)*
or
$p_1 - p_2 = \gamma\, h$ *(5)*

where
$h = z_2 - z_1$ *difference in elevation - the depth down from location* z_2*.*
or
$p_1 = \gamma\, h + p_2$ *(6)*

Static Pressure and Pressure Head in Fluids Continued:

The Pressure Head

(6) can be transformed to:

$h = (p_2 - p_1) / \gamma$ *(6)*

h express **the pressure head** - the height of a column of fluid of specific weight - *γ* - required to give a pressure difference of $(p_2 - p_1)$.

Example - Pressure Head

A pressure difference of 5 psi (lbf/in^2) is equivalent to

$5\ (lbf/in^2)\ 12\ (in/ft)\ 12\ (in/ft) / 62.4\ (lb/ft^3) = \underline{11.6}$ *ft of water*

$5\ (lbf/in^2)\ 12\ (in/ft)\ 12\ (in/ft) / 847\ (lb/ft^3) = \underline{0.85}$ *ft of mercury*

when specific weight of water is 62.4 (lb/ft^3) and specific weight of mercury is 847 (lb/ft^3).

Streamline - Stream Function: A streamline is the path that an imaginary particle would follow if it was embedded in the flow.

Strouhal Number: A quantity describing oscillating flow mechanisms. **The Strouhal Number** is a dimensionless value useful for analyzing oscillating, unsteady fluid flow dynamics problems.

The Strouhal Number can be expressed as

$St = \omega\, l / v$ (1)

where

St = *Strouhal Number*

ω = *oscillation frequency*

l = *characteristic length*

v = *flow velocity*

The Strouhal Number represents a measure of the ratio of inertial forces due to the unsteadiness of the flow or local acceleration to the inertial forces due to changes in velocity from one point to another in the flow field.

The vortices observed behind a stone in a river, or measured behind the obstruction in a vortex flow meter, illustrate these principles.

Stuffing Box: That portion of the pump which houses the packing or mechanical seal.

Submerged: To cover with water or liquid substance.

Supersonic Flow: Flow with speed above the speed of sound, 1,225 km/h at sea level, is said to be supersonic.

Surface Tension: Surface tension is a force within the surface layer of a liquid that causes the layer to behave as an elastic sheet. The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension.

The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface. This forms a surface "film" which makes it more difficult to move an object through the surface than to move it when it is completely submersed.

Surface tension is typically measured in dynes/cm, the force in dynes required to break a film of length 1 cm. Equivalently, it can be stated as surface energy in ergs per square centimeter. Water at 20°C has a surface tension of 72.8 dynes/cm compared to 22.3 for ethyl alcohol and 465 for mercury.

Surface tension is typically measured in *dynes/cm* or *N/m*.

Liquid	Surface Tension	
	N/m	dynes/cm
Ethyl Alcohol	0.0223	22.3
Mercury	0.465	465
Water 20^{o}C	0.0728	72.75
Water 100^{o}C	0.0599	58.9

Surface tension is the energy required to stretch a unit change of a surface area. Surface tension will form a drop of liquid to a sphere since the sphere offers the smallest area for a definite volume.

Surface tension can be defined as

$\sigma = F_s / l$ *(1)*

where
σ *= surface tension (N/m)*
F_s *= stretching force (N)*
l *= unit length (m)*

Alternative Units
Alternatively, surface tension is typically measured in dynes/cm, which is

- the force in dynes required to break a film of length 1 cm

or as surface energy J/m^2 or alternatively ergs per square centimeter.

- 1 dynes/cm = 0.001 N/m = 0.0000685 lb_f/ft = 0.571 10^{-5} lb_f/in = 0.0022 poundal/ft = 0.00018 poundal/in = 1.0 mN/m = 0.001 J/m^2 = 1.0 erg/cm^2 = 0.00010197 kg_f/m

Common Imperial units used are lb/ft and lb/in.
Water surface tension at different temperatures can be taken from the table below:

Temperature (^{o}C)	Surface Tension - σ - (N/m)
0	0.0757
10	0.0742
20	0.0728
30	0.0712
40	0.0696
50	0.0679
60	0.0662
70	0.0644
80	0.0626
90	0.0608
100	0.0588

Surface Tension of some common Fluids

- benzene : 0.0289 (N/m)
- diethyl ether : 0.0728 (N/m)
- carbon tetrachloride : 0.027 (N/m)
- chloroform : 0.0271 (N/m)
- ethanol : 0.0221 (N/m)
- ethylene glycol : 0.0477 (N/m)
- glycerol : 0.064 (N/m)
- mercury : 0.425 (N/m)
- methanol : 0.0227 (N/m)
- propanol : 0.0237 (N/m)
- toluene : 0.0284 (N/m)
- water at 20°C : 0.0729 (N/m)

Surge Tanks: Surge tanks can be used to control Water Hammer. A limitation of hydropneumatic tanks is that they do not provide much storage to meet peak demands during power outages and you have very limited time to do repairs on equipment.

T

Telemetering Systems: The following are common pressure sensing devices: Helical Sensor, Bourdon Tube, and Bellows Sensor. The most frequent problem that affects a liquid pressure-sensing device is air accumulation at the sensor. A diaphragm element being used as a level sensor would be used in conjunction with a pressure sensor. Devices must often transmit more than one signal. You can use several types of systems including: Polling, Scanning and Multiplexing. Transmitting equipment requires installation where temperature will not exceed 130 degrees F.

Thixotropic Fluids: Shear Thinning Fluids or **Thixotropic Fluids** reduce their viscosity as agitation or pressure is increased at a constant temperature. Ketchup and mayonnaise are examples of thixotropic materials. They appear thick or viscous but are possible to pump quite easily.

Transonic: Flow with speed at velocities just below and above the speed of sound is said to be transonic.

Turbidity: A measure of the cloudiness of water caused by suspended particles.

U

U-Tube Manometer: Pressure measuring devices using liquid columns in vertical or inclined tubes are called manometers. One of the most common is the water filled u-tube manometer used to measure pressure difference in pitot or orifices located in the airflow in air handling or ventilation systems.

V

Valve: A device that opens and closes to regulate the flow of liquids. Faucets, hose bibs, and Ball are examples of valves.

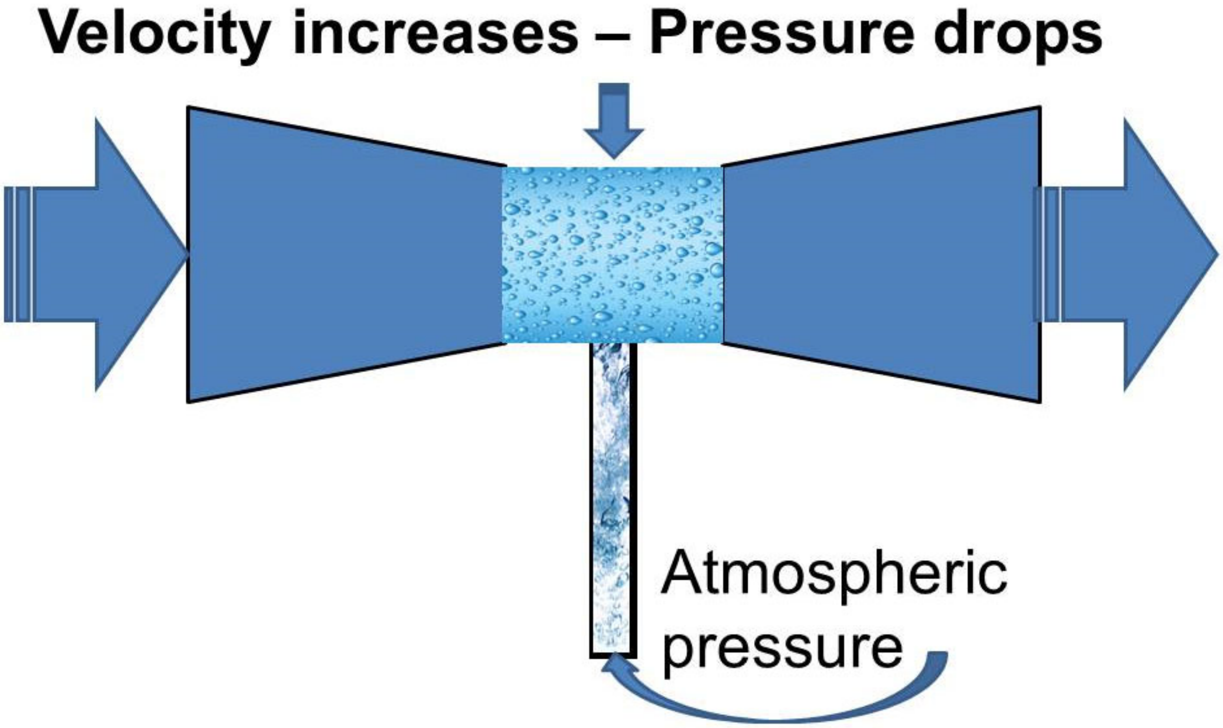
Vane: That portion of an impeller which throws the water toward the volute.

Vapor Pressure: For a particular substance at any given temperature there is a pressure at which the vapor of that substance is in equilibrium with its liquid or solid forms.

Velocity Head: The vertical distance a liquid must fall to acquire the velocity with which it flows through the piping system. For a given quantity of flow, the velocity head will vary indirectly as the pipe diameter varies.

Venturi: A system for speeding the flow of the fluid, by constricting it in a cone-shaped tube. Venturi are used to measure the speed of a fluid, by measuring the pressure changes from one point to another along the venture. A venturi can also be used to inject a liquid or a gas into another liquid. A pump forces the liquid flow through a tube connected to:

- A venturi to increase the speed of the fluid (restriction of the pipe diameter)
- A short piece of tube connected to the gas source
- A second venturi that decrease the speed of the fluid (the pipe diameter increase again)
- After the first venturi the pressure in the pipe is lower, so the gas is sucked in the pipe. Then the mixture enters the second venturi and slow down. At the end of the system a mixture of gas and liquid appears and the pressure rise again to its normal level in the pipe.
- This technique is used for ozone injection in water.



The newest injector design causes complete mixing of injected materials (air, ozone or chemicals), eliminating the need for other in-line mixers. Venturi injectors have no moving parts and are maintenance free. They operate effectively over a wide range of pressures (from 1 to 250 psi) and require only a minimum pressure difference to initiate the vacuum at the suction part. Venturis are often built in thermoplastics (PVC, PE, PVDF), stainless steel or other metals.

The cavitation effect at the injection chamber provides an instantaneous mixing, creating thousands of very tiny bubbles of gas in the liquid. The small bubbles provide and increased gas exposure to the liquid surface area, increasing the effectiveness of the process (i.e. ozonation).

Vibration: A force that is present on construction sites and must be considered. The vibrations caused by backhoes, dump trucks, compactors and traffic on job sites can be substantial.

Viscosity: Informally, viscosity is the quantity that describes a fluid's resistance to flow. Fluids resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them. Formally, viscosity (represented by the symbol η "eta") is the ratio of the shearing stress (F/A) to the velocity gradient ($\Delta v_x/\Delta z$ or dv_x/dz) in a fluid.

$$\eta = \left(\frac{F}{A}\right) \div \left(\frac{\Delta v_x}{\Delta z}\right) \quad \text{or} \quad \eta = \left(\frac{F}{A}\right) \div \left(\frac{dv_x}{dz}\right)$$

The more usual form of this relationship, called Newton's equation, states that the resulting shear of a fluid is directly proportional to the force applied and inversely proportional to its viscosity. The similarity to Newton's second law of motion ($F = ma$) should be apparent.

$$\frac{F}{A} = \eta \frac{\Delta v_x}{\Delta z} \quad \text{or} \quad \frac{F}{A} = \eta \frac{dv_x}{dz}$$

$$\Updownarrow \qquad\qquad\qquad \Updownarrow$$

$$F = m\frac{\Delta v}{\Delta t} \quad \text{or} \quad F = m\frac{dv}{dt}$$

The SI unit of viscosity is the pascal second [Pa·s], which has no special name. Despite its self-proclaimed title as an international system, the International System of Units has had very little international impact on viscosity. The pascal second is rarely used in scientific and technical publications today. The most common unit of viscosity is the dyne second per square centimeter [dyne·s/cm^2], which is given the name poise [P] after the French physiologist Jean Louis Poiseuille (1799-1869). Ten poise equal one pascal second [Pa·s] making the centipoise [cP] and millipascal second [mPa·s] identical.

1 pascal second = 10 poise = 1,000 millipascal second
1 centipoise = 1 millipascal second

There are actually two quantities that are called viscosity. The quantity defined above is sometimes called dynamic viscosity, absolute viscosity, or simple viscosity to distinguish it from the other quantity, but is usually just called viscosity. The other quantity called kinematic viscosity (represented by the symbol v "nu") is the ratio of the viscosity of a fluid to its density.

$$v = \frac{\eta}{\rho}$$

Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity. It is frequently measured using a device called a capillary viscometer -- basically a graduated can with a narrow tube at the bottom. When two fluids of equal volume are placed in identical capillary viscometers and allowed to flow under the influence of gravity, a viscous fluid takes longer than a less viscous fluid to flow through the tube. Capillary viscometers are discussed in more detail later in this section. The SI unit of kinematic viscosity is the square meter per second [m^2/s], which has no special name. This unit is so large that it is rarely used. A more common unit of kinematic viscosity is the square centimeter per second [cm^2/s], which is given the name stoke [St] after the English scientist George Stoke.

Viscosity and Reference Temperatures: The viscosity of a fluid is highly temperature dependent and for either dynamic or kinematic viscosity to be meaningful, the **reference temperature** must be quoted. In ISO 8217 the reference temperature for a residual fluid is 100°C. For a distillate fluid the reference temperature is 40°C.

- For a liquid - the kinematic viscosity will **decrease** with higher temperature.
- For a gas - the kinematic viscosity will **increase** with higher temperature.

Volute: The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Vorticity: Vorticity is defined as the circulation per unit area at a point in the flow field.

Vortex: A vortex is a whirlpool in the water.

W

Water Freezing: The effects of water freezing in storage tanks can be minimized by alternating water levels in the tank.

Water Storage Facility Inspection: During an inspection of your water storage facility, you should inspect the Cathodic protection system including checking the anode’s condition and the connections. The concentration of polyphosphates that is used for corrosion control in storage tanks is typically 5 mg/L or less. External corrosion of steel water storage facilities can be reduced with Zinc or aluminum coatings. All storage facilities should be regularly sampled to determine the quality of water that enters and leaves the facility. One tool or piece of measuring equipment is the Jackson turbidimeter, which is a method to measure cloudiness in water.

Wave Drag: Wave drag refers to a sudden and very powerful drag that appears on aircrafts flying at high-subsonic speeds.

Water Purveyor: The individuals or organization responsible to help provide, supply, and furnish quality water to a community.

Water Works: All of the pipes, pumps, reservoirs, dams and buildings that make up a water system.

Waterborne Diseases: A disease, caused by a virus, bacterium, protozoan, or other microorganism, capable of being transmitted by water (e.g., typhoid fever, cholera, amoebic dysentery, gastroenteritis).

Weber Number: A dimensionless value useful for analyzing fluid flows where there is an interface between two different fluids.

Appendixes and Charts

Density of Common Liquids

The density of some common liquids can be found in the table below:

Liquid	Temperature - *t* - (°C)	Density - *ρ* - (kg/m^3)
Acetic Acid	25	1049
Acetone	25	785
Acetonitrile	20	782
Alcohol, ethyl	25	785
Alcohol, methyl	25	787
Alcohol, propyl	25	780
Ammonia (aqua)	25	823
Aniline	25	1019
Automobile oils	15	880 - 940
Beer (varies)	10	1010
Benzene	25	874
Benzyl	15	1230
Brine	15	1230
Bromine	25	3120
Butyric Acid	20	959
Butane	25	599
n-Butyl Acetate	20	880
n-Butyl Alcohol	20	810
n-Butylhloride	20	886
Caproic acid	25	921
Carbolic acid	15	956
Carbon disulfide	25	1261
Carbon tetrachloride	25	1584
Carene	25	857
Castor oil	25	956
Chloride	25	1560
Chlorobenzene	20	1106
Chloroform	20	1489
Chloroform	25	1465
Citric acid	25	1660
Coconut oil	15	924
Cotton seed oil	15	926
Cresol	25	1024
Creosote	15	1067
Crude oil, 48° API	60°F	790
Crude oil, 40° API	60°F	825
Crude oil, 35.6° API	60°F	847
Crude oil, 32.6° API	60°F	862

Crude oil, California	60ºF	915
Crude oil, Mexican	60ºF	973
Crude oil, Texas	60ºF	873
Cumene	25	860
Cyclohexane	20	779
Cyclopentane	20	745
Decane	25	726
Diesel fuel oil 20 to 60	15	820 - 950
Diethyl ether	20	714
o-Dichlorobenzene	20	1306
Dichloromethane	20	1326
Diethylene glycol	15	1120
Dichloromethane	20	1326
Dimethyl Acetamide	20	942
N,N-Dimethylformamide	20	949
Dimethyl Sulfoxide	20	1100
Dodecane	25	755
Ethane	-89	570
Ether	25	73
Ethylamine	16	681
Ethyl Acetate	20	901
Ethyl Alcohol	20	789
Ethyl Ether	20	713
Ethylene Dichloride	20	1253
Ethylene glycol	25	1097
Fluorine refrigerant R-12	25	1311
Formaldehyde	45	812
Formic acid 10%oncentration	20	1025
Formic acid 80%oncentration	20	1221
Freon - 11	21	1490
Freon - 21	21	1370
Fuel oil	60ºF	890
Furan	25	1416
Furforol	25	1155
Gasoline, natural	60ºF	711
Gasoline, Vehicle	60ºF	737
Gas oils	60ºF	890
Glucose	60ºF	1350 - 1440
Glycerin	25	1259
Glycerol	25	1126
Heptane	25	676
Hexane	25	655
Hexanol	25	811
Hexene	25	671

Hydrazine	25	795
Iodine	25	4927
Ionene	25	932
Isobutyl Alcohol	20	802
Iso-Octane	20	692
Isopropyl Alcohol	20	785
Isopropyl Myristate	20	853
Kerosene	60ºF	817
Linolenic Acid	25	897
Linseed oil	25	929
Methane	-164	465
Methanol	20	791
Methyl Isoamyl Ketone	20	888
Methyl Isobutyl Ketone	20	801
Methyl n-Propyl Ketone	20	808
Methyl t-Butyl Ether	20	741
N-Methylpyrrolidone	20	1030
Methyl Ethyl Ketone	20	805
Milk	15	1020 - 1050
Naphtha	15	665
Naphtha, wood	25	960
Napthalene	25	820
Ocimene	25	798
Octane	15	918
Olive oil	20	800 - 920
Oxygen (liquid)	-183	1140
Palmitic Acid	25	851
Pentane	20	626
Pentane	25	625
Petroleum Ether	20	640
Petrol, natural	60ºF	711
Petrol, Vehicle	60ºF	737
Phenol	25	1072
Phosgene	0	1378
Phytadiene	25	823
Pinene	25	857
Propane	-40	583
Propane, R-290	25	494
Propanol	25	804
Propylenearbonate	20	1201
Propylene	25	514
Propylene glycol	25	965
Pyridine	25	979
Pyrrole	25	966

Rape seed oil	20	920
Resorcinol	25	1269
Rosin oil	15	980
Sea water	25	1025
Silane	25	718
Silicone oil		760
Sodium Hydroxide (caustic soda)	15	1250
Sorbaldehyde	25	895
Soya bean oil	15	924 - 928
Stearic Acid	25	891
Sulphuric Acid 95%onc.	20	1839
Sugar solution 68 brix	15	1338
Sunflower oil	20	920
Styrene	25	903
Terpinene	25	847
Tetrahydrofuran	20	888
Toluene	20	867
Toluene	25	862
Triethylamine	20	728
Trifluoroacetic Acid	20	1489
Turpentine	25	868
Water - pure	4	1000
Water - sea	77ºF	1022
Whale oil	15	925
o-Xylene	20	880

1 kg/m^3 = 0.001 g/cm^3 = 0.0005780 oz/in^3 = 0.16036 oz/gal (Imperial) = 0.1335 oz/gal (U.S.) = 0.0624 lb/ft^3 = 0.000036127 lb/in^3 = 1.6856 lb/yd^3 = 0.010022 lb/gal (Imperial) = 0.008345 lb/gal (U.S) = 0.0007525 ton/yd^3

Dynamic or Absolute Viscosity Units Converting Table

The table below can be used to convert between common dynamic or absolute viscosity units.

Multiply by	Convert to				
Convert from	Poiseuille (Pa s)	Poise (dyne s/ cm^2 = g / cm s)	centiPoise	kg / m h	kg$_f$ s / m^2
Poiseuille (Pa s)	1	10	10^{3}	3.63 10^{3}	0.102
Poise (dyne s / cm^2 = g / cm s)	0.1	1	100	360	0.0102
centiPoise	0.001	0.01	1	3.6	0.00012
kg / m h	2.78 10^{-4}	0.00278	0.0278	1	2.83 10^{-5}
kg$_f$ s / m^2	9.81	98.1	9.81 10^{3}	3.53 10^{4}	1
lb$_f$ s / inch^2	6.89 10^{3}	6.89 10^{4}	6.89 10^{6}	2.48 10^{7}	703
lb$_f$ s / ft^2	47.9	479	4.79 10^{4}	1.72 10^{5}	0.0488
lb$_f$ h / ft^2	1.72 10^{5}	1.72 10^{6}	1.72 10^{8}	6.21 10^{8}	1.76 10^{4}
lb / ft s	1.49	14.9	1.49 10^{3}	5.36 10^{3}	0.152
lb / ft h	4.13 10^{-4}	0.00413	0.413	1.49	4.22 10^{-5}

Multiply by	Convert to				
Convert from	lb$_f$ s / inch^2	lb$_f$ s / ft^2	lb$_f$ h / ft^2	lb / ft s	lb / ft h
Poiseuille (Pa s)	1.45 10^{-4}	0.0209	5.8 10^{-6}	0.672	2.42 10^{3}
Poise (dyne s / cm^2 = g / cm s)	1.45 10^{-5}	0.00209	5.8 10^{-7}	0.0672	242
centiPoise	1.45 10^{-7}	2.9 10^{-5}	5.8 10^{-9}	0.000672	2.42
kg / m h	4.03 10^{-8}	5.8 10^{-6}	1.61 10^{-9}	0.000187	0.672
kg$_f$ s / m^2	0.00142	20.5	5.69 10^{-5}	6.59	2.37 10^{4}
lb$_f$ s / inch^2	1	144	0.04	4.63 10^{3}	1.67 10^{7}
lb$_f$ s / ft^2	0.00694	1	0.000278	32.2	1.16 10^{5}
lb$_f$ h / ft^2	25	3.6 10^{3}	1	1.16 10^{5}	4.17 10^{8}
lb / ft s	0.000216	0.0311	8.63 10^{-6}	1	3.6 10^{3}
lb / ft h	6 10-^{8}	1.16 10^{5}	2.4 10^{-9}	0.000278	1

Friction Loss Chart

The table below can be used to indicate the friction loss - feet of liquid per 100 feet of pipe - in standard schedule 40 steel pipes.

Pipe Size (inches)	Flow Rate		Kinematic Viscosity - SSU					
	(gpm)	(l/s)	31 (Water)	100 (~Cream)	200 (~Vegetable oil)	400 (~SAE 10 oil)	800 (~Tomato juice)	1500 (~SAE 30 oil)
1/2	3	0.19	10.0	25.7	54.4	108.0	218.0	411.0
3/4	3	0.19	2.5	8.5	17.5	35.5	71.0	131.0
	5	0.32	6.3	14.1	29.3	59.0	117.0	219.0
1	3	0.19	0.8	3.2	6.6	13.4	26.6	50.0
	5	0.32	1.9	5.3	11.0	22.4	44.0	83.0
	10	0.63	6.9	11.2	22.4	45.0	89.0	165.0
	15	0.95	14.6	26.0	34.0	67.0	137.0	
	20	1.26	25.1	46	46.0	90.0	180.0	
1 1/4	5	0.32	0.5	1.8	3.7	7.6	14.8	26.0
	10	0.63	1.8	3.6	7.5	14.9	30.0	55.0
	15	0.95	3.7	6.4	11.3	22.4	45.0	84.0
1 1/2	10	0.63	0.8	1.9	4.2	8.1	16.5	31.0
	15	0.95	1.7	2.8	6.2	12.4	25.0	46.0
	20	1.26	2.9	5.3	8.1	16.2	33.0	61.0
	30	1.9	6.3	11.6	12.2	24.3	50.0	91.0
	40	2.5	10.8	19.6	20.8	32.0	65.0	121.0
2	20	1.26	0.9	1.5	3.0	6.0	11.9	22.4
	30	1.9	1.8	3.2	4.4	9.0	17.8	33.0
	40	2.5	3.1	5.8	5.8	11.8	24.0	44.0
	60	3.8	6.6	11.6	13.4	17.8	36.0	67.0
	80	5.0	1.6	3.0	3.2	4.8	9.7	18.3
2 1/2	30	1.9	0.8	1.4	2.2	4.4	8.8	16.6
	40	2.5	1.3	2.5	3.0	5.8	11.8	22.2
	60	3.8	2.7	5.1	5.5	8.8	17.8	34.0
	80	5.0	4.7	8.3	9.7	11.8	24.0	44.0
	100	6.3	7.1	12.2	14.1	14.8	29.0	55.0
3	60	3.8	0.9	1.8	1.8	3.7	7.3	13.8
	100	6.3	2.4	4.4	5.1	6.2	12.1	23.0
	125	7.9	3.6	6.5	7.8	8.1	15.3	29.0
	150	9.5	5.1	9.2	10.4	11.5	18.4	35.0
	175	11.0	6.9	11.7	13.8	15.8	21.4	40.0
	200	12.6	8.9	15.0	17.8	20.3	25.0	46.0
4	80	5.0	0.4	0.8	0.8	1.7	3.3	6.2
	100	6.3	0.6	1.2	1.3	2.1	4.1	7.8
	125	7.9	0.9	1.8	2.1	2.6	5.2	9.8
	150	9.5	1.3	2.4	2.9	3.1	6.2	11.5
	175	11.0	1.8	3.2	4.0	4.0	7.4	13.7

	200	12.6	2.3	4.2	5.1	5.1	8.3	15.5
	250	15.8	3.5	6.0	7.4	8.0	10.2	19.4
6	125	7.9	0.1	0.3	0.3	0.52	1.0	1.9
	150	9.5	0.2	0.3	0.4	0.6	1.2	2.3
	175	11.0	0.2	0.4	0.5	0.7	1.4	2.6
	200	12.6	0.3	0.6	0.7	0.8	1.6	3.0
	250	15.8	0.5	0.8	1.0	1.0	2.1	3.7
	300	18.9	1.1	8.5	10.0	11.6	12.4	23.0
	400	25.2	1.1	1.9	2.3	2.8	3.2	6.0
8	250	15.8	0.1	0.2	0.3	0.4	0.7	1.2
	300	18.9	0.3	1.2	1.4	1.5	2.5	4.6
	400	25.2	0.3	0.5	0.6	0.7	1.1	2.0
10	300	18.9	0.1	0.3	0.4	0.4	0.8	1.5
	400	25.2	0.1	0.2	0.2	0.2	0.4	0.8

Hazen-Williams Coefficients

Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes. Coefficients for some common materials used in ducts and pipes can be found in the table below:

Material	Hazen-Williams Coefficient - *C* -
Asbestos Cement	140
Brass	130 - 140
Brick sewer	100
Cast-Iron - new unlined (CIP)	130
Cast-Iron 10 years old	107 - 113
Cast-Iron 20 years old	89 - 100
Cast-Iron 30 years old	75 - 90
Cast-Iron 40 years old	64-83
Cast-Iron, asphalt coated	100
Cast-Iron, cement lined	140
Cast-Iron, bituminous lined	140
Cast-Iron, wrought plain	100
Concrete	100 - 140
Copper or Brass	130 - 140
Ductile Iron Pipe (DIP)	140
Fiber	140
Galvanized iron	120
Glass	130
Lead	130 - 140
Plastic	130 - 150
Polyethylene, PE, PEH	150
PVC, CPVC	150
Smooth Pipes	140
Steel new unlined	140 - 150
Steel	
Steel, welded and seamless	100
Steel, interior riveted, no projecting rivets	100
Steel, projecting girth rivets	100
Steel, vitrified, spiral-riveted	90 - 100
Steel, corrugated	60
Tin	130
Vitrified Clays	110
Wood Stave	110 - 120

Pressure Head

A pressure difference of 5 psi (lbf/in^2) is equivalent to

5 (lbf/in^2) 12 (in/ft) 12 (in/ft) / 62.4 (lb/ft^3) = 11.6 ft of water

5 (lbf/in^2) 12 (in/ft) 12 (in/ft) / 847 (lb/ft^3) = 0.85 ft of mercury

When specific weight of water is 62.4 (lb/ft^3) and specific weight of mercury is 847 (lb/ft^3).
Heads at different velocities can be taken from the table below:

Velocity (ft/sec)	Head Water (ft)
0.5	0.004
1.0	0.016
1.5	0035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	4.493
18.0	5.037
19.0	5.613
20.0	6.219
21.0	6.856
22.0	7.525

1 ft (foot) = 0.3048 m = 12 in = 0.3333 yd

Thermal Properties of Water

Temperature - t - (°C)	Absolute pressure - p - (kN/m^2)	Density - ρ - (kg/m^3)	Specific volume - v - (m^3/kgx10^{-3})	Specific Heat - c_p - (kJ/kgK)	Specific entropy - e - (kJ/kgK)
0	0.6	1000	100	4.217	0
5	0.9	1000	100	4.204	0.075
10	1.2	1000	100	4.193	0.150
15	1.7	999	100	4.186	0.223
20	2.3	998	100	4.182	0.296
25	3.2	997	100	4.181	0.367
30	4.3	996	100	4.179	0.438
35	5.6	994	101	4.178	0.505
40	7.7	991	101	4.179	0.581
45	9.6	990	101	4.181	0.637
50	12.5	988	101	4.182	0.707
55	15.7	986	101	4.183	0.767
60	20.0	980	102	4.185	0.832
65	25.0	979	102	4.188	0.893
70	31.3	978	102	4.190	0.966
75	38.6	975	103	4.194	1.016
80	47.5	971	103	4.197	1.076
85	57.8	969	103	4.203	1.134
90	70.0	962	104	4.205	1.192
95	84.5	962	104	4.213	1.250
100	101.33	962	104	4.216	1.307
105	121	955	105	4.226	1.382
110	143	951	105	4.233	1.418
115	169	947	106	4.240	1.473
120	199	943	106	4.240	1.527
125	228	939	106	4.254	1.565
130	270	935	107	4.270	1.635
135	313	931	107	4.280	1.687
140	361	926	108	4.290	1.739
145	416	922	108	4.300	1.790
150	477	918	109	4.310	1.842
155	543	912	110	4.335	1.892
160	618	907	110	4.350	1.942
165	701	902	111	4.364	1.992
170	792	897	111	4.380	2.041
175	890	893	112	4.389	2.090
180	1000	887	113	4.420	2.138
185	1120	882	113	4.444	2.187
190	1260	876	114	4.460	2.236

195	1400	870	115	4.404	2.282
200	1550	863	116	4.497	2.329
220					
225	2550	834	120	4.648	2.569
240					
250	3990	800	125	4.867	2.797
260					
275	5950	756	132	5.202	3.022
300	8600	714	140	5.769	3.256
325	12130	654	153	6.861	3.501
350	16540	575	174	10.10	3.781
360	18680	526	190	14.60	3.921

Viscosity Converting Chart

The viscosity of a fluid is its resistance to shear or flow, and is a measure of the fluid’s adhesive/cohesive or frictional properties. This arises because of the internal molecular friction within the fluid producing the frictional drag effect. There are two related measures of fluid viscosity which are known as **dynamic** and **kinematic** viscosity.

Dynamic viscosity is also termed "**absolute viscosity**" and is the tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid.

Centipoise (CPS) Millipascal (mPas)	Poise (P)	Centistokes (cSt)	Stokes (S)	Saybolt Seconds Universal (SSU)
1	0.01	1	0.01	31
2	0.02	2	0.02	34
4	0.04	4	0.04	38
7	0.07	7	0.07	47
10	0.1	10	0.1	60
15	0.15	15	0.15	80
20	0.2	20	0.2	100
25	0.24	25	0.24	130
30	0.3	30	0.3	160
40	0.4	40	0.4	210
50	0.5	50	0.5	260
60	0.6	60	0.6	320
70	0.7	70	0.7	370
80	0.8	80	0.8	430
90	0.9	90	0.9	480
100	1	100	1	530
120	1.2	120	1.2	580
140	1.4	140	1.4	690
160	1.6	160	1.6	790
180	1.8	180	1.8	900
200	2	200	2	1000
220	2.2	220	2.2	1100
240	2.4	240	2.4	1200
260	2.6	260	2.6	1280
280	2.8	280	2.8	1380
300	3	300	3	1475
320	3.2	320	3.2	1530
340	3.4	340	3.4	1630
360	3.6	360	3.6	1730

380	3.8	380	3.8	1850
400	4	400	4	1950
420	4.2	420	4.2	2050
440	4.4	440	4.4	2160
460	4.6	460	4.6	2270
480	4.8	480	4.8	2380
500	5	500	5	2480
550	5.5	550	5.5	2660
600	6	600	6	2900
700	7	700	7	3380
800	8	800	8	3880
900	9	900	9	4300
1000	10	1000	10	4600
1100	11	1100	11	5200
1200	12	1200	12	5620
1300	13	1300	13	6100
1400	14	1400	14	6480
1500	15	1500	15	7000
1600	16	1600	16	7500
1700	17	1700	17	8000
1800	18	1800	18	8500
1900	19	1900	19	9000
2000	20	2000	20	9400
2100	21	2100	21	9850
2200	22	2200	22	10300
2300	23	2300	23	10750
2400	24	2400	24	11200

Various Flow Section Channels and their Geometric Relationships: Area, wetted perimeter and hydraulic diameter for some common geometric sections like

- rectangular channels
- trapezoidal channels
- triangular channels
- circular channels.

Rectangular Channel

Flow Area

Flow area of a rectangular channel can be expressed as

$A = b\ h$ *(1)*

where

A *= flow area* (m^2, in^2)

b *= width of channel (m, in)*

h *= height of flow (m, in)*

Wetted Perimeter

Wetted perimeter of a rectangular channel can be expressed as

$P = b + 2\ h$ *(1b)*

where

P *= wetted perimeter (m, in)*

Hydraulic Radius

Hydraulic radius of a rectangular channel can be expressed as

$R_h = b\ h / (b + 2\ y)$ *(1c)*

where

R_h *= hydraulic radius (m, in)*

Trapezoidal Channel

Flow Area

Flow area of a trapezoidal channel can be expressed as

$A = (a + z\ h)\ h$ *(2)*

where

z *= see figure above (m, in)*

Wetted Perimeter

Wetted perimeter of a trapezoidal channel can be expressed as

$P = a + 2\ h\ (1 + z^2)^{1/2}$ *(2b)*

Hydraulic Radius

Hydraulic radius of a trapezoidal channel can be expressed as

$R_h = (a + z\ h)\ h / a + 2\ h\ (1 + z^2)^{1/2}$ *(2c)*

Triangular Channel

Flow Area

Flow area of a triangular channel can be expressed as

$A = z h^2$ *(3)*

where

z = see figure above (m, in)

Wetted Perimeter

Wetted perimeter of a triangular channel can be expressed as

$P = 2 h (1 + z^2)^{1/2}$ *(3b)*

Hydraulic Radius

Hydraulic radius of a triangular channel can be expressed as

$R_h = z h / 2 (1 + z^2)^{1/2}$ *(3c)*

Circular Channel

Flow Area

Flow area of a circular channel can be expressed as

$A = D^2/4 (\alpha - \sin(2 \alpha)/2)$ *(4)*

where

D = diameter of channel

$\alpha = \cos^{-1}(1 - h/r)$

Wetted Perimeter

Wetted perimeter of a circular channel can be expressed as

$P = \alpha D$ *(4b)*

Hydraulic Radius

Hydraulic radius of a circular channel can be expressed as

$R_h = D/8 [1 - \sin(2 \alpha) / (2 \alpha)]$ *(4c)*

Velocity Head: Velocity head can be expressed as

$h = v^2/2g$ *(1)*

where

v = velocity (ft, m)

g = acceleration of gravity (32.174 ft/s², 9.81 m/s²)

Heads at different velocities can be taken from the table below:

Velocity - v - (ft/sec)	Velocity Head - $v^2/2g$ - (ft Water)
0.5	0.004
1.0	0.016
1.5	0035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	4.493
18.0	5.037
19.0	5.613
20.0	6.219
21.0	6.856
22.0	7.525

Reynolds Number

Turbulent or laminar flow is determined by the dimensionless **Reynolds Number.**

The Reynolds number is important in analyzing any type of flow when there is substantial velocity gradient (i.e., shear.) It indicates the relative significance of the viscous effect compared to the inertia effect. The Reynolds number is proportional to inertial force divided by viscous force.

A definition of the Reynolds' Number.
The flow is

- **laminar** if Re < 2300
- **transient** if 2300 < Re < 4000
- **turbulent** if 4000 < Re

The table below shows Reynolds Number for one liter of water flowing through pipes of different dimensions:

Pipe Size										
(inches)	1	1 ?	2	3	4	6	8	10	12	18
(mm)	25	40	50	75	100	150	200	250	300	450
Reynolds number with **one (1) liter/min**	835	550	420	280	210	140	105	85	70	46
Reynolds number with **one (1) gal/min**	3800	2500	1900	1270	950	630	475	380	320	210

Linear Motion Formulas

Velocity can be expressed as (velocity = constant):

$v = s / t$ *(1a)*

where
v = *velocity (m/s, ft/s)*
s = *linear displacement (m, ft)*
t = *time (s)*

Velocity can be expressed as (acceleration = constant):
$v = V_0 + a\,t$ *(1b)*

where
V_0 = *linear velocity at time zero (m/s, ft/s)*

Linear displacement can be expressed as (acceleration = constant):
$s = V_0\,t + 1/2\,a\,t^2$ *(1c)*

Combining 1a and 1c to express velocity
$v = (V_0^2 + 2\,a\,s)^{1/2}$ *(1d)*

Velocity can be expressed as (velocity variable)
$v = ds / dt$ *(1f)*

where
ds = *change of displacement (m, ft)*
dt = *change in time (s)*

Acceleration can be expressed as
$a = dv / dt$ *(1g)*

where
dv = *change in velocity (m/s, ft/s)*

Water - Dynamic and Kinematic Viscosity

Dynamic and Kinematic Viscosity of Water in Imperial Units (BG units):

Temperature *- t -* *(°F)*	Dynamic Viscosity *- μ -* *10^{-5} (lb.s/ft^2)*	Kinematic Viscosity *- ν -* *10^{-5} (ft^2/s)*
32	3.732	1.924
40	3.228	1.664
50	2.730	1.407
60	2.344	1.210
70	2.034	1.052
80	1.791	0.926
90	1.500	0.823
100	1.423	0.738
120	1.164	0.607
140	0.974	0.511
160	0.832	0.439
180	0.721	0.383
200	0.634	0.339
212	0.589	0.317

Dynamic and Kinematic Viscosity of Water in SI Units:

Temperature *- t -* *(°C)*	Dynamic Viscosity *- μ -* *10^{-3} (N.s/m^2)*	Kinematic Viscosity *- ν -* *10^{-6} (m^2/s)*
0	1.787	1.787
5	1.519	1.519
10	1.307	1.307
20	1.002	1.004
30	0.798	0.801
40	0.653	0.658
50	0.547	0.553
60	0.467	0.475
70	0.404	0.413
80	0.355	0.365
90	0.315	0.326
100	0.282	0.294

Water and Speed of Sound

Speed of sound in water at temperatures between 32 - 212^{o}F (0-100^{o}C) - imperial and SI units.
Speed of Sound in Water - in imperial units (BG units)

Temperature - *t* - (^{o}F)	Speed of Sound - *c* - (ft/s)
32	4,603
40	4,672
50	4,748
60	4,814
70	4,871
80	4,919
90	4,960
100	4,995
120	5,049
140	5,091
160	5,101
180	5,095
200	5,089
212	5,062

Speed of Sound in Water - in SI units

Temperature - *t* - (^{o}C)	Speed of Sound - *c* - (m/s)
0	1,403
5	1,427
10	1,447
20	1,481
30	1,507
40	1,526
50	1,541
60	1,552
70	1,555
80	1,555
90	1,550
100	1,543

Some Commonly used Thermal Properties for Water

1. Density at 4 °C - 1,000 kg/m^3, 62.43 Lbs./Cu.Ft, 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.
2. Freezing temperature - 0 °C
3. Boiling temperature - 100 °C
4. Latent heat of melting - 334 kJ/kg
5. Latent heat of evaporation - 2,270 kJ/kg
6. Critical temperature - 380 - 386 °C
7. Critical pressure - 23.520 kN/m^2
8. Specific heat capacity water - 4.187 kJ/kgK
9. Specific heat capacity ice - 2.108 kJ/kgK
10. Specific heat capacity water vapor - 1.996 kJ/kgK
11. Thermal expansion from 4 °C to 100 °C - 4.2×10^{-2}
12. Bulk modulus elasticity - 2,068,500 kN/m^2

Hyperlink to Biological Appendix and Chlorine Charts

http://www.abctlc.com/downloads/PDF/WTGlossary.pdf

Math Conversion Factors

1 PSI = 2.31 Feet of Water
1 Foot of Water = .433 PSI
1.13 Feet of Water = 1 Inch of Mercury
454 Grams = 1 Pound
1 Gallon of Water = 8.34 lbs./gallon
1 mg/L = 1 PPM
17.1 mg/L = 1 Grain/Gallon
1% = 10,000 mg/L
694 Gallons per Minute = MGD
1.55 Cubic Feet per Second = 1 MGD
60 Seconds = 1 Minute
1440 Minutes = 1 Day
.746 kW = 1 Horsepower

LENGTH
12 Inches = 1 Foot
3 Feet = 1 Yard
5,280 Feet = 1 Mile
AREA
144 Square Inches = 1 Square Foot
43,560 Square Feet = 1 Acre
VOLUME
1000 Milliliters = 1 Liter
3.785 Liters = 1 Gallon
231 Cubic Inches = 1 Gallon
7.48 Gallons = 1 Cubic Foot of Water
62.38 Pounds = 1 Cubic Foot of Water

Dimensions

SQUARE: Area (sq. ft.) = Length X Width
Volume (cu.ft) = Length (ft) X Width (ft) X Height (ft)

CIRCLE: Area (sq. ft.) = 3.14 X Radius (ft) X Radius (ft)

CYLINDER: Volume (Cu. Ft.) = 3.14 X Radius (ft) X Radius (ft) X Depth (ft)

SPHERE: $\frac{(3.14)\ (\text{Diameter})^3}{(6)}$ Circumference = 3.14 X Diameter

General

POUNDS PER DAY AKA SOLIDS APPLIED =
Concentration (mg/L) X Flow (MG) X 8.34

Percent Efficiency = $\frac{\text{In} - \text{Out}}{\text{In}} \times 100$

TEMPERATURE: $^0\text{F} = (^0\text{C} \times 9/5) + 32$
$^0\text{C} = (^0\text{F} - 32) \times 5/9$

CONCENTRATION: Conc. (A) X Volume (A) = Conc. (B) X Volume (B)

FLOW RATE (Q): Q = A X V (Quantity = Area X Velocity)

FLOW RATE (gpm): Flow Rate (gpm) = $\frac{2.83\ (\text{Diameter, in})^2\ (\text{Distance, in})}{\text{Height, in}}$

$$\text{ACTUAL LEAKAGE} = \frac{\text{Leak Rate (GPD)}}{\text{Length (mi.)} \times \text{Diameter (in)}}$$

$$\text{VELOCITY} = \frac{\text{Distance (ft)}}{\text{Time (Sec)}}$$

$$\text{WATER HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960}$$

$$\text{BRAKE HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Efficiency}}$$

$$\text{MOTOR HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Eff.} \times \text{Motor Eff.}}$$

$$\text{MEAN OR AVERAGE} = \frac{\text{Sum of the Values}}{\text{Number of Values}}$$

$$\text{TOTAL HEAD (ft)} = \text{Suction Lift (ft)} \times \text{Discharge Head (ft)}$$

$$\underset{\text{(gal/min/sq.ft)}}{\text{SURFACE LOADING RATE}} = \frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sq. ft)}}$$

$$\underset{\text{STRENGTH (\%)}}{\text{MIXTURE}} = \frac{\text{(Volume 1, gal) (Strength 1, \%)} + \text{(Volume 2, gal) (Strength 2,\%)}}{\text{(Volume 1, gal)} + \text{(Volume 2, gal)}}$$

$$\underset{\text{(\%)}}{\text{FLUORIDE ION PURITY}} = \frac{\text{(Molecular weight of Fluoride) (100\%)}}{\text{Molecular weight of Chemical}}$$

$$\text{INJURY FREQUENCY RATE} = \frac{\text{(Number of Injuries) } 1{,}000{,}000}{\text{Number of hours worked per year}}$$

$$\text{DETENTION TIME (hrs)} = \frac{\text{Volume of Basin (gals)} \times \text{24 hrs}}{\text{Flow (GPD)}}$$

$$\text{BY-PASS WATER (gpd)} = \frac{\text{Total Flow (GPD)} \times \text{Plant Effluent Hardness (gpg)}}{\text{Filtered Hardness (gpg)}}$$

Hardness

$$\text{HARDNESS (mg/L as CaCO}_3\text{)} = \frac{\text{A (mls of titrant) X 1000}}{\text{Mls of Sample}}$$

Ca HARDNESS as mg/L $CaCo_3$ = 2.5 X (Ca, mg/L)

Mg HARDNESS as mg/L $CaCo_3$ = 4.12 (Mg, mg/L)

$$\text{ALKALINITY-TOTAL (mg/L)} = \frac{\text{Mls of Titrant X Normality X 50,000}}{\text{Mls of Sample}}$$

EXCHANGE CAPACITY (grains) = Resin Volume (cu. ft.) X Removal Capacity

$$\text{HARDNESS TO GRAIN/GALLON} = \frac{\text{Hardness (mg/L) X gr./gal}}{\text{17.1 mg/L}}$$

LANGELIER INDEX = $pH - pH_s$

Chemical Addition

$$\text{CHEMICAL FEED RATE} = \frac{\text{Chemical Feed (ml/min)}}{\text{(gpm) 3785 ml/gal}}$$

CHLORINE DOSE (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)

$$\text{POLYMER \%} = \frac{\text{Dry Polymer (lbs.)}}{\text{Dry Polymer (lbs.) + Water (lbs.)}}$$

$$\text{DESIRED PAC (lbs./MG)} = \frac{\text{Volume (MG) X Dose (mg/L) X 8.34}}{\text{1 MG}}$$

$$\text{PAC (lbs./gal)} = \frac{\text{PAC (mg/L) X 3.785 (1/gallon)}}{\text{1000 (mg/g) X 454 (g/lb.)}}$$

Filtration

$$\text{FILTRATION RATE (gpm/sq. ft)} = \frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sq. ft.)}}$$

Post Exam Answers

1. **1. E, 2.B, 3.D, 4.E, 5.D, 6.D, 7.E, 8.A, 9.B, 10.D**
2. **1.B, 2.A, 3.C, 4.A, 5.B, 6.A, 7.A, 8.C, 9.A, 10.E**
3. **1.A, 2.C, 3.C, 4.C, 5.C, 6.A, 7.B, 8.C, 9.E, 10.E**
4. **1.E, 2.D, 3.A, 4.D, 5.C, 6.C, 7.D, 8.C, 9.C, 10.A**
5. **1.B, 2.A, 3.D, 4.C, 5.D, 6.A, 7.C, 8.D, 9.A, 10.E**
6. **1.E, 2.A, 3.C, 4.C, 5.C, 6.A, 7.D, 8.E, 9.A, 10.C**
7. **1.E, 2.E, 3.A, 4.E, 5.E, 6.D, 7.A, 8.E, 9.E, 10.E**
8. **1.E, 2.B, 3F, 4.F, 5.D, 6.B, 7.C, 8.E, 9.B, 10.A**

Hyperlink to Biological Appendix and Chlorine Charts
http://www.abctlc.com/downloads/PDF/WTGlossary.pdf

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