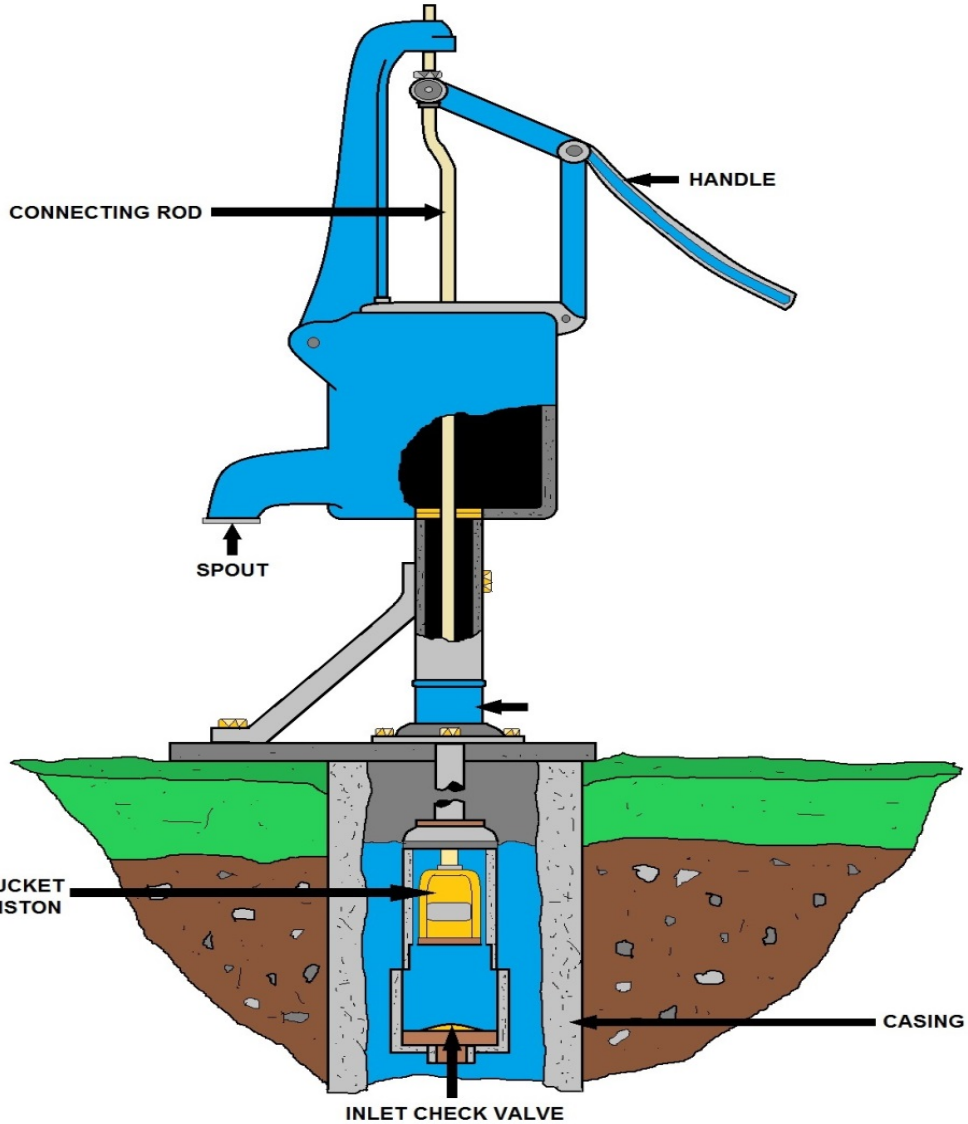
PUMP PRIMER 1

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).

Printing Instructions: Once you have purchased the program, we will give you permission to print this document. If you are going to print this document, it was designed to be printed double-sided or duplexed but can be printed single-sided.

Hyperlink to Assignment…
http://www.abctlc.com/downloads/PDF/PumpPrimer1Ass.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 Do not solely trust our list for it may be outdated.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.

Professional Engineers; Most states will accept our courses for credit but we do not officially list the States or Agencies. Always check with your State Agency to ensure the course is accepted for credit.

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

You can obtain a printed version from TLC for an additional $129.95 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Do not solely depend on TLC's Approval list for it may be outdated.

A second certificate of completion for a second State Agency $25 processing fee.

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 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.

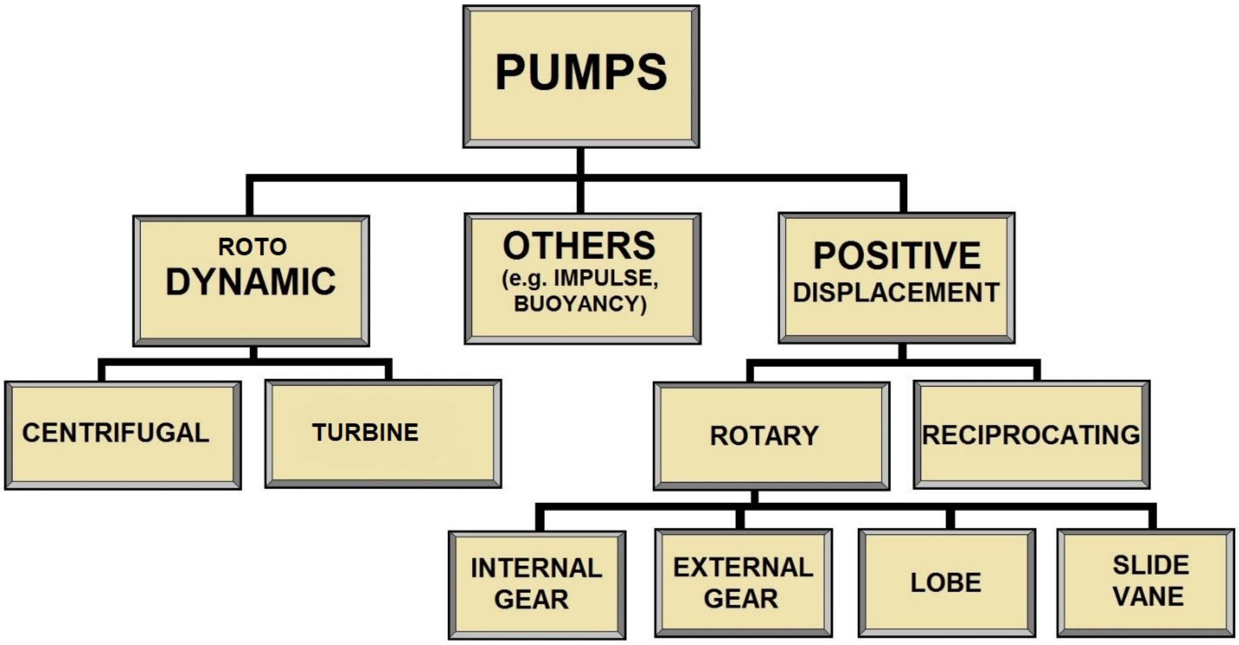
Important Information about this Manual

This manual has been prepared to educate operators in the general education of pumping, pumps, motors, and hydraulic principles including basic water training and different pump applications. For most students, the study of pumping and hydraulics is quite large, requiring a major effort to bring it under control.

This manual should not be used as a guidance document for employees who are involved with cross-connection control. It is not designed to meet the requirements of the United States Environmental Protection Agency (EPA), the Department of Labor-Occupational Safety and Health Administration (OSHA), or your state environmental or health agency. Technical Learning College or Technical Learning Consultants, Inc. makes 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 and is not considered a legal document. Individuals who are responsible for hydraulic equipment, cross-connection control, backflow prevention or 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 OSHA, the EPA and other appropriate federal, state and local agencies.

Copyright Notice



Contributing Editors

Joseph Camerata has a BS in Management with honors (magna cum laude). He retired as a Chemist in 2006 having worked in the field of chemical, environmental, and industrial hygiene sampling and analysis for 40 years. He has been a professional presenter at an EPA analytical conference at the Biosphere in Arizona and a presenter at an AWWA conference in Mesa, Arizona. He also taught safety classes at the Honeywell and City of Phoenix, and is a motivational/inspirational speaker nationally and internationally.

Dr. Eric Pearce S.M.E., chemistry and biological review.

Dr. Pete Greet S.M.E., retired biology instructor.

Jack White, Environmental, Health, Safety expert, 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.)

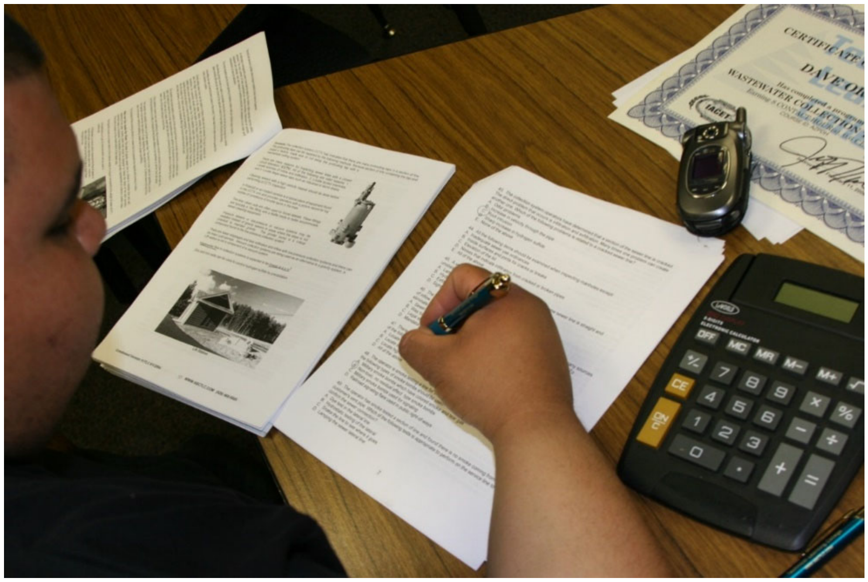
Students have direct contact with their instructor—primarily by e-mail or telephone. TLC’s CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling; i.e., 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

Course Description

Pump Primer I Training Course

This short CEU course will review various hydraulic principles and basic pumping foundations to properly understand the operation and function of primary water/wastewater related pumps and equipment. ***You will not need any other materials for this course.***

Water Distribution, Well Drillers, Pump Installers, Water Treatment Operators, Wastewater Treatment Operators, Wastewater Collection Operators, Industrial Wastewater Operators and General Backflow Assembly Testers. The target audience for this course is the person interested in working in a water or wastewater treatment or distribution/collection facility and/or wishing to maintain CEUs for certification license or to learn how to do the job safely and effectively, and/or to meet education needs for promotion.

Final Examination for Credit

Opportunity to pass the final comprehensive examination is limited to three attempts per course enrollment.

Course Procedures for Registration and Support

All of Technical Learning College's 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 will be assigned to the student.

Instructions for Assignment

The Pump Primer I - 0.8 CEU training course training course uses a multiple choice type answer key. You can find a copy of the answer key r in Word format on TLC's website under the Assignment Page. You can also find complete course support under the Assignment Page. You can write your answers in this manual or type out your own answer key. TLC would prefer that you type out and fax or e-mail the final exam to TLC, but it is not required.

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 rear of the course 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 forfeit all fees and the appropriate agency will be notified.

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.

Required Texts
The Pump Primer I - 0.8 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 your 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. Please check with your State for special instructions.

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. If you should need any assistance, please email all concerns and the final test to: info@tlch2o.com.

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 and environmental education,

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.

Table of Contents

When the Student finishes this course…
At the conclusion of this course:
At the finish of this course, the student should be able to explain and describe the various hydraulic principles, pumping devices, and pumping methods, identify various hydraulic and horsepower principles that are commonly employed in moving fluids. Upon completion of this course, the student will obtain 8 hours of continuing education relating to pump, pumping and hydraulic principles.

Topic Legend

This CEU course covers several educational topics/functions/purposes/objectives of hydraulic and pumping principles including groundwater production, engineering, physic laws, hydraulic theories and pump operation.

Educational topic (objectives assessment) categories were determined by beta-testing.

The topic categories listed below are to assist in determining which educational objective or goal to be covered in a specific topic area:

CROSS-CONNECTION (CC): Having to do with cross-connection control and backflow prevention. Simple hydraulic principles. This may be considered O&M training for many operators.

ELECTRICAL (SPARK): This section has to do with electrical principles and difficult math calculations. Maybe good for credit for those who hold an electrician or instrumentation certification. This may be considered O&M training for many operators.

FLUID MECHANICS (FM): Having to do with hydraulic or fluid mechanics. A highly technical and specialized engineering field. This may be considered O&M training for many operators or credit for pump engineers or well drillers.

GROUNDWATER MINING OR PRODUCTION (GP): This may be considered O&M training for many operators or credit for pump engineers or well drillers.

MOTOR: Having to do with the electrical-mechanical portion of moving water. This may be considered O&M training for many operators. Maybe good for credit for those who hold an electrician or instrumentation certification.

OPERATIONS AND MAINTENANCE O&M: This area is for normal operation and/or maintenance of the distribution system. Part of O&M training requirement for many operators.

PUMP ENGINEERING (PE): The technical science of pumping and pump performance principles. May be a law or theory or calculation related to pumping. Information that a pump engineer or well operator may need.

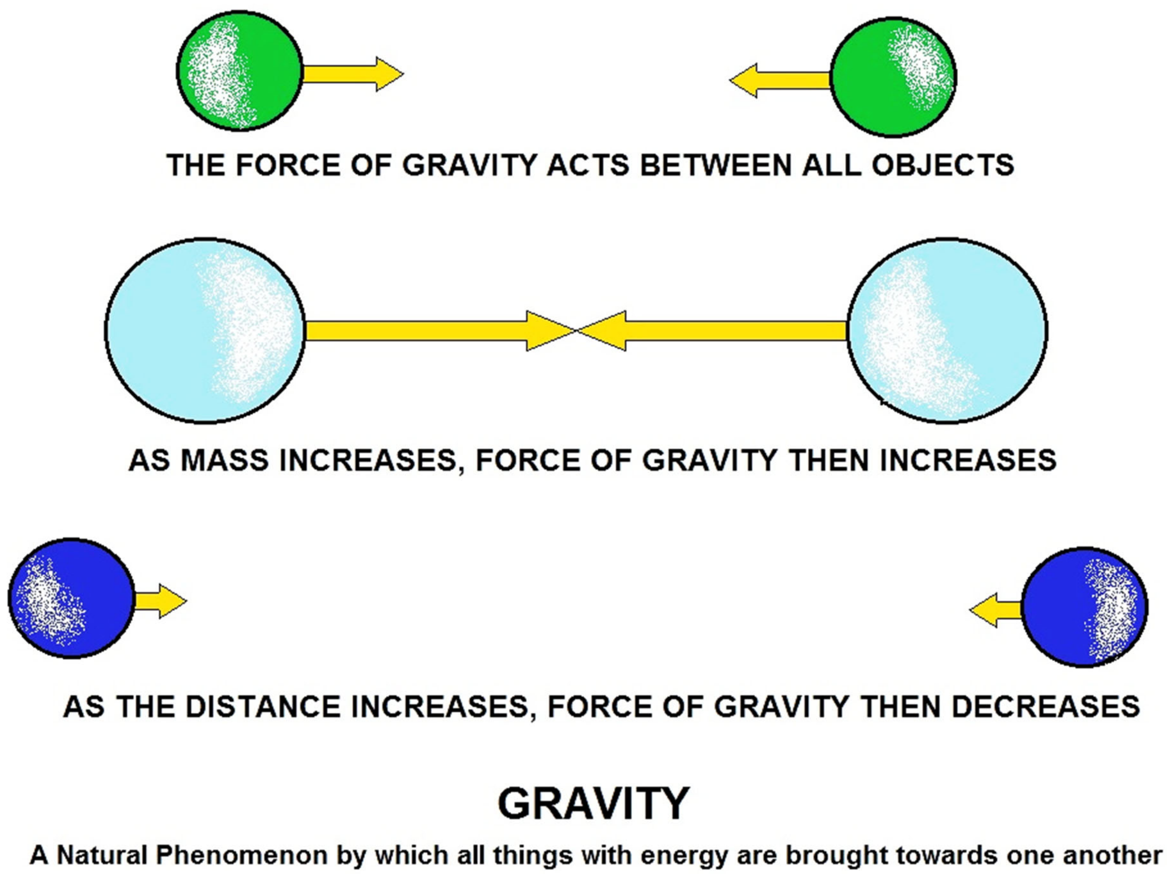
SCIENCE (SCI): Having to do with scientific principles, laws or theories. A principle that can be observed or repeated in the Laborotory. May be good for laboratory or engineering credit.

TECHNICAL (TECH): The engineering or administrative, mechanical or physical pumping related process/component. The applications, engineering, history or theory that is critical to the pump operation or composition of water (pH). May include advanced groundwater treatment methods or centrifugal pump operation. This may be considered O&M training for many operators or credit for pump engineers or well drillers.

Section 1 - Physical Science and Related Laws

Section Focus: You will learn the basics of hydraulic science, theories, laws and principles. At the end of this section, you the student will be able to describe scientific laws relating to water and hydraulics. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: Fluid mechanics (water, hydraulics and hydrodynamics) entails many different scientific laws and theories. At the end of this section, you will describe the properties of water, various laws of physics, examine thermodynamics and friction.



Without gravity, water would not flow downhill. The gravity of Earth pulls the water onto the surface of the planet and is responsible for some of the propagation of waves. The gravity of the Moon and Sun pull on Earth's water and are responsible for the tides.

When you put something in water, gravity can pull the object down through the water only if an equal volume of water is allowed to go up against the force of gravity; this is called displacement. In effect gravity has to choose which it will pull down, the water or the immersed object. What we call buoyancy is, in effect, forcing gravity to make this choice.

Physical Law

What is a Physical Law?
A **physical law** or **scientific law** is a theoretical statement "inferred from particular facts, applicable to a defined group or class of phenomena, and expressible by the statement that a particular phenomenon always occurs if certain conditions be present."

Physical laws are typically conclusions based on repeated scientific experiments and observations over many years and which have become accepted universally within the scientific community. The production of a summary description of our environment in the form of such laws is a fundamental aim of science. These terms are not used the same way by all authors.

The distinction between natural law in the political-legal sense and law of nature or physical law in the scientific sense is a modern one, both concepts being equally derived from *physis*, the Greek word (translated into Latin as *natura*) for *nature.*

Physical Law Description
Several general properties of physical laws have been identified.

Physical laws are:
- True, at least within their regime of validity. By definition, there have never been repeatable contradicting observations.
- Universal. They appear to apply everywhere in the universe.
- Simple. They are typically expressed in terms of a single mathematical equation.
- Absolute. Nothing in the universe appears to affect them.
- Stable. Unchanged since first discovered (although they may have been shown to be approximations of more accurate laws.
- Omnipotent. Everything in the universe apparently must comply with them (according to observations).
- Generally conservative of quantity.
- Often expressions of existing homogeneities (symmetries) of space and time.
- Typically, theoretically reversible in time (if non-quantum), although time itself is irreversible.

Physical Science Key Terms

Bernoulli's Principle
In fluid dynamics, Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. The principle is named after Daniel Bernoulli who published it in his book Hydrodynamica in 1738.

Continuum Assumption
The continuum assumption is the assumption that a fluid is composed of a continuous material so that properties such as density, pressure, temperature, and velocity are well-defined at "infinitely" small. points; that is, we can take the limit as volume goes to zero.

Force
In physics, a **force** is any interaction that, when unopposed, will change the motion of an object. A force can cause an object with mass to change its velocity (which includes to begin moving from a state of rest), i.e., to accelerate. Force can also be described intuitively as a push or a pull. A force has both magnitude and direction, making it a vector quantity. It is measured in the SI unit of newtons and represented by the symbol **F**.

Gravity
The force that attracts a body toward the center of the earth, or toward any other physical body having mass. For most purposes Newton's laws of gravity apply, with minor modifications to take the general theory of relativity into account.

Inertia
Inertia is the resistance of any physical object to any change in its state of motion (this includes changes to its speed, direction or state of rest). It is the tendency of objects to keep moving in a straight line at constant velocity.

Laws of Thermodynamics
The four laws of thermodynamics define fundamental physical quantities (temperature, energy, and entropy) that characterize thermodynamic systems. The laws describe how these quantities behave under various circumstances, and forbid certain phenomena (such as perpetual motion).

Mass
Mass is both a property of a physical body and a measure of its resistance to acceleration (a change in its state of motion) when a net force is applied. It also determines the strength of its mutual gravitational attraction to other bodies. The basic SI unit of mass is the kilogram (kg). In physics, mass is not the same as weight, even though mass is often determined by measuring the object's weight using a spring scale, rather than balance scale comparing it directly with known masses.

Newton’s Laws
Newton's laws of motion are three physical **laws** that, together, laid the foundation for classical mechanics. They describe the relationship between a body and the forces acting upon it, and its motion in response to those forces.

Pascal's Law
Pascal's law or the principle of transmission of fluid-pressure (also Pascal's Principle) is a principle in fluid mechanics that states that pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure variations (initial differences) remain the same. The law was established by French mathematician Blaise Pascal.

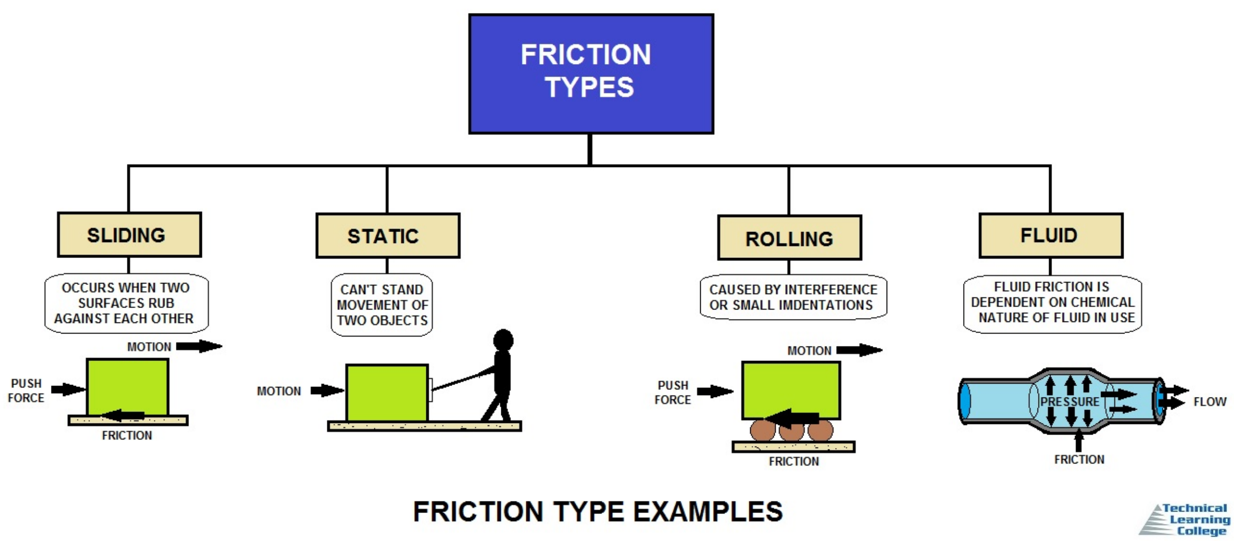
Physical Law
A physical law or scientific law "is a theoretical statement inferred from particular facts, applicable to a defined group or class of phenomena, and expressible by the statement that a particular phenomenon always occurs if certain conditions be present."

Science
Science (from Latin *scientia*, meaning "knowledge") is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe.

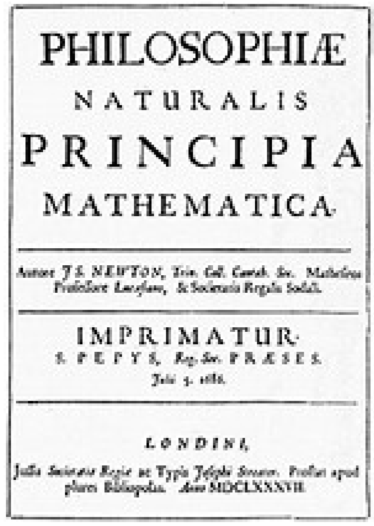
Static Pressure
In fluid mechanics, the term static pressure has several uses: In the design and operation of aircraft, static pressure is the air pressure in the aircraft's static pressure system. In fluid dynamics, many authors use the term static pressure in preference to just pressure to avoid ambiguity.

Often however, the word 'static' may be dropped and in that usage pressure is the same as static pressure at a nominated point in a fluid. The term static pressure is also used by some authors in fluid statics.

Three Laws of Motion
Newton's **laws** of **motion** are **three** physical **laws** that directly relate the forces acting on a body to the **motion** of the body. The first **law** states that every object in a state of uniform **motion** tends to remain in that state of **motion** unless an external force is applied to it.



Physical Science and Related Laws - Introduction


PHILOSOPHIÆ

NATURALIS

PRINCIPIA

MATHEMATICA

Autore JS. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR

S. PEPYS, Reg. Soc. PRÆSES.

Julii 5. 1686.

LONDINI,

Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

Newton's Laws

Sir Isaac Newton's groundbreaking work in physics was first published in 1687 in his book "The Mathematical Principles of Natural Philosophy," generally known as the *Principia*. In it, he outlined theories about gravity and of motion.

Newton's physical law of gravity states that an object attracts another object in direct proportion to their combined mass and inversely related to the square of the distance between them.

Newton developed the theories of gravitation in 1666, when he was only 23 years old. Some twenty years later, in 1686, he exhibited his three laws of motion in the "Principia Mathematica Philosophiae Naturalis."

Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This is normally taken as the definition of **inertia.**

The key point here is that if there is **no net force** acting on an object (if all the external forces cancel each other out) then the object will maintain a **constant velocity**. If that velocity is zero, then the object remains at rest.

If an external force is applied, the velocity will change because of the force.

The second law explains how the velocity of an object changes when it is subjected to an external force.

The law defines a **force** to be equal to change in **momentum** (mass times velocity) per change in time.

Newton also established the calculus of mathematics, and the "changes" expressed in the second law are most accurately defined in differential forms. (Calculus can also be used to determine the velocity and location variations experienced by an object subjected to an external force.)

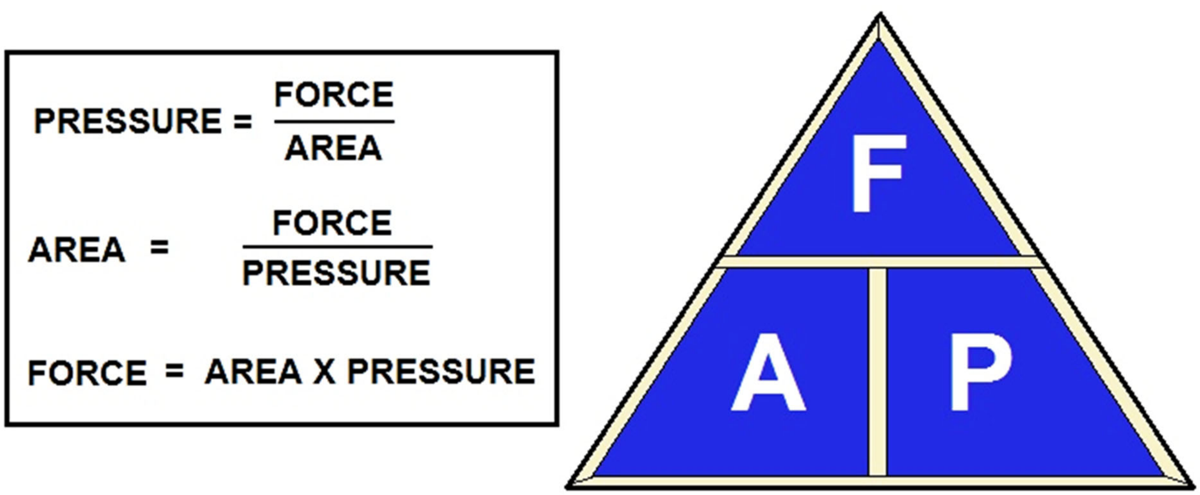
For an object with a constant mass **m**, the second law states that the force **F** is the product of an object's mass and its acceleration **a**:

$$F = m * a$$

For an external applied force, the change in velocity depends on the mass of the object. A force will cause a change in velocity; and likewise, a change in velocity will generate a force. The equation works both ways.

The third law states that for every action (force) in nature there is an equal and opposite reaction. In other words, if object A exerts a force on object B, then object B also exerts an equal force on object A.

Notice that the forces are exerted on different objects. The third law can be used to explain the production of lift by a wing and the generation of thrust by a jet engine.



FORMULAS TO CALCULATE FORCE, AREA & PRESSURE

Technical Learning College

Force

In physics, a **force** is any interaction that, when unopposed, will change the motion of an object. A force can cause an object with mass to change its velocity (which includes to begin moving from a state of rest), i.e., to accelerate.

Force can also be described intuitively as a push or a pull. A force has both magnitude and direction, making it a vector quantity. It is measured in the SI unit of newtons and represented by the symbol **F**.

The prototype form of Newton's second law states that the net force acting upon an object is equal to the rate at which its momentum changes with time.

If the mass of the object is constant, this law implies that the acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object

Concepts related to force include: thrust, which increases the velocity of an object; drag, which decreases the velocity of an object; and torque, which produces changes in rotational speed of an object. In an extended body, each part usually applies forces on the adjacent parts; the distribution of such forces through the body is the internal mechanical stress.

Such internal mechanical stresses cause no acceleration of that body as the forces balance one another.

Pressure, the distribution of many small forces applied over an area of a body, is a simple type of stress that if unbalanced can cause the body to accelerate. Stress usually causes deformation of solid materials, or flow in fluids.

Gravity

The force that attracts a body toward the center of the earth, or toward any other physical body having mass. For most purposes, Newton's laws of gravity will apply, along with minor alterations to taking the General Theory of Relativity into account.

Gravity is one of the four forces of nature. The strength of the gravitational force between two objects depends on their masses.

The more immense or massive the objects are, the stronger the gravitational attraction. When you pour water out of a bucket, the earth's gravity pulls the water towards the ground. The same thing happens when you put two containers of water, with a tube between them, at two different heights. You must work to start the flow of water from one bucket to the other, but then gravity takes over and the process will continue on its own.

Gravity, applied forces, and atmospheric pressure are static factors that apply equally to fluids at rest or in motion, while inertia and friction are dynamic factors that apply only to fluids in motion.

The mathematical sum of gravity, applied force, and atmospheric pressure is the static pressure obtained at any one point in a fluid at any given time.

Fundamental Interactions
Fundamental interactions, also known as fundamental forces, are the interactions in physical systems that do not appear to be reducible to more basic interactions. There are four conventionally accepted fundamental interactions—gravitational, electromagnetic, strong nuclear, and weak nuclear. Each one is understood as the dynamics of a field.

Inertia
Inertia is the resistance of any physical object to any change in its state of motion (this includes changes to its speed, direction or state of rest). It is the tendency of objects to keep moving in a straight line at constant velocity.

Mass
Mass is both a property of a physical body and a measure of its resistance to acceleration (a change in its state of motion) when a net force is applied. It also determines the strength of its mutual gravitational attraction to other bodies. The basic SI unit of mass is the kilogram (kg).

In physics, mass is not the same as weight, even though mass is often determined by measuring the object's weight using a spring scale, rather than balance scale comparing it directly with known masses.

An object on the Moon would weigh less than it does on Earth because of the lower gravity, but it would still have the same mass. This is because weight is a force, while mass is the property that (along with gravity) determines the strength of this force.

In Newtonian physics, mass can be generalized as the amount of matter in an object. However, at very high speeds, special relativity states that the kinetic energy of its motion becomes a significant additional source of mass.

Therefore, any stationary body having mass has an equivalent amount of energy, and all forms of energy resist acceleration by a force and have gravitational attraction. In modern physics, matter is not a fundamental concept because its definition has proven elusive.

There are several distinct experiences which can be used to measure mass. Although some theorists have speculated that some of these experiences could be independent of each other, current experiments have found no difference in results regardless of how it is measured:

- *Inertial mass* measures an object's resistance to being accelerated by a force (represented by the relationship $F = ma$).
- *Active gravitational mass* measures the gravitational force exerted by an object.
- *Passive gravitational mass* measures the gravitational force exerted on an object in a known gravitational field.

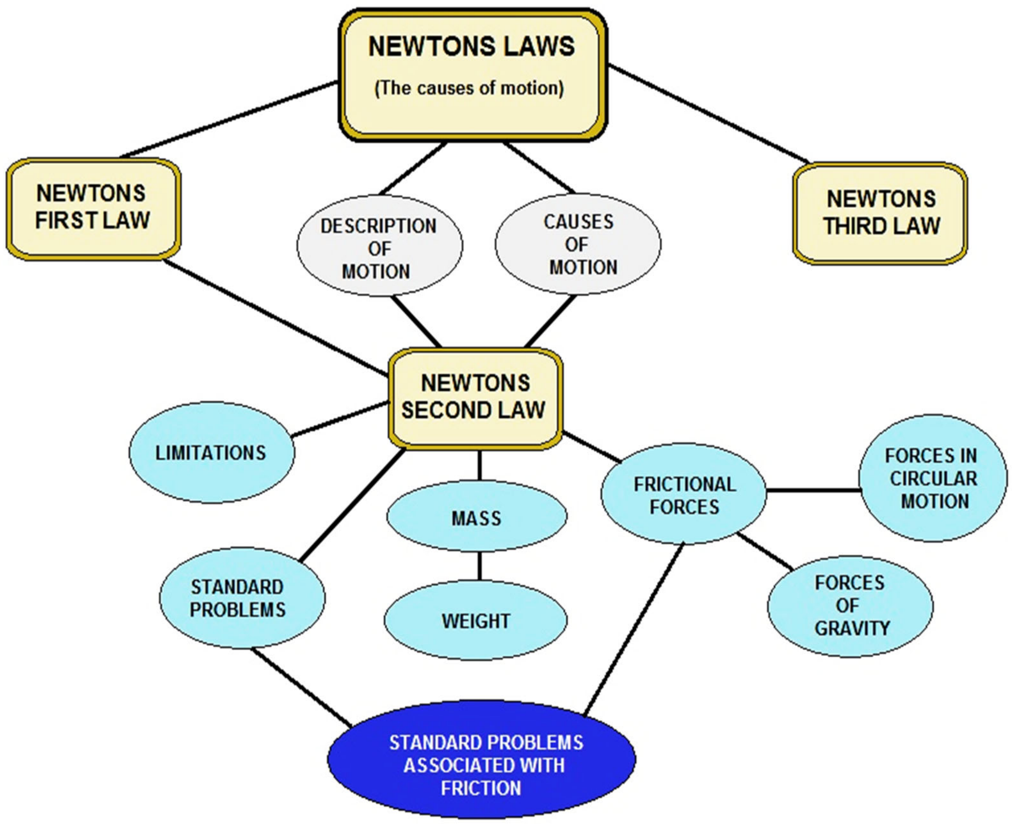
The mass of an object determines its acceleration in the presence of an applied force.

The inertia and the inertial mass describe the same properties of physical bodies at the qualitative and quantitative level respectively, by other words, the mass quantitatively describes the inertia. According to Newton's second law of motion, if a body of fixed mass m is subjected to a single force F, its acceleration a is given by F/m.

A body's mass also determines the degree to which it generates or is affected by a gravitational field.

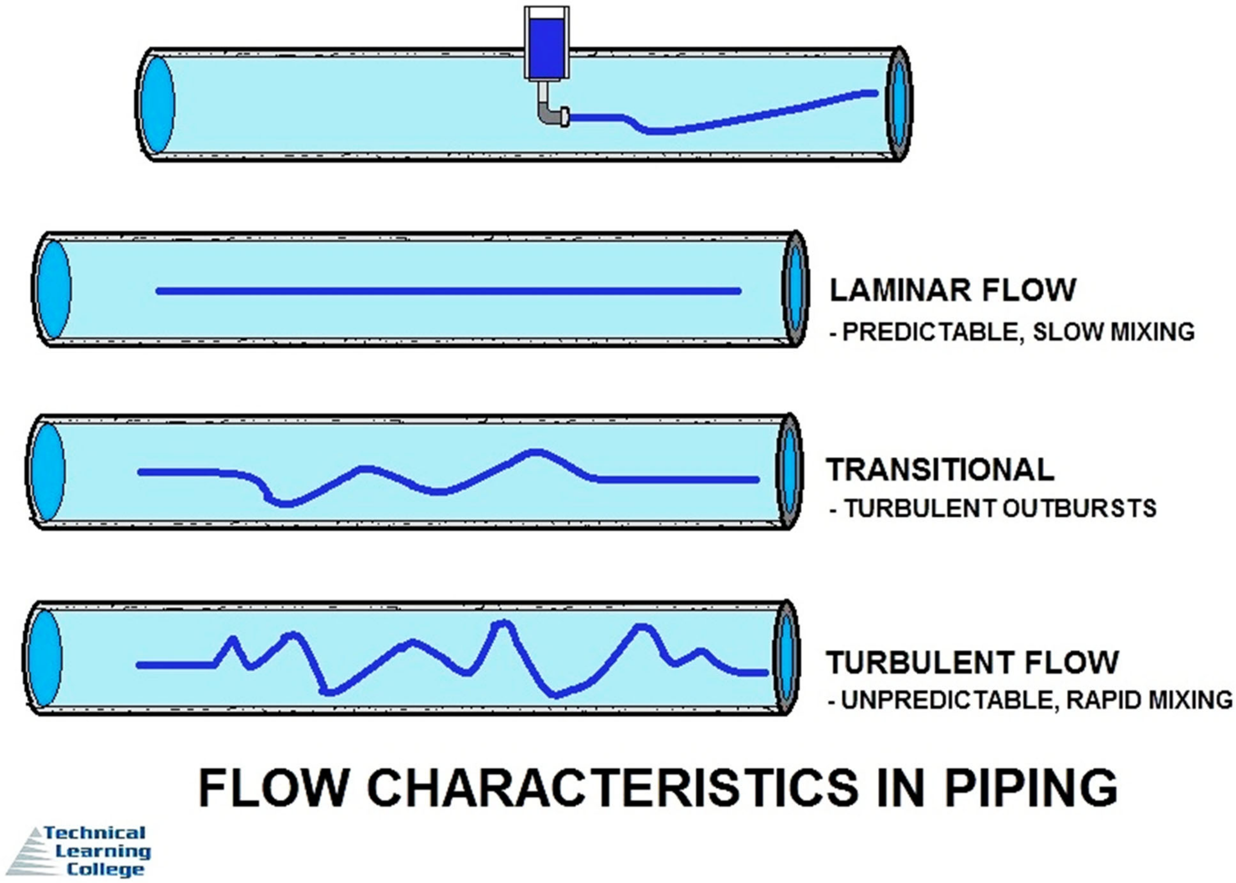
If a first body of mass m_A is placed at a distance r (center of mass to center of mass) from a second body of mass m_B, each body is subject to an attractive force $F_g = Gm_Am_B/r^2$, where $G = 6.67 \times 10^{-11}$ N kg^{-2} m^2 is the "universal gravitational constant".

This at times is referred to as gravitational mass. Repeated experiments since the 17th century have demonstrated that inertial and gravitational mass are identical; since 1915, this observation has been entailed *a priori* in the equivalence principle of general relativity.



FIRST LAW:	**Objects at rest remain at rest and objects in motion in a straight line unless acted upon by an unbalanced force.**
SECOND LAW:	**Forces equal mass times acceleration (f = ma).**
THIRD LAW:	**For every action, there is an equal and opposite reaction**

NEWTON'S THREE LAWS OF MOTION


LAMINAR FLOW
- PREDICTABLE, SLOW MIXING
TRANSITIONAL
- TURBULENT OUTBURSTS
TURBULENT FLOW
- UNPREDICTABLE, RAPID MIXING
FLOW CHARACTERISTICS IN PIPING
Technical
Learning
College

Technical Understanding

In the absence of forces, ("body") at rest will stay at rest, and a body **moving at a constant velocity in a straight line** continues doing so indefinitely.

When a force is applied to an object, it accelerates. The acceleration *a* is in the direction of the force and proportional to its strength, and is also inversely proportional to the mass being moved. In suitable units:

$$a = F/m$$

or in the form usually found in textbooks

$$F = m\,a$$

More accurately, one should write

$$\mathbf{F} = m\mathbf{a}$$

with both **F** and **a** vectors in the same direction (denoted here in bold face). However, when only a single direction is understood, the simpler form can also be used.

"The law of reaction," sometimes stated as "to every action there exists an equal and opposite reaction." In more explicit terms:

Forces are always produced in pairs, with opposite directions and equal magnitudes. If body #1 acts with a force F on body #2, then body #2 acts on body #1 with a force of equal strength and opposite direction.

The Hypothesis of Force

As a functioning definition, "force" is that which **causes or changes motion**.

One force everyone is familiar with is the **weight** of objects, the force which tries to make them move downwards, to fall towards the center of the Earth.

We may therefore measure force (at least now, temporarily) in kilograms of weight, and view as force anything that can be matched by weight.

For instance, a **spiral spring** can be compressed or stretched by weight, so it is reasonable to say that it, too, exerts a force when compressed or stretched.

Based on hindsight--on experience with forces noted by many people, including Newton--we may distinguish **two basic situations** in which force creates motion:

1. The force moves an object **overcoming** external resistance.
2. The force moves an object against **negligible** external resistance.

Motion against Outside Resistance

This kind of motion will be covered later, in connection with the concept of "**work**."

Examples include:

- --Lifting a book from the floor to the table (the force produced by the hand doing the lifting must overcome the downward pull of gravity)
- --Dragging a table across the room (the pull of your hand must overcome the friction of the floor),
- --An airliner flying at 600 mph (the thrust of its engines overcomes air resistance)

The **speed of the motion** does not enter here, so in principle it can even cover the case when the opposing force **completely balances** the applied one, resulting in **no motion at all**:

- --A table stands on the floor, without moving. The downward force of the weight of the table encounters resistance by the floor, which does not allow it to move any further downwards. The downward velocity is zero and the forces are balanced or "**in equilibrium.**"

Motions without Significant Resistance

It was Sir Isaac Newton's insight that in the absence of external resistance, motions in a straight line and at constant speed would continue indefinitely. **No force is necessary**. That is **Newton's first law of motion:**

" In the absence of external forces, motion in a straight line and at constant speed continues indefinitely. "

A smooth rock sliding on a sheet of ice can travel great distances, and the smoother the ice, the further it goes. Newton realized that what ultimately stopped such motions was the **friction** of the surface. If an ideally smooth ice could be produced, with no friction at all and extending to unlimited distances, the rock would continue indefinitely, never stopping, in the same direction and with the same velocity as the ones with which it had started.

What a force can do in the absence of resistance is **increase the velocity of an object -- accelerate it.**

Nevertheless, even without external resistance, there remains an **internal resistance, by the object itself**.

An astronaut pushing a one-ton satellite out of the cargo bay of the space shuttle quickly finds that even though the satellite seems "weightless," it is not easily moved. Given a push by the astronaut, it will indeed start to move, but **very slowly**. It resists being put in motion, and once moving, it resists just as much being slowed down or stopped.

People were quite familiar with the docking of ships and large boats. A heavy boat acts very much like a "weightless" satellite: the water supports its weight, but offers very little resistance to slow motion. And there too, when such a boat is pushed away from the dock, it starts moving very gradually: but once it is moving, it is just as hard to stop.) Newton named that internal resistance **inertia**.

Clearly, inertia increases with the amount of matter. A bowling ball is harder to get moving and harder to stop than a hollow rubber ball of the same size. The bowling ball is also **heavier**, that is, it is pulled downward with greater force: but weight is an effect of gravity, while inertia is not.

Three Laws of Motion Review

Newton's three laws of motion, also found in the *Principia*, govern how the motion of physical objects change. They define the fundamental relationship between the acceleration of an object and the forces acting upon it.

- **First rule**: An object will remain at rest or in a uniform state of motion unless that state is changed by an external force.

- **Second rule**: Force is equal to the change in momentum (mass times velocity) over time. In other words, the rate of change is directly proportional to the amount of force applied.

- **Third rule**: For every action in nature there is an equal and opposite reaction.

Jointly, these three principles in which Newton outlined form the basis of classical mechanics, describes how bodies behave physically under the influence of outside forces.

Conservation of Mass and Energy

Albert Einstein introduced his famous equation *E = mc2* in 1905 journal submission titled, "On the Electrodynamics of Moving Bodies." The paper presented his theory of special relativity, based on two postulates:

- **Principle of relativity**: The laws of physics are the same for all inertial reference frames.
- **Principle of constancy of the speed of light**: Light always propagates through a vacuum at a definite velocity, which is independent of the state of motion of the emitting body.

The first principle describes that the laws of physics apply equally to everyone in all situations. The second principle is the more important one. It stipulates that the speed of light in a vacuum is constant. Unlike all other forms of motion, it is not measured differently for observers in different inertial frames of reference.

Laws of Thermodynamics

The four laws of thermodynamics define basic physical quantities (temperature, energy, and entropy) that characterize thermodynamic systems. The laws define how these quantities behave under various circumstances, and forbid certain phenomena (such as perpetual motion).

The laws of thermodynamics are actually specific manifestations of the law of conservation of mass-energy as it relates to thermodynamic processes. The field was first explored in the 1650s by Otto von Guericke in Germany and Robert Boyle and Robert Hooke in Britain.

All three scientists used vacuum pumps, which von Guericke pioneered, to study the principles of pressure, temperature, and volume.

- **The zeroeth law of thermodynamics** makes the notion of temperature possible.
- **The first law of thermodynamics** demonstrates the relationship between internal energy, added heat, and work within a system.
- **The second law of thermodynamics** relates to the natural flow of heat within a closed system.
- **The third law of thermodynamics** states that it is impossible to create a thermodynamic process that is perfectly efficient.

Thermodynamics Defined

Thermodynamics is a division of physics concerned with heat and temperature and their relation to energy and work. The performance of these quantities is governed by the four laws of thermodynamics, irrespective of the composition or specific properties of the material or system in question.

The laws of thermodynamics are explained in terms of microscopic elements by statistical mechanics. Thermodynamics applies to a wide variety of topics in science and engineering, especially physical chemistry, chemical engineering and mechanical engineering.

Thermodynamic research developed out of a desire to increase the efficiency of early steam engines, particularly through the work of French physicist Nicolas Léonard Sadi Carnot (1824) who believed that engine efficiency was the key that could help France win the Napoleonic Wars.

Scottish physicist Lord Kelvin was the first to formulate a concise definition of thermodynamics in 1854 which stated, *"Thermo-dynamics is the subject of the relation of heat to forces acting between contiguous parts of bodies, and the relation of heat to electrical agency."*

Chemical thermodynamics studies the nature of the role of entropy in the process of chemical reactions and has provided the bulk of expansion and knowledge of the field. The initial application of thermodynamics to mechanical heat engines was extended early on to the study of chemical compounds and chemical reactions.

Other formulations of thermodynamics emerged in the following decades. Statistical thermodynamics, or statistical mechanics, concerned itself with statistical predictions of the collective motion of particles from their microscopic behavior.

In 1909, Constantin Carathéodory presented a purely mathematical approach to the field in his axiomatic formulation of thermodynamics, a description often referred to as *geometrical thermodynamics*.

More on the Law of Thermodynamics

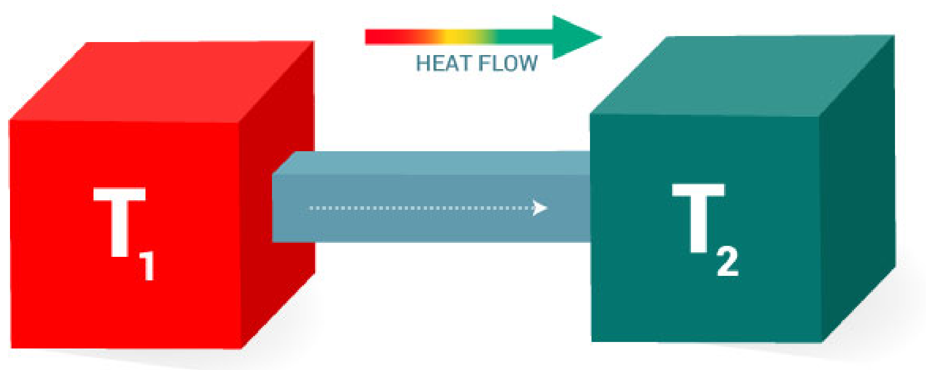
The four laws of thermodynamics define fundamental physical quantities (temperature, energy, and entropy) that characterize thermodynamic systems at thermal equilibrium.

The laws describe how these quantities behave under various circumstances, and forbid certain phenomena (such as perpetual motion).

The four laws of thermodynamics are

- Zeroth law of thermodynamics: If two systems are in thermal equilibrium with a third system, they are in thermal equilibrium with each other. This law helps define the concept of temperature.
- First law of thermodynamics: When energy passes, as work, as heat, or with matter, into or out from a system, the system's internal energy changes in accord with the law of conservation of energy. Equivalently, perpetual motion machines of the first kind (machines that produce work with no energy input) are impossible.
- Second law of thermodynamics: In a natural thermodynamic process, the sum of the entropies of the interacting thermodynamic systems increases. Equivalently, perpetual motion machines of the second kind (machines that spontaneously convert thermal energy into mechanical work) are impossible.
- Third law of thermodynamics: The entropy of a system approaches a constant value as the temperature approaches absolute zero. With the exception of non-crystalline solids (glasses) the entropy of a system at absolute zero is typically close to zero, and is equal to the natural logarithm of the product of the quantum ground states.

The laws of thermodynamics are important fundamental laws in physics and they are applicable in other natural sciences.



More on Energy Conservation

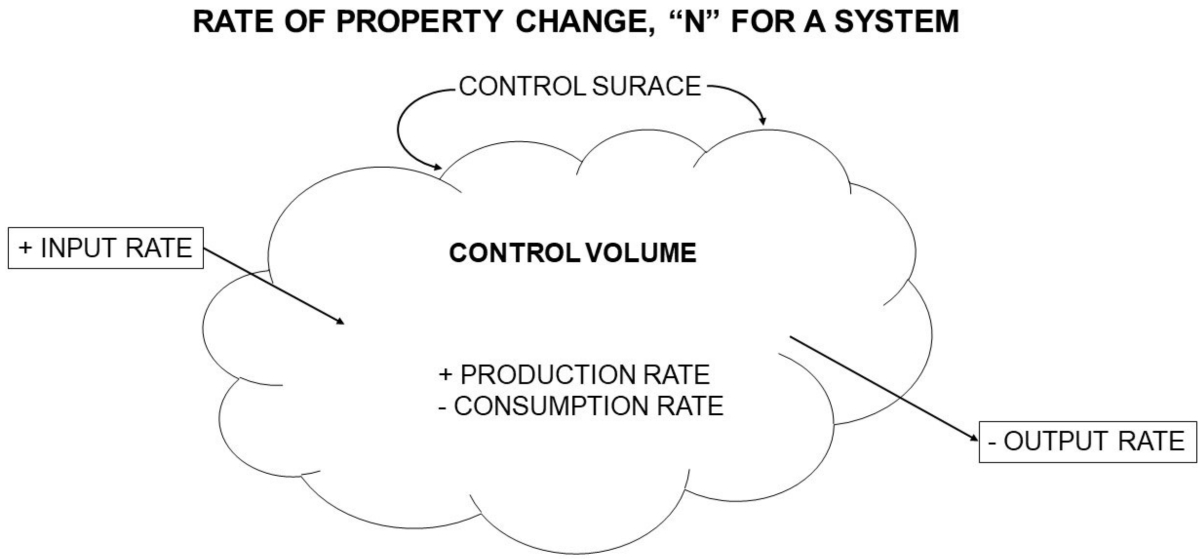
The first law of thermodynamics asserts that energy must be conserved in any process involving the exchange of heat and work between a system and its surroundings. A machine that violated the first law would be called a perpetual motion machine of the first kind because it would manufacture its own energy out of nothing and thereby run forever. Such a machine would be impossible even in theory. However, this impossibility would not prevent the construction of a machine that could extract essentially limitless amounts of heat from its surroundings (earth, air, and sea) and convert it entirely into work. Although such a hypothetical machine would not violate conservation of energy, the total failure of inventors to build such a machine, known as a perpetual motion machine of the second kind, led to the discovery of the second law of thermodynamics. The second law of thermodynamics can be precisely stated in the following two forms, as originally formulated in the 19th century by the Scottish physicist William Thomson (Lord Kelvin) and the German physicist Rudolf Clausius, respectively:

A cyclic transformation whose only final result is to transform heat extracted from a source which is at the same temperature throughout into work is impossible.

A cyclic transformation whose only final result is to transfer heat from a body at a given temperature to a body at a higher temperature is impossible.

The two statements are in fact equivalent because, if the first were possible, then the work obtained could be used, for example, to generate electricity that could then be discharged through an electric heater installed in a body at a higher temperature. The net effect would be a flow of heat from a lower temperature to a higher temperature, thereby violating the second (Clausius) form of the second law. Conversely, if the second form were possible, then the heat transferred to the higher temperature could be used to run a heat engine that would convert part of the heat into work. The final result would be a conversion of heat into work at constant temperature—a violation of the first (Kelvin) form of the second law.

Assumptions



INTEGRATED FLUID QUANTITY BALANCE

Equilibrium for some integrated fluid quantity in a control volume enclosed by a control surface.

The assumptions inherent to a fluid mechanical treatment of a physical system can be expressed in terms of mathematical equations. Basically, every fluid mechanical system is assumed to obey:

- Conservation of mass
- Conservation of energy
- Conservation of momentum
- The continuum assumption

For example, the assumption that mass is conserved means that for any fixed control volume (for example, a spherical volume) – enclosed by a control surface – the rate of change of the mass contained in that volume is equal to the rate at which mass is passing through the surface from *outside* to *inside*, minus the rate at which mass is passing from *inside* to *outside*. This can be expressed as an equation in integral form over the control volume.

Continuum Assumption

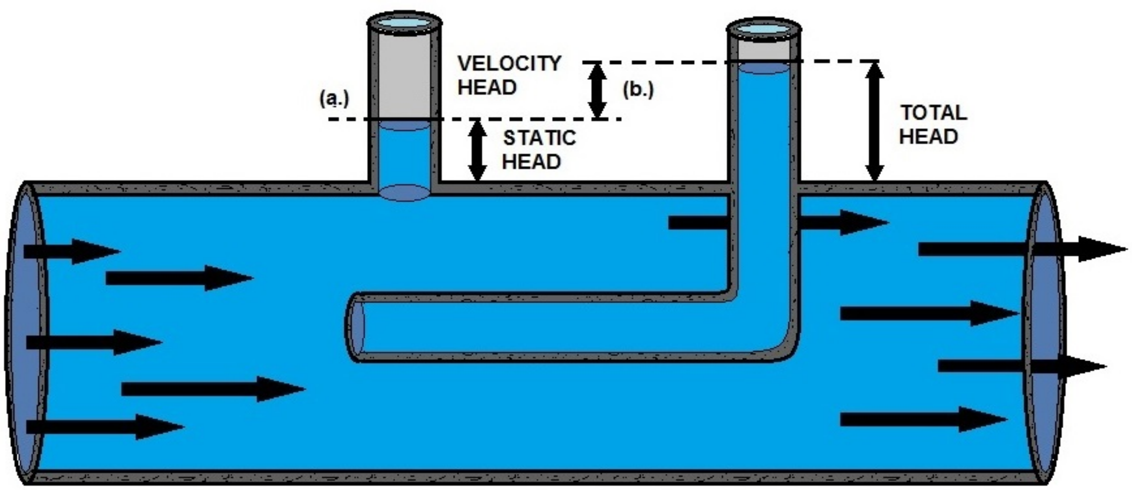
The continuum assumption is an invention of continuum mechanics under which fluids can be treated as continuous, even though, on a microscopic scale, they are composed of molecules.

Under the continuum assumption, macroscopic (observed/measurable) properties such as density, pressure, temperature, and bulk velocity are taken to be well-defined at "infinitesimal" volume elements -- small in comparison to the characteristic length scale of the system, but large in comparison to molecular length scale.

Fluid properties can vary continuously from one volume element to another and are average values of the molecular properties. The continuum hypothesis can lead to inaccurate results in applications like supersonic speed flows, or molecular flows on nano scale. Those problems for which the continuum hypothesis fails, can be solved using statistical mechanics.

Knudsen Number

To determine whether or not the continuum hypothesis relates, the Knudsen number, defined as the ratio of the molecular mean free path to the characteristic length scale, is evaluated. Problems with Knudsen numbers below 0.1 can be evaluated using the continuum hypothesis, but molecular approach (statistical mechanics) can be applied for all ranges of Knudsen numbers. You can find more on this subject in the glossary.



MEASURING STATIC HEAD (a) AND TOTAL HEAD (b) OF WATER THROUGH A PIPE

Pascal's Law- Introduction

The groundwork of modern hydraulics was established when Pascal discovered that pressure in a fluid acts equally in all directions. This pressure acts at right angles to the containing surfaces.

If some type of pressure gauge, with an exposed face, is placed beneath the surface of a liquid at a specific depth and pointed in different directions, the pressure will read the same. Therefore, we can say that pressure in a liquid is independent of direction.

Pressure due to the weight of a liquid, at any level, depends on the depth of the fluid from the surface. If the exposed face of the pressure gauges is moved closer to the surface of the liquid, the indicated pressure will be less.

When the depth is doubled, the indicated pressure is doubled. Thus the pressure in a liquid is directly proportional to the depth.

Consider a container with vertical sides that is 1-foot-long and 1 foot wide. Let it be filled with water 1-foot-deep, providing 1 cubic foot of water.

1 cubic foot of water weighs 62.4 pounds. Using this information and equation, **P = F/A**, we can calculate the pressure on the bottom of the container.

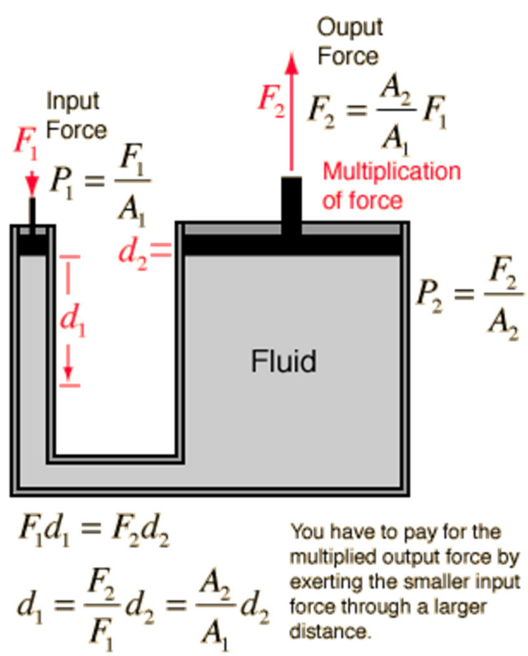
Since there are 144 square inches in 1 square foot, this can be stated as follows: the weight of a column of water 1-foot-high, having a cross-sectional area of 1 square inch, is 0.433 pound.

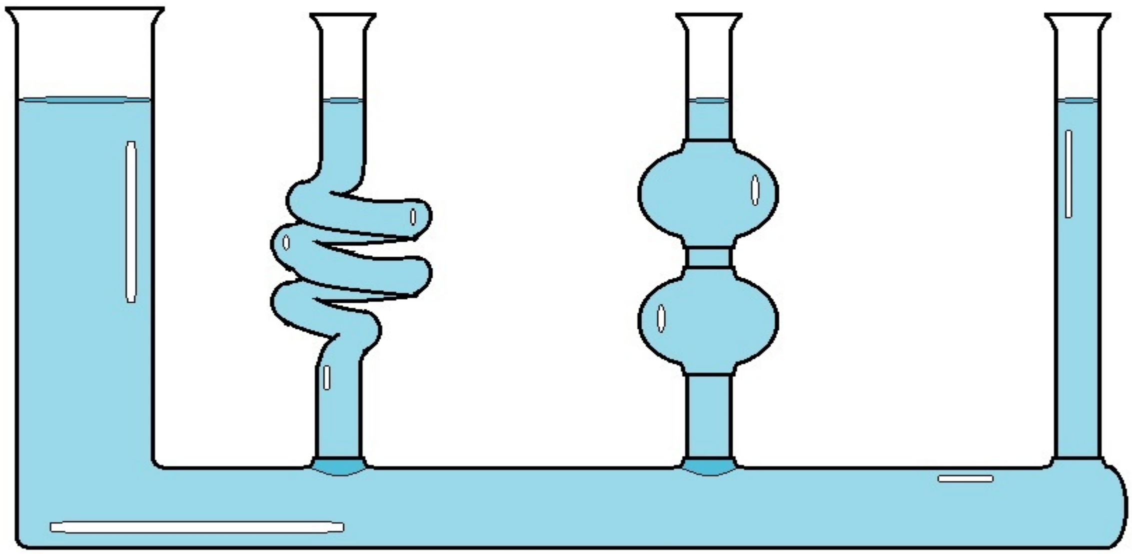
If the depth of the column is tripled, the weight of the column will be 3 x 0.433, or 1.299 pounds, and the pressure at the bottom will be 1.299 lb/in^2 (psi), since pressure equals the force divided by the area.

Therefore, the pressure at any depth in a liquid is equal to the weight of the column of liquid at that depth divided by the cross-sectional area of the column at that depth.

The volume of a liquid that produces the pressure is referred to as the fluid head of the liquid.

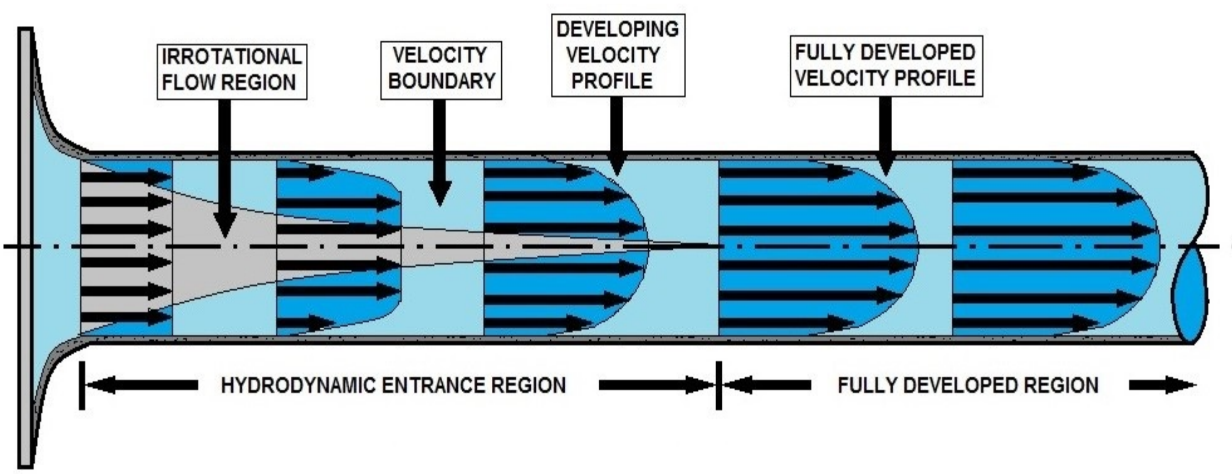
The pressure of a liquid due to its fluid head is also dependent on the density of the liquid.





PRESSURE IN LIQUIDS

PASCAL'S VASES DEMONSTRATE THE FACT THAT THE PRESSURE OF THE LIQUID DEPENDS SOLELY ON THE DEPTH ALONE, AND NOT THE VOLUME OR THE SHAPE OF THE FLUID



BREAKDOWN OF WATER'S ACTION IN A PIPE

Static Pressure

We will cover these areas in detail in another section.

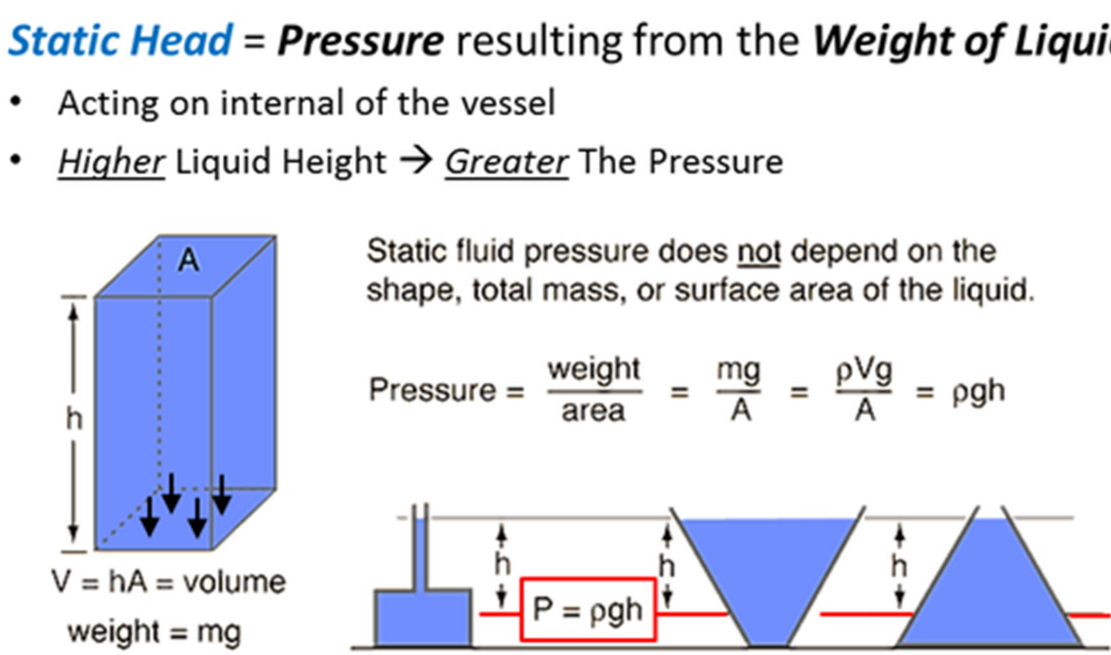
Static pressure exists in addition to any dynamic factors that may also be present at the same time. Pascal's law states that a pressure set up in a fluid acts equally in all directions and at right angles to the containing surfaces. This will cover the situation only for fluids at rest or practically at rest. It is true only for the factors making up static head.

Clearly, when velocity becomes a factor it must have a direction, and as previously explained, the force related to the velocity must also have a direction, so that Pascal's law alone does not apply to the dynamic factors of fluid power.

The dynamic factors of inertia and friction are related to the static factors.

Velocity head and friction head are obtained at the expense of static head. Nevertheless, a portion of the velocity head can always be reconverted to static head.

Force, which can be produced by pressure or head when dealing with fluids, is necessary to start a body moving if it is at rest, and is present in some form when the motion of the body is arrested; thus, whenever a fluid is given velocity, some part of its original static head is used to impart this velocity, which then exists as velocity head.



Volume and Velocity of Flow

The volume of a liquid passing a point in a given time is known as its *volume of flow* or flow rate.

The volume of flow is usually expressed in gallons per minute (gpm) and is associated with relative pressures of the liquid, such as 5 gpm at 40 psi.

The *velocity of flow* or velocity of the fluid is defined as the average speed at which the fluid moves past a given point. It is usually expressed in feet per second (fps) or feet per minute (fpm).

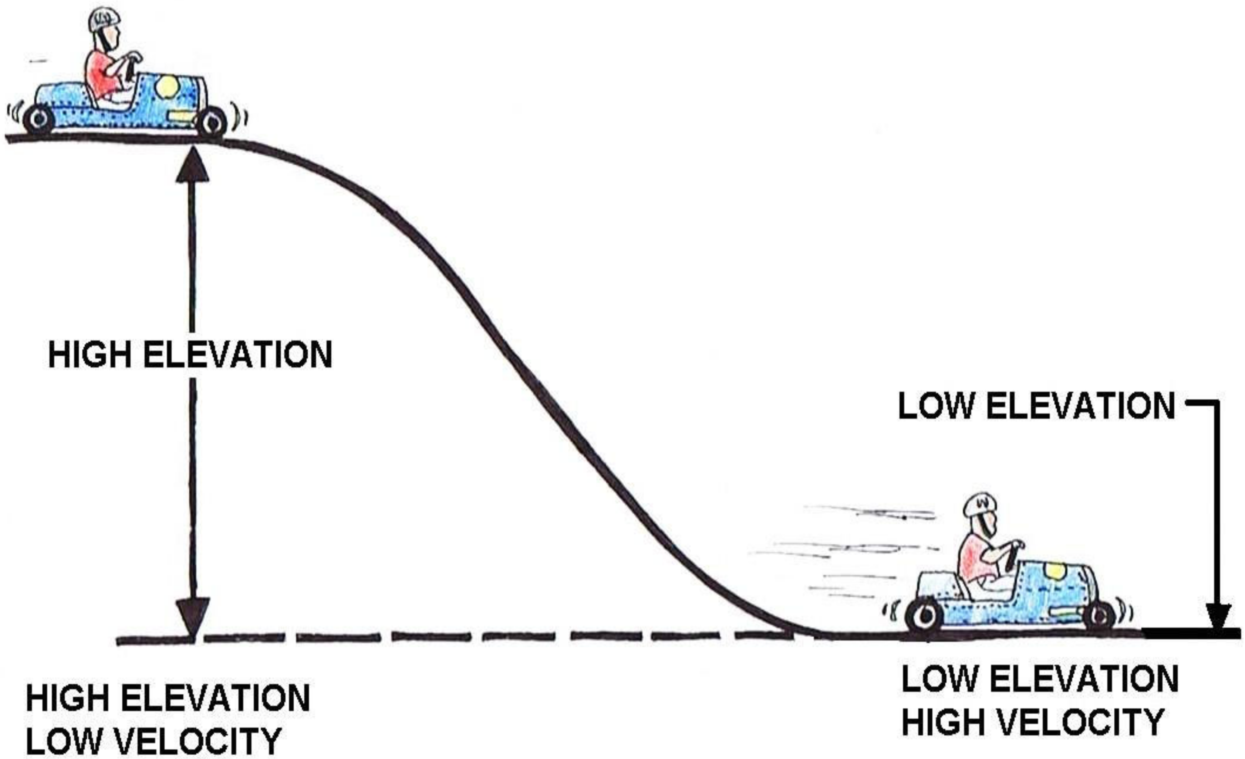
Velocity of flow is an important consideration in sizing the hydraulic lines.

Volume and velocity of flow are often considered together. With other conditions unaltered—that is, with volume of input unchanged—the velocity of flow increases as the cross section or size of the pipe decreases, and the velocity of flow decreases as the cross section increases.

For example, the velocity of flow is slow at wide parts of a stream and rapid at narrow parts, yet the volume of water passing each part of the stream is the same.

$$Q = AV$$

Where: Q = Quantity of flow in *cubic feet per minute*
A = Cross sectional area of duct in *square feet*
V = Average velocity in *feet per minute*



Understanding the Venturi

It is difficult to understand the reason low pressure occurs in the small diameter area of the venturi. The following explanation may seem to help the principle.

It is clear that all the flow must pass from the larger section to the smaller section. Or in other words, the flow rate will remain the same in the large and small portions of the tube. The flow rate is the same rate, but the velocity changes.

The velocity is greater in the small portion of the tube. There is a relationship between the pressure energy and the velocity energy; if velocity increases the pressure energy must decrease.

This is known as the principle of conservation of energy at work which is also Bernoulli's law. This is similar to the soapbox derby car in the illustration at the top of a hill. At the top or point, the elevation of the soapbox derby car is high and the velocity low.

At the bottom the elevation is low and the velocity is high, elevation (potential) energy has been converted to velocity (kinetic) energy.

Pressure and velocity energies behave in the same way. In the large part of the pipe the pressure is high and velocity is low, in the small part, pressure is low and velocity high.

Bernoulli's Principle

Bernoulli's principle thus says that a rise (fall) in pressure in a flowing fluid must always be accompanied by a decrease (increase) in the speed, and conversely, if an increase (decrease) in, the speed of the fluid results in a decrease (increase) in the pressure.

This is at the heart of a number of everyday phenomena. As an example, Bernoulli's principle is responsible for the fact that a shower curtain gets "***sucked inwards***" when the water is first turned on. What happens is that the increased water/air velocity inside the curtain (relative to the still air on the other side) causes a pressure drop.

The pressure difference between the outside and inside causes a net force on the shower curtain which sucks it inward.

A practical example is provided by the functioning of a perfume bottle: squeezing the bulb over the fluid creates a low pressure area due to the higher speed of the air, which subsequently draws the fluid up. This is illustrated in the following figure.

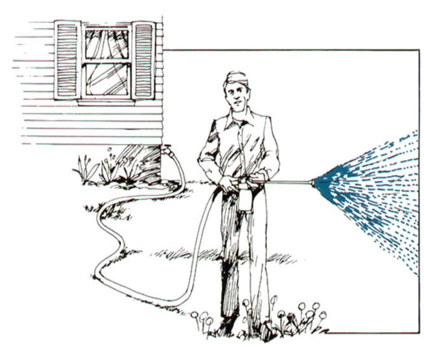
Bernoulli's principle also tells us why windows tend to explode, rather than implode in hurricanes: the very high speed of the air just outside the window causes the pressure just outside to be much less than the pressure inside, where the air is still.

The difference in force pushes the windows outward, and hence they explode. If you know that a hurricane is coming it is therefore better to open as many windows as possible, to equalize the pressure inside and out.

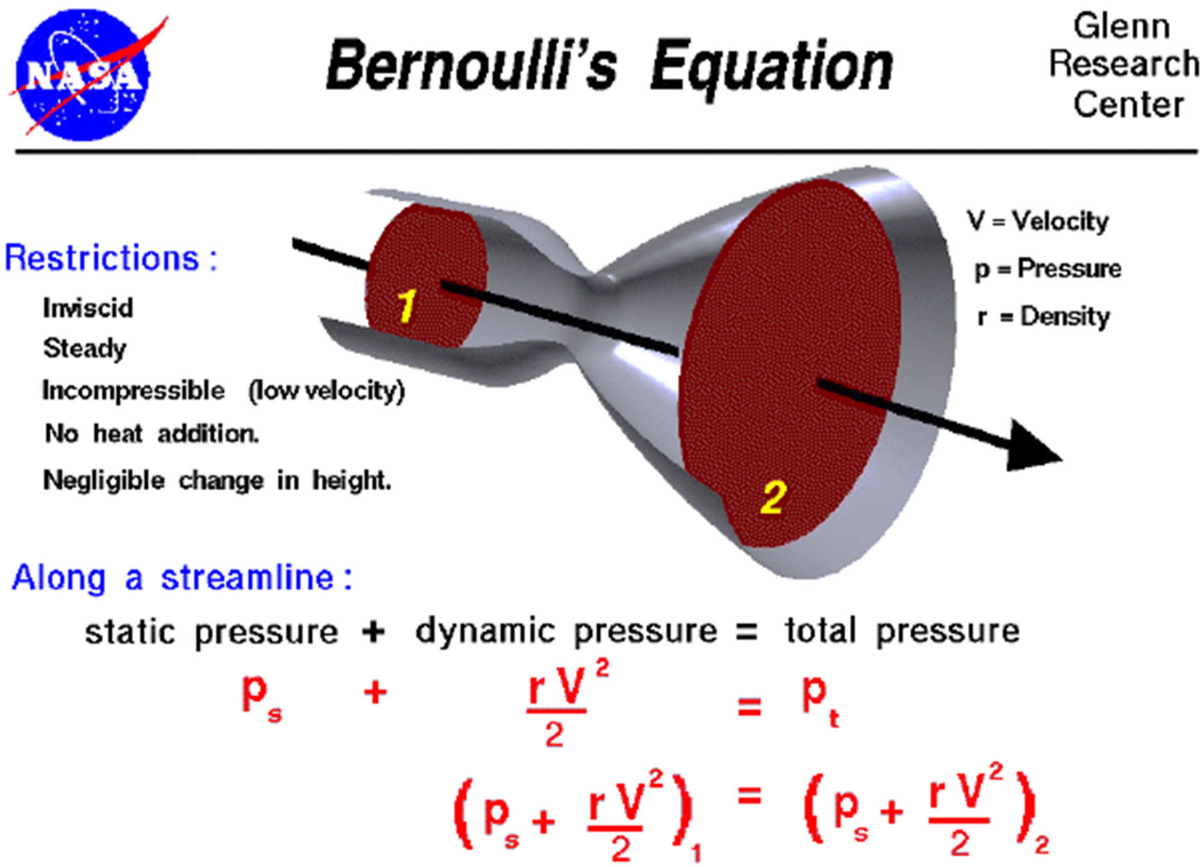
Another example of Bernoulli's principle at work is in the lift of aircraft wings and the motion of "***curve balls"*** in baseball.

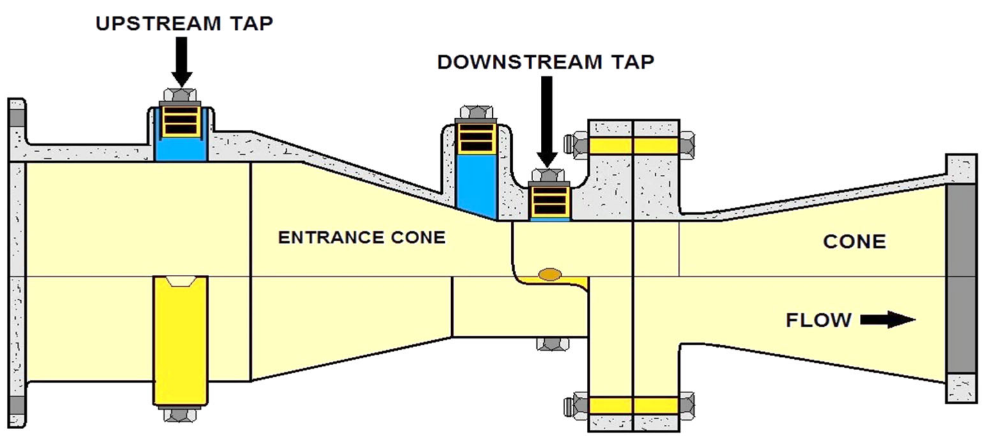
In both cases, the design is such as to create a speed differential of the flowing air past the object on the top and the bottom - for aircraft wings this comes from the movement of the flaps, and for the baseball it is the presence of ridges.

Such a speed differential leads to a pressure difference between the top and bottom of the object, resulting in a net force being exerted, either upwards or downwards.



Action of a spray atomizer





VENTURI TUBE

Physical Science and Laws Section- Post Quiz

Hyperlink to Assignment…
http://www.abctlc.com/downloads/PDF/PumpPrimer1Ass.pdf

Physical Law Description
Physical laws are:
1. Absolute. ___________in the universe appears to affect them.

2. ___________. Unchanged since first discovered (although they may have been shown to be approximations of more accurate laws.

Three Laws of Motion
3. **First rule**: An object will remain at rest or in a uniform state of motion unless that state is changed by?

4. **Second rule**: _____________ is equal to the change in momentum (mass times velocity) over time. In other words, the rate of change is directly proportional to the amount of force applied.

5. **Third rule**: For ____________in nature there is an equal and opposite reaction.

Laws of Thermodynamics
6. **The first law of thermodynamics** demonstrates the relationship between internal energy, added heat, and ____________within a system.

7. **The third law of thermodynamics** states that it is impossible to create a thermodynamic process that is?

Pascal's Law
8. Pressure due to the weight of a liquid, at any level, depends on the depth of the fluid from the?

Gravity
9. Gravity is one of the four forces of nature. The strength of the _______________between two objects depends on their masses.

Static Pressure

10. Which term states that a pressure set up in a fluid acts equally in all directions and at right angles to the containing surfaces?

Answers 1. Nothing, 2. Stable, 3. An external force, 4. Force, 5. Every action, 6. Work, 7. Perfectly efficient, 8. Surface, 9. Gravitational force, 10. Pascal's law

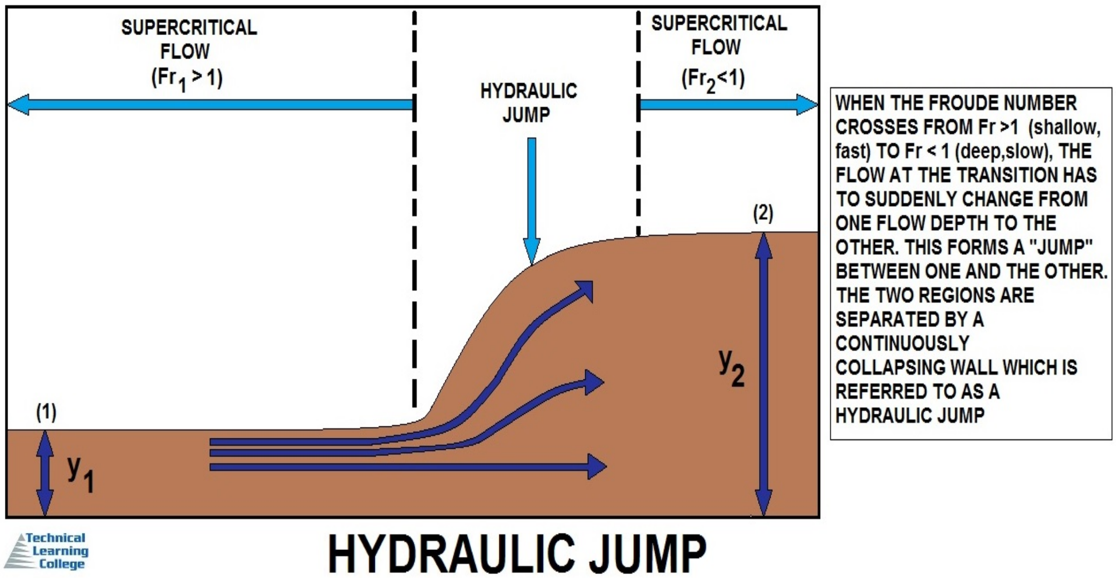
Physical Science and Laws References

Adkins, C.J. (1968). Equilibrium Thermodynamics, McGraw-Hill, London, ISBN 0-07-084057-1.
Adkins, C.J. (1968/1983). Equilibrium Thermodynamics, (first edition 1968), third edition 1983, Cambridge University Press, ISBN 0-521-25445-0, pp. 18–20.
Bailyn, M. (1994). A Survey of Thermodynamics, American Institute of Physics Press, New York, ISBN 0-88318-797-3, p. 26.
Belkin, A.; et., al. (2015). "Self-Assembled Wiggling Nano-Structures and the Principle of Maximum Entropy Production". Sci. Rep. 5. Bibcode:2015NatSR...5E8323B. doi:10.1038/srep08323.
Ben-Naim, A. (2008). A Farewell to Entropy: Statistical Thermodynamics Based on Information, World Scientific, New Jersey, ISBN 978-981-270-706-2.
Buchdahl, H.A. (1966), The Concepts of Classical Thermodynamics, Cambridge University Press, London, pp. 30, 34ff, 46f, 83.
Chris Vuille; Serway, Raymond A.; Faughn, Jerry S. (2009). College physics. Belmont, CA: Brooks/Cole, Cengage Learning. p. 355. ISBN 0-495-38693-6.
De Groot, S.R., Mazur, P. (1962). Non-equilibrium Thermodynamics, North Holland, Amsterdam.
Glansdorff, P., Prigogine, I. (1971). Thermodynamic Theory of Structure, Stability and Fluctuations, Wiley-Interscience, London, ISBN 0-471-30280-
Guggenheim (1985), p. 8.
Guggenheim, E.A. (1985). Thermodynamics. An Advanced Treatment for Chemists and Physicists, seventh edition, North Holland, Amsterdam, ISBN 0-444-86951-4.
Kittel, C. Kroemer, H. (1980). Thermal Physics, second edition, W.H. Freeman, San Francisco, ISBN 0-7167-1088-9.
Lebon, G., Jou, D., Casas-Vázquez, J. (2008). Understanding Non-equilibrium Thermodynamics. Foundations, Applications, Frontiers, Springer, Berlin, ISBN 978-3-540-74252-4.
Münster, A. (1970), Classical Thermodynamics, translated by E.S. Halberstadt, Wiley–Interscience, London, ISBN 0-471-62430-6, p. 22.
Onsager, L. (1931). "Reciprocal Relations in Irreversible Processes". Phys.Rev.37. Bibcode:1931PhRv...37..405O. doi:10.1103/PhysRev.37.405.
Pippard, A.B. (1957/1966). Elements of Classical Thermodynamics for Advanced Students of Physics, original publication 1957, 1966, Cambridge University Press, Cambridge UK, p. 10.
Serrin, J. (1978). The concepts of thermodynamics, in Contemporary Developments in Continuum Mechanics and Partial Differential Equations. Proceedings of the International Symposium on Continuum Mechanics and Partial Differential Equations, Rio de Janeiro, August 1977, edited by G.M. de La Penha, L.A.J. Medeiros, North-Holland, Amsterdam, ISBN 0-444-85166-6, pages 411-451.
Serrin, J. (1986). Chapter 1, 'An Outline of Thermodynamical Structure', pages 3-32, in New Perspectives in Thermodynamics, edited by J. Serrin, Springer, Berlin, ISBN 3-540-15931-2.
Sommerfeld, A. (1951/1955). Thermodynamics and Statistical Mechanics, vol. 5 of Lectures on Theoretical Physics, edited by F. Bopp, J. Meixner, translated by J. Kestin, Academic Press, New York, page 1.
Wilson, H.A. (1966). Thermodynamics and Statistical Mechanics, Cambridge University Press, London UK, pp. 4, 8, 68, 86, 97, 311.
Ziegler, H. (1983). An Introduction to Thermomechanics. North Holland, Amsterdam.

Section 2- Fluid Mechanics and Hydraulic Principles

Section Focus: You will learn the basics of fluid mechanics and hydraulic principles. At the end of this section, you the student will be able to describe primary water mechanics and hydraulic principles. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: In order to design flow rates, pumping system, calculate pump flows, we need to master this area of engineering.



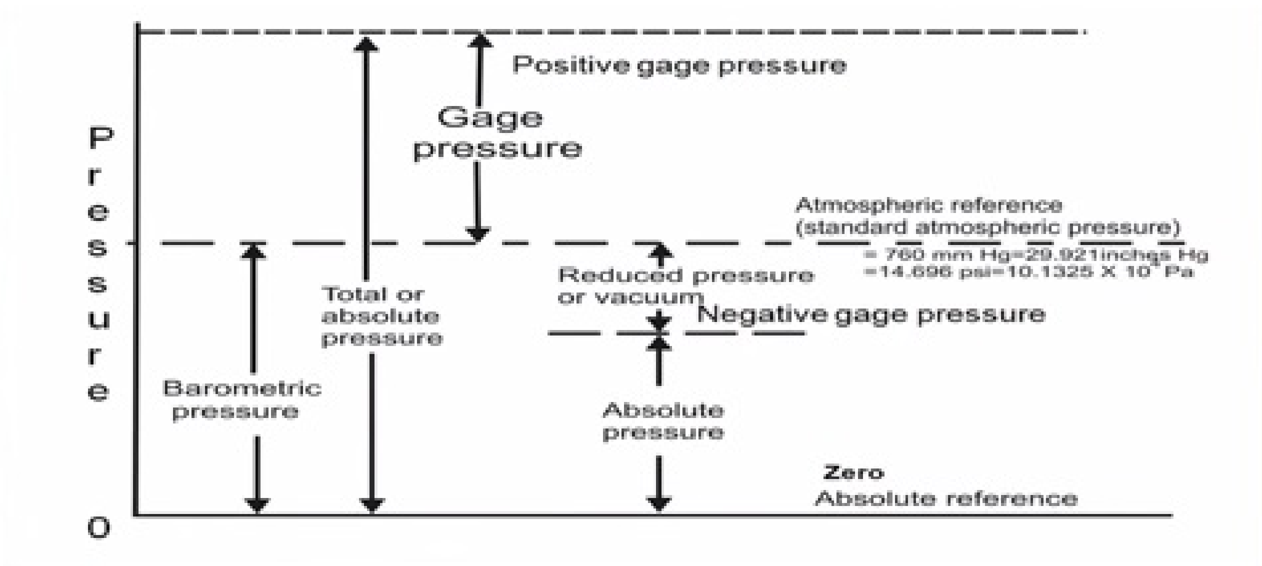
A hydraulic jump is a phenomenon in the science of hydraulics which is frequently observed in open channel flow such as rivers and spillways. When liquid at high velocity discharges into a zone of lower velocity, a rather abrupt rise occurs in the liquid surface. Hydraulic jump is the jump or standing wave formed when the depth of flow of water changes from supercritical to subcritical state.

Applicable Equations
Froude Number: $Fr = V/\sqrt{(gL)}$
Where: Fr = Froude number V = Velocity g = gravity L = depth of flow

Critical Flow Depth: $yc = (y_1/2)(\sqrt{(1+8Fr_1^2)}-1)$
Where: yc = critical flow depth y_1 = upstream measured depth Fr = Froude number

Upstream Energy Level: $E_1 = y_1 + (V_1^2/2g)$
Where: E_1 = upstream energy level V_1 = Velocity upstream y_1 = upstream measured depth g = gravity

Head Loss: $hL = (y_2-y_1)^8/(4y_1y_2)$
Where: hL = head loss in the hydraulic jump y_1 = upstream measured depth y_2 = downstream measured depth



UNIT	ABBREVIATION	EQUIVALENT NUMBER OF PASCALS
ATMOSPHERE	atm	1 atm = 101,325 Pa
BAR	bar	1 bar = 100,025 Pa
MILLIMETER OF MERCURY	mmHg	1 mmHg = 133.322 Pa
INCHES OF MERCURY	inHg	1 inHg = 3386 Pa
PASCAL	Pa	1
KILOPASCAL	kPa	1 kPa = 1000 Pa
POUNDS PER SQUARE INCH	psi	1 psi = 6,893 Pa
TORR	torr	1 torr = 133.322 Pa

DIFFERENT UNITS OF PRESSURE

Fluid Mechanics and Hydraulic Principles Key Terms

Fluid Dynamics
In physics, fluid dynamics is a sub-discipline of fluid mechanics that deals with fluid flow—the natural science of fluids (liquids and gases) in motion. It has several sub-disciplines itself, including aerodynamics (the study of air and other gases in motion) and hydrodynamics (the study of liquids in motion).

Head
The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid.

Head, Friction
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.

Head, Static
The height of a column or body of fluid above a given point.

Hydraulics
Engineering science pertaining to liquid pressure and flow.

Hydrokinetics
Engineering science pertaining to the energy of liquid flow and pressure.

Pascal's Law
A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

Pressure
The application of continuous force by one body upon another that it is touching; compression. Force per unit area, usually expressed in pounds per square inch (Pascal or bar).

Pressure, Absolute
The pressure above zero absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury. (mmHg).

Pressure, Atmospheric
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.)

Pressure, Gauge
Pressure differential above or below ambient atmospheric pressure.

Pressure, Static
The pressure in a fluid at rest.

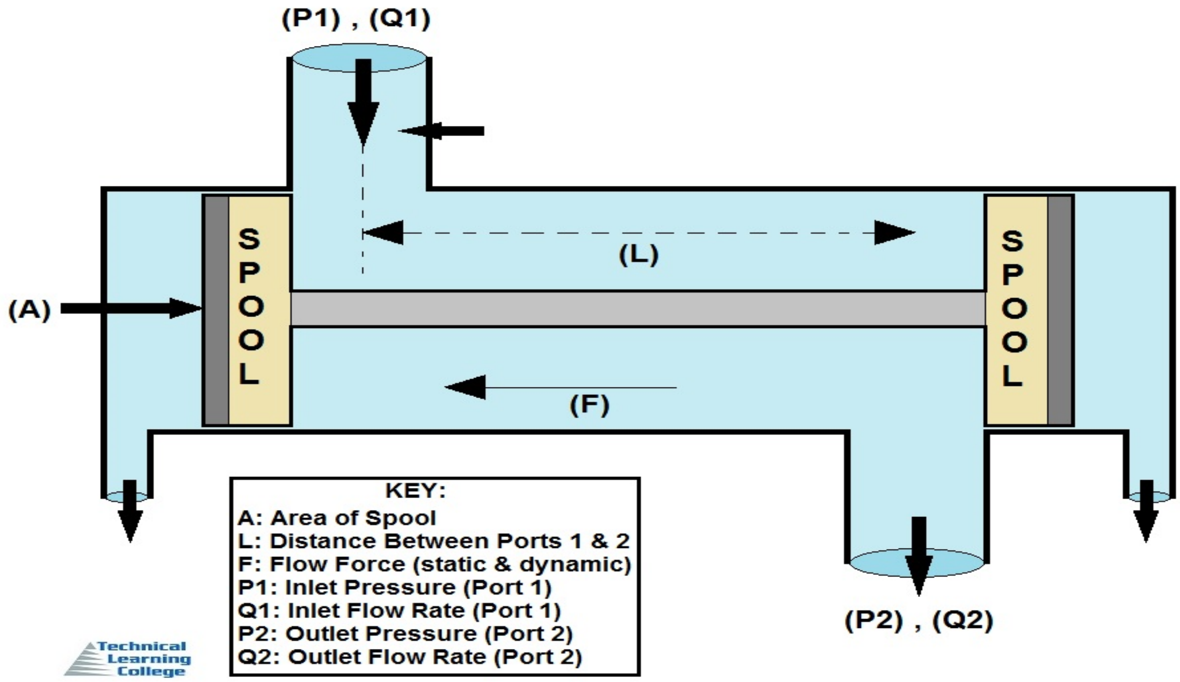
Fluid Fiction

We need to think about complicated piping arrangements and the fiction loses that are created that restrict water flows.

The concepts of fluid friction vary depending on whether the motion is taking place in a liquid or gas. One item that both media share is that the resistance to motion contributes to an object reaching its terminal velocity. This occurs when the resistance from a gas or fluid is equal to the weight of the object, and it remains constant until another force is introduced.

For motion in a liquid, viscous resistance caused by a drag force is proportional to the velocity of the object at slow speeds. This drag force is based on the object's geometry and the viscosity of the liquid, which can vary between fluids.

For motion through air, friction at slow speeds is proportional to the velocity. At higher speeds, the drag force depends on the cross-sectional area of an object, the object's density and the drag coefficient. This drag force has a negative value, as the resistance is always opposite the direction of velocity.



BASIC HYDRAULIC PRINCIPAL

Hydraulic Systems - Closed or Open Systems

A closed loop system is one where the inlet of the pump is supplied by the oil leaving outlet of the actuator (usually a motor) the pump is driving, hence the closed loop.

An open loop system is one where the outlet of the actuator will return to the tank via a directional valve, with the pump inlet drawing fluid from the same common tank.

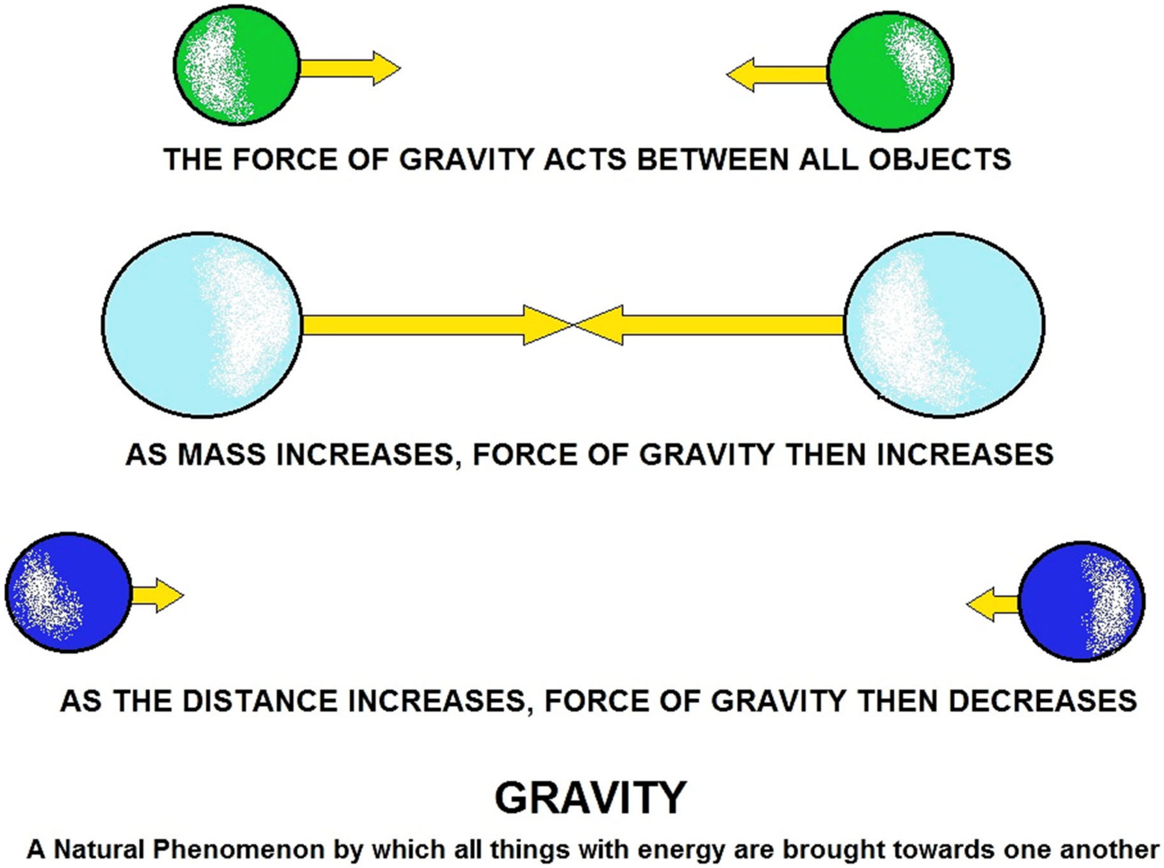
The open loop system relatively speaking has no pressurized connection between actuator outlet and pump inlet and is the most common type used in industrial hydraulics as it can perform multiple tasks and therefore multiple sequences.

The closed loop with its pressurized connection is most commonly found hydro-static transmissions in mobile applications.

Fluid Mechanics Review

Fluid mechanics provides the theoretical foundation for hydraulics, which focuses on the applied engineering using the properties of fluids. In its fluid power applications, hydraulics is used for the generation, control, and transmission of power by the use of pressurized liquids.

Hydraulic topics range through some parts of science and most of engineering modules, and cover concepts such as pipe flow, dam design, fluidics and fluid control circuitry. The principles of hydraulics are in use naturally in the human body within the vascular system and erectile tissue. Free surface hydraulics is the branch of hydraulics dealing with free surface flow, such as occurring in rivers, canals, lakes, estuaries and seas. Its sub-field open-channel flow studies the flow in open channels.



Specific Gravity Introduction

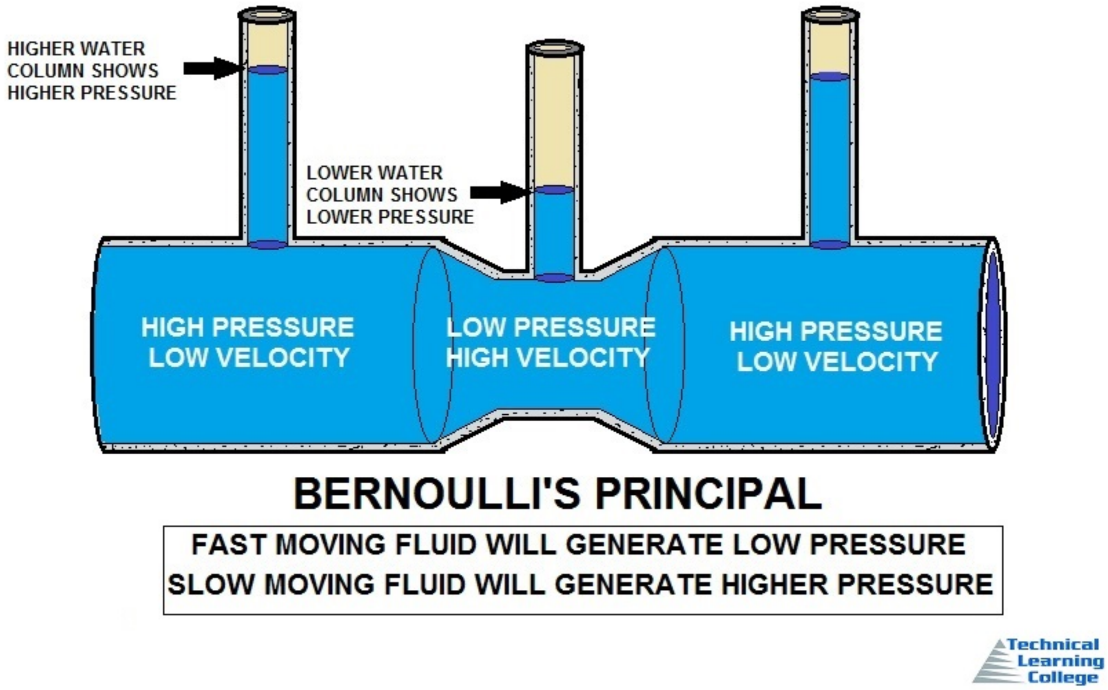
When you put something in water, gravity can pull the object down through the water only if an equal volume of water is allowed to go up against the force of gravity; this is called displacement. In effect, gravity has to choose which it will pull down, the water or the immersed object. What we call buoyancy is, in effect, forcing gravity to make this choice.

Faced with this choice, gravity will act more strongly on whichever has more mass (thus, more weight) per given volume. So if the thing you immerse is denser than water it will sink, but its apparent weight is reduced by the volume of water that gets displaced upward. If instead the water is denser, the immersed object will float up to the point where the displaced volume of water matches the whole object's mass. Then the net weight is zero

Specific gravity is the ratio of the density of a substance to the density of a reference substance; equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume. *Apparent* specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance.

The reference substance for liquids is nearly always water at its densest (at 4 °C or 39.2 °F); for gases it is air at room temperature (20 °C or 68 °F). Nonetheless, the temperature and pressure must be specified for both the sample and the reference. Pressure is nearly always 1 atm (101.325 kPa).

Fluid Mechanics and Hydraulic Principles- Introduction



Hydraulics

The Engineering science pertaining to liquid pressure and flow.

Hydraulics is a branch of engineering concerned mainly with moving liquids. This term is applied commonly to the study of the mechanical properties of water, other liquids, and even gases when the effects of compressibility are small. Hydraulics can be separated into two areas, hydrostatics and hydrokinetics.

The word *hydraulics* is based on the Greek word for water, and originally covered the study of the physical behavior of water at rest and in motion. Use has broadened its meaning to include the behavior of all liquids, although it is primarily concerned with the motion of liquids.

Hydraulics includes the method in which liquids act in tanks and pipes, deals with their properties, and explores ways to take advantage of these properties.

Hydrostatics is the study of liquids at rest, involves problems of buoyancy and flotation, pressure on dams and submerged devices, and hydraulic presses. The relative incompressibility of liquids is one of hydrostatics' basic principles.

Hydrodynamics is the study of liquids in motion, is concerned with such matters as friction and turbulence generated by flowing liquids inside pipes, the flow of water over weirs and through nozzles, and the use of hydraulic pressure in machinery.

Hydrostatics

Hydrostatics is the study about the pressures exerted by a fluid at rest. Any fluid is meant, not just water. Research and careful study on water yields many useful results of its own, thus, such as forces on dams, buoyancy and hydraulic actuation, and is well worth studying for such practical reasons.

Hydrostatics is a superb example of deductive mathematical physics, one that can be understood easily and completely from a very few fundamentals, and in which the predictions agree closely with experiment.

There are few better illustrations of the use of the integral calculus, as well as the principles of ordinary statics, available to the student.

A great deal can be done with only elementary mathematics. Properly adapted and converted, the material can be used from the earliest introduction of school science, giving an excellent example of a quantitative science with many possibilities for hands-on experiences. The definition of a fluid deserves careful thought.

Generally, time is not a factor in hydrostatics, it enters in the approach to hydrostatic equilibrium. It is usually stated that a fluid is a substance that cannot resist a shearing stress, so that pressures are normal to confining surfaces.

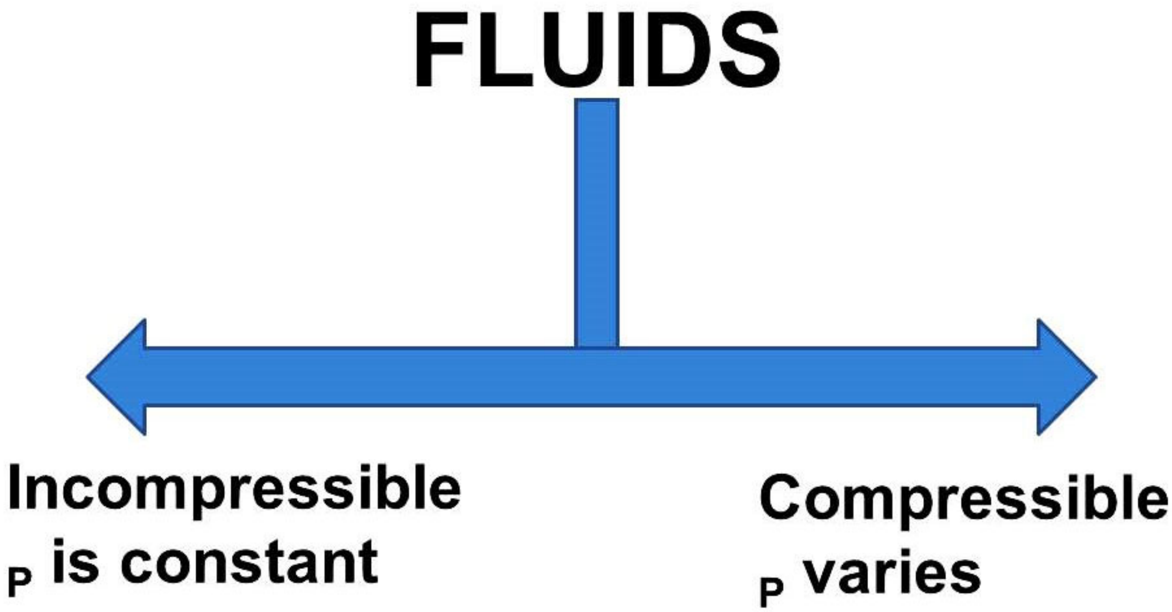
The study of geology has now shown us that there are substances which can resist shearing forces over short time intervals, and appear to be typical solids, but which flow like liquids over long time intervals. Such materials include wax and pitch, ice, and even rock.

A ball of pitch, which can be shattered by a hammer, will spread out and flow in months. Ice, a typical solid, will flow in a period of years, as shown in glaciers, and rock will flow over hundreds of years, as in convection in the mantle of the earth.

Shear earthquake waves, with periods of seconds, propagate deep in the earth, though the rock there can flow like a liquid when considered over centuries. The rate of shearing may not be strictly proportional to the stress, but exists even with low stress.

Viscosity may be the physical property that varies over the largest numerical range, competing with electrical resistivity. There are several familiar topics in hydrostatics which often appears in expositions of introductory science, and which are also of historical interest and can enliven their presentation.

Fluid Mechanics-Introduction



What is Fluid Mechanics?

Fluid mechanics is a science concerned with the response of fluids to forces exerted upon them. It is a branch of classical physics with applications of great importance in hydraulic and aeronautical engineering, chemical engineering, meteorology, and zoology.

Fluid mechanics research and history goes back at least to the days of ancient Greece, when Archimedes investigated fluid statics and buoyancy and formulated his famous law known now as the Archimedes' principle, which was published in his work On Floating Bodies – generally considered to be the first major work on fluid mechanics. Rapid advancement in fluid mechanics began with Leonardo da Vinci (observations and experiments), Evangelista Torricelli (invented the barometer), Isaac Newton (investigated viscosity) and Blaise Pascal (researched hydrostatics, formulated Pascal's law), and was continued by Daniel Bernoulli with the introduction of mathematical fluid dynamics in Hydrodynamica (1739).

Inviscid flow was further analyzed by various mathematicians (Leonhard Euler, Jean le Rond d'Alembert, Joseph Louis Lagrange, Pierre-Simon Laplace, Siméon Denis Poisson) and viscous flow was explored by a multitude of engineers including Jean Léonard Marie Poiseuille and Gotthilf Hagen.

Further mathematical justification was provided by Claude-Louis Navier and George Gabriel Stokes in the Navier–Stokes equations, and boundary layers were investigated (Ludwig Prandtl, Theodore von Kármán), while various scientists such as Osborne Reynolds, Andrey Kolmogorov, and Geoffrey Ingram Taylor advanced the understanding of fluid viscosity and turbulence. We will examine these scientists and their laws/theories/concepts in detail.

Archimedes
Archimedes instituted the study of hydrostatics in about 250 B.C. when, according to legend, he leapt out of his bath and ran naked through the streets of Syracuse crying “Eureka!”; it has undergone rather little development since.

The foundations of hydrodynamics, on the other hand, were not laid until the 18th century when mathematicians such as Leonhard Euler and Daniel Bernoulli began to explore the consequences, for a virtually continuous medium like water, of the dynamic principles that Newton had enunciated for systems composed of discrete particles. Their work was continued in the 19th century by several mathematicians and physicists of the first rank, notably G.G. Stokes and William Thomson.

By the end of the century, explanations had been found for a host of intriguing phenomena having to do with the flow of water through tubes and orifices, the waves that ships moving through water leave behind them, raindrops on windowpanes, and the like. There was still no proper understanding, thus, of problems as fundamental as that of water flowing past a fixed obstacle and exerting a drag force upon it; the theory of potential flow, which worked so well in other contexts, yielded results that at relatively high flow rates were grossly at variance with experiment.

Ludwig Prandtl
This problem was not properly comprehended until 1904, when the German physicist Ludwig Prandtl introduced the concept of the boundary layer. Prandtl’s career continued into the period in which the first manned aircraft were developed. Since that time, the flow of air has been of as much interest to physicists and engineers as the flow of water, and hydrodynamics has, as an after-affect , become fluid dynamics. The term fluid mechanics, as used here, embraces both fluid dynamics and the subject still generally referred to as hydrostatics.

Geoffrey Taylor
One other representative of the 20th century who deserves reference here besides Prandtl is Geoffrey Taylor of England. Taylor remained a classical physicist while most of his contemporaries were turning their attention to the problems of atomic structure and quantum mechanics, and he made several unexpected and important discoveries in the field of fluid mechanics.

The value of fluid mechanics is due in large part to a term in the basic equation of the motion of fluids which is nonlinear—*i.e.,* one that involves the fluid velocity twice over. It is characteristic of systems described by nonlinear equations that under certain conditions they become unstable and begin behaving in ways that seem at first sight to be totally chaotic. In the case of fluids, chaotic behavior is very common and is called turbulence.

Mathematicians have now begun to recognize patterns in chaos that can be analyzed fruitfully, and this development suggests that fluid mechanics will remain a field of active research well into the 21st century.

Fluid mechanics is a subject with almost endless results, and the account that follows is necessarily incomplete. Some knowledge of the basic properties of fluids will be needed; a survey of the most relevant properties will be given in the next section.

Properties of Fluids

Fluids are not strictly continuous media in the way that all the successors of Euler and Bernoulli have assumed, for fluids are composed of discrete molecules. The molecules, though, are so small and, except in gases at very low pressures, the number of molecules per milliliter is so enormous that they need not be viewed as individual entities.

There are a few liquids, known as liquid crystals, in which the molecules are packed together in such a way as to make the properties of the medium locally anisotropic, but the vast majority of fluids -including air and water- are isotropic.

In fluid mechanics, the state of an isotropic fluid may be completely described by defining its mean mass per unit volume, or density (ρ), its temperature (T), and its velocity (v) at every point in space, and just what the connection is between these macroscopic properties and the positions and velocities of individual molecules is of no direct relevance.

Isotropic Fluid or Newtonian Fluid
If the fluid is also isotropic (that is, its mechanical properties are the same along any direction), the viscosity tensor reduces to two real coefficients, describing the fluid's resistance to continuous shear deformation and continuous compression or expansion, respectively.

Fluid Statics
Fluid statics or hydrostatics is the branch of fluid mechanics that studies fluids at rest. It embraces the study of the conditions under which fluids are at rest in stable equilibrium; and is contrasted with fluid dynamics, the study of fluids in motion.

Hydrostatics offers physical explanations for many wonders of everyday life, such as why atmospheric pressure changes with altitude, why wood and oil float on water, and why the surface of water is always flat and horizontal whatever the shape of its container.

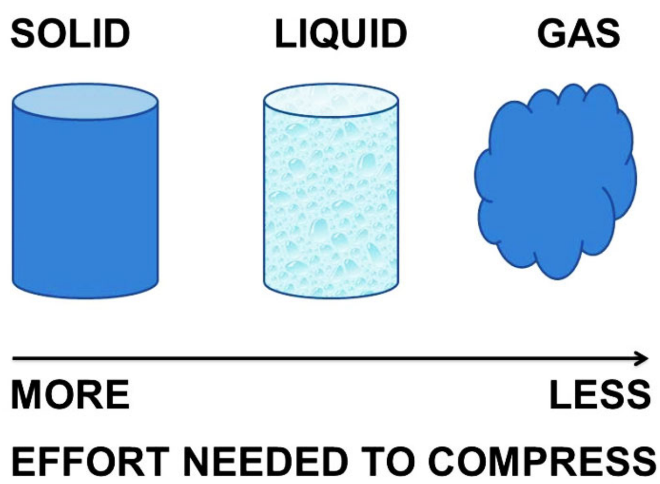
Hydrostatics is fundamental to hydraulics, the engineering of equipment for storing, transporting and using fluids. It is also relevant to some aspect of geophysics and astrophysics (i.e., in understanding plate tectonics and anomalies in the Earth's gravitational field), to meteorology, to medicine (with the context of blood pressure), and many other fields.

Fluid Dynamics
Fluid dynamics is a sub-discipline of fluid mechanics that deals with fluid flow—the science of liquids and gases in motion. Fluid dynamics offers a systematic structure—which underlies these practical disciplines—that embraces empirical and semi-empirical laws derived from flow measurement and used to solve practical problems.

The solution to a fluid dynamics problem typically involves calculating various properties of the fluid, such as velocity, pressure, density, and temperature, as functions of space and time.

It has several sub-disciplines itself, including aerodynamics (the study of air and other gases in motion) and hydrodynamics (the study of liquids in motion).

Fluid dynamics has a wide range of applications, including calculating forces and moments on aircraft, determining the mass flow rate of petroleum through pipelines, predicting evolving weather patterns, even understanding nebulae in interstellar space and modeling explosions.



Gases and Liquids

A word is needed about the difference between gases and liquids, though the difference is easier to perceive than to describe.

In gases, the molecules are sufficiently far apart to move almost independently of one another, and gases tend to expand to fill any volume available to them.

In liquids, the molecules are more or less in contact, and the short-range attractive forces between them make them cohere; the molecules are moving too fast to settle down into the ordered arrays that are characteristic of solids, but not so fast that they can fly apart.

Thus, samples of liquid can exist as drops or as jets with free surfaces, or they can sit in beakers constrained only by gravity, in a way that samples of gas cannot.

Such samples may evaporate in time, as molecules one by one pick up enough speed to escape across the free surface and are not replaced. The lifetime of liquid drops and jets, yet, is normally long enough for evaporation to be ignored.

Properties of Fluids Key Terms

The term fluid includes both liquid and gases. The main difference between a liquid and a gas is that the volume of a liquid remains definite because it takes the shape of the surface on or in which it comes into contact, whereas a gas occupies the complete space available in the container in which it is kept. In hydraulics in civil engineering, the fluid for consideration is liquid, so, we will examine some terms and properties of the liquids

1. DENSITY OR MASS DENSITY

Density or mass density of a fluid is defined as the ratio of the mass of a fluid to its volume.
Thus mass per unit volume of a fluid is called density.

It is denoted by the symbol ρ (rho). The unit of mass density in SI unit is kg per cubic meter. The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.

$$\rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}$$

The value of density of water is 1gm per cubic centimeter or 1000 kg per cubic meter.

2. SPECIFIC WEIGHT AND WEIGHT DENSITY

Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume. Thus weight per unit volume of a fluid is called weight density and it is denoted by the symbol

w .

$$w = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{(\text{Mass of fluid}) \times \text{Acceleration due to gravity}}{\text{Volume of fluid}}$$

$$= \frac{\text{Mass of fluid} \times g}{\text{Volume of fluid}} = \rho \times g$$

$$=> w = \rho g$$

The value of specific weight of specific density (w) of water is $9.81 \times 1000 \text{ Newton/m}^3$

3. SPECIFIC VOLUME

Specific volume of a fluid is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid.

Specific volume = $$\frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\frac{\text{Mass of fluid}}{\text{Volume of fluid}}} = \frac{1}{\rho}$$

Thus, specific volume is the reciprocal of mass density. It is expressed as m^3/kg. It is commonly applied to gases.

4. SPECIFIC GRAVITY

Specific gravity is defined as the ratio of the weight density (or density) of a fluid to the weight density (or density) of a standard fluid. For liquids, the standard fluid is taken as water and for gases, the standard fluid is taken as air.

Specific gravity is also called relative density. It is a dimensionless quantity and is denoted by the symbol S.

$$S \text{ (for liquids)} = \frac{\text{Weight density of liquid}}{\text{Weight density of water}}$$

$$S \text{ (for gases)} = \frac{\text{Weight density of gas}}{\text{Weight density of air}}$$

Thus, weight density of a liquid = S x weight density of water = S x $9.81 \times 1000 \text{ Newton/m}^3$

The density of liquid = S x Density of water = S x 1000 kg/m^3.

If the specific gravity of a fluid is known, then the density of the liquid will be equal to specific gravity of fluid multiplied by the density of water. For example, the specific gravity of mercury is 13.6. Hence density of mercury = 13.6 x 1000 kg/m^3.

5. VISCOSITY OF LIQUID:

Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of fluid. When two layers of a fluid, a distance apart move over one other at different velocities, the viscosity together with relative velocity causes a shear stress acting between the fluid layers.

The top layer causes a shear stress on the adjacent layer while the lower layer causes a shear stress on the top layer. This shear stress is proportional to the rate of change of velocity. It is denoted by the symbol τ.

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

Where μ (mu) is the constant of proportionality and is known as the coefficient of dynamic viscosity or only viscosity, $\frac{du}{dy}$ represents the rate of shear strain or rate of shear deformation or velocity gradient.

$$=> \mu = \frac{\tau}{\frac{du}{dy}}$$

The viscosity is also defined as the shear stress required to produce unit rate of shear strain.

Units of Viscosity

In MKS system, unit of viscosity = $\frac{kgf \cdot cm}{m^2}$

CGS unit of viscosity (also called Poise) = $\frac{dyne \cdot \sec}{cm^2}$

SI unit of viscosity = Ns/m^2 =Pa-s

Unit Conversion
Conversion between MKS and CGS system

$$\frac{1\ \text{kgf-sec}}{m^2} = \frac{9.81\text{N-sec}}{m^2}$$

$$dyne = gm \times \frac{cm}{\sec^2}$$

1 N = 1000 x 100 dyne

$$\frac{1\ \text{kgf-sec}}{m^2} = \frac{9.81\text{N-sec}}{m^2} = 98.1\,poise$$

$$1\,poise = \frac{1}{10}\frac{Ns}{m^2}$$

$$1\ \text{centipoise} = \frac{1}{100}\,poise$$

KINEMATIC VISCOSITY
It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by the Greek symbol (υ) called nu. Thus,

$$\upsilon = \frac{\text{Viscosity}}{\text{Density}} = \frac{\mu}{\rho}$$

In MKS and SI, the unit of kinematic viscosity is $\text{m}^2/\sec$ while in CGS units, it is written as cm^2/s. In CGS system, kinematic viscosity is also known as stoke.

One stoke =1 cm^2/s

Newton's Law of Viscosity:
It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of change of shear strain. The constant of proportionality is called the co-efficient of viscosity.

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

Fluids which obey the above relation are known as Newtonian fluids and the fluids which do not obey the above relation are called Non-Newtonian fluids.

Variation of Viscosity with temperature:
The viscosity of liquids decreases with the increase in temperature, while the viscosity of gases increases with the increase in temperature.

(i) For liquids:

$$\mu = \mu_0 \left(\frac{1}{1 + \alpha t + \beta t^2} \right)$$

Where, μ = viscosity of liquid at $t^\circ C$ in poise

μ_0 = viscosity of liquid at $0^\circ C$ in poise

α, β are constants for the liquid.

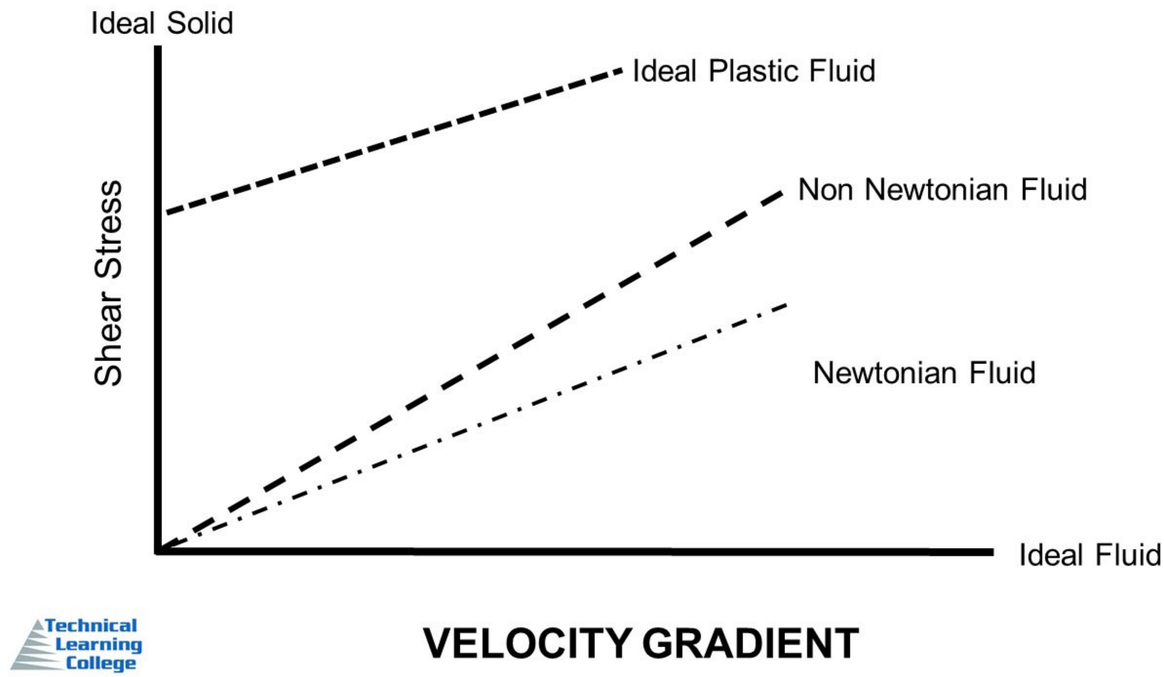
For water, $\mu_0 = 1.79 \times 10^{-3}$ poise, $\alpha = 0.03368$ and $\beta = 0.000221$

(ii) For Gases

$$\mu = \mu_0 + \alpha t - \beta t^2$$

For air, $\mu_0 = 000017$, $\alpha = 0.000000056$ and $\beta = 0.1189 \times 10^{-9}$

TYPES OF FLUIDS BASED ON VISCOSITY
The fluids may be classified into following five types:
1. Ideal fluid
2. Real fluid
3. Newtonian fluid
4. Non-Newtonian fluid
5. Ideal plastic fluid



Type of Fluids

1. Ideal Fluid
A fluid which is incompressible and is having no viscosity, is known as ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids which exists have some viscosity.

2. Real Fluids
A fluid which possesses viscosity is known as real fluid. All the fluids in actual practice are real fluids.

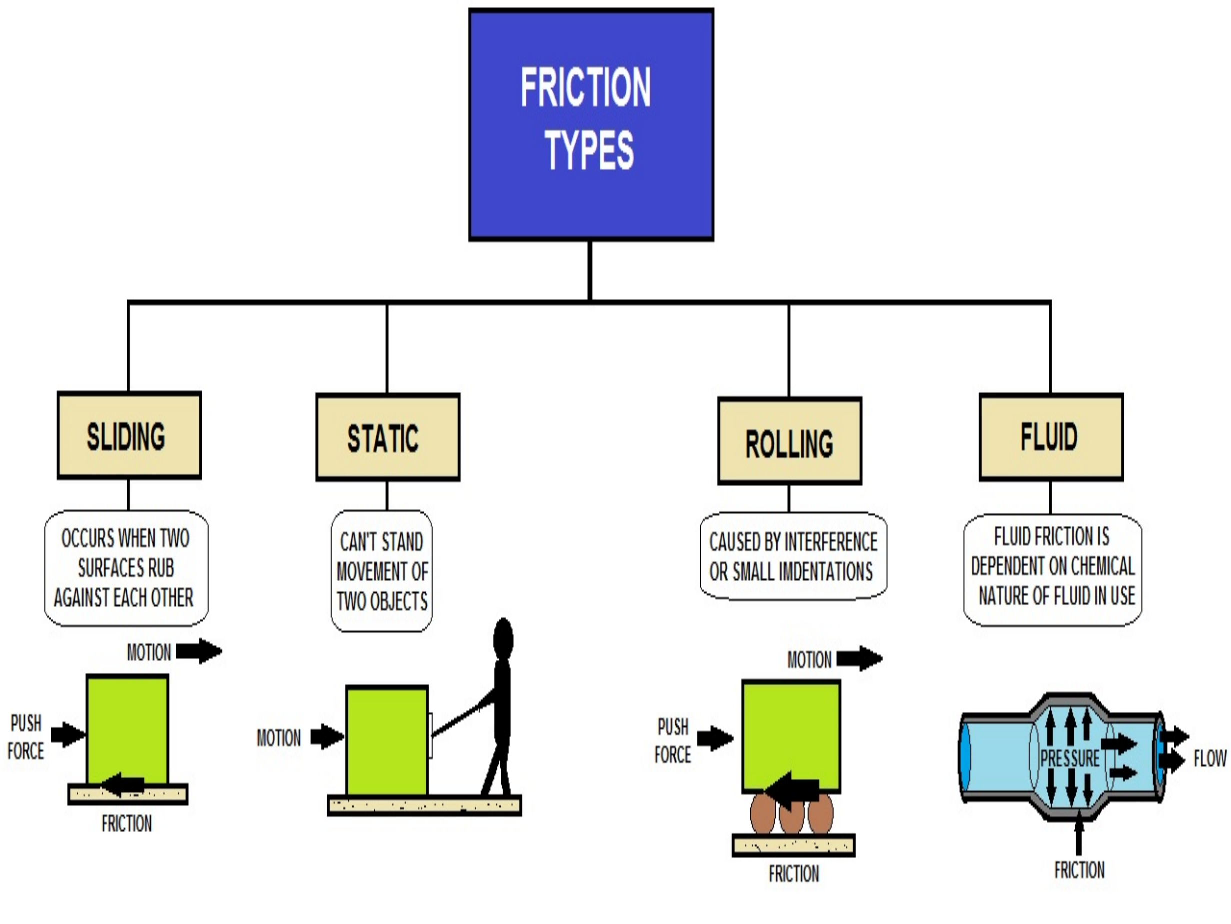
3. Newtonian Fluids
A real fluid in which the shear stress is directly proportional to rate of shear strain (or velocity gradient).

4. Non-Newtonian Fluid
A real fluid in which the shear stress is not proportional to the rate of shear strain.

5. Ideal Plastic Fluid
A fluid in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain (or velocity gradient).

UNITS OF PRESSURE

	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Standard atmosphere (atm)	Torr (Torr)	Pounds per square inch (lbf/in^2)
1 Pa	≡ 1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	0.000 145 037 737 730
1 bar	10^5	≡ 100 kPa ≡ 10^6 dyn/cm^2	1.0197	0.986 92	750.06	14.503 773 773 022
1 at	98 066.5	0.980 665	≡ 1 kgf/cm^2	0.967 841 105 354 1	735.559 240 1	14.223 343 307 120 3
1 atm	101 325	1.013 25	1.0332	1	760	14.695 948 775 514 2
1 Torr	133.322 368 421	0.001 333 224	0.001 359 51	$\frac{1}{760}$ ≈ 0.001 315 789	1 Torr ≈ 1 mmHg	0.019 336 775
1 lbf/in^2	6894.757 293 168	0.068 947 573	0.070 306 958	0.068 045 964	51.714 932 572	≡ 1 lbf/in^2



FRICTION TYPE EXAMPLES

Stresses and Pressure

There are two sorts of stress that may exist in any solid or fluid medium, and the difference between them may be demonstrated by holding a brick held between two hands. If the holder moves his hands toward each other, he exerts pressure on the brick; if he moves one hand toward his body and the other away from it, then he exerts what is called a shear stress.

A solid substance such as a brick can withstand stresses of both types, but fluids, by definition, yield to shear stresses no matter how small these stresses may be. They do so at a rate determined by the fluid's viscosity.

This property, about which more will be said later, is a measure of the friction that arises when adjacent layers of fluid slip over one another. It follows that the shear stresses are everywhere zero in a fluid at rest and in equilibrium, and from this it follows that the pressure (that is, force per unit area) acting perpendicular to all planes in the fluid is the same irrespective of their orientation (Pascal's law).

For an isotropic fluid in equilibrium there is only one value of the local pressure (*p*) consistent with the stated values for ρ and *T*. These three quantities are linked together by what is called the equation of state for the fluid.

For gases at low pressures the equation of state is simple and well known. It is

$$p = \left(\frac{RT}{M}\right)\rho \qquad (118)$$

where *R* is the universal gas constant (8.3 joules per degree Celsius per mole) and *M* is the molar mass, or an average molar mass if the gas is a mixture; for air, the appropriate average is about 29×10^{-3} kilogram per mole.

For other fluids, knowledge of the equation of state is often incomplete. Except under very extreme conditions, however, all one needs to know is how the density changes when the pressure is changed by a small amount, and this is described by the compressibility of the fluid—either the isothermal compressibility, β_T, or the adiabatic compressibility, β_S, according to circumstance. When an element of fluid is compressed, the work done on it tends to heat it up.
If the heat has time to dissipate away to the surroundings and the temperature of the fluid remains essentially unchanged throughout, then β_T is the relevant quantity.

If virtually none of the heat escapes, as is more commonly the case in flow problems because the thermal conductivity of most fluids is poor, then the flow is said to be adiabatic, and β_S is needed instead.

(The *S* refers to entropy, which remains constant in an adiabatic process provided that it takes place slowly enough to be treated as "reversible" in the thermodynamic sense.)

For gases that obey equation (118), it is evident that *p* and ρ are proportional to one another in an isothermal process, and

$$\beta_T = \rho^{-1} \left(\frac{\partial \rho}{\partial P}\right)_T = p^{-1} \quad (119)$$

Reversible Adiabatic Processes

In reversible adiabatic processes for such gases, however, the temperature rises on compression at a rate such that

$$T \propto p^{(y-1)}, \ \mathrm{p} \propto p^{y} \quad (120)$$

and

$$\beta_S = \rho^{-1} \left(\frac{\partial \rho}{\partial P}\right)_S = (yp)^{-1} = \frac{\beta T}{\gamma} \quad (121)$$

where γ is about 1.4 for air and takes similar values for other common gases. For liquids the ratio between the isothermal and adiabatic compressibilities is much closer to unity. For liquids, however, both compressibilities are normally much less than p^{-1}, and the simplifying assumption that they are zero is often justified.

The factor γ is not only the ratio between two compressibilities; it is also the ratio between two principal specific heats.

The molar specific heat is the amount of heat required to raise the temperature of one mole through one degree. This is greater if the substance is allowed to expand as it is heated, and therefore to do work, than if its volume is fixed.

The principal molar specific heats, C_P and C_V, refer to heating at constant pressure and constant volume, respectively, and

$$\gamma = \left(\frac{Cp}{C_V}\right) \quad (122)$$

For air, C_P is about 3.5 *R*.

Solids

Solids can be stretched without breaking, and liquids, though not gases, can withstand stretching, too. Therefore, if the pressure is steadily reduced in a specimen of very pure water, bubbles will ultimately appear, but they may not do so until the pressure is negative and well below -10^7 newton per square meter; this is 100 times greater in magnitude than the (positive) pressure exerted by the Earth's atmosphere.

Water owes its high ideal strength to the fact that rupture involves breaking links of attraction between molecules on either side of the plane on which rupture occurs; work must be done to break these links.

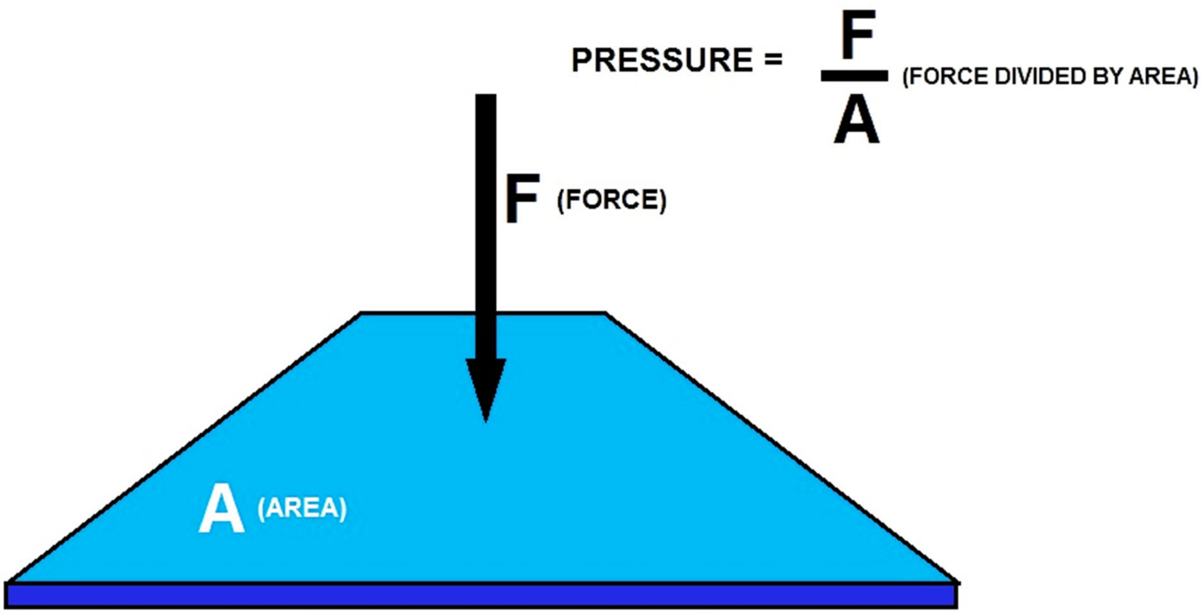
Yet, its strength is drastically reduced by anything that provides a nucleus at which the process known as cavitation (formation of vapor- or gas-filled cavities) can begin, and a liquid containing suspended dust particles or dissolved gases is liable to cavitate quite easily.

Surface Tension

Work also must be done if a free liquid drop of spherical shape is to be drawn out into a long thin cylinder or deformed in any other way that increases its surface area. Here again work is needed to break intermolecular links.

The surface of a liquid behaves as if it were an elastic membrane under tension, except that the tension exerted by an elastic membrane increases when the membrane is stretched in a way that the tension exerted by a liquid surface does not.

Surface tension is what causes liquids to rise up capillary tubes, what supports hanging liquid drops, what limits the formation of ripples on the surface of liquids, and so on.

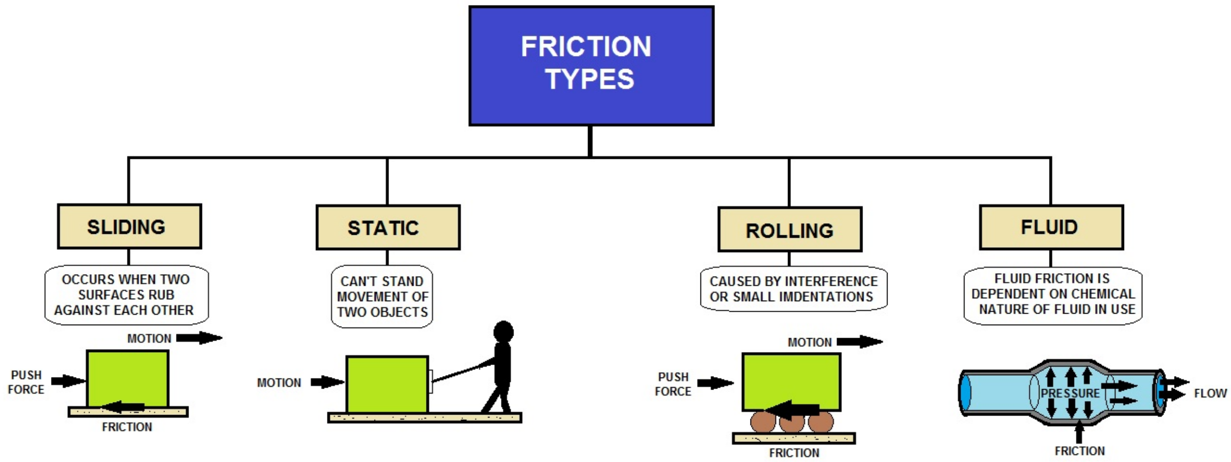


WHAT IS PRESSURE?

PRESSURE IS THE AMOUNT OF FORCE ACTING ON A SPECIFIC AREA AND IS EQUAL TO THE FORCE DIVIDED BY THE AREA

Technical Learning College

Friction Sub-Section



FRICTION TYPE EXAMPLES

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.

There are several classes or types of friction:

- Dry friction is a force that opposes the relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into static friction ("stiction") between non-moving surfaces, and kinetic friction between moving surfaces. With the exception of atomic or molecular friction, dry friction generally arises from the interaction of surface features, known as asperities.
- Fluid friction explains the friction between layers of a viscous fluid that are moving relative to each other.
- Lubricated friction is a case of fluid friction where a lubricant fluid separates two solid surfaces.
- Skin friction is a component of drag, the force resisting the motion of a fluid across the surface of a body.
- Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation.

Kinetic Energy

When surfaces in contact move relative to each other, the friction between the two surfaces converts kinetic energy into thermal energy -that is, it converts work to heat. This property can have dramatic consequences, as illustrated by the use of friction created by rubbing pieces of wood together to start a fire.

Kinetic energy is converted to thermal energy whenever motion with friction occurs, for example when a viscous fluid is stirred. Another important consequence of many types of friction can be wear, which may lead to performance degradation or damage to components. Friction is a component of the science of tribology.

Friction is desirable and important in supplying traction to facilitate motion on land. Most land vehicles rely on friction for acceleration, deceleration and changing direction. Sudden reductions in traction can cause loss of control and accidents. Friction is not itself a fundamental force.

Dry friction arises from a combination of inter-surface adhesion, surface roughness, surface deformation, and surface contamination. The complexity of these interactions makes the calculation of friction from first principles impractical and necessitates the use of empirical methods for analysis and the development of theory. Friction is a non-conservative force - work done against friction is path dependent. In the presence of friction, some energy is always lost in the form of heat. Thus mechanical energy is not conserved.

What is Tribology?
Tribology is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear. Tribology is a branch of mechanical engineering and materials science.

Fluid Friction (Drag)
Fluid friction is observed in the flow of liquids and gases. Fluid friction causes are similar to those responsible for friction between solid surfaces, for it also depends on the chemical nature of the fluid and the nature of the surface over which the fluid is flowing. The tendency of the liquid to resist flow, one example, is its degree of viscosity, is another important factor.

Fluid friction is affected by increased velocities, and the modern streamline design of airplanes and automobiles is the result of engineers' efforts to minimize fluid friction while retaining speed and protecting structure.

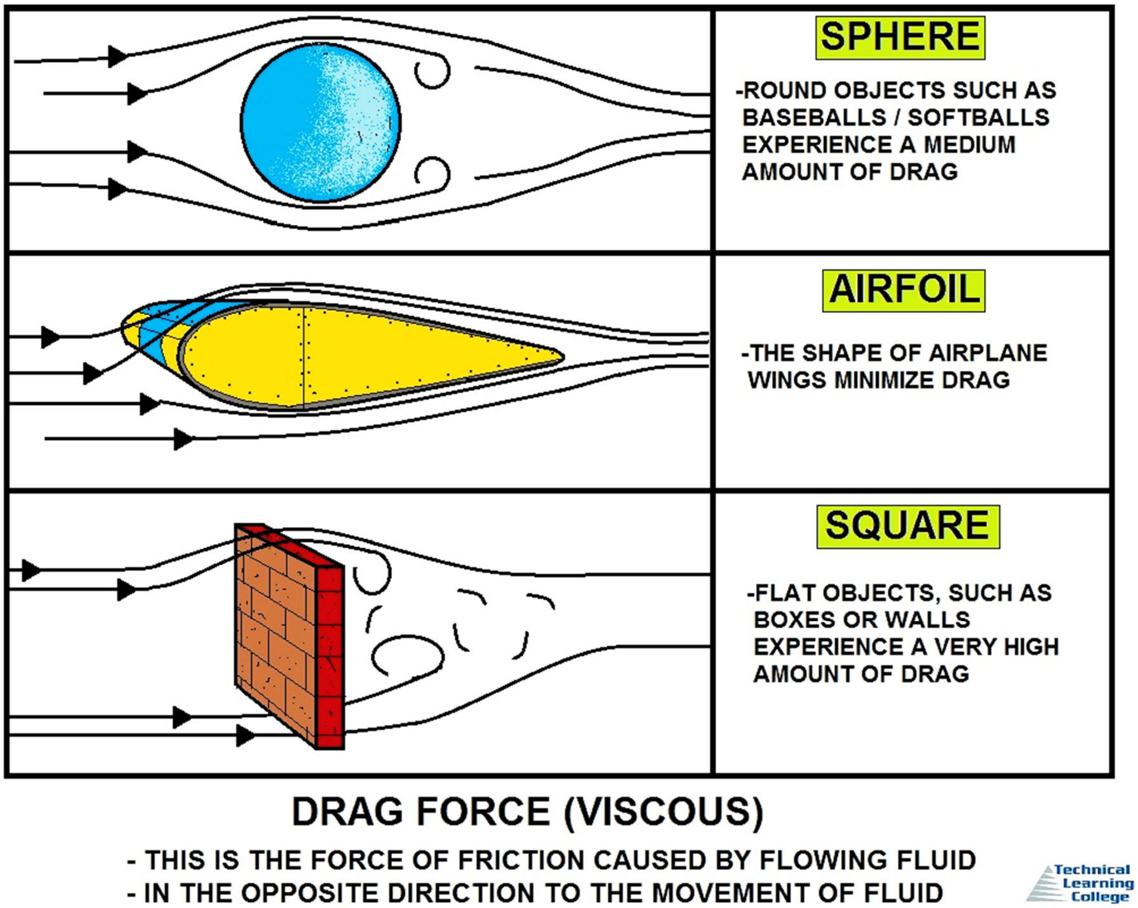
In fluid dynamics, drag (occasionally called air resistance, a type of friction, or fluid resistance, another type of friction or fluid friction) is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid. This can exist between two fluid layers (or surfaces) or a fluid and a solid surface. Unlike other resistive forces, such as dry friction, which are nearly independent of velocity, drag forces depend on velocity.

Drag Force
Drag force is proportional to the velocity for a laminar flow and the squared velocity for a turbulent flow. Even though the basic cause of a drag is viscous friction, the turbulent drag is independent of viscosity. Drag forces always decrease fluid velocity relative to the solid object in the fluid's path.

Examples of Drag
Examples of drag include the component of the net aerodynamic or hydrodynamic force acting opposite to the direction of movement of a solid object such as cars, aircraft and boat hulls; or acting in the same geographical direction of motion as the solid, as for sails attached to a downwind sail boat, or in intermediate directions on a sail depending on points of sail.

In the case of viscous drag of fluid in a pipe, drag force on the immobile pipe decreases fluid velocity relative to the pipe.

In physics of sports, the drag force is necessary to explain the performance of runners, particularly of sprinters.



Types of Drag

Types of drag are generally divided into the following categories:

Parasitic drag, consisting of

- ✓ form drag,
- ✓ skin friction,
- ✓ interference drag,
- ✓ lift-induced drag, and
- ✓ wave drag (aerodynamics) or wave resistance (ship hydrodynamics).

The phrase parasitic drag is mainly used in aerodynamics, since for lifting wings drag it is in general small compared to lift. For flow around bluff bodies, form and interference drags often dominate, and then the qualifier "parasitic" is meaningless.

Further, lift-induced drag is only relevant when wings or a lifting body are present, and is therefore usually discussed either in aviation or in the design of semi-planing or planing hulls.

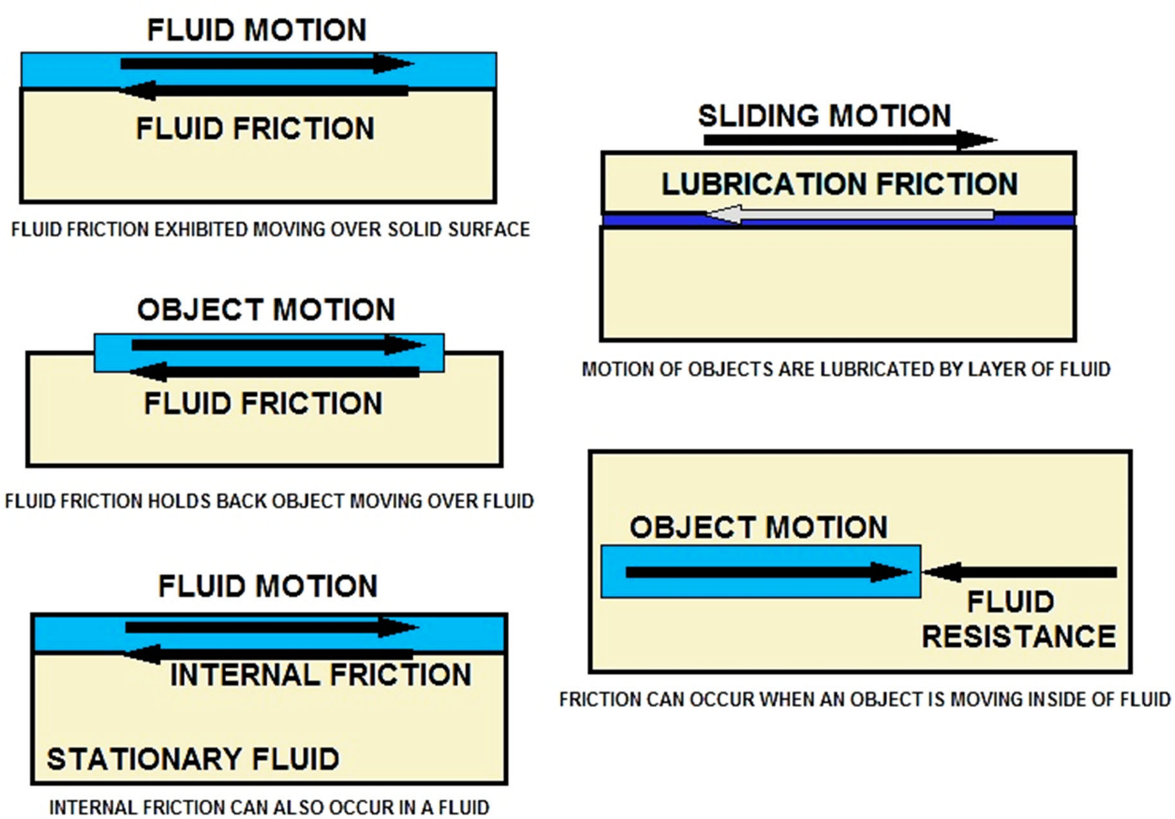
Wave drag occurs either when a solid object is moving through a fluid at or near the speed of sound or when a solid object is moving along a fluid boundary, as in surface waves.

What is Fluid Friction?

Fluid friction occurs between fluid layers that are moving relative to each other. This internal resistance to flow is named viscosity. In everyday terms, the viscosity of a fluid is described as its “thickness”. All real fluids offer some resistance to shearing and therefore are viscous. It is helpful to use the concept of an inviscid fluid or an ideal fluid which offers no resistance to shearing and so is not viscous.

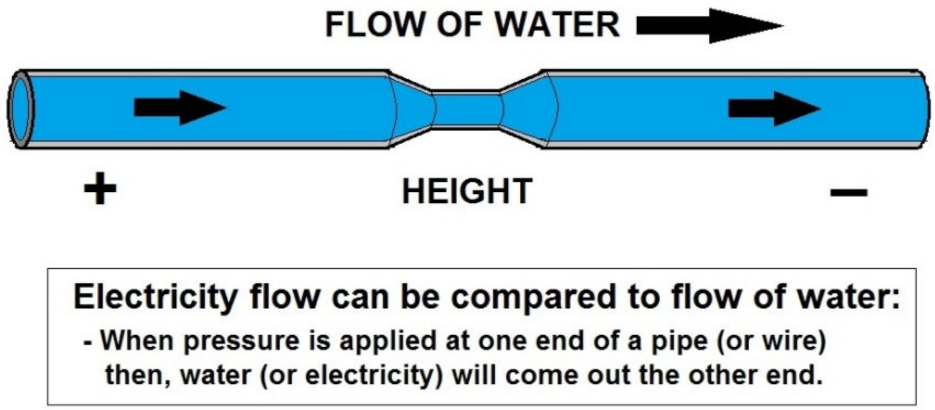
Several Types of Friction

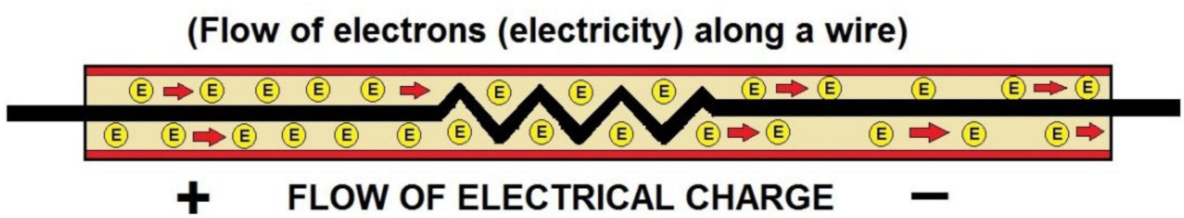
- **Dry friction** resists relative lateral motion of two solid surfaces in contact.
- **Fluid friction** describes the friction between layers of a viscous fluid that are moving relative to each other.
- **Lubricated friction** is a case of fluid friction where a lubricant fluid separates two solid surfaces.
- **Skin friction** is a component of drag, the force resisting the motion of a fluid across the surface of a body.
- **Internal friction** is the force resisting motion between the elements making up a solid material while it undergoes deformation.



Technical Learning College **EXAMPLES OF FLUID FRICTION**

Hydraulic/Electrical Analogy Principles



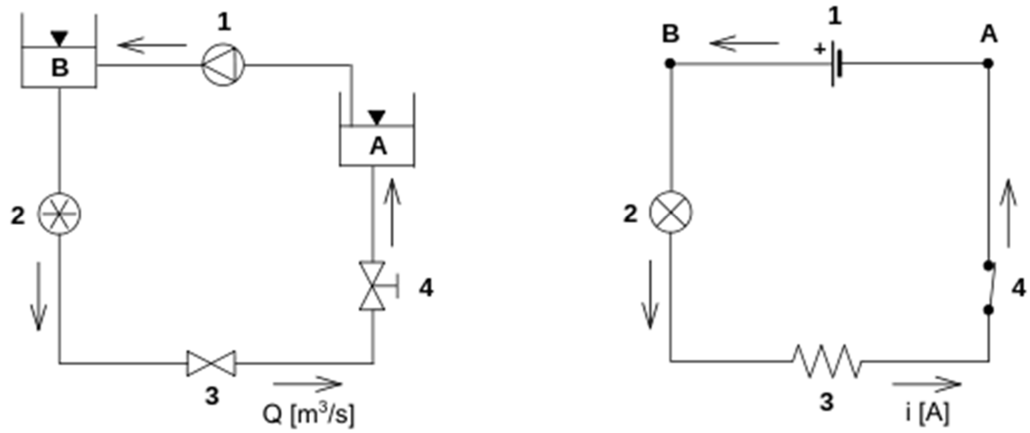


BASIC ELECTRICAL CONCEPT DIAGRAM

Water (Hydraulic) and Electrical Principles Are Very Similar

The electronic–**hydraulic analogy** (derisively referred to as the **drain-pipe theory** by Oliver Heaviside) is the most widely used analogy for "electron fluid" in a metal conductor. Since electric current is invisible and the processes at play in electronics are often difficult to demonstrate, the various electronic components are represented by hydraulic equivalents.

Electricity (as well as heat) was originally understood to be a kind of fluid, and the names of certain electric quantities (such as current) are derived from hydraulic equivalents. As all analogies, it demands an intuitive and competent understanding of the baseline paradigms (electronics and hydraulics).



Analogy between a hydraulic circuit (left) and an electronic circuit (right).

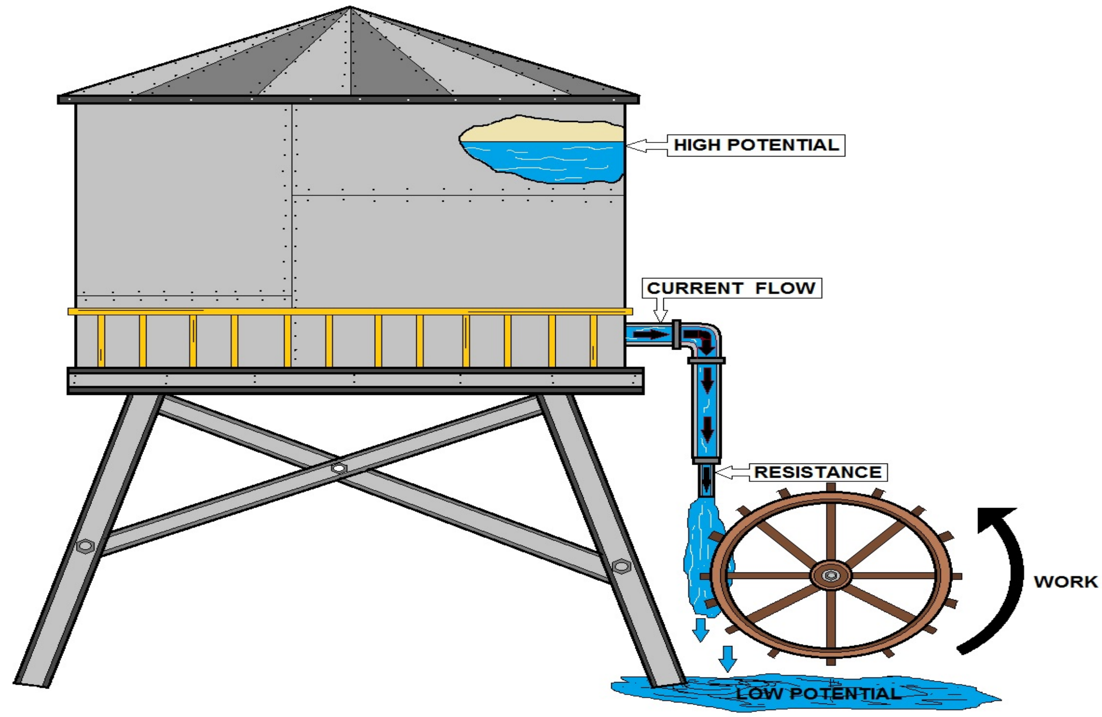
Basic Hydraulic Ideas

There are two basic paradigms:

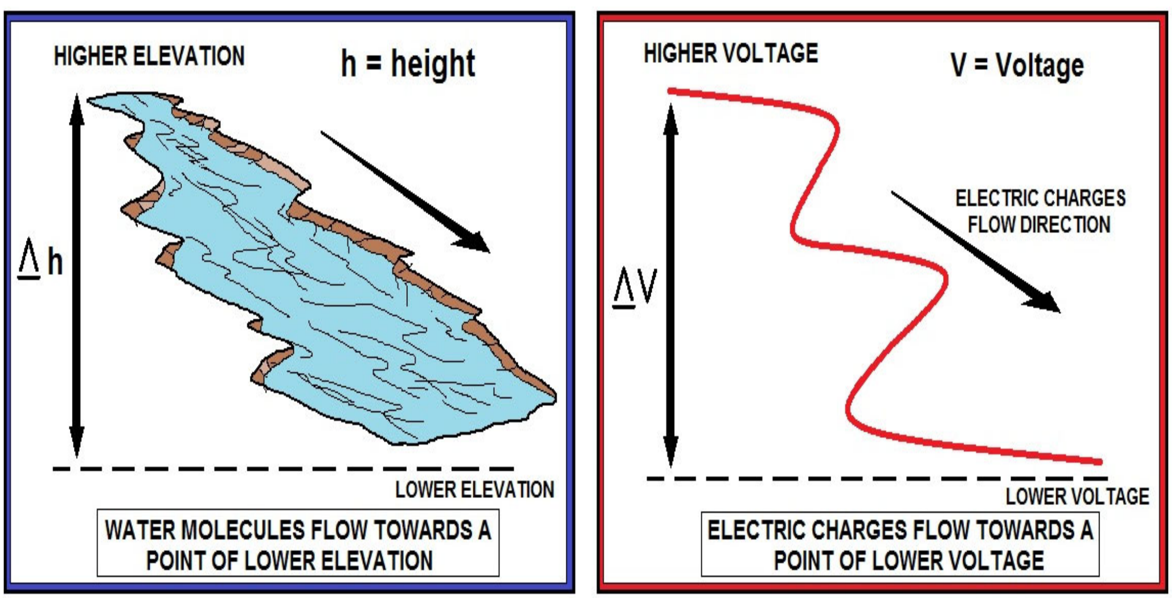
- Version with pressure induced by gravity. Large tanks of water are held up high, or are filled to differing water levels, and the potential energy of the water head is the pressure source. This is reminiscent of electrical diagrams with an up arrow pointing to +V, grounded pins that otherwise are not shown connecting to anything, and so on.

- Completely enclosed version with pumps providing pressure only; no gravity. This is reminiscent of a circuit diagram with a voltage source shown and the wires actually completing a circuit.

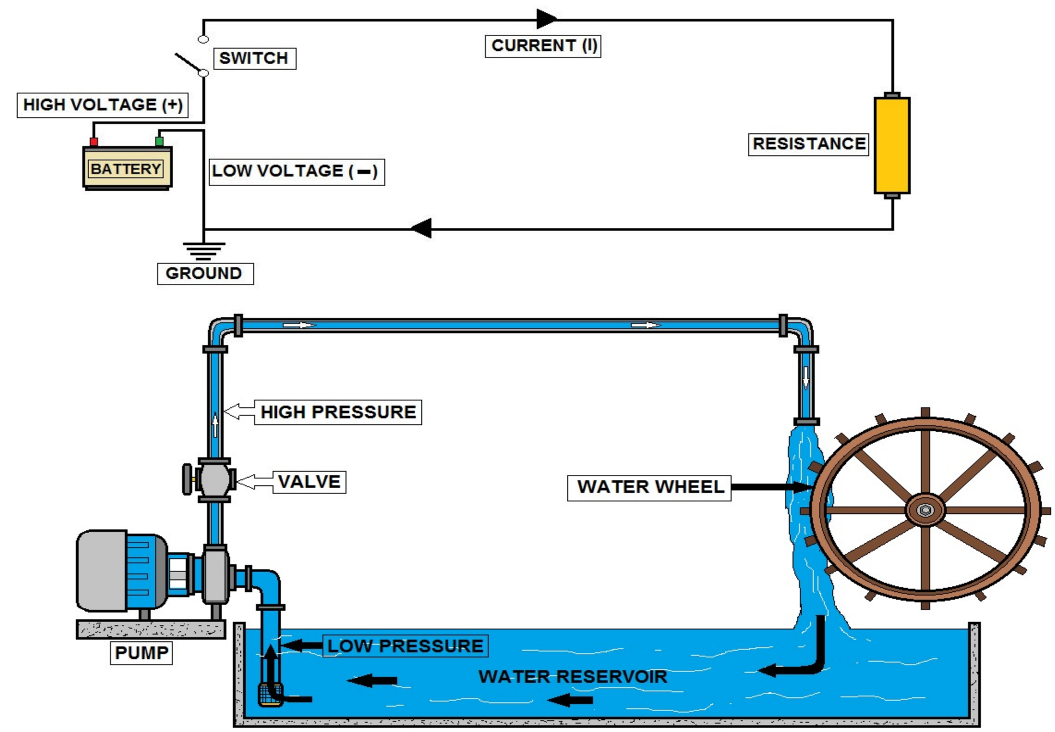
Applications: Flow and pressure variables can be calculated in fluid flow network with the use of the hydraulic ohm analogy. The method can be applied to both steady and transient flow situations.



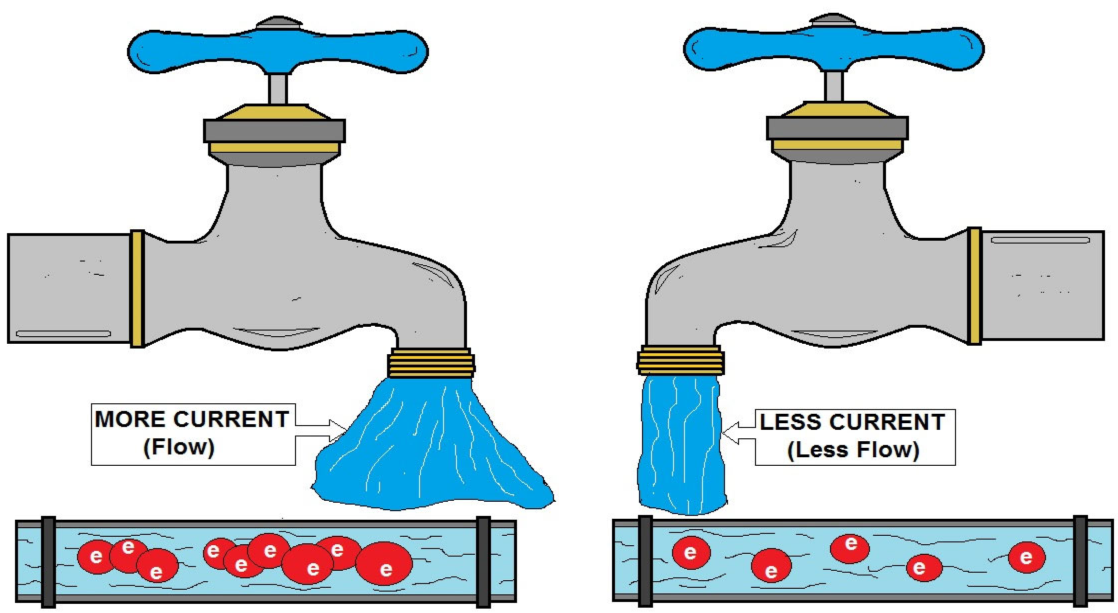
WATER FLOWS LIKE ELECTRICITY



WATER FLOWS LIKE ELECTRICITY EXAMPLE



EXAMPLE OF HOW WATER FLOWS SIMILAR TO ELECTRICITY



ELECTRIC CURRENT - WATER ANALOGY

Hydraulic Component Equivalents

Wires
A relatively wide pipe completely filled with water is equivalent to a piece of wire. When comparing to a piece of wire, the pipe should be thought of as having semi-permanent caps on the ends. Connecting one end of a wire to a circuit is equivalent to forcibly un-capping one end of the pipe and attaching it to another pipe. With few exceptions (such as a high-voltage power source), a wire with only one end attached to a circuit will do nothing; the pipe remains capped on the free end, and thus adds nothing to the circuit.

Electric potential
In general, it is equivalent to hydraulic head. In this article, it is assumed that the water is flowing horizontally, so that the force of gravity can be ignored, and then electric potential is equivalent to pressure.

Voltage
Also called voltage drop or *potential difference*. A difference in pressure between two points. Usually measured in volts.

Electric charge
Equivalent to a quantity of water.

Current
Equivalent to a hydraulic volume flow rate; that is, the volumetric quantity of flowing water over time. Usually measured in amperes.

Ideal voltage source, or ideal battery
A dynamic pump with feedback control. A pressure meter on both sides shows that regardless of the current being produced, this kind of pump produces constant pressure difference. If one terminal is kept fixed at ground, another analogy is a large body of water at a high elevation, sufficiently large that the drawn water does not affect the water level.

Ideal current source
A positive displacement pump. A current meter (little paddle wheel) shows that when this kind of pump is driven at a constant speed, it maintains a constant speed of the little paddle wheel.

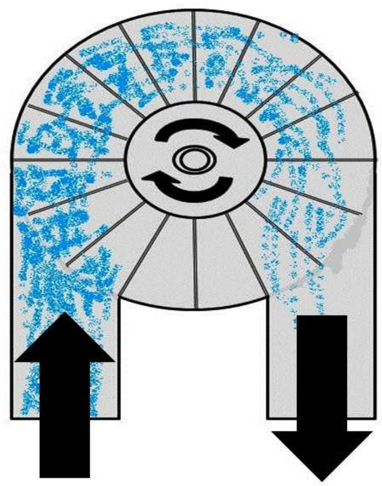
Resistor
A constriction in the bore of the pipe which requires more pressure to pass the same amount of water. All pipes have some resistance to flow, just as all wires have some resistance to current.

Capacitor
A tank with one connection at each end and a rubber sheet dividing the tank in two lengthwise (a hydraulic accumulator). When water is forced into one pipe, equal water is simultaneously forced out the other pipe, yet no water can penetrate the rubber diaphragm. Energy is stored by the stretching of the rubber. As more current flows "through" the capacitor, the back-pressure (voltage) becomes greater, thus current "leads" voltage in a capacitor. As the back-pressure from the stretched rubber approaches the applied pressure, the current becomes less and less. Thus capacitors "filter out" constant pressure differences and slowly varying, low-frequency pressure differences, while allowing rapid changes in pressure to pass through.

Note that the device described will pass all changes in pressure "through" equally well, regardless of rate of change, just as an electrical capacitor will. Any device in series must obey (electrical) Kirchhoff's Current Law, or its hydraulic equivalent. Considering the "filter" action, a better and more exact analogy is the hydraulic accumulator "pressure tank", as described, but with a closed, pressurized air bladder and only one water connection. Such accumulators are commonly used in hydraulic power systems exactly for the purpose of damping out pressure surges and "hammers" due to valves opening and closing.

Inductor

A heavy paddle wheel placed in the current. The mass of the wheel and the size of the blades restrict the water's ability to rapidly change its rate of flow (current) through the wheel due to the effects of inertia, but, given time, a constant flowing stream will pass mostly unimpeded through the wheel, as it turns at the same speed as the water flow. The mass and surface area of the wheel and its blades are analogous to inductance, and friction between its axle and the axle bearings corresponds to the resistance that accompanies any non-superconducting inductor.



TURBINE INDUCTOR PADDLE

Inductors are analogous to a heavy paddle wheel/turbine placed in the current.

An alternative inductor model is simply a long pipe, perhaps coiled into a spiral for convenience. This fluid-inertia device is used in real life as an essential component of a hydraulic ram. The inertia of the water flowing through the pipe produces the inductance effect; inductors "filter out" rapid changes in flow, while allowing slow variations in current to be passed through. The drag imposed by the walls of the pipe is somewhat analogous to parasitic resistance.

In either model, the pressure difference (voltage) across the device must be present before the current will start moving, thus in inductors voltage "leads" current. As the current increases, approaching the limits imposed by its own internal friction and of the current that the rest of the circuit can provide, the pressure drop across the device becomes lower and lower.

Diode
Equivalent to a one-way check valve with a slightly leaky valve seat. As with a diode, a small pressure difference is needed before the valve opens. And like a diode, too much reverse bias can damage or destroy the valve assembly.

Transistor
A valve in which a diaphragm, controlled by a low-current signal (either constant current for a BJT or constant pressure for a FET), moves a plunger which affects the current through another section of pipe.

CMOS
A combination of two MOSFET transistors. As the input pressure changes, the pistons allow the output to connect to either zero or positive pressure.

Memristor
A needle valve operated by a flow meter. As water flows through in the forward direction, the needle valve restricts flow more; as water flows the other direction, the needle valve opens further providing less resistance.

Hydraulic - Electrical Principle Equivalents

EM Wave Speed (velocity of propagation)
Speed of sound in water. When a light switch is flipped, the electric wave travels very quickly through the wires.

Charge Flow Speed (drift velocity)
Particle speed of water. The moving charges themselves move rather slowly.

DC
Constant flow of water in a circuit of pipe.

Low Frequency AC
Water oscillating back and forth in a pipe.

Higher-Frequency AC and Transmission Lines
Sound being transmitted through the water pipes: Be aware that this does not properly mirror the cyclical reversal of alternating electric current. As described, the fluid flow conveys pressure fluctuations, but fluids “do not” reverse at high rates in hydraulic systems, which the above "low frequency" entry does accurately describe. A better concept (if sound waves are to be the phenomenon) is that of direct current with high-frequency "ripple" superimposed.

Inductive Spark
Used in induction coils, similar to water hammer, caused by the inertia of water.

Hydraulic Equation Examples

Some examples of equivalent electrical and hydraulic equations:

type	hydraulic	electric	thermal	mechanical
quantity	volume V[m^3]	charge q[C]	heat Q[J]	momentum P [Ns]
potential	pressure P[Pa=J/m^3]	potential ϕ[V=J/C]	temperature T [K=J/k_B]	velocity v[m/s]
flux	Volumetric flow rate Φ_V [m^3/s]	current I[A=C/s]	heat transfer rate $\dot{Q}$[J/s]	force F[N]
flux density	velocity v[m/s]	current density j [C/(m^2·s) = A/m^2]	heat flux $\dot{Q}''$ [W/m^2]	stress σ[N/m^2 = Pa]
linear model	Poiseuille's law $\Phi_V = \frac{\pi r^4}{8\eta}\frac{\Delta p^\star}{\ell}$	Ohm's law $j = -\sigma\nabla\phi$	Fourier's law $\dot{Q}'' = \kappa\nabla T$	Dashpot $\sigma = c\Delta v$

If the differential equations have the same form, the response will be similar.

Limits to the Hydraulic Analogy

If taken too far, the water analogy can create misconceptions. For it to be useful, we must remain aware of the regions where electricity and water behave very differently.

Fields (Maxwell equations, Inductance)
Electrons can push or pull other distant electrons via their fields, while water molecules experience forces only from direct contact with other molecules. For this reason, waves in water travel at the speed of sound, but waves in a sea of charge will travel much faster as the forces from one electron are applied to many distant electrons and not to only the neighbors in direct contact. In a hydraulic transmission line, the energy flows as mechanical waves through the water, but in an electric transmission line the energy flows as fields in the space surrounding the wires, and does not flow inside the metal. Also, an accelerating electron will drag its neighbors along while attracting them, both because of magnetic forces.

Charge
Unlike water, movable charge carriers can be positive or negative, and conductors can exhibit an overall positive or negative net charge. The mobile carriers in electric currents are usually electrons, but sometimes they are charged positively, such as H^+ ions in proton conductors or holes in p-type semiconductors and some (very rare) conductors.

Leaking Pipes
The electric charge of an electrical circuit and its elements is usually almost equal to zero, hence it is (almost) constant. This is formalized in Kirchhoff's current law, which does not have an analogy to hydraulic systems, where amount of the liquid is not usually constant. Even with incompressible liquid the system may contain such elements as pistons and open pools, so the volume of liquid contained in a part of the system can change. For this reason, continuing electric currents require closed loops rather than hydraulics' open source/sink resembling spigots and buckets.

James Thurber spoke of his maternal grandmother thus:
She came naturally by her confused and groundless fears, for her own mother lived the latter years of her life in the horrible suspicion that electricity was dripping invisibly all over the house. - My Life and Hard Times (1933).

Fluid Velocity and Resistance of Metals
As with water hoses, the carrier drift velocity in conductors is directly proportional to current. However, water only experiences drag via the pipes' inner surface, while charges are slowed at all points within a metal. Also, typical velocity of charge carriers within a conductor is less than centimeters per minute, and the "electrical friction" is extremely high. If charges ever flowed as fast as water can flow in pipes, the electric current would be immense, and the conductors would become incandescently hot and perhaps vaporize.

To model the resistance and the charge-velocity of metals, perhaps a pipe packed with sponge, or a narrow straw filled with syrup, would be a better analogy than a large-diameter water pipe. Resistance in most electrical conductors is a linear function: as current increases, voltage drop increases proportionally (Ohm's Law). Liquid resistance in pipes is not linear with volume, varying as the square of volumetric flow (see Darcy–Weisbach equation).

Quantum Mechanics
Conductors and insulators contain charges at more than one discrete level of atomic orbit energy, while the water in one region of a pipe can only have a single value of pressure. For this reason there is no hydraulic explanation for such things as a battery's charge pumping ability, a diode's voltage drop, solar cell functions, Peltier effect, etc., however equivalent devices can be designed which exhibit similar responses, although some of the mechanisms would only serve to regulate the flow curves rather than to contribute to the component's primary function.

Usefulness requires that the reader or student has a substantial understanding of the model (hydraulic) system's principles. It also requires that the principles can be transferred to the target (electrical) system. Hydraulic systems are deceptively simple: the phenomenon of pump cavitation is a known, complex problem that few people outside of the fluid power or irrigation industries would understand. For those who do, the hydraulic analogy is amusing, as no "cavitation" equivalent exists in electrical engineering. The hydraulic analogy can give a mistaken sense of understanding that will be exposed once a detailed description of electrical circuit theory is required.

One must also consider the difficulties in trying to make the analogy work. The above "electrical friction" example, where the hydraulic analog is a pipe filled with sponge material, illustrates the problem: the model must be increased in complexity beyond any realistic scenario.

Electrical Measurements and Equipment

Molecule of liquid ⟶ electron of electricity

Flow rate (gpm) ⟶ current (ampere) I, A

Pressure (psi) ⟶ potential (V)

Pressure drop ⟶ voltage drop

Pump ⟶ generator

Fluid Mechanics and Hydraulic Principles Post Quiz

Hydraulics

1. Hydraulics can be divided into two areas, hydrostatics and?

Hydrostatics

2. Which term may be the physical property that varies over the largest numerical range, competing with electrical resistivity?

Fluid Statics

3. The solution to a fluid dynamics problem typically involves calculating various properties of the fluid, such as velocity, pressure, density, and temperature, as functions of?

Gases and Liquids

4. In liquids the molecules are more or less in contact, and the short-range attractive forces between them make them cohere; the molecules are moving too _____________into the ordered arrays that are characteristic of solids, but not so fast that they can fly apart.

Solids

5. Water owes its high ideal strength to the fact that rupture involves breaking links of attraction between molecules on either side of the plane on which ____________occurs; work must be done to break these links.

Surface Tension

6. The surface of a liquid behaves, in fact, as if it were an elastic membrane under tension, except that the tension exerted by ______________increases when the membrane is stretched in a way that the tension exerted by a liquid surface does not.

Friction

7. Which term is a force that opposes the relative lateral motion of two solid surfaces in contact?

Kinetic Energy

8. Kinetic energy is converted to thermal energy whenever ______________occurs, for example when a viscous fluid is stirred.

Fluid Friction (Drag)

9. Fluid friction is affected by increased_______________, and the modern streamline design of airplanes and automobiles is the result of engineers' efforts to minimize fluid friction while retaining speed and protecting structure.

Drag Force
10. Drag force is proportional to the velocity for a ________________and the squared velocity for a turbulent flow.

Answers 1. Hydrokinetics, 2. Viscosity, 3. Space and time, 4. Fast to settle down, 5. Rupture, 6. An elastic membrane, 7. Dry friction, 8. Motion with friction, 9. Velocities, 10. Laminar flow

Fluid Mechanics and Hydraulic Principles References

"Coefficients of Friction of Human Joints".
"Friction Factors - Coefficients of Friction".
"friction". Merriam-Webster Dictionary.
"Leonhard Euler". Friction Module. Nano World. 2002.
"SriLanka – History". Asian Studies Center, Michigan State University.
"SriLanka-A Country study" (PDF). USA Government, Department of Army. 1990.
"The Engineering Toolbox: Friction and Coefficients of Friction".
"Ultra-low friction coefficient in alumina–silicon nitride pair lubricated with water". Wear. 296: 656–659. doi:10.1016/j.wear.2012.07.030.
1974-, Fu, Chunjiang,; Liping., Yang,; N., Han, Y.; Editorial., Asiapac (2006). Origins of Chinese science and technology. Asiapac. ISBN 9812293760. OCLC 71370433.
Acary, V.; Brogliato, B. (2008). Numerical Methods for Nonsmooth Dynamical Systems. Applications in Mechanics and Electronics. 35. Springer Verlag Heidelberg.
Acary, V.; Cadoux, F.; Lemaréchal, C.; Malick, J. (2011). "A formulation of the linear discrete Coulomb friction problem via convex optimization". Journal of Applied Mathematics and Mechanics / Zeitschrift für Angewandte Mathematik und Mechanik. 91 (2): 155–175. Bibcode:2011ZaMM...91..155A. doi:10.1002/zamm.201000073.
Adams, G. G. (1995). "Self-excited oscillations of two elastic half-spaces sliding with a constant coefficient of friction". Journal of Applied Mechanics. 62: 867–872. Bibcode:1995JAM....62..867A. doi:10.1115/1.2896013.
Air Brake Association (1921). The Principles and Design of Foundation Brake Rigging. Air brake association. p. 5.
Alart, P.; Curnier, A. (1991). "A mixed formulation for frictional contact problems prone to Newton like solution method". Computer Methods in Applied Mechanics and Engineering. 92 (3): 353–375. Bibcode:1991CMAME..92..353A. doi:10.1016/0045-7825(91)90022-X.
Armstrong-Hélouvry, Brian (1991). Control of machines with friction. USA: Springer. p. 10. ISBN 0-7923-9133-0.
Beatty, William J. "Recurring science misconceptions in K-6 textbooks".
Beer, Ferdinand P.; Johnston, E. Russel, Jr. (1996). Vector Mechanics for Engineers (Sixth ed.). McGraw-Hill. p. 397. ISBN 0-07-297688-8.
Bhavikatti, S. S.; K. G. Rajashekarappa (1994). Engineering Mechanics. New Age International. p. 112. ISBN 978-81-224-0617-7.
Bigoni, D. Nonlinear Solid Mechanics: Bifurcation Theory and Material Instability. Cambridge University Press, 2012. ISBN 9781107025417.
Bigoni, D.; Noselli, G. (2011). "Experimental evidence of flutter and divergence instabilities induced by dry friction". Journal of the Mechanics and Physics of Solids. 59 (10): 2208–2226. Bibcode:2011JMPSo..59.2208B. doi:10.1016/j.jmps.2011.05.007.
Bird, David. Pliny's Arrugia Water Mining in Roman Gold-Mining. Papers Presented at the National Association of Mining History Organizations' Conference July 2002. Obtained from: http://www.goldchartsrus.com/papers/PlinysArrugia-
Centre, UNESCO World Heritage. "Las Médulas". whc.unesco.org. Retrieved 2017-06-13.
Chatterjee, Sudipta (2008). Tribological Properties of Pseudo-elastic Nickel-titanium (Thesis). University of California. pp. 11–12. ISBN 9780549844372 – via ProQuest. Classical Greek philosophers like Aristotle, Pliny the Elder and Vitruvius wrote about the existence of friction, the effect of lubricants and the advantages of metal bearings around 350 B.C.

De Saxcé, G.; Feng, Z.-Q. (1998). "The bipotential method: A constructive approach to design the complete contact law with friction and improved numerical algorithms". Mathematical and Computer Modelling. 28 (4): 225–245. doi:10.1016/S0895-7177(98)00119-8.
Deng, Zhao; et al. (October 14, 2012). "Adhesion-dependent negative friction coefficient on chemically modified graphite at the nanoscale". Nature. 11: 1032–7.
Bibcode:2012NatMa..11.1032D. doi:10.1038/nmat3452. PMID 23064494. Retrieved November 18, 2012. Lay summary – R&D Magazine (October 17, 2012).
Dienwiebel, Martin; et al. (2004). "Superlubricity of Graphite" (PDF). Phys. Rev. Lett. 92 (12): 126101. Bibcode:2004PhRvL..92l6101D. doi:10.1103/PhysRevLett.92.126101.
Dowson, Duncan (1997). History of Tribology (2nd ed.). Professional Engineering Publishing. ISBN 1-86058-070-X.
Einstein, A. (1909). On the development of our views concerning the nature and constitution of radiation. Translated in: The Collected Papers of Albert Einstein, vol. 2 (Princeton University Press, Princeton, 1989). Princeton, NJ: Princeton University Press.
EngineersHandbook.com
Feynman, Richard P.; Leighton, Robert B.; Sands, Matthew (1964). "The Feynman Lectures on Physics, Vol. I, p. 12-5". Addison-Wesley.
Fishbane, Paul M.; Gasiorowicz, Stephen; Thornton, Stephen T. (1993). Physics for Scientists and Engineers. I (Extended ed.). Englewood Cliffs, New Jersey: Prentice Hall. p. 135. ISBN 0-13-663246-7. Themistius first stated around 350 B.C. [SIC] that kinetic friction is weaker than the maximum value of static friction.
Fleeming Jenkin & James Alfred Ewing (1877) "On Friction between Surfaces moving at Low Speeds", Philosophical Magazine Series 5, volume 4, pp 308–10; link from Biodiversity Heritage Library
Forest de Bélidor, Bernard. "Richtige Grund-Sätze der Friction-Berechnung" ("Correct Basics of Friction Calculation"), 1737, (in German)
Goedecke, Andreas (2014). Transient Effects in Friction: Fractal Asperity Creep. Springer Science and Business Media. p. 3. ISBN 370911506X.
Greenwood J.A. and JB Williamson (1966). "Contact of nominally flat surfaces". Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences. 295 (1442).
Hanaor, D.; Gan, Y.; Einav, I. (2016). "Static friction at fractal interfaces" (PDF). Tribology International. 93: 229–238.
Haslinger, J.; Nedlec, J.C. (1983). "Approximation of the Signorini problem with friction, obeying the Coulomb law". Mathematical Methods in the Applied Sciences. 5: 422–437.
Bibcode:1983MMAS....5..422H. doi:10.1002/mma.1670050127.
Hecht, Eugene (2003). Physics: Algebra/Trig (3rd ed.). Cengage Learning.
ISBN 9780534377298.
Hibbeler, R. C. (2007). Engineering Mechanics (Eleventh ed.). Pearson, Prentice Hall. p. 393. ISBN 0-13-127146-6.
Higdon, C.; Cook, B.; Harringa, J.; Russell, A.; Goldsmith, J.; Qu, J.; Blau, P. (2011). "Friction and wear mechanisms in AlMgB14-TiB2 nanocoatings". Wear. 271 (9–10): 2111–2115. doi:10.1016/j.wear.2010.11.044.
http://mechanicalemax.blogspot.com/2016/03/tribology-introduction.html
http://www.industrialoutpost.com/human-circulatory-system-heart-modern-hydraulic
Hutchings, Ian M. (2016). "Leonardo da Vinci's studies of friction" (PDF).
doi:10.1016/j.wear.2016.04.019.
Hutchings, Ian M. (2016-08-15). "Leonardo da Vinci's studies of friction". Wear. 360–361: 51–66. doi:10.1016/j.wear.2016.04.019.

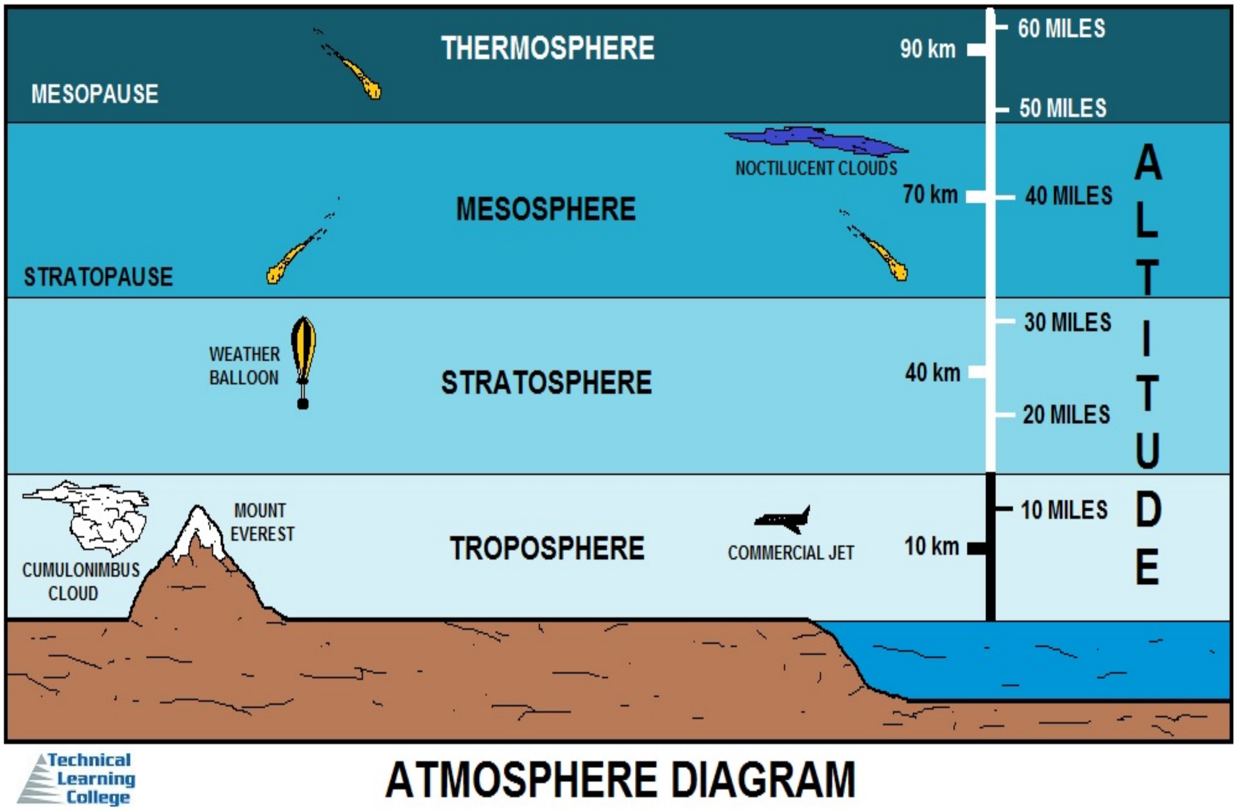
J., Flint,; J., Hultén, (2002). "Lining-deformation-induced modal coupling as squeal generator in a distributed parameter disk brake model". J. Sound and Vibration. 254: 1–21. Bibcode:2002JSV...254....1F. doi:10.1006/jsvi.2001.4052.
Kirk, Tom (July 22, 2016). "Study reveals Leonardo da Vinci's 'irrelevant' scribbles mark the spot where he first recorded the laws of friction". phys.org.
Kleiner, Kurt (2008-11-21). "Material slicker than Teflon discovered by accident".
M, Nosonovsky,; G., Adams G. (2004). "Vibration and stability of frictional sliding of two elastic bodies with a wavy contact interface". Journal of Applied Mechanics. 71: 154–161. Bibcode:2004JAM....71..154N. doi:10.1115/1.1653684.
M., Kröger,; M., Neubauer,; K., Popp, (2008). "Experimental investigation on the avoidance of self-excited vibrations". Phil. Trans. R. Soc. A. 366 (1866): 785–810. Bibcode:2008RSPTA.366..785K. doi:10.1098/rsta.2007.2127. PMID 17947204.
Makkonen, L (2012). "A thermodynamic model of sliding friction". AIP Advances. 2: 012179. Bibcode:2012AIPA....2a2179M. doi:10.1063/1.3699027.
Martins, J.A., Faria, L.O. & Guimarães, J. (1995). "Dynamic surface solutions in linear elasticity and viscoelasticity with frictional boundary conditions". Journal of Vibration and Acoustics. 117: 445–451. doi:10.1115/1.2874477.
Meriam, J. L.; Kraige, L. G. (2002). Engineering Mechanics (fifth ed.). John Wiley & Sons. p. 328. ISBN 0-471-60293-0.
Meriam, James L.; Kraige, L. Glenn; Palm, William John (2002). Engineering Mechanics: Statics. Wiley and Sons. p. 330. ISBN 0-471-40646-5. Kinetic friction force is usually somewhat less than the maximum static friction force.
Museum, Victoria and Albert. "Catalogue of the mechanical engineering collection in the Science Division of the Victoria and Albert Museum, South Kensington, with descriptive and historical notes." Ulan Press. 2012.
Nichols, Edward Leamington; Franklin, William Suddards (1898). The Elements of Physics. 1. Macmillan. p. 101.
Nosonovsky, Michael (2013). Friction-Induced Vibrations and Self-Organization: Mechanics and Non-Equilibrium Thermodynamics of Sliding Contact. CRC Press. p. 333. ISBN 978-1466504011.
Persson, B. N. J. (2000). Sliding friction: physical principles and applications. Springer. ISBN 978-3-540-67192-3.
Persson, B. N.; Volokitin, A. I (2002). "Theory of rubber friction: Nonstationary sliding". Physical Review B. 65 (13): 134106. Bibcode:2002PhRvB..65m4106P. doi:10.1103/PhysRevB.65.134106.
R., Rice, J.; L., Ruina, A. (1983). "Stability of Steady Frictional Slipping" (PDF). Journal of Applied Mechanics. 50 (2): 343–349. Bibcode:1983JAM....50..343R. doi:10.1115/1.3167042.
ricardo (2014-10-30). "Las Médulas". Castilla y León World Heritage UNESCO (in Spanish).
Ruina, Andy; Pratap, Rudra (2002). Introduction to Statics and Dynamics (PDF). Oxford University Press. p. 713.
Sambursky, Samuel (2014). The Physical World of Late Antiquity. Princeton University Press. pp. 65–66. ISBN 9781400858989.
Sheppard, Sheri; Tongue, Benson H.; Anagnos, Thalia (2005). Statics: Analysis and Design of Systems in Equilibrium. Wiley and Sons. p. 618. ISBN 0-471-37299-4. In general, for given contacting surfaces
Simo, J.C.; Laursen, T.A. (1992). "An augmented lagrangian treatment of contact problems involving friction" Computers and Structures42 (2): 97–116. doi:10.5-7949(92)90540-G.
Soutas-Little, Robert W.; Inman, Balint (2008). Engineering Mechanics. Thomson. p. 329. ISBN 0-495-29610-4.

Ternes, Markus; Lutz, Christopher P.; Hirjibehedin, Cyrus F.; Giessibl, Franz J.; Heinrich, Andreas J. (2008-02-22). "The Force Needed to Move an Atom on a Surface". Science. 319 (5866): 1066–1069. Bibcode:2008Sci...319.1066T. doi:10.1126/science.1150288. PMID 18292336.
Tian, Y.; Bastawros, A. F.; Lo, C. C. H.; Constant, A. P.; Russell, A.M.; Cook, B. A. (2003). "Superhard self-lubricating AlMgB[sub 14] films for microelectromechanical devices". Applied Physics Letters. 83 (14): 2781. Bibcode:2003ApPhL..83.2781T. doi:10.1063/1.1615677.
Tomlinson, R. A. (2013). "The Perachora Waterworks: Addenda". The Annual of the British School at Athens. 71: 147–8. doi:10.1017/S0068245400005864. JSTOR 30103359.
Traditional SriLanka or Ceylon". Sam Houston State University.
van Beek, Anton. "History of Science Friction". tribology-abc.com. Retrieved 2011-03-24.

Section 3 - Fluid/Hydraulic Forces & Pressures

Section Focus: You will learn advanced fluid mechanics and hydraulic principle theories. At the end of this section, you the student will be able to describe primary water mechanics and hydraulic theories and related components. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

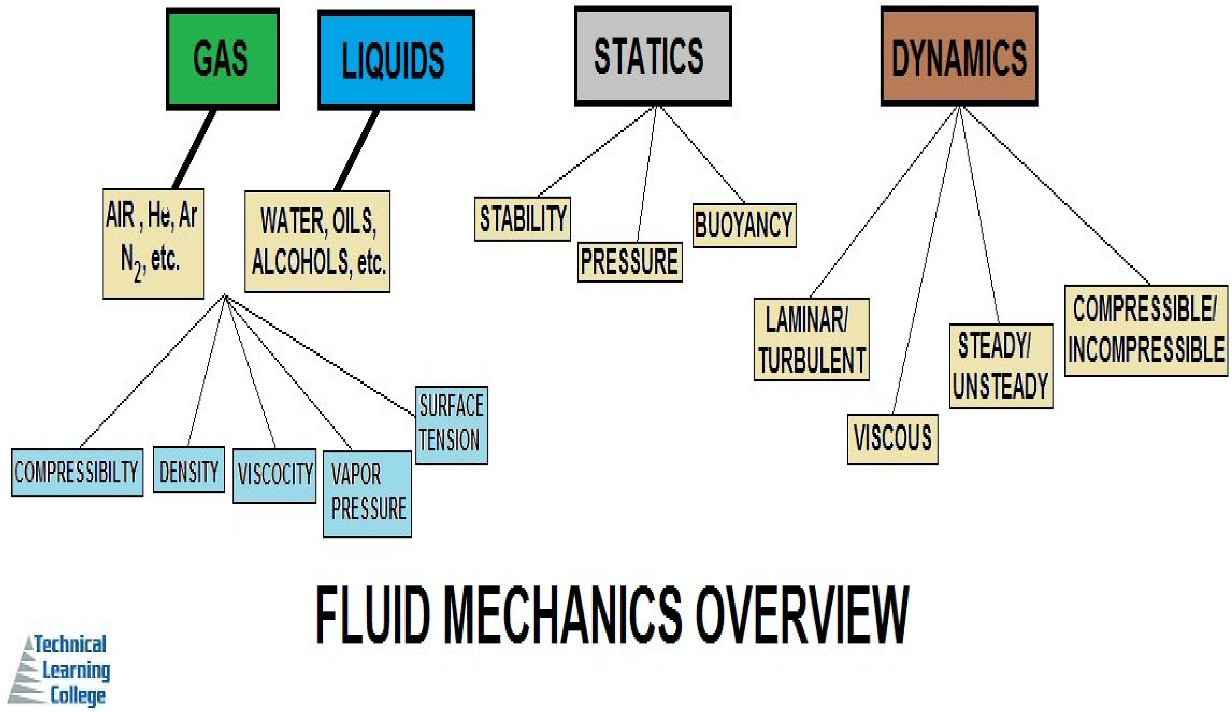
Scope/Background: In order to design hydraulic or water distribution systems or calculate pumping rates or flow rates, we need to master this area of engineering.



ATMOSPHERE DIAGRAM

The actual pressure of the atmosphere on the Earth's surface -- at sea level it's always around 1 bar, or 14.7 pounds per square inch. The other is the proportion of this pressure attributable to water vapor in the air, or saturated vapor pressure, which rises or falls with water vapor levels.

Air pressure is ruled by Dalton's Law. John Dalton was the nineteenth century scientist who first stated that the total pressure of the air is the sum of the partial pressures of all of its components. These components include major and minor gases, water vapor and particulate matter -- tiny solid pieces, such as dust and smoke. The vast majority of pressure is contributed by nitrogen, which comprises around 78 percent of the Earth's atmosphere. Oxygen is second, at around 21 percent. Argon, which comes in third, makes up only 1 percent of the Earth's atmosphere. All other gases normally exist in proportions of less than 1 percent -- except for highly variable water vapor.



A Fluid

A fluid is a substance that may flow like water. Particles making up the fluid continuously change their positions relative to one another. Fluids do not offer any lasting resistance to the displacement of one layer over another when a shear force is applied. This means that if a fluid is at rest, then no shear forces can exist in it, which is different from solids; solids can resist shear forces while at rest. To summarize, if a shear force (like a moving impeller) is applied to a fluid it will cause flow.

Fluid/Hydraulic Forces & Pressures Key Terms

Atmospheric Pressure
Atmospheric pressure, sometimes also called barometric pressure, is the pressure exerted by the weight of air in the atmosphere of Earth (or that of another planet). In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point.

ATM – Standard Atmosphere Pressure Unit
Standard Atmosphere is mainly used as a reference value for the average atmospheric pressure at sea level. It is often used to indicate the depth rating for a water resistant watch, but otherwise is rarely used as a unit for measuring pressure. 1 standard atmosphere is defined as being exactly equal to 101,325 pascals. Since the atmospheric pressure varies with changes in weather and altitude, it is convenient to standardize on a single value so that ratings, measurements and specifications can be compared. In particular, 1 Standard Atmosphere is used by the Aviation industry as the reference standard for sea level pressure.

Barometric Loop
The barometric loop consists of a continuous section of supply piping that abruptly rises to a height of **approximately 33-35 feet** and then returns back down to the originating level. It is a loop in the piping system that effectively protects against back-siphonage. It may not be used to protect against back-pressure.

Geometric Arguments
An input to a function: a variable that affects a functions result. Example: imagine a function that works out the height of a tree is: **h(year) = 20 × year**, then "year" is an argument of the function "h".

Liquids at Rest
Fluid statics or **hydrostatics** is the branch of fluid mechanics that studies fluids at rest. It encompasses the study of the conditions under which fluids are at rest in stable equilibrium as opposed to fluid dynamics, the study of fluids in motion. Hydrostatics are categorized as a part of the fluid statics, which is the study of all fluids, incompressible or not, at rest. Hydrostatics is fundamental to hydraulics, the engineering of equipment for storing, transporting and using fluids.

Mean Sea Level Pressure
The mean sea level pressure (MSLP) is the average atmospheric pressure at sea level. This is the atmospheric pressure normally given in weather reports on radio, television, and newspapers or on the Internet. When barometers in the home are set to match the local weather reports, they measure pressure adjusted to sea level, not the actual local atmospheric pressure. The altimeter setting in aviation, is an atmospheric pressure adjustment. Average sea-level pressure is 1013.25 mbar (101.325 kPa; 29.921 inHg; 760.00 mmHg). In aviation weather reports (METAR), QNH is transmitted around the world in millibars or hectopascals (1 hectopascal = 1 millibar), except in the United States, Canada, and Colombia where it is reported in inches (to two decimal places) of mercury. The United States and Canada also report sea level pressure SLP, which is adjusted to sea level by a different method, in the remarks section, not in the internationally transmitted part of

the code, in hectopascals or millibars. However, in Canada's public weather reports, sea level pressure is instead reported in kilopascals.

In the US weather code remarks, three digits are all that are transmitted; decimal points and the one or two most significant digits are omitted: 1013.2 mbar (101.32 kPa) is transmitted as 132; 1000.0 mbar (100.00 kPa) is transmitted as 000; 998.7 mbar is transmitted as 987; etc. The highest sea-level pressure on Earth occurs in Siberia, where the Siberian High often attains a sea-level pressure above 1050 mbar (105 kPa; 31 inHg), with record highs close to 1085 mbar (108.5 kPa; 32.0 inHg). The lowest measurable sea-level pressure is found at the centers of tropical cyclones and tornadoes, with a record low of 870 mbar (87 kPa; 26 inHg) (see Atmospheric pressure records).

Pressure
Pressure is the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Gauge pressure is the pressure relative to the ambient pressure. Various units are used to express pressure.

Standard Temperature and Pressure
Standard temperature and pressure, abbreviated STP, refers to nominal conditions in the atmosphere at sea level. This value is important to physicists, chemists, engineers, and pilots and navigators.

Standard temperature is defined as zero degrees Celsius (0 ^{0}C), which translates to 32 degrees Fahrenheit (32 ^{0}F) or 273.15 degrees kelvin (273.15 ^{0}K). This is essentially the freezing point of pure water at sea level, in air at standard pressure.

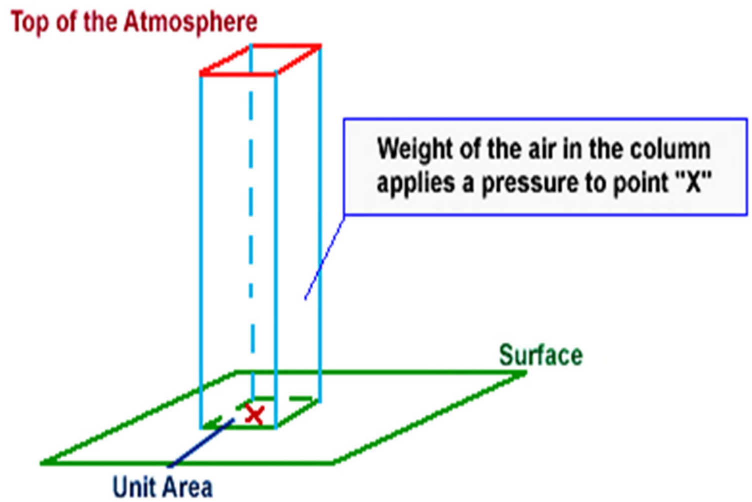
Standard pressure supports 760 millimeters in a mercurial barometer (760 mmHg). This is about 29.9 inches of mercury, and represents approximately 14.7 pounds per inch (14.7 lb/in^2).

Imagine a column of air measuring one inch square, extending straight up into space beyond the atmosphere. The air in such a column would weigh about 14.7 pounds. The density of air at STP is approximately 1.29 kilogram per meter cubed (1.29 kg/m^3). This fact comes as a surprise to many people; a cubic meter of air weighs nearly three pounds!

Vacuum
Vacuum is space void of matter. The word stems from the Latin adjective vacuus for "vacant" or "void". An approximation to such vacuum is a region with a gaseous pressure much less than atmospheric pressure.

Water Pressure
Water pressure is a term used to describe the flow strength of water through a pipe or other type of channel.

Fluid/Hydraulic Forces & Pressures Introduction



In the diagram, the pressure at point "**X**" increases as the weight of the air above it increases. The same can be said about decreasing pressure, where the pressure at point "**X**" decreases if the weight of the air above it also decreases.

Atmospheric Pressure

The atmosphere is the entire mass of air that surrounds the earth. While it extends upward for about 300 miles, the section of primary interest is the portion that rests on the earth's surface and extends upward for about 7 1/2 miles. This layer is called the troposphere.

If a column of air 1-inch square extending all the way to the "***top***" of the atmosphere could be weighed, this column of air would weigh approximately 14.7 pounds at sea level. Thus, atmospheric pressure at sea level is approximately 14.7 psi.

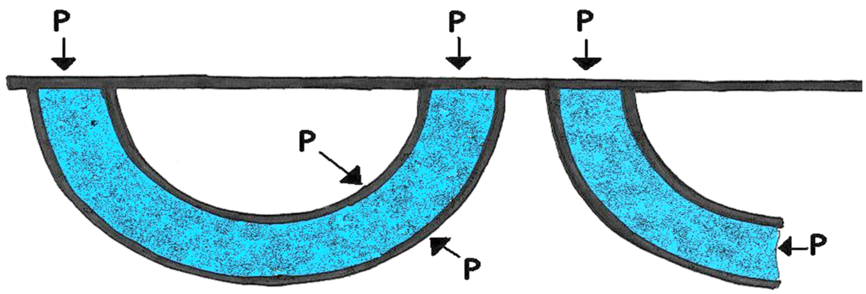
As one ascends, the atmospheric pressure decreases by approximately 1.0 psi for every 2,343 feet. However, below sea level, in excavations and depressions, atmospheric pressure increases. Pressures under water differ from those under air because the weight of the water must be added to the pressure of the air.

Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0° Celsius (**C**), the height of the mercury column is approximately 30 inches, or 76 centimeters. This represents a pressure of approximately 14.7 psi. The 30-inch column is used as a reference standard.

Another device used to measure atmospheric pressure is the aneroid barometer. The aneroid barometer uses the change in shape of an evacuated metal cell to measure variations in atmospheric pressure. The thin metal of the aneroid cell moves in or out with the variation of pressure on its external surface. This movement is transmitted through a system of levers to a pointer, which indicates the pressure.

The atmospheric pressure does not vary uniformly with altitude. It changes very rapidly. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface.

Fluid and Pressure
By a fluid, we have a material in mind like water or air, two very common and important fluids. Water is incompressible, while air is very compressible, but both are fluids. Water has a definite volume; air does not. Water and air have low viscosity; that is, layers of them slide very easily on one another, and they quickly change their shapes when disturbed by rapid flows. Other fluids, such as molasses, may have high viscosity and take a long time to come to equilibrium, but they are no less fluids. The coefficient of viscosity is the ratio of the shearing force to the velocity gradient. Hydrostatics deals with permanent, time-independent states of fluids, so viscosity does not appear.



EQUALITY OF PRESSURE –CURTIAN RINGS DIAGRAM

Pressure Definition
A fluid, therefore, is a substance that cannot exert any permanent forces tangential to a boundary. Any force that it exerts on a boundary must be normal perpendicular to the boundary. Such a force is proportional to the area on which it is exerted, and is called a pressure.

We can imagine any surface in a fluid as dividing the fluid into parts pressing on each other, as if it were a thin material membrane, and so think of the pressure at any point in the fluid, not just at the boundaries. In order for any small element of the fluid to be in equilibrium, the pressure must be the same in all directions (or the element would move in the direction of least pressure), and if no other forces are acting on the body of the fluid, the pressure must be the same at all neighboring points.

Pascal's Principle
Therefore, in this case the pressure will be the same throughout the fluid, and the same in any direction at a point (Pascal's Principle). Pressure is expressed in units of force per unit area such as dyne/cm^2, N/cm^2 (pascal), pounds/in^2 (psi) or pounds/ft^2 (psf). The axiom that if a certain volume of fluid were somehow made solid, the equilibrium of forces would not be disturbed, is useful in reasoning about forces in fluids.

Equality of Pressure
On earth, fluids are also subject to the force of gravity, which acts vertically downward, and has a magnitude $\gamma = \rho g$ per unit volume, where g is the acceleration of gravity, approximately 981 cm/s^2 or 32.15 ft/s^2, ρ is the density, the mass per unit volume, expressed in g/cm^3, kg/m^3, or $slug/ft^3$, and γ is the specific weight, measured in lb/in^3, or lb/ft^3 (pcf).

Atmospheric Pressure and its Effects

Suppose a vertical pipe is stood in a pool of water, and a vacuum pump applied to the upper end. Before we start the pump, the water levels outside and inside the pipe are equal, and the pressures on the surfaces are also equal and are equal to the atmospheric pressure.

Now start the pump. When it has sucked all the air out above the water, the pressure on the surface of the water inside the pipe is zero, and the pressure at the level of the water on the outside of the pipe is still the atmospheric pressure. There is the vapor pressure of the water to worry about if you want to be precise, but we neglect this complication in making our point.

A column of water 33.9 ft. high inside the pipe, with a vacuum above it, to balance the atmospheric pressure is required. If you were to do the same thing with liquid mercury, whose density at 0 °C is 13.5951 times that of water. The height of the column is 2.494 ft., 29.92 in, or 760.0 mm.

Standard Atmospheric Pressure

This definition of the standard atmospheric pressure was established by Regnault back in the mid-19th century. In Great Britain, 30 in. Hg (inches of mercury) had been used previously. As a real-world matter, it is convenient to measure pressure differences by measuring the height of liquid columns, a practice known as manometry.

The barometer is a familiar example of this, and atmospheric pressures are traditionally given in terms of the length of a mercury column. To make a barometer, the barometric tube, closed at one end, is filled with mercury and then inverted and placed in a mercury reservoir.

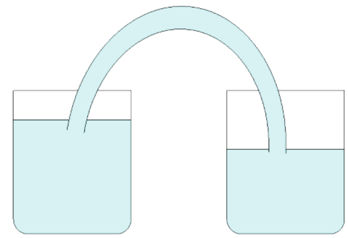
Corrections must be made for temperature, because the density of mercury depends on the temperature, and the brass scale expands for capillarity if the tube is less than about 1 cm in diameter, and even slightly for altitude, since the value of g changes with altitude.

The vapor pressure of mercury is only 0.001201 mmHg at 20°C, so a correction from this source is negligible. For the usual case of a mercury column ($\alpha = 0.000181792$ per °C) and a brass scale (&alpha = 0.0000184 per °C) the temperature correction is -2.74 mm at 760 mm and 20°C.

Before reading the barometer scale, the mercury reservoir is raised or lowered until the surface of the mercury just touches a reference point, which is mirrored in the surface so it is easy to determine the proper position.

An aneroid barometer uses a partially evacuated chamber of thin metal that expands and contracts according to the external pressure. This movement is communicated to a needle that revolves in a dial. The materials and construction are arranged to give a low temperature coefficient. The instrument must be calibrated before use, and is usually arranged to read directly in elevations.

An aneroid barometer is much easier to use in field observations, such as in reconnaissance surveys. In a particular case, it would be read at the start of the day at the base camp, at various points in the vicinity, and then finally at the starting point, to determine the change in pressure with time.



Siphon

The height differences can be calculated from h = 60,360 log (P/p) [1 + (T + t - 64)/986) feet, where P and p are in the same units, and T, t are in °F.

An absolute pressure is referring to a vacuum, while a gauge pressure is referring to the atmospheric pressure at the moment.

A negative gauge pressure is a partial vacuum. When a vacuum is stated to be so many inches, this means the pressure below the atmospheric pressure of about 30 in.

A vacuum of 25 inches is the same thing as an absolute pressure of 5 inches (of mercury).

Vacuum

The term ***vacuum*** indicates that the absolute pressure is less than the atmospheric pressure and that the gauge pressure is negative.

A complete or total vacuum would mean a pressure of 0 psia or –14.7 psig.

Since it is impossible to produce a total vacuum, the term vacuum, as used in this document, will mean all degrees of partial vacuum.

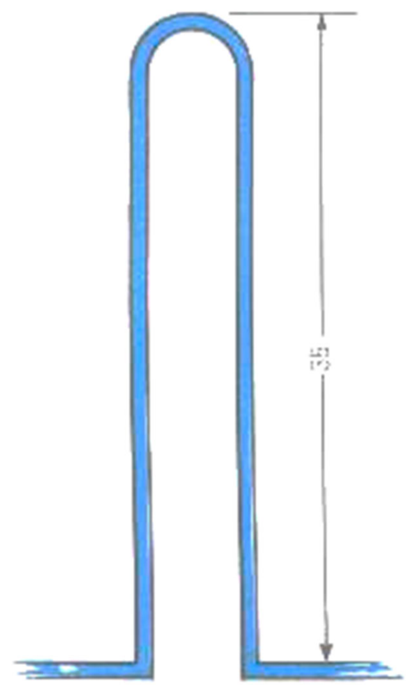
In a partial vacuum, the pressure would range from slightly less than 14.7 psia (0 psig) to slightly greater than 0 psia (-14.7 psig).

Again, backsiphonage results from atmospheric pressure exerted on a liquid, forcing it toward a supply system that is under a vacuum.

Barometric Loop

The barometric loop consists of a continuous section of supply piping that rises to a height of approximately 35 feet and then returns back down to the originating level. It is a loop in the piping system that effectively protects against backsiphonage. It may not be used to protect against backpressure. Backpressure refers to pressure opposed to the desired flow of a fluid in a confined place such as a pipe. It is often caused by obstructions or tight bends in the confinement vessel along which it is moving, such as piping or air vents.

The barometric loop's operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet.



Generally speaking, barometric loops are locally fabricated, and are 35 feet high.

Pressure may be referred to using an absolute scale, pounds per square inch absolute (psia), or gauge scale, (psiag). Absolute pressure and gauge pressure are related.

Absolute pressure is equal to gauge pressure plus the atmospheric pressure.

At sea level, the atmospheric pressure is 14.7 psai.

Absolute pressure is the total pressure.

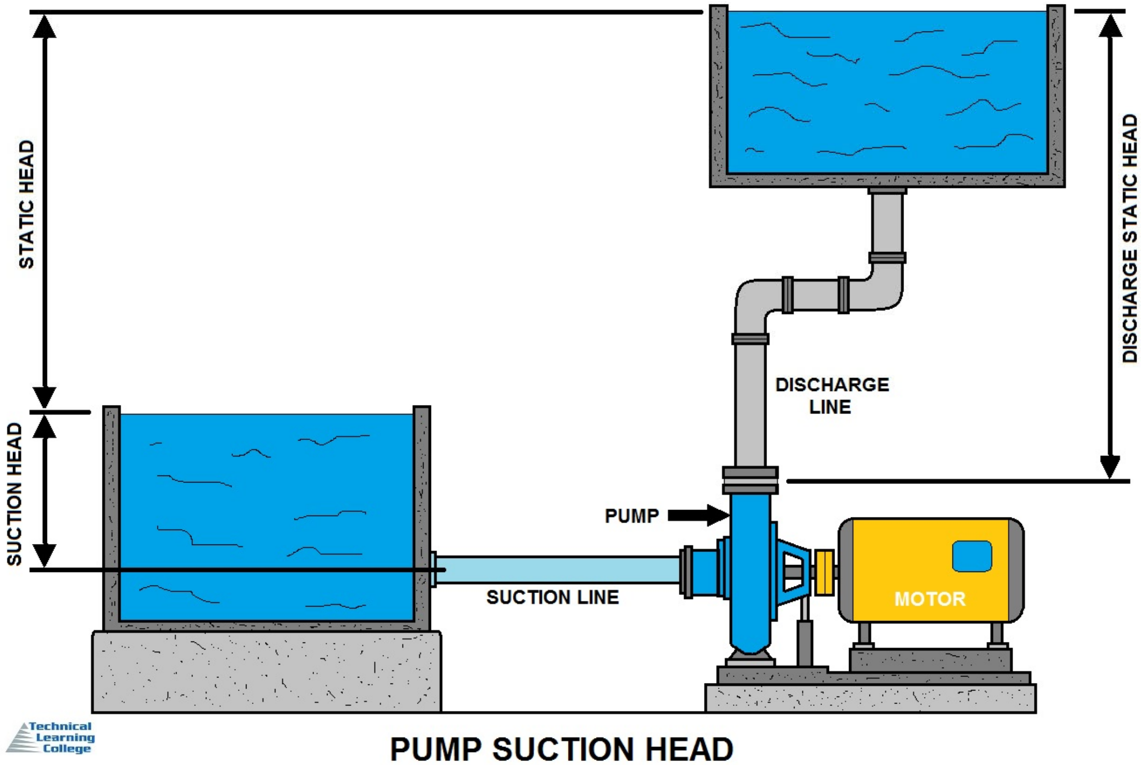
Gauge pressure is simply the pressure read on the gauge. If there is no pressure on the gauge other than atmospheric, the gauge will read zero. Then the absolute pressure would be equal to 14.7 psi, which is the atmospheric pressure.

Barometric Pressure

Generally speaking, barometric pressure, or atmospheric pressure, drops as you go up in elevation. For example, at 18,000 ft. above sea level, the average barometric pressure is about half the average pressure at sea level.

Barometric pressure also varies widely with the weather (weather charts almost always show the movement of low pressure and high pressure zones), so true barometric pressure cannot simply be calculated, but must be measured.

In the United States, the National Oceanic and Atmospheric Administration provides hourly barometric readings for many locations across the country.



PUMP SUCTION HEAD

Pump Suction Head
A **pump**'s **suction head** is similar to its **pump head** except it is the opposite. Rather than being a measure of the maximum discharge, it is a measure of the maximum depth from which a **pump** can raise water via **suction**.

Water Head Pressure
Water head pressure is static pressure caused by the weight of water solely due to its height above the measuring point. The pressure at the bottom of a 30-foot deep lake or a 30-foot high thin tube would be identical, since only height is involved.

The value may be expressed as pounds-per-square-inch (psi) or inches-of-water column pressure (in. W.C. or in.H2O), or metric. This basic calculation is widely used to solve many different practical problems involving water and other liquids of known density.

Water Head Pressure Calculation
Divide the depth in inches by **27.71-inches/psi**, or the depth in feet by 2.31-feet/psi, which are the conversion factors. The result is the water head pressure expressed in psi.

We will cover this area (pressure) in more detail later in the course.

Pressure Sub-Section

Water Pressure

The weight of a cubic foot of water is 62.4 pounds per square foot. The base can be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig. Suppose you placed another cubic foot of water on top of the first cubic foot. The pressure on the top surface of the first cube which was originally atmospheric, or 0 psig, would now be 0.4333 psig as a result of the additional cubic foot of water. The pressure of the base of the first cubic foot would be increased by the same amount of 0.866 psig or two times the original pressure.

Pressures are very frequently stated in terms of the height of a fluid. If it is the same fluid whose pressure is being given, it is usually called "head," and the factor connecting the head and the pressure is the weight density ρg.

In the English engineering system, weight density is in pounds per cubic inch or cubic foot.

A head of 10 ft is equivalent to a pressure of 624 psf, or 4.33 psi. It can also be considered an energy availability of ft-lb per lb.

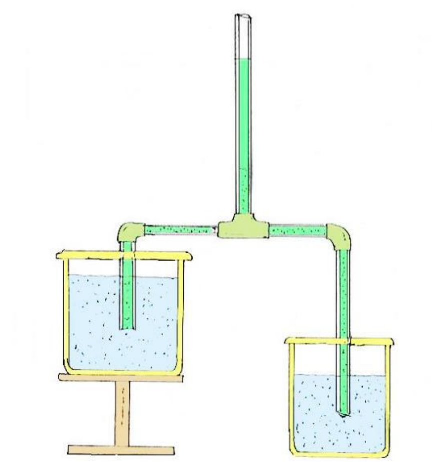
Water with a pressure head of 10 ft can furnish the same energy as an equal amount of water raised by 10 ft. Water flowing in a pipe is subject to head loss because of friction.

Take a jar and a basin of water. Fill the jar with water and invert it under the water in the basin. Raise the jar as far as you can without allowing its mouth to come above the water surface. It is always a little surprising to see that the jar does not empty itself, but the water remains with no visible means of support.

By blowing through a straw, one can put air into the jar, and as much water leaves as air enters. In fact, this is a famous method of collecting insoluble gases in the chemical laboratory, or for supplying hummingbird feeders. It is good to remind oneself of exactly the balance of forces involved.

Another application of pressure is the siphon. The name is Greek for the tube that was used for pulling wine from a cask. This is a tube filled with fluid connecting two containers of fluid, normally rising higher than the water levels in the two containers, at least to pass over their rims.

In the diagram on the right side, the two water levels are the same, so there will be no flow. When a siphon goes below the free water levels, it is called an inverted siphon.



PASCAL'S SIPHON

If the levels in the two basins are not equal, fluid flows from the basin with the higher level into the one with the lower level, until the levels are equal.

A siphon can be made by filling the tube, closing the ends, and then putting the ends under the surface on both sides.

Alternatively, the tube can be placed in one fluid and filled by sucking on it. When it is full, the other end is put in place.

The examination of the siphon is easy, and should be obvious. The pressure rises or falls as described by the barometric equation through the siphon tube.

There is obviously a maximum height for the siphon which is the same as the limit of the suction pump, about 34 feet. Inverted siphons are sometimes used in pipelines to cross valleys.

Differences in elevation are usually too great to use regular siphons to cross hills, so the fluids must be pressurized by pumps so the pressure does not fall to zero at the crests.

Liquids at Rest

In studying fluids at rest, we are concerned with the transmission of force and the factors which affect the forces in liquids. Furthermore, pressure in and on liquids and factors affecting pressure are of great importance.

Pressure and Force

Pressure is the force that pushes water through pipes. Water pressure determines the flow of water from the tap. If pressure is not sufficient then the flow can reduce to a trickle and it will take a long time to fill a kettle or a cistern.

The terms ***force*** and ***pressure*** are used extensively in the study of fluid power. It is essential that we distinguish between the terms.

Force means a total push or pull. It is the push or pull exerted against the total area of a particular surface and is expressed in pounds or grams.

Pressure means the amount of push or pull (force) applied to each unit area of the surface and is expressed in pounds per square inch (lb/in^2) or grams per square centimeter (gm/cm^2).

Pressure maybe exerted in one direction, in several directions, or in all directions.

Other Pressure Terms and Conditions
Everyday pressure measurements, such as for vehicle tire pressure, are usually made relative to ambient air pressure. In other cases measurements are made relative to a vacuum or to some other specific reference. When distinguishing between these zero references, the following terms are used:

- **Absolute pressure** is zero-referenced against a perfect vacuum, using an absolute scale, so it is equal to gauge pressure plus atmospheric pressure.
- **Gauge pressure** is zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure. Negative signs are usually omitted. To distinguish a negative pressure, the value may be appended with the word "vacuum" or the gauge may be labeled a "vacuum gauge". These are further divided into two subcategories: high and low vacuum (and sometimes ultra-high vacuum). The applicable pressure ranges of many of the techniques used to measure vacuums have an overlap. Hence, by combining several different

types of gauge, it is possible to measure system pressure continuously from 10 mbar down to 10^{-11} mbar.

- **Differential pressure** is the difference in pressure between two points.

For most working fluids where a fluid exists in a closed system, gauge pressure measurement prevails. Pressure instruments connected to the system will indicate pressures relative to the current atmospheric pressure. The situation changes when extreme vacuum pressures are measured, then absolute pressures are typically used instead.

Differential pressures are commonly used in industrial process systems. Differential pressure gauges have two inlet ports, each connected to one of the volumes whose pressure is to be monitored. In effect, such a gauge performs the mathematical operation of subtraction through mechanical means, obviating the need for an operator or control system to watch two separate gauges and determine the difference in readings.

Moderate vacuum pressure readings can be ambiguous without the proper context, as they may represent absolute pressure or gauge pressure without a negative sign. Thus a vacuum of 26 inHg gauge is equivalent to an absolute pressure of 4 inHg, calculated as 30 inHg (typical atmospheric pressure) − 26 inHg (gauge pressure).
Atmospheric pressure is typically about 100 kPa at sea level, but is variable with altitude and weather. If the absolute pressure of a fluid stays constant, the gauge pressure of the same fluid will vary as atmospheric pressure changes. For example, when a car drives up a mountain, the (gauge) tire pressure goes up because atmospheric pressure goes down. The absolute pressure in the tire is essentially unchanged.

Using atmospheric pressure as reference is usually signified by a "g" for gauge after the pressure unit, e.g. 70 psig, which means that the pressure measured is the total pressure minus atmospheric pressure. There are two types of gauge reference pressure: vented gauge (vg) and sealed gauge (sg).

Gravitation
Gravitation is an example of a body force that disturbs the equality of pressure in a fluid. The presence of the gravitational body force causes the pressure to increase with depth, according to the equation $dp = \rho g\, dh$, in order to support the water above.

We call this relation the barometric equation, for when this equation is integrated, we find the variation of pressure with height or depth. If the fluid is incompressible, the equation can be integrated at once, and the pressure as a function of depth h is $p = \rho gh + p0$.
The density of water is about 1 g/cm^3, or its specific weight is 62.4 pcf.

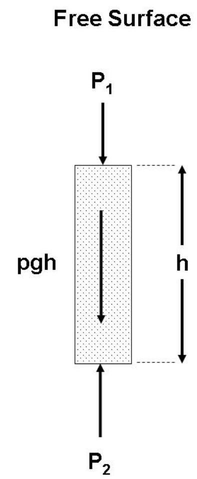
We may ask what depth of water gives the normal sea-level atmospheric pressure of 14.7 psi, or 2117 psf.

This is simply 2117 / 62.4 = 33.9 ft of water. This is the maximum height to which water can be raised by a suction pump, or, more correctly, can be supported by atmospheric pressure.

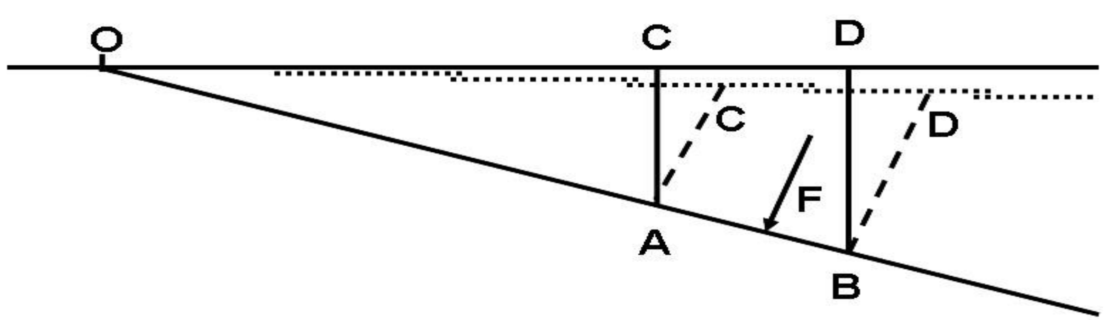
Equality of Pressure
Professor James Thomson (brother of William Thomson, Lord Kelvin) illustrated the equality of pressure by a "curtain-ring" analogy shown in the diagram. A section of the toroid was identified, imagined to be solidified, and its equilibrium was analyzed.

The forces exerted on the curved surfaces have no component along the normal to a plane section, so the pressures at any two points of a plane must be equal, since the fluid represented by the curtain ring was in equilibrium.

The diagrams illustrates the equality of pressures in orthogonal directions. This can be extended to any direction whatever, so Pascal's Principle is established. This demonstration is similar to the usual one using a triangular prism and considering the forces on the end and lateral faces separately.



Increase of Pressure with Depth



THRUST ON A PLANE DIAGRAM

Free Surface Perpendicular to Gravity

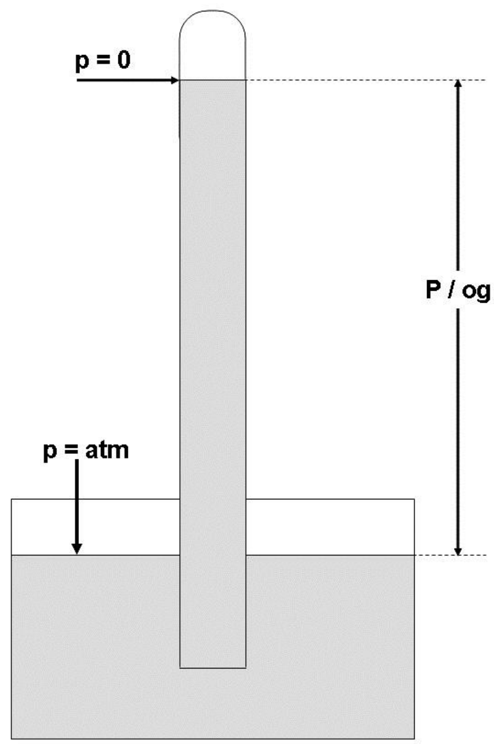
With the action of gravity, a liquid assumes a free surface perpendicular to gravity, which can be proved by Thomson's method. A straight cylinder of unit cross-sectional area (assumed only for ease in the arithmetic) can be used to find the increase of pressure with depth. Definitely, we see that $p2 = p1 + \rho gh$.

The upper surface of the cylinder can be placed at the free surface if desired. The pressure is now the same in any direction at a point, but is greater at points that lie deeper.

From this calculation, it is easy to prove Archimedes' Principle that the buoyant force is equal to the weight of the displaced fluid, and passes through the center of mass of this displaced fluid.

Geometric Arguments

Creative geometric arguments can be used to substitute for easier, but less transparent arguments using calculus.



Barometer

One example, the force acting on one side of an inclined plane surface whose projection is AB can be found as in the diagram on the previous page.

O is the point at which the prolonged projection intersects the free surface.

The line AC' perpendicular to the plane is made equal to the depth AC of point A, and line BD' is similarly drawn equal to BD.

The line OD' also passes through C', by proportionality of triangles OAC' and OAD'.

Therefore, the thrust F on the plane is the weight of a prism of fluid of cross-section AC'D'B, passing through its centroid normal to plane AB.

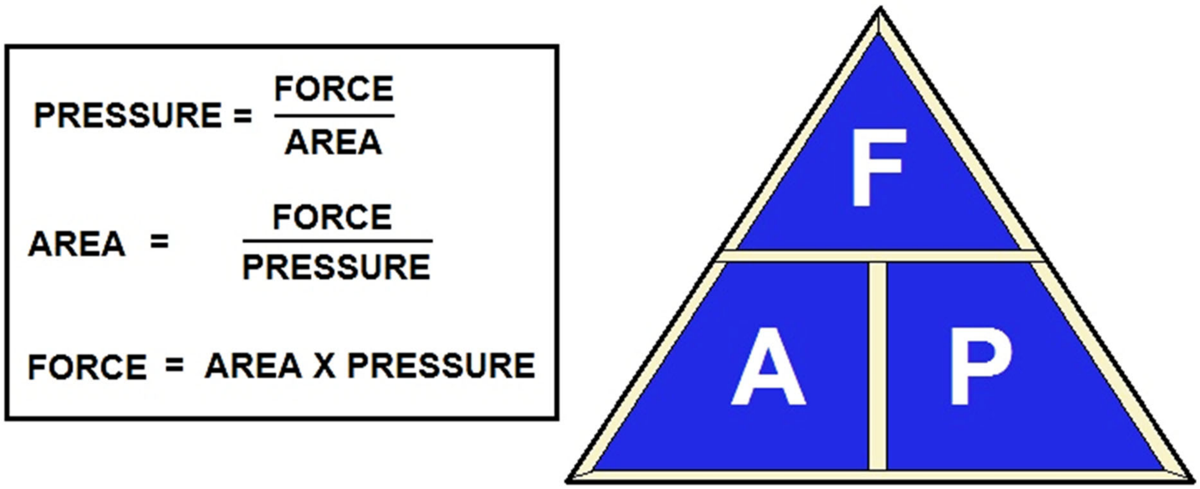
Note that the thrust is equal to the density times the area times the depth of the center of the area; its line of action does not pass through the center, but below it, at the center of thrust.

The same result can be obtained with calculus by summing the pressures and the moments.

Computing Force, Pressure, and Area

A formula is used in computing force, pressure, and area in fluid power systems. In this formula, P refers to pressure, F indicates force, and A represents area. Force equals pressure times area.

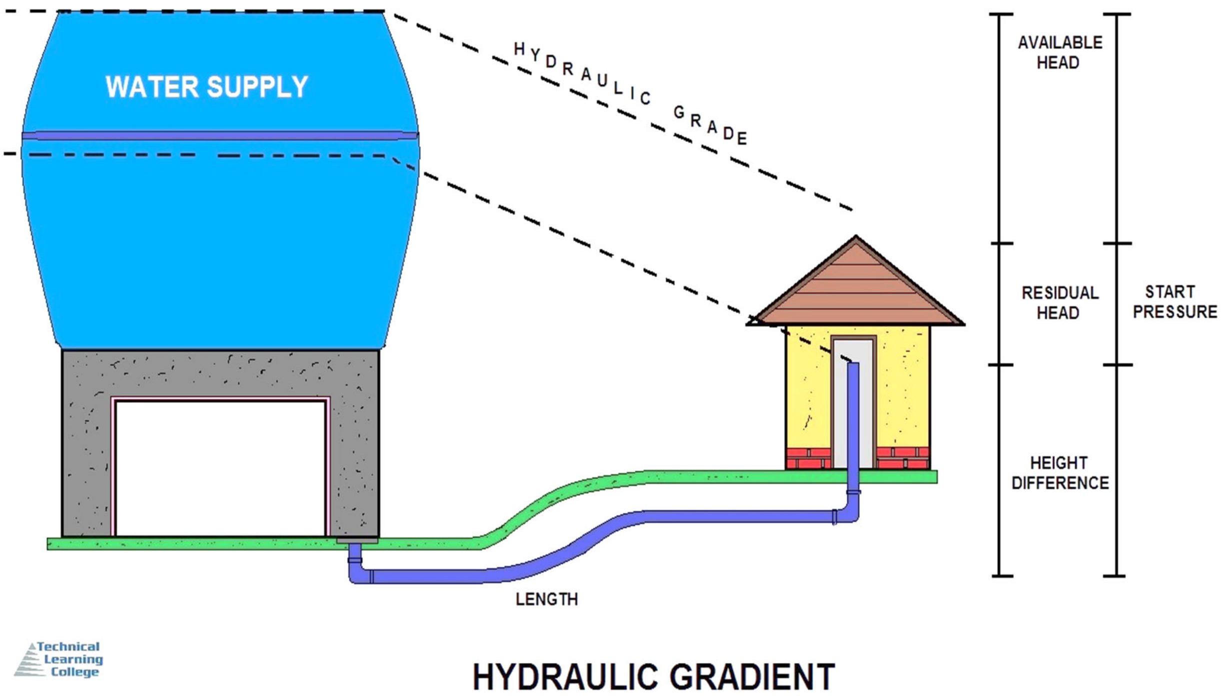
Therefore, the formula is written:



FORMULAS TO CALCULATE FORCE, AREA & PRESSURE

Hydraulic Gradient

The hydraulic gradient is a **vector gradient between two or more hydraulic head measurements over the length of the flow path**. For groundwater, it is also called the 'Darcy slope', since it determines the quantity of a Darcy flux or discharge.



What is Static Pressure?

Static pressure is the **pressure when water is motionless**. In a closed level piping system, the static pressure is the same at every point. There are two ways to create static pressure, by elevating water in tanks and reservoirs above where the water is needed and by utilizing a pump.

Quick Definitions

Water Pressure

The **force of water pushing on a unit area**, usually measured in pounds per square inch (psi).

Static Water Pressure

Water pressure, measured in psi, at the service line when there is not any water running.

Residual Water Pressure

Water pressure at the service line when faucets are running.

A Pressure of 1 atm can also be Stated as:

≡ 1.01325 bar
≡ 101325 pascal (Pa) or 101.325 kilopascal (kPa)
≡ 1013.25 millibars (mbar, also mb)
≡ 760 torr
≈ 760.001 mm-Hg, 0 °C, subject to revision as more precise measurements of mercury's density become available
≈ 29.9213 in-Hg, 0 °C, subject to revision as more precise measurements of mercury's density become available
≈ 1.033 227 452 799 886 kgf/cm²
≈ 1.033 227 452 799 886 technical atmosphere
≈ 1033.227 452 799 886 cm–H_2O, 4 °C
≈ 406.782 461 732 2385 in–H_2O, 4 °C
≈ 14.695 948 775 5134 pounds-force per square inch (psi)
≈ 2116.216 623 673 94 pounds-force per square foot (psf)
= 1 ata (atmosphere absolute).

The ata unit is used in place of atm to indicate that the pressure shown is the total ambient pressure, compared to vacuum, of the system being calculated or measured. For example, for underwater pressures, a pressure of 3.1 ata would mean that the 1 atm of the air above water is included in this value and the pressure due to water would total 2.1 atm.

Notes:

1. Torr and mm-Hg, 0°C are often taken to be identical. For most practical purposes (to 5 significant digits), they are interchangeable.
2. This is the customarily accepted value for cm–H_2O, 4 °C. It is precisely the product of 1 kg-force per square centimeter (one technical atmosphere) times 1.013 25 (bar/atmosphere) divided by 0.980 665 (one gram-force). It is not accepted practice to define the value for water column based on a true physical realization of water (which would be 99.997 495% of this value because the true maximum density of Vienna Standard Mean Ocean Water is 0.999 974 95 kg/l at 3.984 °C). Also, this "physical realization" would *still* ignore the 8.285 cm–H_2O reduction that would actually occur in a true physical realization due to the vapor pressure over water at 3.984 °C.
3. NIST value of 13.595 078(5) g/ml assumed for the density of Hg at 0 °C

Fluid/Hydraulic Forces & Pressures Post Quiz

Barometric Loop
1. Its operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above ___________ feet.

2. Absolute pressure is the ____ pressure.

3. Which term is an example of a body force that disturbs the equality of pressure in a fluid?

Standard Atmospheric Pressure
4. An absolute pressure is referring to a vacuum, while a ___________ pressure is referring to the atmospheric pressure at the moment.

Vacuum
5. A complete or total vacuum would mean a pressure of 0 psia or __________ psig.

Water Pressure
6. The weight of a cubic foot of water is _______ pounds per square foot.

Pressure and Force
7. Pressure is the __________ that pushes water through pipes. Water pressure determines the flow of water from the tap.

8. Which term means a total push or pull?

9. Pressure means the amount of push or pull (force) applied to each unit area of the ________ and is expressed in pounds per square inch (lb/in^2) or grams per square centimeter (gm/cm^2).

10. Which term maybe exerted in one direction, in several directions, or in all directions?

Answers 1. 33.9, 2. Total, 3. Gravitation, 4. Gauge, 5. –14.7, 6. 62.4, 7. Force, 8. Force, 9. Surface, 10. Pressure

Fluid/Hydraulic Forces & Pressures References

"Fermions & Bosons". The Particle Adventure.
"Introduction to Free Body Diagrams". Physics Tutorial Menu. University of Guelph. Archived from the original on 2008-01-16.
"Powerful New Black Hole Probe Arrives at Paranal".
"Seminar: Visualizing Special Relativity". The Relativistic Raytracer.
"Sir Isaac Newton: The Universal Law of Gravitation". Astronomy 161 The Solar System. Retrieved 2008-01-04.
"Standard model of particles and interactions". Contemporary Physics Education Project. 2000. Retrieved 2 January 2017.
"Static Equilibrium". Physics Static Equilibrium (forces and torques). University of the Virgin Islands. Archived from the original on October 19, 2007. Retrieved 2008-01-02.
"Tension Force". Non-Calculus Based Physics I.
A quick derivation relating altitude to air pressure Archived 2011-09-28 at the Wayback Machine. by Portland State Aerospace Society, 2004, accessed 05032011
Berberan-Santos, M. N.; Bodunov, E. N.; Pogliani, L. (1997). "On the barometric formula". American Journal of Physics. 65 (5): 404–412. Bibcode:1997AmJPh..65..404B. doi:10.1119/1.18555.
BIPM Definition of the standard atmosphere
C. Hellingman (1992). "Newton's third law revisited". Phys. Educ. 27 (2): 112–115. Bibcode:1992PhyEd.27..112H. doi:10.1088/0031-9120/27/2/011. Quoting Newton in the Principia: It is not one action by which the Sun attracts Jupiter, and another by which Jupiter attracts the Sun; but it is one action by which the Sun and Jupiter mutually endeavor to come nearer together.
Chris Landsea (2010-04-21). "Subject: E1), Which is the most intense tropical cyclone on record?". Atlantic Oceanographic and Meteorological Laboratory. Archived from the original on 6 December 2010. Retrieved 2010-11-23.
Cook, A. H. (1965). "A New Absolute Determination of the Acceleration due to Gravity at the National Physical Laboratory". Nature. 208 (5007): 279. Bibcode:1965Natur.208..279C. doi:10.1038/208279a0.
Coulomb, Charles (1784). "Recherches théoriques et expérimentales sur la force de torsion et sur l'élasticité des fils de metal". Histoire de l'Académie Royale des Sciences: 229–269.
Cutnell & Johnson 2003
Davis, Doug. "Conservation of Energy". General physics. Retrieved 2008-01-04.
Dr. Nikitin (2007). "Dynamics of translational motion". Retrieved 2008-01-04.
Drake, Stillman (1978). Galileo At Work. Chicago: University of Chicago Press. ISBN 0-226-16226-5
Duffin, William (1980). Electricity and Magnetism, 3rd Ed. McGraw-Hill. pp. 364–383. ISBN 0-07-084111-X.
Feynman volume 1- Feynman volume 2
Fitzpatrick, Richard (2006-02-02). "Strings, pulleys, and inclines".
Fitzpatrick, Richard (2007-01-07). "Newton's third law of motion".
Heath, T.L. "The Works of Archimedes (1897). The unabridged work in PDF form (19 MB)". Internet Archive. Retrieved 2007-10-14.
Henderson, Tom (2004). "The Physics Classroom". The Physics Classroom and Mathsoft Engineering & Education, Inc. Archived from the original on 2008-01-01.

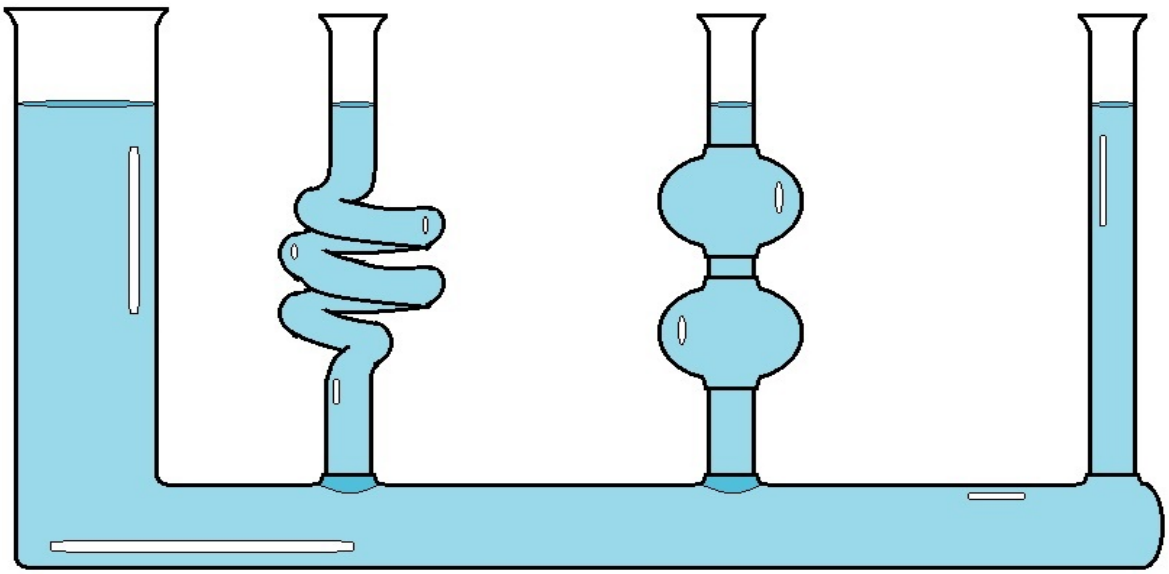
Hetherington, Norriss S. (1993). Cosmology: Historical, Literary, Philosophical, Religious, and Scientific Perspectives. Garland Reference Library of the Humanities. p. 100. ISBN 0-8153-1085-4.
Hewitt, Rachel, Map of a Nation – a Biography of the Ordnance Survey ISBN 1-84708-098-7
Hibbeler, Russell C. (2010). Engineering Mechanics, 12th edition. Pearson Prentice Hall. p. 222. ISBN 0-13-607791-9.
High Altitude Cooking, Crisco.com, 2010-09-30.
Howland, R. A. (2006). Intermediate dynamics a linear algebraic approach (Online-Ausg. ed.). New York: Springer. pp. 255–256. ISBN 9780387280592.
International Civil Aviation Organization. Manual of the ICAO Standard Atmosphere, Doc 7488-CD, Third Edition, 1993. ISBN 92-9194-004-6.
IUPAC.org, Gold Book, Standard Pressure
Jammer, Max (1999). Concepts of force: a study in the foundations of dynamics (Facsim. ed.). Mineola, N.Y.: Dover Publications. pp. 220–222. ISBN 9780486406893.
Kleppner & Kolenkow 2010
Kollerstrom, Nick (2001). "Neptune's Discovery. The British Case for Co-Prediction". University College London. Archived from the original on 2005-11-11. Retrieved 2007-03-19.
Kramer, MR; Springer C; Berkman N; Glazer M; Bublil M; Bar-Yishay E; Godfrey S (March 1998). "Rehabilitation of hypoxemic patients with COPD at low altitude at the Dead Sea, the lowest place on earth" (PDF). Chest. 113 (3): 571–575. doi:10.1378/chest.113.3.571. PMID 9515826. Archived from the original (PDF) on 2013-10-29. PMID 9515826
Lang, Helen S. (1998). The order of nature in Aristotle's physics: place and the elements (1. publ. ed.). Cambridge: Cambridge Univ. Press. ISBN 9780521624534.
Mallette, Vincent (1982–2008). "Inwit Publishing, Inc. and Inwit, LLC – Writings, Links and Montreal Current Weather, CBC Montreal, Canada.
Nave, C. R. (2014). "Force". Hyperphysics. Dept. of Physics and Astronomy, Georgia State University.
Nave, Carl Rod. "Centripetal Force". HyperPhysics. University of Guelph.
Nave, Carl Rod. "Elasticity". HyperPhysics. University of Guelph.
Nave, Carl Rod. "Newton's 2nd Law: Rotation". HyperPhysics. University of Guelph.
Nave, Carl Rod. "Pauli Exclusion Principle". HyperPhysics. University of Guelph. Retrieved 2013-10-28.
Newton, Isaac (1999). The Principia Mathematical Principles of Natural Philosophy. Berkeley: University of California Press. ISBN 0-520-08817-4. This is a recent translation into English by I. Bernard Cohen and Anne Whitman, with help from Julia Budenz.
Noll, Walter (April 2007). "On the Concept of Force" (pdf). Carnegie Mellon University. Retrieved 28 October 2013.
One exception to this rule is: Landau, L. D.; Akhiezer, A. I.; Lifshitz, A. M. (196). General Physics; mechanics and molecular physics (First English ed.). Oxford: Pergamon Press. ISBN 0-08-003304-0. Translated by: J. B. Sykes, A. D. Petford, and C. L. Petford. Library of Congress Catalog Number 67-30260. In section 7, pages 12–14, this book defines force as dp/dt.
Sample METAR of CYVR Nav Canada
Scharf, Toralf (2007). Polarized light in liquid crystals and polymers. John Wiley and Sons. p. 19. ISBN 0-471-74064-0. , Chapter 2, p. 19
Shifman, Mikhail (1999). ITEP lectures on particle physics and field theory. World Scientific. ISBN 981-02-2639-X.
Siegel, Ethan (20 May 2016). "When Did Isaac Newton Finally Fail?". Forbes. Retrieved 3 January 2017.

Singh, Sunil Kumar (2007-08-25). "Conservative force". Connexions. Retrieved 2008-01-04.
Software Distributions – The Coriolis Force". Publications in Science and Mathematics, Computing and the Humanities. Inwit Publishing, Inc. Retrieved 2008-01-04.
Stevens, Tab (10 July 2003). "Quantum-Chromodynamics: A Definition – Science Articles". The Science Realm: John's Virtual Sci-Tech Universe.
Young, Hugh; Freedman, Roger; Sears, Francis and Zemansky, Mark (1949) University Physics. Pearson Education. pp. 59–82
University Physics, Sears, Young & Zemansky, pp.18–38
Vapour Pressure, Hyperphysics.phy-astr.gsu.edu.
Wandmacher, Cornelius; Johnson, Arnold (1995). Metric Units in Engineering. ASCE Publications. p. 15. ISBN 0-7844-0070-9.
Watkins, Thayer. "Perturbation Analysis, Regular and Singular". Department of Economics. San José State University.
Weinberg, S. (1994). Dreams of a Final Theory. Vintage Books USA. ISBN 0-679-74408-8.
Wilson, John B. "Four-Vectors (4-Vectors) of Special Relativity: A Study of Elegant Physics".
World: Highest Sea Level Air Pressure Above 750 m, Wmo.asu.edu, 2001-12-19.
World: Highest Sea Level Air Pressure Below 750 m, Wmo.asu.edu, 1968-12-31.

Section 4 – Experiments and Early Applications

Section Focus: You will learn the history of hydraulic principle theories and pumps. At the end of this section, you the student will be able to describe simple hydraulic theories and the start of modern pumping principles. There is a post quiz at the end of this section to review your comprehension and a final examination in the Assignment for your contact hours.

Scope/Background: You will be able to explain various and commonly found water/fluid mechanic related components and principles**.** In order to understand how pumps operate or to manufacture a simple pump or to calculate pumping raters or flow rates, we need to master this area of engineering.



PRESSURE IN LIQUIDS

PASCAL'S VASES DEMONSTRATE THE FACT THAT THE PRESSURE OF THE LIQUID DEPENDS SOLELY ON THE DEPTH ALONE, AND NOT THE VOLUME OR THE SHAPE OF THE FLUID

Pascal's Vases

A liquid in a number of different shaped communicating vessels will find the same level in each. The pressure at the bottom of the fluid depends upon the depth of the fluid and not on the shape of the container. The apparatus consists of a group of glass flasks of assorted shape (see *above diagram*) linked at their base by a communal reservoir. With the pressure being dependent on the depth of liquid only, an equilibrium situation must have the surface level in each vase equal. This proves pressure depends on depth only and not on the shape of the vessel. The reservoir on the right is adjusted for the same level of fluid in each "vase", and the gauge reads the corresponding pressure.

Early Hydraulic Foundations

Many of these devices or methods are still in use today.

Ancient public toilet with running water.

Ancient Rome

In Ancient Rome, many different hydraulic applications were developed, including public water supplies, innumerable aqueducts, power using watermills and hydraulic mining. They were among the first to make use of the siphon to carry water across valleys, and used hushing on a large scale to prospect for and then extract metal ores. They used lead widely in plumbing systems for domestic and public supply, such as feeding thermae.

Hydraulic mining was used in the gold-fields of northern Spain, which was conquered by Augustus in 25 BC. The alluvial gold-mine of Las Medulas was one of the largest of their mines. It was worked by at least 7 long aqueducts, and the water streams were used to erode the soft deposits, and then wash the tailings for the valuable gold content.

Ancient Greek

The Greeks constructed sophisticated water and hydraulic power systems. An example is the construction by Eupalinos, under a public contract, of a watering channel for Samos, the Tunnel of Eupalinos. An early example of the usage of hydraulic wheel, probably the earliest in Europe, is the Perachora wheel (3rd century BC).

The construction of the first hydraulic automata by Ctesibius (flourished c. 270 BC) and Hero of Alexandria (c. 10 – 80 AD) is notable. Hero describes a number of working machines using hydraulic power, such as the force pump, which is known from many Roman sites as having been used for raising water and in fire engines.

Experiments and Early Applications Key Terms

Archimedes' Principle
Archimedes' principle indicates that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces and it acts in the upward direction at the center of mass of the displaced fluid. Archimedes' principle is a law of physics fundamental to fluid mechanics.

Buoyancy
In physics, **buoyancy** or **upthrust**, is an upward force exerted by a fluid that opposes the weight of an immersed object. In a column of fluid, pressure increases with depth as a result of the weight of the overlying fluid. Thus the pressure at the bottom of a column of fluid is greater than at the top of the column. Similarly, the pressure at the bottom of an object submerged in a fluid is greater than at the top of the object. This pressure difference results in a net upwards force on the object. The magnitude of that force exerted is proportional to that pressure difference, and (as explained by Archimedes' principle) is equivalent to the weight of the fluid that would otherwise occupy the volume of the object, i.e. the displaced fluid.

Coriolis Force
An effect whereby a mass moving in a rotating system experiences a force (the Coriolis force) acting perpendicular to the direction of motion and to the axis of rotation. On the earth, the effect tends to deflect moving objects to the right in the northern hemisphere and to the left in the southern and is important in the formation of cyclonic weather systems.

Electrolysis
In chemistry and manufacturing, electrolysis is a technique that uses a direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction. Electrolysis is commercially important as a stage in the separation of elements from naturally occurring sources such as ores using an electrolytic cell.

Galileo's Thermometer
A Galileo thermometer (or Galilean thermometer) is a thermometer made of a sealed glass cylinder containing a clear liquid and several glass vessels of varying densities. As the temperature changes, the individual floats rise or fall in proportion to their respective density.

Hydrometer
A hydrometer is an instrument that measures the specific gravity (relative density) of liquids—the ratio of the density of the liquid to the density of water. A hydrometer is usually made of glass, and consists of a cylindrical stem and a bulb weighted with mercury or lead shot to make it float upright.

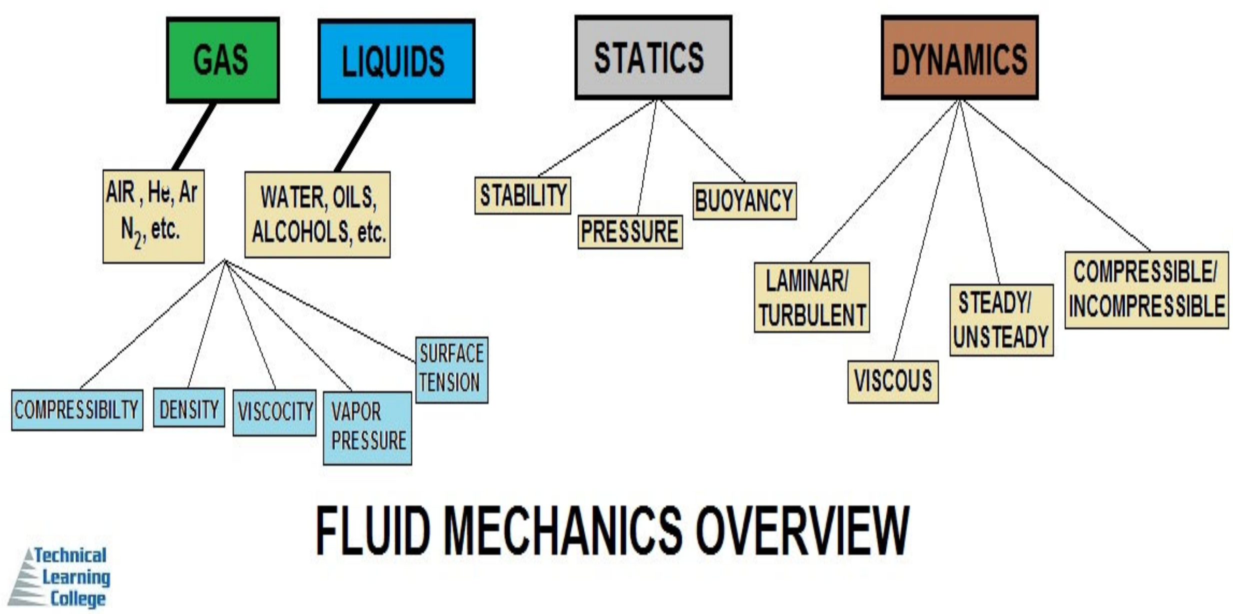
Hydrostatic Paradox
The hydrostatic paradox arises from our failure to accept, at first sight, the conclusion published by Blaise Pascal in 1663: the pressure at a certain level in a fluid is proportional to the *vertical* distance to the surface of the liquid.

Isobar(s)
Isobar may refer to:
- Isobar (meteorology), a line connecting points of equal atmospheric pressure
- Isobaric process, a process taking place at constant pressure
- Isobar (nuclide), one of multiple nuclides with the same mass but with different numbers of protons (or, equivalently, different numbers of neutrons).

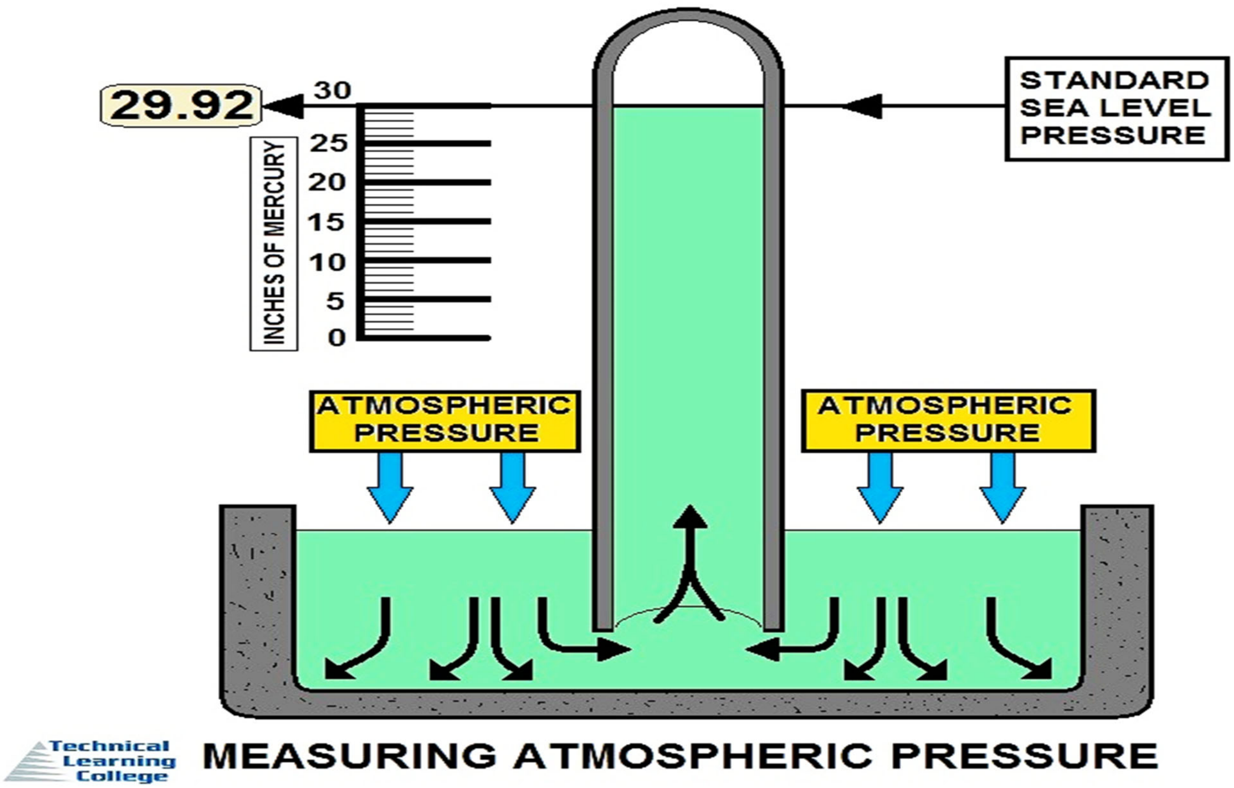
Meteorology
Meteorology is a branch of the atmospheric sciences which includes atmospheric chemistry and atmospheric physics, with a major focus on weather forecasting. The study of meteorology dates back millennia, though significant progress in meteorology did not occur until the 18th century. The 19th century saw modest progress in the field after weather observation networks were formed across broad regions. Prior attempts at prediction of weather depended on historical data. It wasn't until after the elucidation of the laws of physics and, more particularly, the development of the computer, allowing for the automated solution of a great many equations that model the weather, in the latter half of the 20th century that significant breakthroughs in weather forecasting were achieved.

Pycnometer
A standard container of accurately defined volume used to determine the relative density of liquids and solids.

Specific Gravity
Specific gravity is the ratio of the density of a substance to the density of a reference substance; equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume. Apparent specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance.



Modern Applications of Ancient Technology



Meteorology

The study of atmospheric pressure is of great importance in meteorology. Atmospheric pressure determines the winds, which generally move at right angles to the direction of the most rapid change of pressure, that is, along the isobars, which are contours of constant pressure.

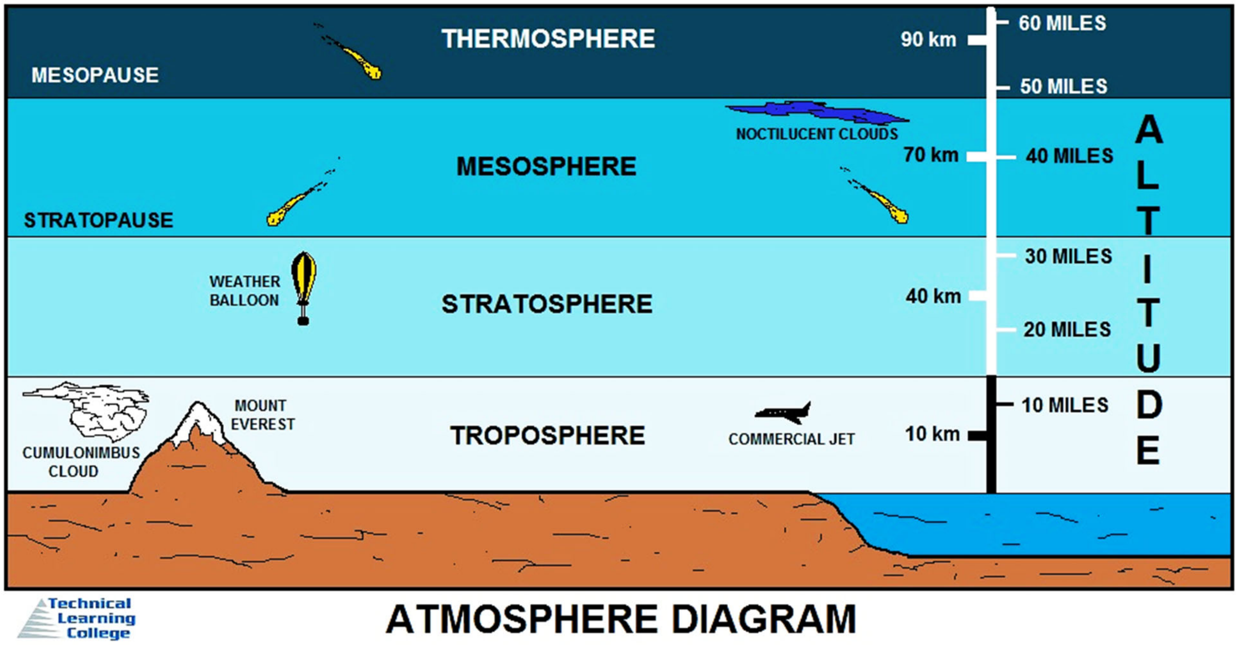
Certain characteristic weather patterns are associated with relatively high and relatively low pressures, and how they vary with time. The barometric pressure may be given in popular weather forecasts, though few people know what to do with it.

If you live at a high altitude, your local weather reporter may report the pressure to be, 29.2 inches, but if you have a real barometer, you may well find that it is closer to 25 inches. At an elevation of 1500 m (near Denver, or the top of the Puy de Dôme), the atmospheric pressure is about 635 mm, and water boils at 95 °C.

Actually, altitude is quite a problem in meteorology, since pressures must be measured at a common level to be meaningful.

The barometric pressures quoted in the weather report are reduced to sea level by standard formulas that amount to assuming that there is a column of air from your feet to sea level with a certain temperature distribution, and adding the weight of this column to the actual barometric pressure.

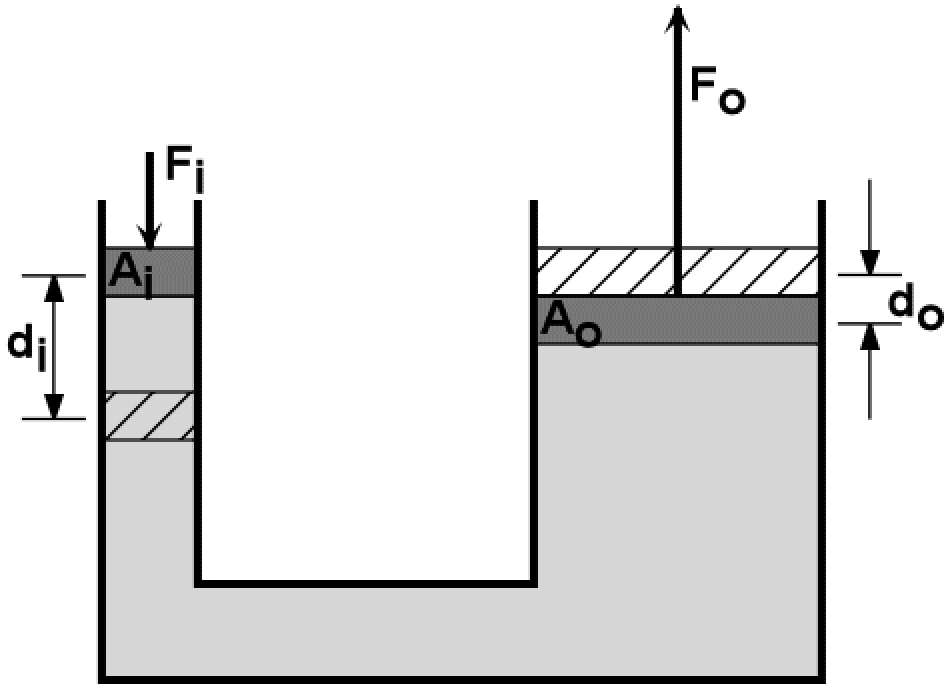
This is only an arbitrary 'fix' and leads to some strange conclusions, such as the permanent winter highs above high plateaus that are really imaginary.



ATMOSPHERE DIAGRAM

The Hydraulic Lever

Hydraulic systems use an incompressible fluid, such as oil or water, to transmit forces from one location to another within the fluid. Most aircraft use hydraulics in the braking systems and landing gear.



The hydraulic lever is a cylinder and piston is a chamber of variable volume, a mechanism for transforming pressure to force.

If A is the area of the cylinder, and p the pressure of the fluid in it, then F = pA is the force on the piston. If the piston moves outwards a distance dx, then the change in volume is dV = A dx.

The work done by the fluid in this displacement is dW = F dx = pA dx = p dV. If the movement is slow enough that inertia and viscosity forces are negligible, then hydrostatics will still be valid.

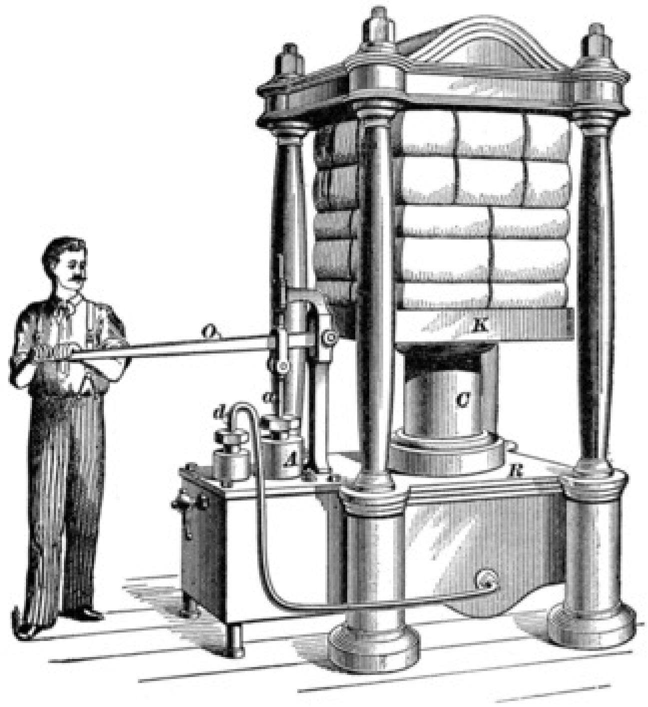
A process for which this is true is called quasi-static. Now consider two cylinders, possibly of different areas A and A', connected with each other and filled with fluid. For simplicity, suppose that there are no gravitational forces.

Then the pressure is the same, p, in both cylinders. If the fluid is incompressible, then dV + dV' = 0, so that dW = p dV + p dV' = F dx + F' dx' = 0.

This says the work done on one piston is equal to the work done by the other piston: the conservation of energy.

The ratio of the forces on the pistons is F' / F = A' / A, the same as the ratio of the areas, and the ratios of the displacements dx' / dx = F / F' = A / A' is in the inverse ratio of the areas. This mechanism is the hydrostatic analogue of the lever, and is the basis of hydraulic activation.

Bramah Hydraulic Press



The most famous application of the hydraulic press/lever principle is the Bramah hydraulic press, invented by Joseph Bramah (1748-1814), who also invented many other useful machines, including a lock and a toilet.

Today, it was not very remarkable to see the possibility of a hydraulic press. It was difficult to find a way to seal the large cylinder properly. This was the crucial problem that Bramah solved by his leather seal that was held against the cylinder and the piston by the hydraulic pressure itself.

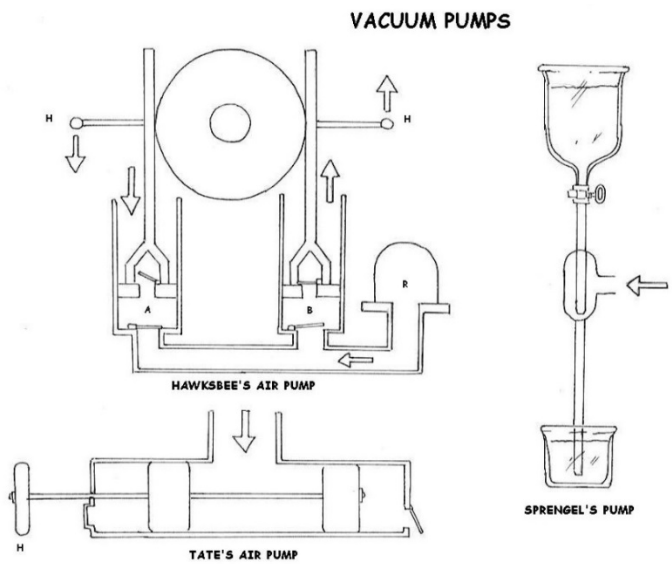
In the presence of gravity, $p' = p + \rho gh$, where h is the difference in elevation of the two cylinders.

Now, $p' dV' = -dV (p + \rho gh) =-p\ dV - (\rho\ dV)\ gh$, or the net work done in the process is $p' dV' + p\ dV = -dM\ gh$, where dM is the mass of fluid displaced from the lower cylinder to the upper cylinder.

Once more, energy is conserved if we take into account the potential energy of the fluid. Pumps are seen to fall within the province of hydrostatics if their operation is quasi-static, which means that dynamic or inertia forces are insignificant.

Dudley Castle Engine

The first operating engine may have been erected in Cornwall in 1710, but the Dudley Castle engine of 1712 is much better known and thoroughly documented. The first pumps used in Cornwall were called bucket pumps, which we know now as lift pumps, with the pistons somewhat miscalled buckets.



These pumped on the up-stroke, when a clack in the bottom of the pipe opened and allowed water to enter beneath the piston. At the same time, the piston lifted the column of water above it, which could be of any length. The piston could only "suck" water 33 ft., or 28 ft. more practically, of course, but this occurred at the bottom of the shaft, so this was only a limit on the piston stroke.

On the down stroke, a clack in the bucket opened, allowing it to sink through the water to the bottom, where it would be ready to make another lift. More satisfactory were the plunger pumps, also placed at the bottom of the shaft.

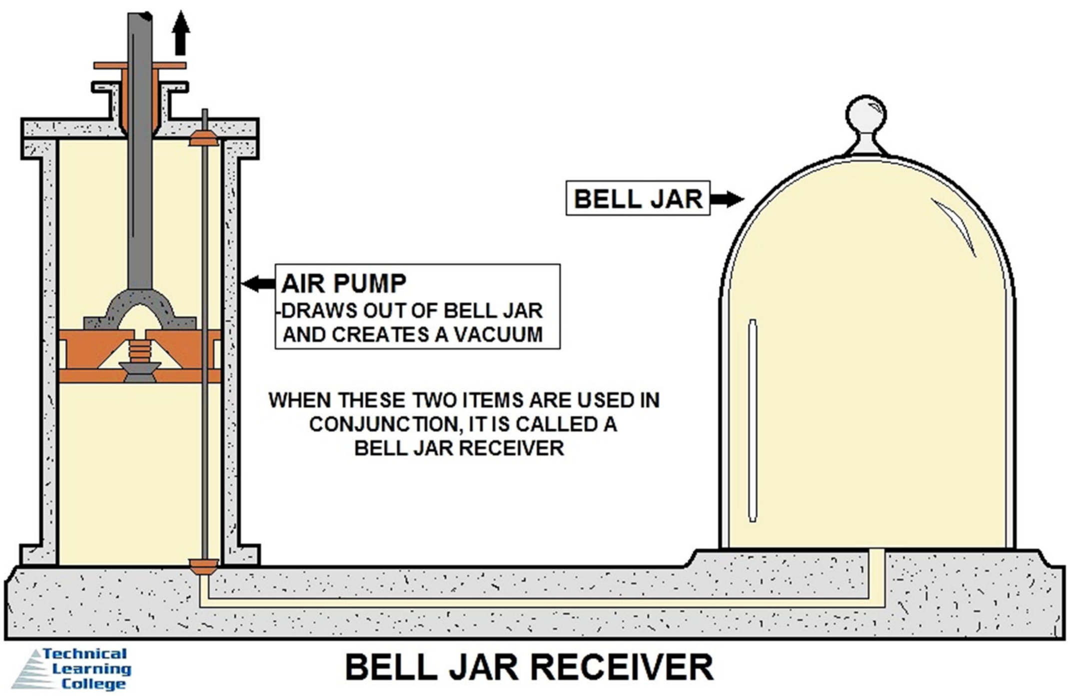
A plunger displaced volume in a chamber, forcing the water in it through a check valve up the shaft, when it descended. When it rose, water entered the pump chamber through a clack, as in the bucket pump.

Only the top of the plunger had to be packed; it was not necessary that it fit the cylinder accurately. In this case, the engine at the surface lifted the heavy pump rods on the up-stroke. When the atmospheric engine piston returned, the heavy timber pump rods did the actual pumping, borne down by their weight. A special application for pumps is to produce a vacuum by exhausting a container, called the receiver.

Hawksbee's Dual Cylinder Pump

Hawksbee's dual cylinder pump, designed in the 18th century, is the final form of the air pump invented by Guericke by 1654.

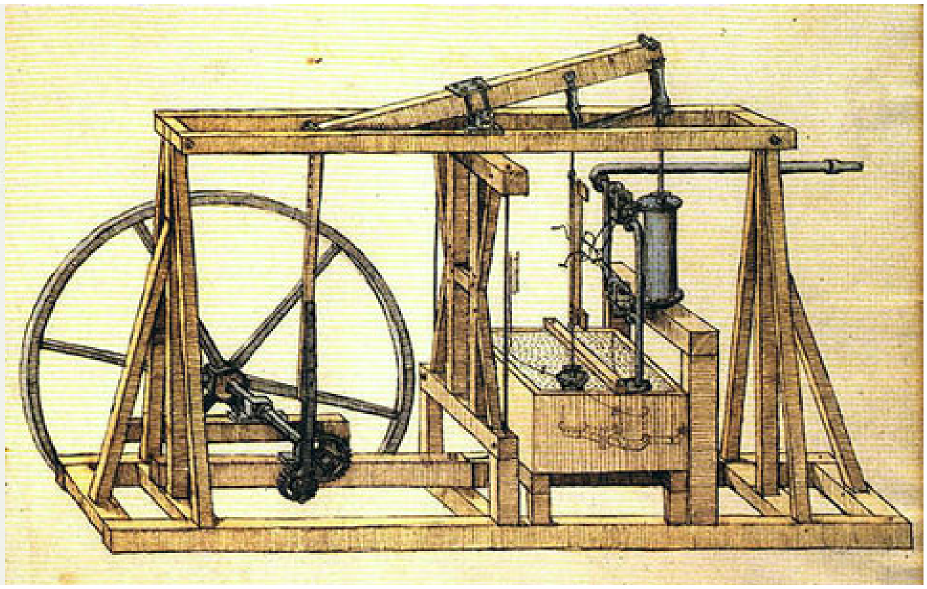
It is a useful and good pump could probably reach about 5-10 mmHg, the limit set by the valves. The cooperation of the cylinders made the pump much easier to work when the pressure was low. In the diagram, piston A is descending, helped by the partial vacuum remaining below it, while piston B is rising, filling with the low-pressure air from the receiver.



BELL JAR RECEIVER

Bell-Jar Receiver

The bell-jar receiver, invented by Huygens, a cumbersome globe was the usual receiver. Tate's air pump is a 19th century pump that would be used for simple vacuum demonstrations and for utility purposes in the lab. It has no valves on the low-pressure side, just exhaust valves V, V', so it could probably reach about 1 mmHg. It is operated by pushing and pulling the handle H. At the present day, motor-driven rotary-seal pumps sealed by running in oil are used for the same purpose. Below on the left is Sprengel's pump, with the valves replaced by drops of mercury.



Small amounts of gas are trapped at the top of the fall tube as the mercury drops, and moves slowly down the fall tube as mercury is steadily added, coming out at the bottom carrying the air with it. The length of the fall tube must be greater than the barometric height, of course.

Theoretically, a vacuum of about 1 µm can be obtained with a Sprengel pump, but it is very slow and can only evacuate small volumes. Later, Langmuir's mercury diffusion pump, which was much faster, replaced Sprengel pumps, and led to oil diffusion pumps that can reach very high vacua. The column of water or hydrostatic engine is the inverse of the force pump, used to turn a large head (pressure) of water into rotary motion. It looks like a steam engine, with valves operated by valve gear, but of course is not a heat engine and can be of high efficiency.

However, it is not of as high efficiency as a turbine, and is much more complicated, but has the advantage that it can be operated at variable speeds, as for lifting. A few very impressive column of water engines were made in the 19th century, but they were never popular and remained rare. Richard Trevithick, famous for high pressure steam engines, also built hydrostatic engines in Cornwall.

The drawing on the top right shows a column-of-water engine built by Georg von Reichenbach, and placed in service in 1917. It was used to pump brine for the Bavarian state salt industry.

Solehebemaschine

This machine, a Solehebemaschine or "brine-lifting machine", entered service in 1821. It had two pressure-operated poppet valves for each cylinder. These engines are brass to resist corrosion by the salt water. Water pressure engines must be designed taking into account the incompressibility of water, so both valves must not close at the same time, and abrupt changes of rate of flow must not be made.

Air chambers can be used to eliminate shocks. Georg von Reichenbach (1771-1826) is much better known as an optical designer than as a mechanical engineer. He was associated with Joseph Fraunhofer, and they died within days of each other in 1826. He was of an aristocratic family, and was Salinenrat, or manager of the state salt works, in southeastern Bavaria, which was centered on the town of Reichenhall, now Bad Reichenhall, near Salzburg.

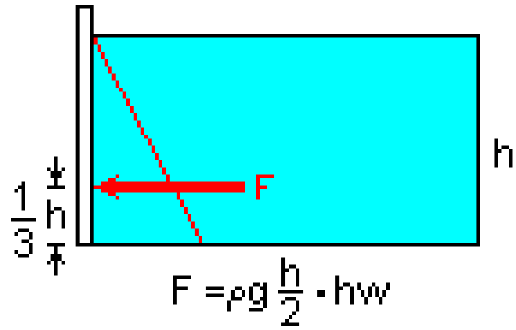
The name derives from "rich in salt." This famous salt region had salt springs flowing nearly saturated brine, at 24% to 26% (saturated is 27%) salt, that from ancient times had been evaporated over wood fires. A brine pipeline to Traunstein was constructed in 1617-1619, since wood fuel for evaporating the brine was exhausted in Reichenhall. The pipeline was further extended to Rosenheim, where there was turf as well as wood, in 1818-10.

Von Reichenbach is said to have built this pipeline, for which he designed a water-wheel-driven, four-barrel pump. Maximilian I, King of Bavaria, commissioned von Reichenbach to bring brine from Berchtesgaden, elevation 530 m, to Reichenhall, elevation 470 m, over a summit 943 m high. Fresh water was also allowed to flow down to the salt beds, and the brine was then pumped to the surface. This was a much easier way to mine salt than underground mining.

Ancient Hydraulic Foundations –Explained

Forces on Submerged Surfaces

Assume we wanted to know the force exerted on a vertical surface of any shape with water on one side, assuming gravity to act, and the pressure on the surface of the water zero. We have already solved this problem by a geometrical argument, but now we apply calculus, which is easier but not as enlightening.



Force on a Surface

The force on a small area dA a distance x below the surface of the water is dF = p dA = ρgx dA, and the moment of this force about a point on the surface is dM = px dA = ρgx2 dA.

By integration, we can find the total force F, and the depth at which it acts, c = M / F. If the surface is not symmetrical, the position of the total force in the transverse direction can be obtained from the integral of dM' = ρgxy dA, the moment about some vertical line in the plane of the surface.

If there happens to be a pressure on the free surface of the water, then the forces due to this pressure can be evaluated separately and added to this result. We must add a force equal to the area of the surface times the additional pressure, and a moment equal to the product of this force and the distance to the centroid of the surface.

The simplest case is a rectangular gate of width w, and height h, whose top is a distance H below the surface of the water.

In this case, the integrations are very easy, and F = ρgw [(h + H) 2 - h2]/2 = ρgH (H + 2h)/2 = ρg (h + H/2) Hw.

The total force on the gate is equal to its area times the pressure at its center. M = ρgw [(h + H) 3 - h3]/3 = ρg (H2/3 + Hh + h2) Hw, so that c = (H2/3 + Hh + h2)/ (h + H/2).

In the simple case of h = 0, c = 2H/3, or two-thirds of the way from the top to the bottom of the gate. If we take the atmospheric pressure to act not only on the surface of the water, but also the dry side of the gate, there is no change to this result. This is the reason atmospheric pressure often seems to have been neglected in solving sub h problems.

Consider a curious rectangular tank, with one side vertical but the opposite side inclined inwards or outwards. The horizontal forces exerted by the water on the two sides must be equal and opposite, or the tank would scoot off. If the side is inclined outward, then there must be a downward vertical force equal to the weight of the water above it, and passing through the centroid of this water.

If the side is inclined inward, there must be an upward vertical force equal to the weight of the 'missing' water above it. In both cases, the result is demanded by ordinary statics.

Hydrostatic Paradox

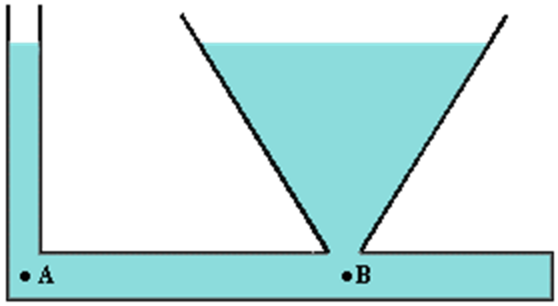


FIGURE #1

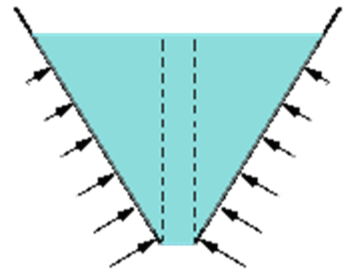


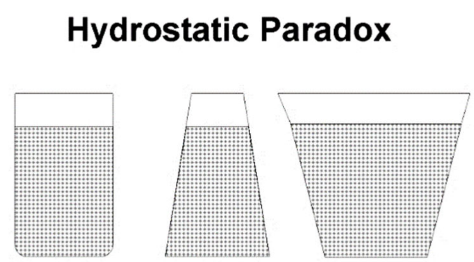
FIGURE #2

Blaise Pascal asked the question of this paradox nearly 300 years ago. He even built an apparatus, now known as 'Pascal's vases', to demonstrate the paradox. It was basically the vessel shown in Figure 1 with several more differently shaped chambers, but all open at the top and having the same base areas. In effect, if Pascal's vases are generalized to include compartments with any shapes, inclinations, or different base areas, the results will always be the same: the water levels in all chambers will be identical.

What we have here has been called the 'hydrostatic paradox.' It was conceived by the celebrated Flemish engineer Simon Stevin (1548-1620) of Brugge, the first modern scientist to investigate the statics of fluids and solids.

Consider three tanks with bottoms of equal sizes and equal heights, filled with water. The pressures at the bottoms are equal, so the vertical force on the bottom of each tank is the same. But suppose that one tank has vertical sides, one has sides inclined inward, and third sides inclined outwards. The tanks do not contain the same weight of water, yet the forces on their bottoms are equal! I am sure that you can spot the resolution of this paradox.

Occasionally the forces are required on curved surfaces. The vertical and horizontal components can be found by considering the equilibrium of volumes with a plane surface equal to the projected area of the curved surface in that direction.

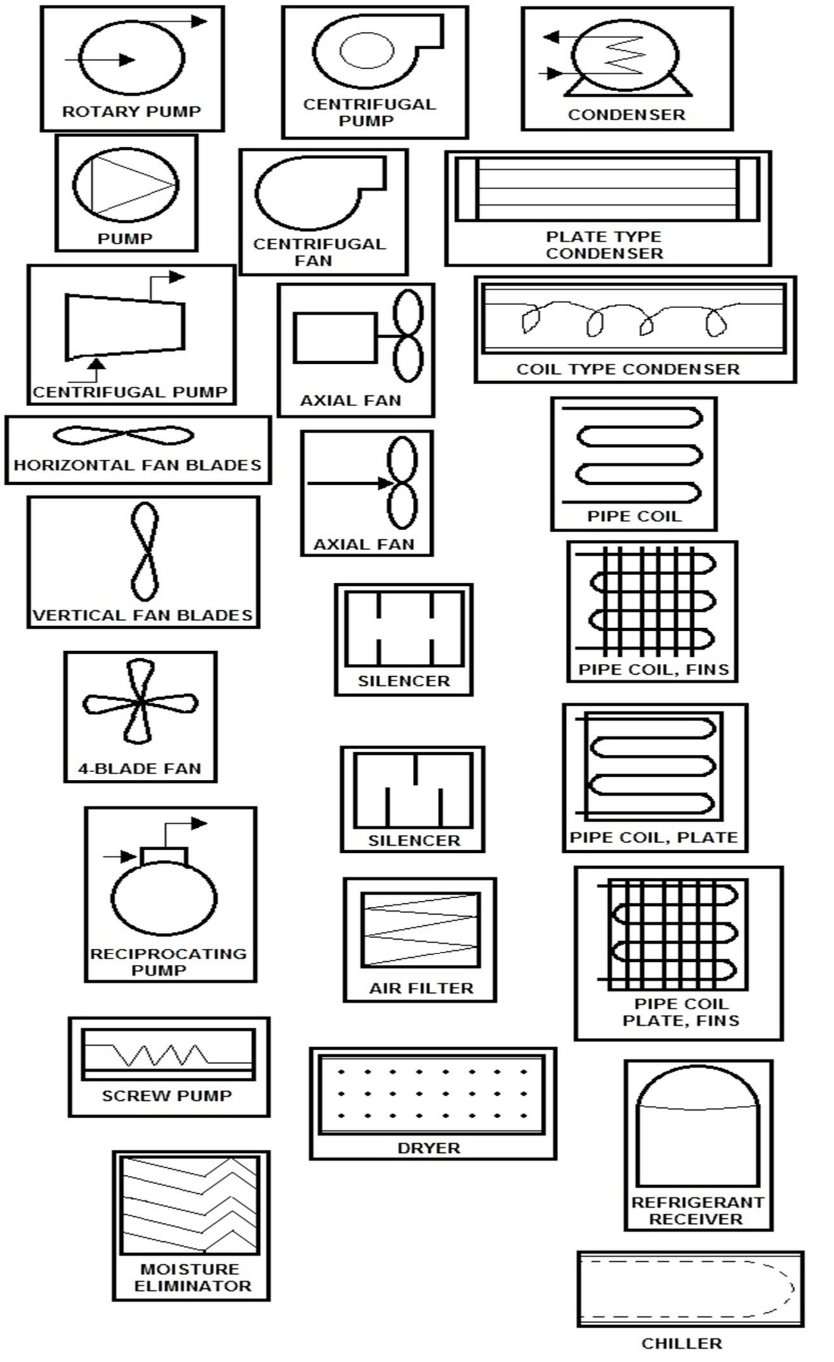


The general result is usually a force plus a couple, since the horizontal and vertical forces are not necessarily in the same plane.

Simple surfaces, such as cylinders, spheres and cones, may often be easy to solve. In general, however, it is necessary to sum the forces and moments numerically on each element of area, and only in simple cases can this be done analytically.

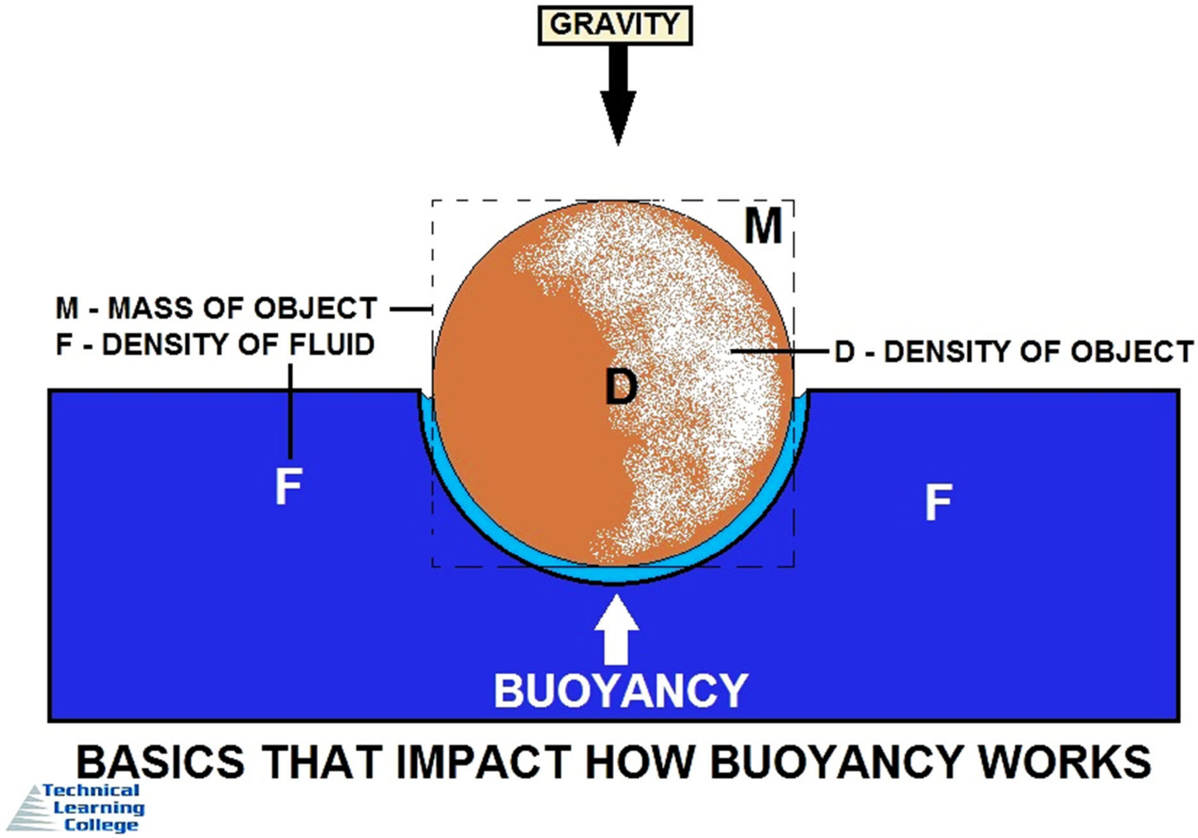
If a volume of fluid is accelerated uniformly, the acceleration can be added to the acceleration of gravity. A free surface now becomes perpendicular to the total acceleration, and the pressure is proportional to the distance from this surface.

The same can be done for a rotating fluid, where the centrifugal acceleration is the important quantity. The earth's atmosphere is an example. When air moves relative to the rotating system, the Coriolis force must also be taken into account. However, these are dynamic effects and are not strictly a part of hydrostatics.



FLUID MECHANIC SYMBOLS (Common)

Buoyancy



In physics or fluid mechanics, **buoyancy** or **upthrust**, is an upward force exerted by a fluid that opposes the weight of an immersed object. In a column of fluid, pressure increases with depth as a result of the weight of the overlying fluid. Thus the pressure at the bottom of a column of fluid is greater than at the top of the column.

Likewise, the pressure at the bottom of an object submerged in a fluid is greater than at the top of the object. This pressure difference results in a net upwards force on the object. The magnitude of that force exerted is proportional to that pressure difference, and as explained by Archimedes' principle is equivalent to the weight of the fluid that would otherwise occupy the volume of the object, i.e. the displaced fluid.

For this reason, an object whose density is greater than that of the fluid in which it is submerged tends to sink. If the object is either less dense than the liquid or is shaped appropriately (as in a boat), the force can keep the object afloat.

This can occur only in a non-inertial reference frame, which either has a gravitational field or is accelerating due to a force other than gravity defining a "downward" direction. In a situation of fluid statics, the net upward buoyancy force is equal to the magnitude of the weight of fluid displaced by the body.

The center of buoyancy of an object is the centroid of the displaced volume of fluid

Archimedes

Archimedes, so the legend runs, was asked to determine if the goldsmith who made a golden crown for Hieron, Tyrant of Syracuse, had substituted cheaper metals for gold. The story is told by Vitruvius. A substitution could not be detected by simply weighing the crown, since it was craftily made to the same weight as the gold supplied for its construction. Archimedes realized that finding the density of the crown, that is, the weight per unit volume, would give the answer.

The weight was known, of course, and Archimedes cunningly measured its volume by the amount of water that ran off when it was immersed in a vessel filled to the brim. By comparing the results for the crown, and for pure gold, it was found that the crown displaced more water than an equal weight of gold, and had, hence, been adulterated.

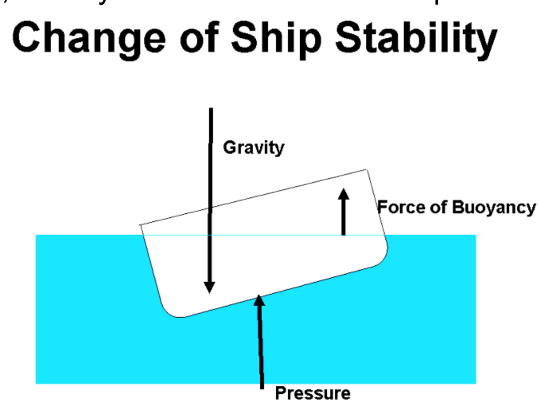
This story, typical of the charming way science was made more interesting in classical times, may or may not actually have taken place, but whether it did or not, Archimedes taught that a body immersed in a fluid lost apparent weight equal to the weight of the fluid displaced, called Archimedes' Principle.

Specific gravity is the ratio of the density of a substance to the density of water, can be determined by weighing the body in air, and then in water. The specific gravity is the weight in air divided by the loss in weight when immersed. This avoids the difficult determination of the exact volume of the sample.

How Buoyancy Works

To see how buoyancy works, consider a submerged brick, of height h, width w and length l. The difference in pressure on top and bottom of the brick is ρgh, so the difference in total force on top and bottom of the brick is simply (ρgh) (wl) = ρgV, where V is the volume of the brick.

The forces on the sides have no vertical components, so they do not matter. The net upward force is the weight of a volume V of the fluid of density ρ.



Anybody can be considered made up of brick shapes, as small as desired, so the result applies in general.

Consider a man in a rowboat on a lake, with a large rock in the boat. He throws the rock into the water. What is the effect on the water level of the lake?

Suppose you make a drink of ice water with ice cubes floating in it. What happens to the water level in the glass when the ice has melted?

The force exerted by the water on the bottom of a boat acts through the center of gravity B of the displaced volume, while the force exerted by gravity on the boat acts through its own center of gravity A. This looks bad for the boat, since the boat's c.g. will naturally be higher than the c.g. of the displaced water, so the boat will tend to capsize. Well, a board floats, and can tell us why. Should the board start to rotate to one side, the displaced volume immediately moves to that side, and the buoyant force tends to correct the rotation.
A floating body will be stable provided the line of action of the buoyant force passes through a point M above the c.g. of the body, called the metacenter, so that there is a restoring couple when the boat heels. A ship with an improperly designed hull will not float. It is not as easy to make boats as it might appear.

Pycnometer

A pycnometer is a flask with a close-fitting ground glass stopper with a fine hole through it, so a given volume can be accurately obtained.

The name comes from the Greek word meaning "density." If the flask is weighed empty, full of water, and full of a liquid whose specific gravity is desired, the specific gravity of the liquid can easily be calculated.

A sample in the form of a powder, to which the usual method of weighing cannot be used, can be put into the pycnometer. The weight of the powder and the weight of the displaced water can be determined, and from them the specific gravity of the powder.

The specific gravity of a liquid can be found with a collection of small weighted, hollow spheres that will just float in certain specific gravities.

The closest spheres that will just float and just sink put limits on the specific gravity of the liquid. This method was once used in Scotland to determine the amount of alcohol in distilled liquors.

Since the density of a liquid decreases as the temperature increases, the spheres that float are an indication of the temperature of the liquid. Galileo's thermometer worked this way.

Measurement of Specific Gravity

The specific gravity of a material is the ratio of the mass (or weight) of a certain sample of it to the mass or weight of an equal volume of water, the conventional reference material.

In the metric system, the density of water is 1 g/cc, which makes the specific gravity numerically equal to the density.

Strictly speaking, density has the dimensions' g/cc, while specific gravity is a dimensionless ratio. Nevertheless, in casual speech the two are often confounded.

In English units, however, density, perhaps in lb/cu.ft or pcf, is numerically different from the specific gravity, since the weight of water is 62.5 lb/cu.ft.

Variations in Specific Gravity

The basic idea in finding specific gravity is to weigh a sample in air, and then immersed in water. Then the specific gravity is W/ (W - W'), if W is the weight in air, and W' the weight immersed.

The denominator is the buoyant force, the weight of a volume of water equal to the volume of the sample. This can be carried out with an ordinary balance, but special balances, such as the Jolly balance, have been created specifically for this application.

Adding an extra weight to the sample allows measurement of specific gravities less than 1.

Things are complicated by the variation of the density of water with temperature, and also by the confusion that gave us the distinction between cc and ml.

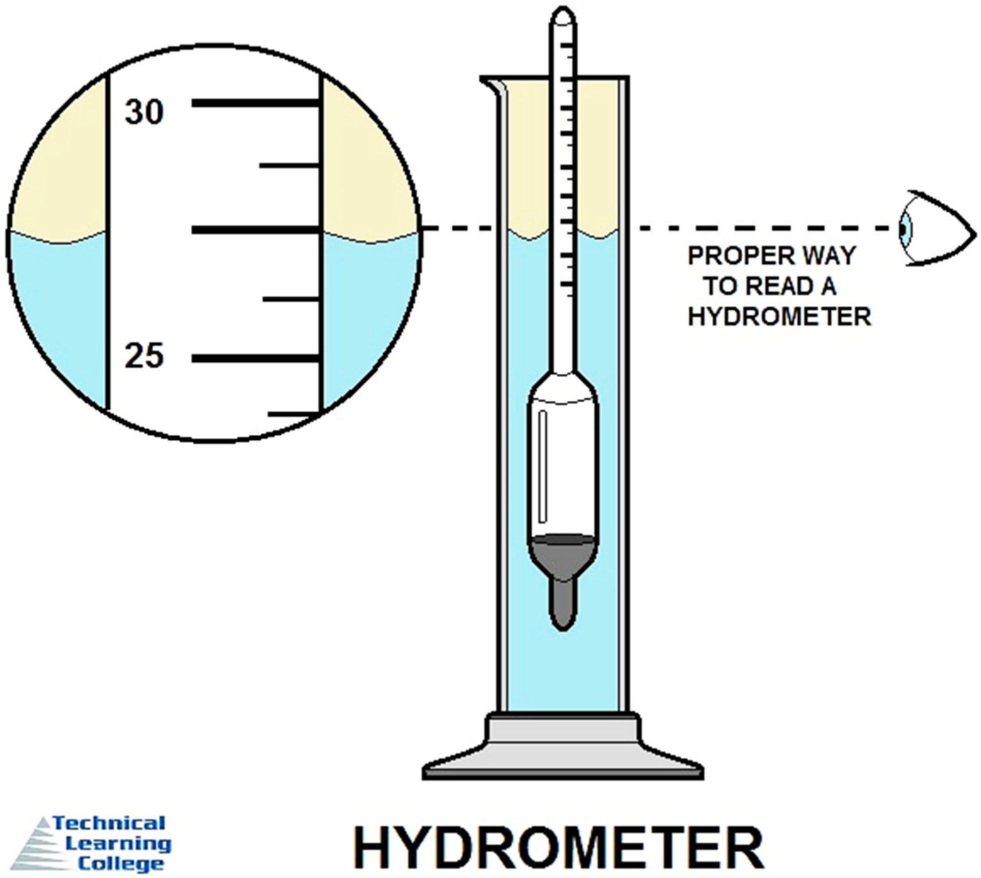
The milliliter is the volume of 1.0 g of water at 4°C, by definition. The actual volume of 1.0 g of water at 4°C is 0.999973 cm3 by measurement.

Since most densities are not known, or needed, to more than three significant figures, it is clear that this difference is of no practical importance, and the ml can be taken equal to the cc.

The density of water at 0°C is 0.99987 g/ml, at 20° 0.99823, and at 100°C 0.95838.

The temperature dependence of the density may have to be taken into consideration in accurate work. Mercury, while we are at it, has a density 13.5955 at 0°C, and 13.5461 at 20°C.

Hydrometer



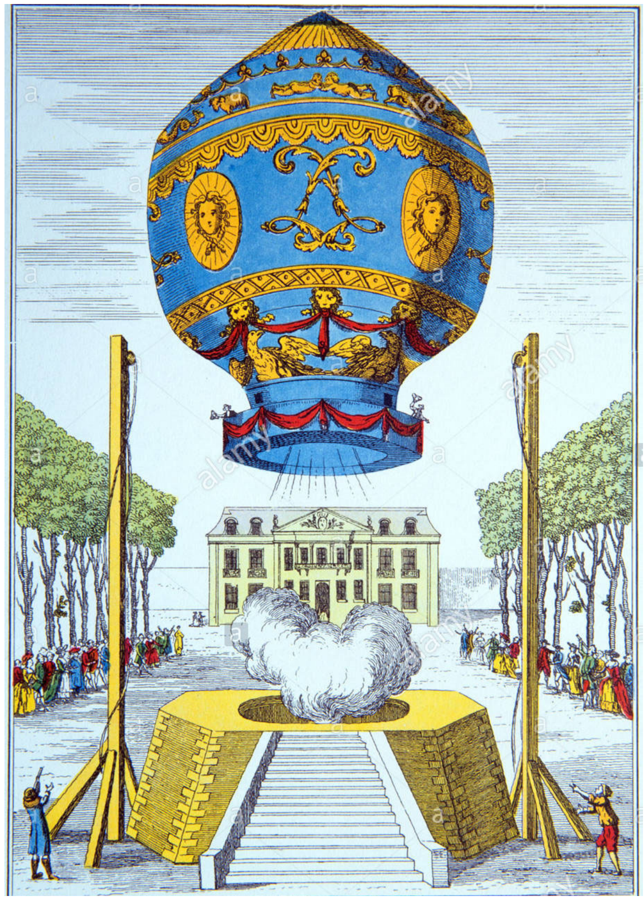
A better instrument for the measurement of specific gravity is the hydrometer, which consists of a weighted float and a calibrated stem that protrudes from the liquid when the float is entirely immersed.

A higher specific gravity will result in a greater length of the stem above the surface, while a lower specific gravity will cause the hydrometer to float lower.

The small cross-sectional area of the stem makes the instrument very sensitive. Obviously, it must be calibrated against standards. In most cases, the graduations or "degrees" are arbitrary and reference is made to a table to determine the specific gravities.

Hydrometers are used to determine the specific gravity of lead-acid battery electrolyte, and the concentration of antifreeze compounds in engine coolants, as well as the alcohol content of whiskey.

Montgolfier Brothers' Hot Air Balloon



Archimedes' Principle can also be functional with balloons. The Montgolfier brothers' hot air balloon with a paper envelope ascended first in 1783 with the brothers got Pilâtre de Rozier and Chevalier d'Arlandes to go up in it. These early "fire balloons" were then replaced with hydrogen-filled balloons, and then with balloons filled with coal gas, which was easier to obtain and did not diffuse through the envelope quite as rapidly.

Methane would be a good filler, with a density 0.55 that of air. Slack balloons, like most large ones, can be contrasted with taut balloons with an elastic envelope, such as weather balloons. Slack balloons will not be filled full on the ground, and will plump up at altitude. Balloons are naturally stable, since the center of buoyancy is above the center of gravity in all practical balloons.

Submarines are another application of buoyancy, with their own characteristic problems. Small neoprene or natural rubber balloons have been used for meteorological observations, with hydrogen filling. A 10g ceiling balloon was about 17" in diameter when inflated to have a free lift of 40g. It ascended 480ft the first minute, 670ft in a minute and a half, and 360ft per minute afterwards, to find cloud ceilings by timing, up to 2500ft, when it subtended about 2' of arc, easily seen in binoculars.

Large sounding balloons were used to lift a radiosonde and a parachute for its recovery. An AN/AMT-2 radiosonde of the 1950's weighed 1500g, the paper parachute 100g, and the balloon 350g. The balloon was inflated to give 800g free lift, so it would rise 700-800 ft/min to an altitude of about 50,000 ft. (15 km) before it burst. This balloon was about 6 ft. in diameter when inflated at the surface, 3 ft. in diameter before inflation.

The information was returned by radio telemetry, so the balloon did not have to be followed optically. Of intermediate size was the pilot balloon, which was followed with a theodolite to determine wind directions and speeds. At night, a pilot balloon could carry a light for ceiling determinations.

Weather Balloons

Weather balloons had to be launched promptly after filling, or the desired free lift would not be obtained. Helium is a little better in this respect, but it also diffuses rapidly.

The lift obtained with helium is almost the same as with hydrogen - density 4 compared to 2, where air is 28.97. But helium is exceedingly rare, and only its unusual occurrence in natural gas from Kansas makes it available. Great caution must be taken when filling balloons with hydrogen to avoid sparks and the accumulation of hydrogen in air, since hydrogen is exceedingly flammable and explosive over a wide range of concentrations. Helium has the great advantage in that it is not inflammable.

The hydrogen for filling weather balloons came from compressed gas in cylinders, from the reaction of granulated aluminum with sodium hydroxide and water, or from the reaction of calcium hydroxide with water. The chemical reactions are $2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$, or $CaH_2 + 2H_2O \rightarrow Ca(OH)_2 + 2H_2$.

In the first formula, silicon or zinc could be used instead of aluminum, and in the second, any similar metal hydride. Both are rather expensive sources of hydrogen, but very convenient when only small amounts are required. Most hydrogen is made from the catalytic decomposition of hydrocarbons, or the reaction of hot coke with steam.

Electrolysis of water is an expensive source, since more energy is used than is recovered with the hydrogen. Any enthusiasm for a "hydrogen economy" should be tempered by the fact that there are no hydrogen wells, and all the hydrogen must be made with an input of energy usually greater than that available from the hydrogen, and often with the appearance of carbon.

Although about 60,000 Btu/lb is available from hydrogen, compared to 20,000 Btu/lb from gasoline, hydrogen compressed to 1000 psi requires 140 times as much volume for the same weight as gasoline.

For the energy content of a 13-gallon gasoline tank, a 600-gallon hydrogen tank would be required. The critical temperature of hydrogen is 32K, so liquid storage is out of the question for general use.

Experiments and Early Applications Post Quiz

Meteorology

1. The atmospheric pressure is of great importance in meteorology, since it determines the winds, which generally move at __________ to the direction of the most rapid change of pressure, that is, along the isobars, which are contours of constant pressure.

2. The barometric pressures quoted in the news are reduced to sea level by standard formulas that amount to assuming that there is a __________ from your feet to sea level with a certain temperature distribution, and adding the weight of this column to the actual barometric pressure.

The Hydraulic Lever

3. A cylinder and piston is a chamber of variable volume, a mechanism for transforming?

Bramah Hydraulic Press

4. The most famous application of this principle is the Bramah hydraulic press, invented by Joseph Bramah (1748-1814), who also invented many other useful machines, including a lock and a?

5. Pumps are seen to fall within the province of hydrostatics if their operation is quasi-static, which means that ________________ are negligible.

Bell-Jar Receiver

6. Small amounts of gas are trapped at the top of the fall tube as the _______________drops, and moves slowly down the fall tube as mercury is steadily added, coming out at the bottom carrying the air with it. The length of the fall tube must be greater than the barometric height, of course.

Solehebemaschine

7. Water pressure engines must be designed taking into account the___________, so both valves must not close at the same time, and abrupt changes of rate of flow must not be made.

8. This missing term can be used to eliminate shocks?

Forces on Submerged Surfaces

9. Suppose we want to know the force exerted on a vertical surface of any shape with water on one side, assuming gravity to act, and the pressure on the surface of the water?

Hydrostatic Paradox

10. Sometimes the forces are required on curved surfaces. The vertical and horizontal components can be found by considering the ________________with a plane surface equal to the projected area of the curved surface in that direction.

Answers 1. Right angles, 2. Column of air, 3. Pressure to force, 4. Toilet, 5. Dynamic or inertia forces, 6. Mercury, 7. Incompressibility of water, 8. Air chambers, 9. Zero, 10. Equilibrium of volumes

Experiments and Early Applications References

"A Course of Experimental Philosophy", John Theophilus Desaguliers, 1744, Vol II p. 474.
"Advantages of Hydraulic Presses". MetalFormingFacts.com. The Lubrizol Corporation.
"Bramah, Joseph". Encyclopædia Britannica. Encyclopædia Britannica Online.
"BRAMAH'S HISTORY - Chronological History of Bramah" (PDF). bramah.co.uk. Retrieved 6 November 2014.
"Chapter 7: Second Patent". www.history.rochester.edu.
"Floater clustering in a standing wave: Capillarity effects drive hydrophilic or hydrophobic particles to congregate at specific points on a wave" (PDF).
"Memories of Dartmouth – Dartmouth Museum". Dartmouth Museum. Retrieved 22 May 2012. The engine on display in Dartmouth was donated by the British Transport Commission to the Newcomen Society in 1963 and erected within an old electricity substation. This particular engine was built around 1725 at Griff Colliery, before moving elsewhere.
"Science and Society Picture Library – Search". www.scienceandsociety.co.uk. Retrieved 6 July 2009.
"Science Museum – Home – Atmospheric engine by Francis Thompson, 1791". www.sciencemuseum.org.uk.
"Welcome to the 'Hydraulic Press' YouTube channel, a truly crushing experience". The Washington Post..
"What Hydraulic Press Machine Is". BPThai. Retrieved 2016-06-19.
Acott, Chris (1999). "The diving "Law-ers": A brief resume of their lives". South Pacific Underwater Medicine Society journal. 29 (1). ISSN 0813-1988. OCLC 16986801. Archived from the original on 2 April 2011. Retrieved 13 June 2009..
B. Trinder, Industrial Revolution in Shropshire (3rd edn, Phillimore, Chichester, 2000), 48.
Belford, P. (2007). "Sublime cascades: Water and Power in Coalbrookdale" (PDF). Industrial Archaeology Review. 29 (2): 136. doi:10.1179/174581907x234027. Archived from the original (PDF) on 22 February 2012.
Black Country Living Museum: Newcomen Steam Engine
Blackmore, H. (1986). "A Dictionary of London Gunmakers" p59
Carlisle, Rodney (2004). Scientific American Inventions and Discoveries, p. 266. John Wiley & Sons, Inc., New Jersey. ISBN 0-471-24410-4.
Chamber Colliery Co, Grace's Guide, retrieved 17 September 2011
Day, L and McNeil, I, Biographical Dictionary of the History of Technology, p163
Dionysius Lardner, The steam engine familiarly explained and illustrated
Earl, Bryan (1994). Cornish Mining: The Techniques of Metal Mining in the West of England, Past and Present (2nd ed.). St Austell: Cornish Hillside Pub. p. 38. ISBN 0-9519419-3-3.
Figuer, Louis "Merveilles de la science" Furne Jouvet et Cie, Paris 1868. Vol 1, pp. 53,54
GB 177801177, Bramah, Joseph, "Flushing Toilet"
GB 178501478, Bramah, Joseph, "Hydrostatical Machine and Boiler, Propelling Vessels, Carriages, &c."
GB 179502045, Bramah, Joseph, "Obtaining and Applying Motive Power"
Hills, Richard L. (1970). Power in the Industrial revolution. Manchester University Press. pp. 134–135. ISBN 0719003776.
http://www.bramah.co.uk/ accessed 2 March 2015
J. H. Andrew and J. S. Allen, 'A confirmation of the location of the 1712 "Dudley Castle" Newcomen engine at Coneygree, Tipton' International Journal for the history of Engineering and Technology 72(2) (2009), 174–182.

Morris, Charles R. Morris; illustrations by J.E. (2012). The dawn of innovation the first American Industrial Revolution (1st ed.). New York: PublicAffairs. p. 42. ISBN 978-1-61039-049-1.
Parker, Dana T. Building Victory: Aircraft Manufacturing in the Los Angeles Area in World War II, p. 87, Cypress, CA, 2013. ISBN 978-0-9897906-0-4.
Preece, Geoff; Ellis, Peter (1981). Coalmining, a handbook to the History of Coalmining Gallery, Salford Museum of Mining. City of Salford Cultural Services. p. 16.
Roach, Peter (2011), Cambridge English Pronouncing Dictionary (18th ed.), Cambridge: Cambridge University Press, ISBN 9780521152532
Rolt, L. T. C. (1963). Thomas Newcomen – The Prehistory of the Steam Engine. Dawlish: David & Charles. p. 86.
Skempton (2002), p.70
Suhail Rana, 'New evidence supporting Wolverhampton as the location of the first working Newcomen engine' International Journal for the history of Engineering and Technology 72(2) (2009), 162–173.
The Miners Friend Archived 11 May 2009 at the Wayback Machine.
University of Rochester, NY, The growth of the steam engine online history resource, chapter one. Archived 4 February 2012 at the Wayback Machine.
Wells, John C. (2008), Longman Pronunciation Dictionary (3rd ed.), Longman, ISBN 9781405881180

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.)

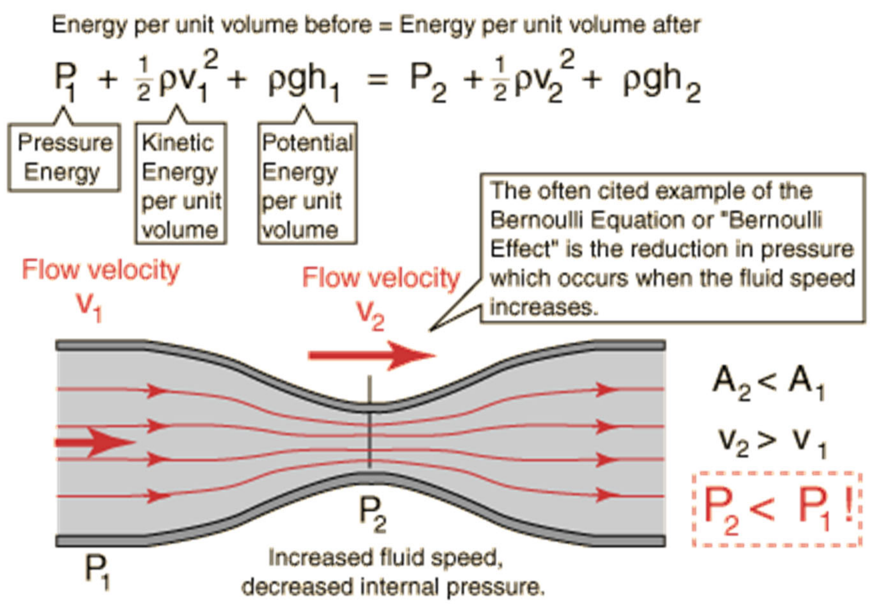
B

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

$\gamma=\rho\cdot g$

$$\frac{\rho\cdot v^2}{2}+p=\text{Constant} \qquad (4)$$

$$\frac{\rho\cdot v^2}{2}=p_d \qquad (5)$$

$$\frac{\rho\cdot v_1^2}{2}+p_1=\frac{\rho\cdot v_2^2}{2}+p_2=\text{Constant} \qquad (6)$$

www.engineeringtoolbox.com

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
dρ = 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/ft³, kg/m³)
g = acceleration due to gravity (32.174 ft/s², 9.81 m/s²)
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/m³)
v = flow velocity (m/s)
E = bulk modulus elasticity (N/m²)

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 ^{o}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 (^{o}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.

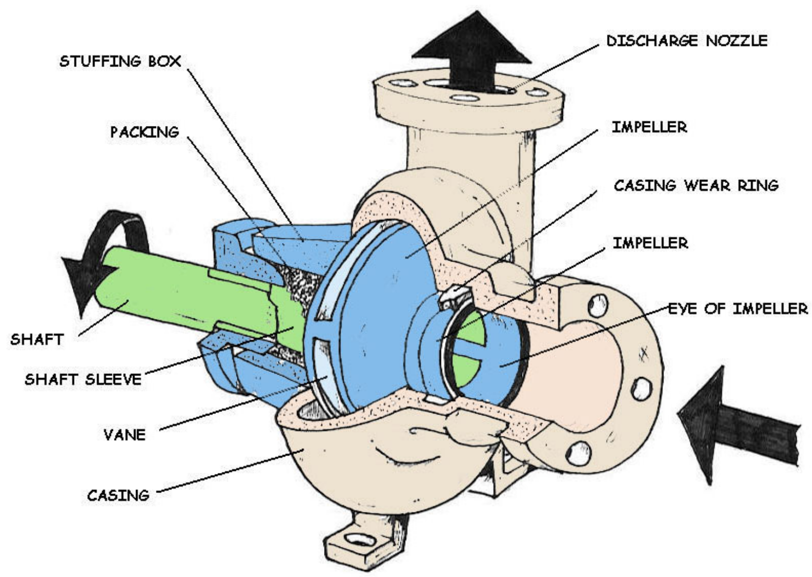
Cavitations Number: A "special edition" of the dimensionless Euler Number.

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.

$$1 / \lambda^{1/2} = -2 \log ((2.51 / (Re\ \lambda^{1/2})) + ((k / d_h) / 3.72)) \quad (1)$$

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.

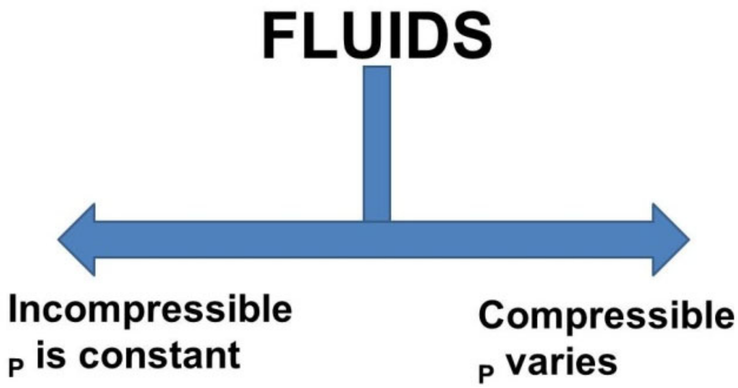
Compressible Flow: We know that fluids are classified as Incompressible and Compressible fluids. Incompressible fluids do not undergo significant changes in density as they flow. In general, liquids are incompressible; water being an excellent example. In contrast compressible fluids do undergo density 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:

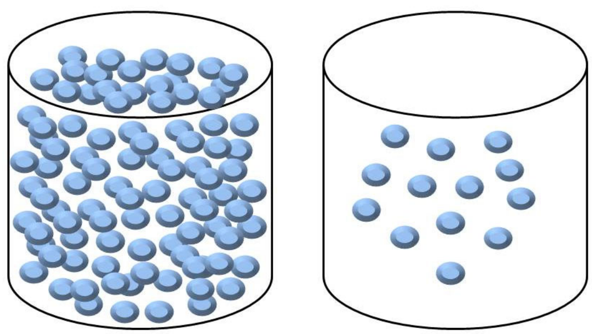
$\Delta p = \lambda\ (l\ /\ d_h)\ (\rho\ v^2\ /\ 2)\ (1)$

where
Δp = *pressure loss (Pa, N/m², lbf/ft²)*
λ = *D'Arcy-Weisbach friction coefficient*
l = *length of duct or pipe (m, ft)*
d_h = *hydraulic diameter (m, ft)*
ρ = *density (kg/m³, lb/ft³)*

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/m³)*
m = *mass (kg)*
V = *volume (m³)*
v_g = *specific volume (m³/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

$\rho = [18.5\ (g) / 1000\ (g/kg)] / [23.4\ (ml) / 1000\ (ml/l)\ 1000\ (l/m^3)\ ]$
$= 18.5\ 10^{-3}\ (kg) / 23.4\ 10^{-6}\ (m^3)$
$= \underline{790}\ kg/m^3$

If we look up densities of some common substances, we can find that ethyl alcohol, or ethanol, has a density of <u>790</u> 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!

$m = 0.17\ (m^3)\ 4507\ (kg/m^3)$
$= \underline{766.2}\ kg$

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/m^2**, **Pa s** or **kg/m s** where
- *1 Pa s = 1 N s/m^2 = 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/cm^2** or **poise (p)** where
- *1 poise = dyne s/cm^2 = 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^{o}F (20.2^{o}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:

$p_{in} + \rho v_{in}^2 / 2 + \gamma h_{in} + \rho w_{shaft} = p_{out} + \rho v_{out}^2 / 2 + \gamma h_{out} + w_{loss}$ *(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:

$h_{shaft} = W_{shaft} / \gamma Q = (4\ hp)(550\ ft.lb/s/hp) / (62.4\ lb/ft^3)(2\ ft^3/s) = 17.6\ ft$

- 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:

$$f = 0.2083 \, (100/c)^{1.852} \, q^{1.852} / d_h^{4.8655} \quad (1)$$

where

f = friction head loss in feet of water per 100 feet of pipe (ft_{h2o}*/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^o F (15.6^o C) with kinematic viscosity 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130^o F (54.4^o C)) the error will be significant. Since the Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 to 75^o 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

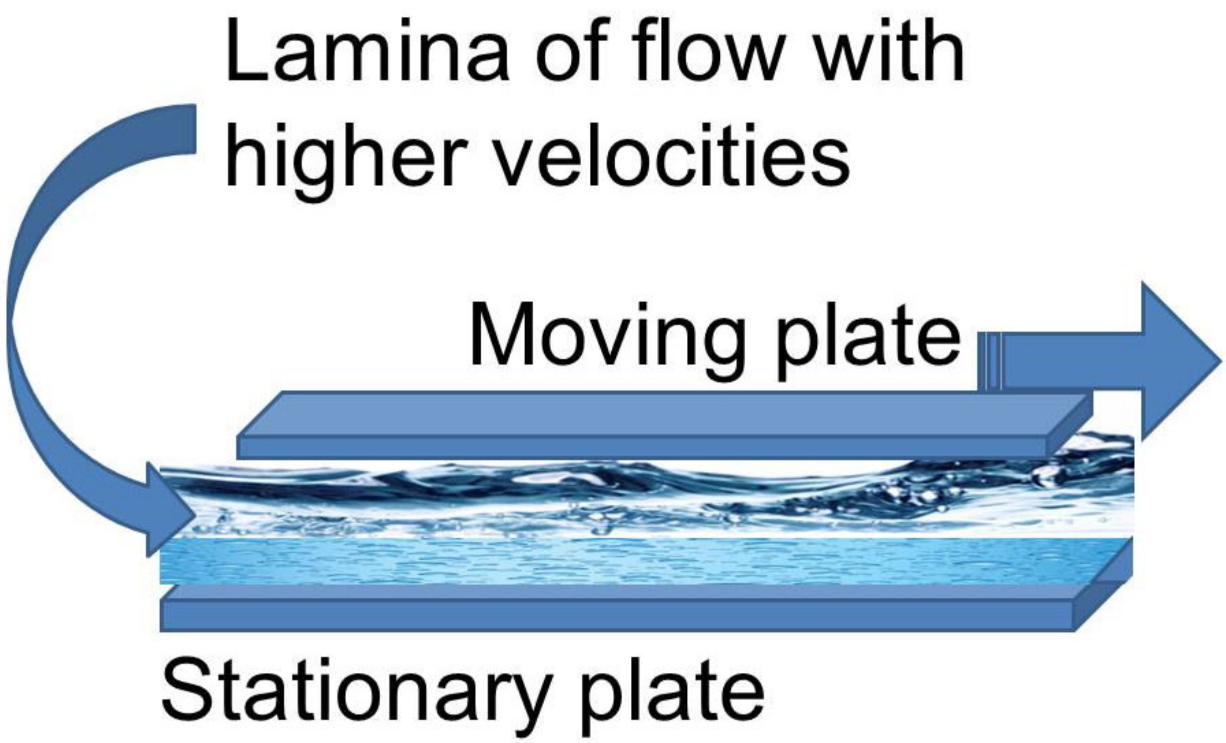
Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

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 $\rho = 0$.

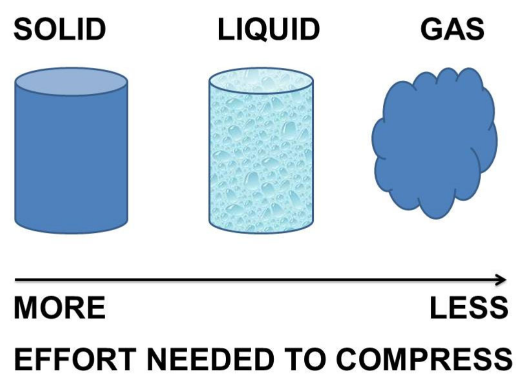
The vector Laplace's equation is given by

$$\nabla^2 \mathbf{F} = \mathbf{0}. \qquad (4)$$

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

Microbe, Microbial: Any minute, simple, single-celled form of life, especially one that causes disease.

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 °F))
k = thermal conductivity (W/m K, Btu/(h ft^2 °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^o C (39^oF) 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 ^oF 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) = <u>11.6</u> ft of water

5 (lbf/in^2) 12 (in/ft) 12 (in/ft) / 847 (lb/ft^3) = <u>0.85</u> 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°C	0.0728	72.75
Water 100°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 (°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^{o}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.

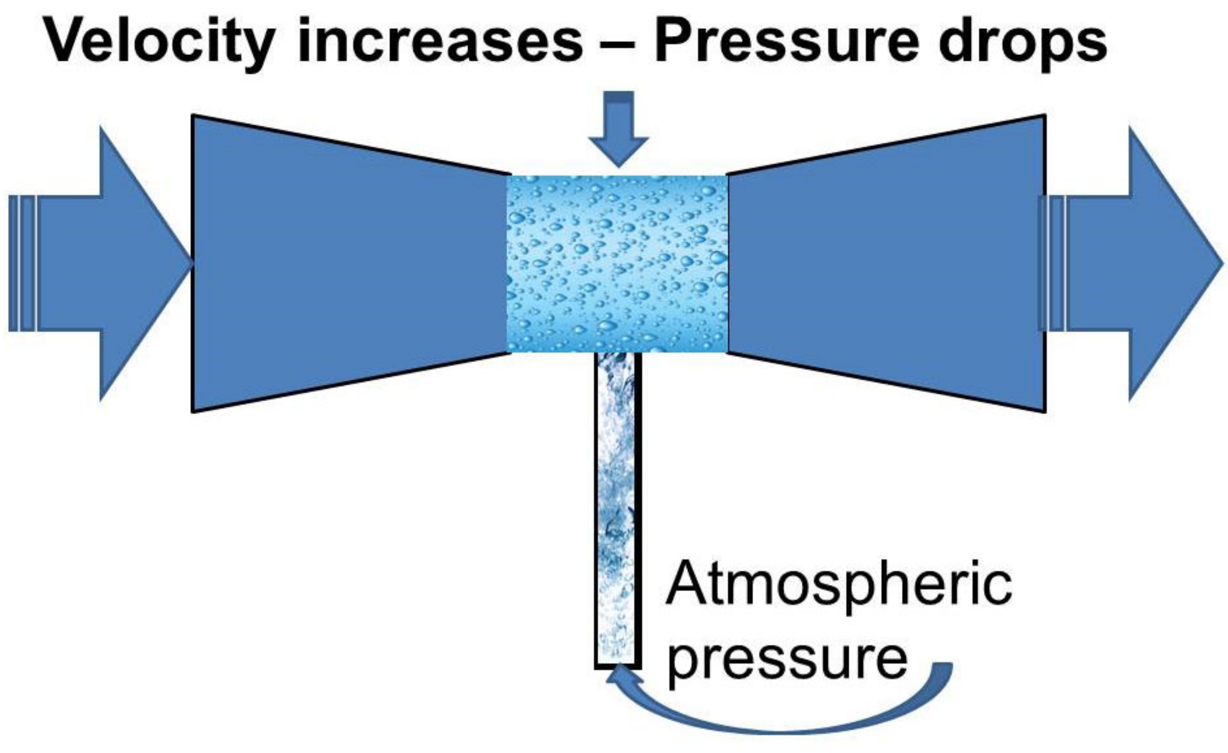
Vane: That portion of an impeller which throws the water toward the volute.

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.

$$\frac{F}{A} = \eta\frac{\Delta v_x}{\Delta z} \quad \text{or} \quad \frac{F}{A} = \eta\frac{dv_x}{dz}$$

$$\Updownarrow \qquad\qquad \Updownarrow$$

$$F = m\frac{\Delta v}{\Delta t} \quad \text{or} \quad F = m\frac{dv}{dt}$$

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. This unit is also a bit too large and so the most common unit is probably the square millimeter per second [mm^2/s] or centistoke [cSt].

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^{o}C. For a distillate fluid the reference temperature is 40^{o}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. Since the Weber Number represents an index of the inertial force to the surface tension force acting on a fluid element, it can be useful analyzing thin films flows and the formation of droplets and bubbles.

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/m³)
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, 40º API	60ºF	825
Crude oil, 35.6º API	60ºF	847
Crude oil, 32.6º API	60ºF	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
Sulfuric 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) = <u>*11.6*</u> *ft of water*

5 (lbf/in^2) 12 (in/ft) 12 (in/ft) / 847 (lb/ft^3) = <u>*0.85*</u> *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:

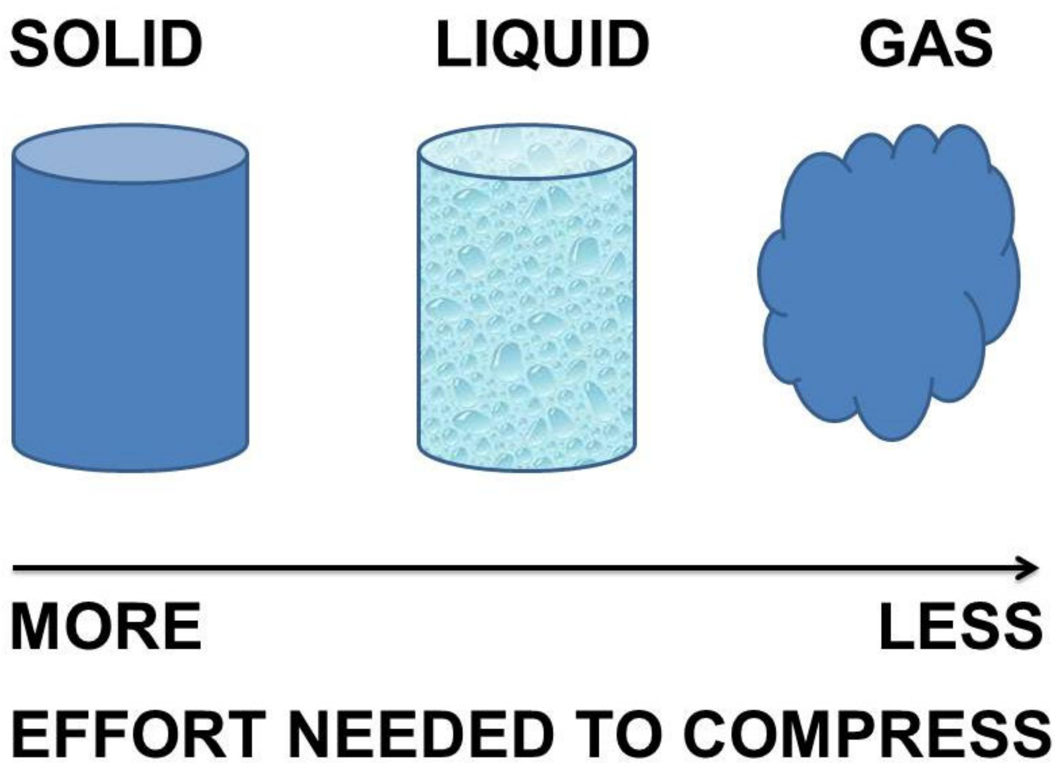
Velocity (ft/sec)	Head Water (ft)
0.5	0.004
1.0	0.016
1.5	0035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	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/m²)	Density - ρ - (kg/m³)	Specific volume - v - (m³/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/s^2, 9.81 m/s^2)

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

Some Commonly used Thermal Properties for Water

- Density at 4 ^oC - 1,000 kg/m^3, 62.43 Lbs./Cu.Ft., 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.
- Freezing temperature - 0 ^oC
- Boiling temperature - 100 ^oC
- Latent heat of melting - 334 kJ/kg
- Latent heat of evaporation - 2,270 kJ/kg
- Critical temperature - 380 - 386 ^oC
- Critical pressure - 23.520 kN/m^2
- Specific heat capacity water - 4.187 kJ/kgK
- Specific heat capacity ice - 2.108 kJ/kgK
- Specific heat capacity water vapor - 1.996 kJ/kgK
- Thermal expansion from 4 ^oC to 100 ^oC - $4.2x10^{-2}$
- Bulk modulus elasticity - 2,068,500 kN/m^2

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 -* *(^{o}F)*	Dynamic Viscosity *- μ -* *10^{-5} (lbs./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 -* *(^{o}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°F (0-100°C) - imperial and SI units

Speed of Sound in Water - in imperial units (BG units)

Temperature - *t* - (°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* - (°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

References

"A High-Quality Digital X-Y Plotter Designed for Reliability, Flexibility and Low Cost". Hewlett-Packard Journal. http://www.hpl.hp.com/hpjournal/pdfs/IssuePDFs/1979-02.pdf. Retrieved 9 February 2012.
"A.O.Smith: The AC's and DC's of Electric Motors" (PDF). http://www.aosmithmotors.com/uploadedFiles/AC-DC%20manual.pdf. Retrieved 2009-12-07.
"Cobham plc :: Aerospace and Security, Aerospace Communications, Annemasse". Cobham.com. 2011-02-13. http://www.cobham.com/about-cobham/aerospace-and-security/about-us/aerospace-communications/annemasse.aspx.
"Encyclopædia Britannica, "Galileo Ferraris"". http://www.britannica.com/EBchecked/topic/204963/Galileo-Ferraris.
"Frequently Asked Slip Ring Questions". Moog.com. 2009-06-23. http://www.moog.com/products/slip-rings/slip-rings-faq-s/. Retrieved 2011-09-02.
"Galileo Ferraris". http://profiles.incredible-people.com/galileo-ferraris/.
"how slip rings work". Uea-inc.com. http://www.uea-inc.com/products/slip-rings/how-they-work.aspx.
"Slip Ring Connector - SenRing Electronics". Senring.com. http://www.senring.com/hnr67.html.
Alan Hendrickson, Colin Buckhurst Mechanical design for the stage Focal Press, 2008 ISBN 0-240-80631-X, page 379 with an illustration of pancake and drum-type slip rings.
B. R. Pelly, "Thyristor Phase-Controlled Converters and Cycloconverters: Operation, Control, and Performance" (New York: John Wiley, 1971).
Bakshi U.A. and Bakshi V.U. Basics of Electrical Engineering. Technical Publications Pune. 2008.
Bakshi U.A., Godse and Bakshi M.V. Electrical Machines and Electronics. Technical Publications Pune, 2009.
Bedford, B. D.; Hoft, R. G. et al. (1964). Principles of Inverter Circuits. New York: John Wiley & Sons, Inc.. ISBN 0-471-06134-4. (Inverter circuits are used for variable-frequency motor speed control)
Bishop, Robert H., Ed. The Mechatronics Handbook, ISA—The Instrumentation, Systems and Automation Society, CRC Press, 2002.
Briere D. and Traverse, P. (1993) “Airbus A320/A330/A340 Electrical Flight Controls: A Family of Fault-Tolerant Systems” Proc. FTCS, pp. 616–623.
Brumbach Michael E. Industrial Electricity. Thomason Delmar Learning, 2005.
Cyril W. Lander, Power Electronics 3rd Edition, McGraw Hill International UK Limited, London 1993 ISBN 0-07-707714-8 Chapter 9–8 Slip Ring Induction Motor Control
Deshpande, M.V. Electric Motors: Application and Control. PHI Learning Private Ltd., 2010.
Deshpande, M.V. Electric Motors: Application and Control. PHI Learning Private Ltd., 2010.
Donald G. Fink and H. Wayne Beaty, Standard Handbook for Electrical Engineers, Eleventh Edition, McGraw-Hill, New York, 1978, ISBN 0-07-020974-X.
Edwin J. Houston and Arthur Kennelly, Recent Types of Dynamo-Electric Machinery, copyright American Technical Book Company 1897, published by P.F. Collier and Sons New York, 1902
Electric motors use 60% of china's electric energy, for example
Electricity and magnetism, translated from the French of Amédée Guillemin. Rev. and ed. by Silvanus P. Thompson. London, MacMillan, 1891
Faraday, Michael (1844). Experimental Researches in Electricity. 2. See plate 4.
Fitzgerald/Kingsley/Kusko (Fitzgerald/Kingsley/Umans in later years), Electric Machinery, classic text for junior and senior electrical engineering students. Originally published in 1952, 6th edition published in 2002.

Ganot's Physics, 14th Edition, N.Y., 1893 translated by Atkinson, pp. 907 and 908. (Section 899, and Figure 888).
Garrison, Ervan G., "A history of engineering and technology". CRC Press, 1998. ISBN 0-8493-9810-X, 9780849398100. Retrieved May 7, 2009.
Gee, William (2004). "Sturgeon, William (1783–1850)". Oxford Dictionary of National Biography. Oxford, England: Oxford University Press. doi:10.1093/ref:odnb/26748.
Gill, Paul. Electrical Power Equipment Maintenance and Testing. CRC Press: Taylor & Francis Group, 2009.
Herman, Stephen L. Electric Motor Control. 9th ed. Delmar Cengage Learning, 2010.
Herman, Stephen L. Industrial Motor Control. 6th ed. Delmar Cengage Learning, 2010.
http://books.google.it/books?id=CxQdC6xPFSwC&pg=PA45&lpg=PA45&dq=GALILEO+FERRARIS+AC+MOTOR+INVENTION&source=web&ots=jjeS-hcv2T&sig=cYbNfNNeVwvMIhR-JCP8uReedRU&hl=it&sa=X&oi=book_result&resnum=1&ct=result#v=onepage&q&f=false.
http://www.circuitcellar.com/ Motor Comparison, Circuit Cellar Magazine, July 2008, Issue 216, Bachiochi, p.78 (Table edited in Wikipedia, May 2011)
http://www.daytronic.com/products/trans/t-magpickup.htm
http://www.electronicsweekly.com/Articles/2010/08/13/46377/dyson-vacuums-104000rpm-brushless-dc-technology.htm
http://www.frankfurt.matav.hu/angol/magytud.htm
http://www.mpoweruk.com/history.htm
http://www.mpoweruk.com/timeline.htm
http://www.physics.umd.edu/lecdem/services/demos/demosk4/k4-21.gif
http://www.traveltohungary.com/english/articles/article.php?id=135
Hughes, Austin. Electric Motors and Drives: fundamentals, types and applications. 3rd ed. Linacre House, 2006.
Irwin, David J., Ed. The Industrial Electronics Handbook. CRC Press: IEEE Press, 1997.
Jiles, David. Introduction to Magnetism and Magnetic Materials. CRC Press: Taylor Francis Group, 1998.
John N. Chiasson, Modeling and High Performance Control of Electric Machines, Wiley-IEEE Press, New York, 2005, ISBN 0-471-68449-X.
Kuphaldt, Tony R. (2000–2006). "Chapter 13 AC MOTORS". Lessons In Electric Circuits—Volume II. http://www.ibiblio.org/obp/electricCircuits/AC/AC_13.html. Retrieved 2006-04-11.
Laughton M.A. and Warne, D.F., Eds. Electrical Engineer's Reference Book. 16th ed. Elsevier Science, 2003.
linear Electric Machines- A Personal View - Eric R. Laithwaite, Proceedings of the IEEE, Vol. 63, No. 2, February 1975 page 250
Miller, Rex and Mark R. Miller, Industrial Electricity and Motor Controls. McGraw Hill, 2008.
Nature 53. (printed in 1896) page: 516
Neidhöfer, Gerhard. [http://www.ieee.org/organizations/pes/public/2007/sep/peshistory.html "Early Three-Phase Power Winner in the development of polyphase ac"]. http://www.ieee.org/organizations/pes/public/2007/sep/peshistory.html.
North, David. (2000) "Finding Common Ground in Envelope Protection Systems". Aviation Week & Space Technology, Aug 28, pp. 66–68.
Pansini, Anthony, J (1989). Basic of Electric Motors. Pennwell Publishing Company. p. 45. ISBN 0-13-060070-9.
Patrick, Dale R. and Fardo, Stephen W. Electrical Distribution Systems. 2nd ed. The Fairmont Press, 2009.
Patrick, Dale R. and Stephen W. Fardo. Rotating Electrical Machines and Power Systems. 2nd ed. The Fairmont Press, 1997.

Patrick, Dale R; Fardo, Stephen W., Rotating Electrical Machines and Power Systems (2nd Edition)1997 Fairmont Press, Inc. ISBN 978-0-88173-239-9 chapter 11
Peter W. Fortescue, John Stark, Graham Swinerd Spacecraft systems engineering John Wiley and Sons, 2003 ISBN 0-470-85102-3
Rajput R.K. Basic Electrical and Electronics Engineering. Laxmi Publications Ltd., 2007.
Resenblat & Frienman DC and AC machinery
Schoenherr, Steven F. (2001), "Loudspeaker History". Recording Technology History. Retrieved 2010-03-13.
Shanefield D. J., Industrial Electronics for Engineers, Chemists, and Technicians, William Andrew Publishing, Norwich, NY, 2001.
Singh,Yaduvir Dr. and Verma M. Fundamentals of Electrical Engineering. University Science Press, 2010.
Sivanagaraju S., Reddy and Prasad. Power Semiconductor Drives. PHI Learning Private Ltd., 2009.
Slow Speed Torque Drive Units
Subrahmanyam, V., Electric Drives: Concepts and Applications. 2nd ed. Tata McGraw Hill, 2011.
The “Goodness” of Small Contemporary Permanent Magnet Electric Machines - D J Patterson, C W Brice, R A Dougal, D Kovuri
Tokai University Unveils 100W DC Motor with 96% Efficiency
http://techon.nikkeibp.co.jp/english/NEWS_EN/20090403/168295/
Toliyat, Hamid A. and Kliman G.B. Handbook of Electric Motors. Marcel Dekker, Inc., 2004.
US Department of Energy indicates over half US electricity generation is used by electric motors
Wayne Saslow. Electricity, Magnetism and Light. Thomson Learning Inc., 2002.

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
2.54 CM =Inch
1 Gallon of Water = 8.34 Pounds
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)

PIPE VOLUME: .785 X Diameter ^{2} X Length = ? To obtain gallons multiply by 7.48

SPHERE: $\frac{(3.14)\ (\text{Diameter})^3}{(6)}$

Circumference = 3.14 X Diameter

General Conversions

Multiply	—>	to get
to get	**<—**	**Divide**
cc/min	1	mL/min
cfm (ft^3/min)	28.31	L/min
cfm (ft^3/min)	1.699	m^3/hr
cfh (ft^3/hr)	472	mL/min
cfh (ft^3/hr)	0.125	GPM
GPH	63.1	mL/min
GPH	0.134	cfh
GPM	0.227	m^3/hr
GPM	3.785	L/min
oz/min	29.57	mL/min

POUNDS PER DAY= Flow (MG) X Concentration (mg/L) X 8.34
***AKA* Solids Applied Formula** = Flow X Dose X 8.34

PERCENT EFFICIENCY = $\frac{\text{In} - \text{Out}}{\text{In}} \times 100$

TEMPERATURE: $^0F = (^0C \times 9/5) + 32$ 9/5 =1.8
$^0C = (^0F - 32) \times 5/9$ 5/9 = .555

CONCENTRATION: Conc. (A) X Volume (A) = Conc. (B) X Volume (B)

FLOW RATE (Q): Q = A X V (**Q**uantity = **A**rea X **V**elocity)

FLOW RATE (gpm): Flow Rate (gpm) = $\frac{2.83\ (\text{Diameter, in})^2\ (\text{Distance, in})}{\text{Height, in}}$

% SLOPE = $\frac{\text{Rise (feet)}}{\text{Run (feet)}} \times 100$

ACTUAL LEAKAGE = $\frac{\text{Leak Rate (GPD)}}{\text{Length (mi.)} \times \text{Diameter (in)}}$

VELOCITY = $\frac{\text{Distance (ft)}}{\text{Time (Sec)}}$

N = Manning's Coefficient of Roughness
R = Hydraulic Radius (ft.)
S = Slope of Sewer (ft/ft.)

HYDRAULIC RADIUS (ft) = $\frac{\text{Cross Sectional Area of Flow (ft)}}{\text{Wetted pipe Perimeter (ft)}}$

WATER HORSEPOWER = $\frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960}$

BRAKE HORSEPOWER = $\frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Efficiency}}$

MOTOR HORSEPOWER = $\frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Eff.} \times \text{Motor Eff.}}$

MEAN OR AVERAGE = $\frac{\text{Sum of the Values}}{\text{Number of Values}}$

TOTAL HEAD (ft) = Suction Lift (ft) X Discharge Head (ft)

SURFACE LOADING RATE (gal/min/sq.ft.) = $\frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sq. ft)}}$

MIXTURE STRENGTH (%) = $\frac{\text{(Volume 1, gal) (Strength 1, \%) + (Volume 2, gal) (Strength 2,\%)}}{\text{(Volume 1, gal) + (Volume 2, gal)}}$

DETENTION TIME (hrs.) = $\frac{\text{Volume of Basin (gals)} \times \text{24 hrs.}}{\text{Flow (GPD)}}$

SLOPE = $\frac{\text{Rise (ft)}}{\text{Run (ft)}}$

SLOPE (%) = $\frac{\text{Rise (ft)} \times 100}{\text{Run (ft)}}$

POPULATION EQUIVALENT (PE):

1 PE = .17 Pounds of BOD per Day
1 PE = .20 Pounds of Solids per Day
1 PE = 100 Gallons per Day

LEAKAGE (GPD/inch) = $\frac{\text{Leakage of Water per Day (GPD)}}{\text{Sewer Diameter (inch)}}$

CHLORINE DEMAND (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L)

MANNING'S EQUATION

τQ = Allowable time for decrease in pressure from 3.5 PSI to 2.5 PSI
τq = As below

$\tau Q = (0.022)\,(d_1^2 L_1)/Q \quad \tau q = \frac{[\,0.085]}{q}\,[(d_1^2 L1)/(d_1 L_1)]$

Q = 2.0 cfm air loss
θ = .0030 cfm air loss per square foot of internal pipe surface
δ = Pipe diameter (inches)
L = Pipe Length (feet)

$V = \frac{1.486}{\nu} R^{2/3} S^{1/2}$

V = Velocity (ft./sec.)
ν = Pipe Roughness
R = Hydraulic Radius (ft)
S= Slope (ft/ft)

HYDRAULIC RADIUS (ft) = $\frac{\text{Flow Area (ft. 2)}}{\text{Wetted Perimeter (ft.)}}$

WIDTH OF TRENCH (ft) = Base (ft) + (2 Sides) X $\frac{\text{Depth (ft 2)}}{\text{Slope}}$

We welcome you to complete the assignment in Microsoft Word. You can easily find the assignment at www.abctlc.com. Once complete, just simply fax or e-mail the answer key along with the registration page to us and allow two weeks for grading.

Once we grade it, we will e-mail a certificate of completion to you. Call us if you need any help.

If you need your certificate back within 48 hours, you may be asked to pay a rush service fee of $50.00.

You can download the assignment in Microsoft Word from TLC's website under the Assignment Page. www.abctlc.com

You will have 90 days in order to successfully complete this assignment with a score of 70% or better. If you need any assistance, please contact TLC's Student Services.

Once you are finished, please mail, e-mail or fax your answer sheet along with your registration form.