Chapter 9

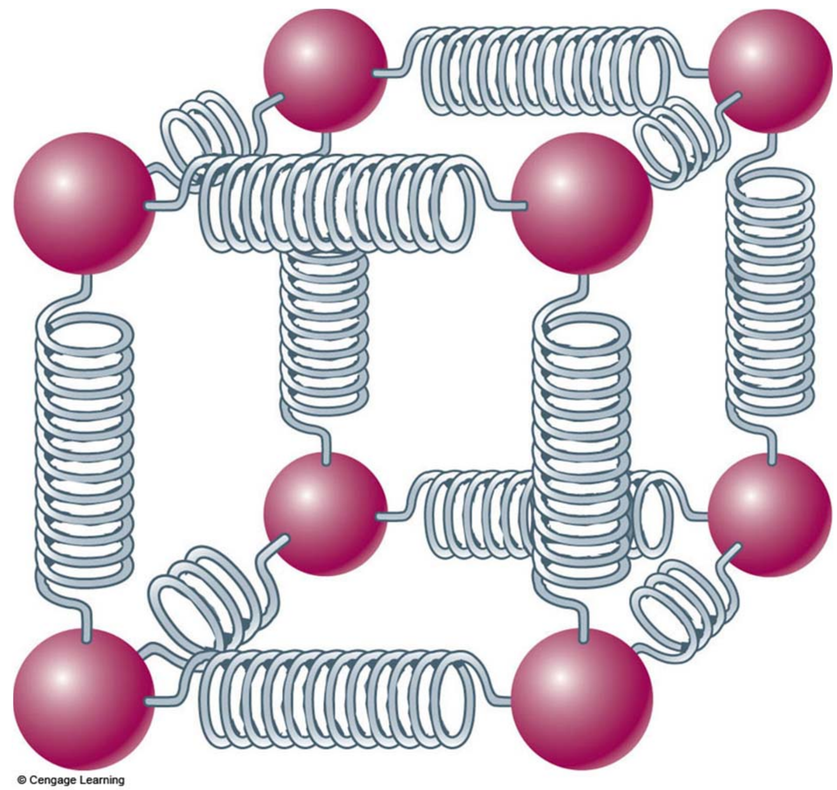
Solids and Fluids

States of Matter

- Solid
- Liquid
- Gas
- Plasma

Solids

- Have definite volume
- Have definite shape
- Atoms or molecules are held in specific locations
  - By electrical forces
- Vibrate about equilibrium positions
- Can be modeled as springs connecting molecules

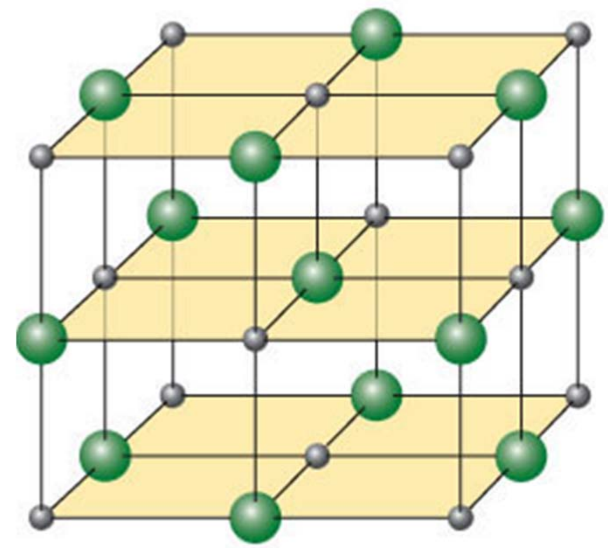


More About Solids

- External forces can be applied to the solid and compress the material
  - In the model, the springs would be compressed
- When the force is removed, the solid returns to its original shape and size
  - This property is called *elasticity*

Crystalline Solid

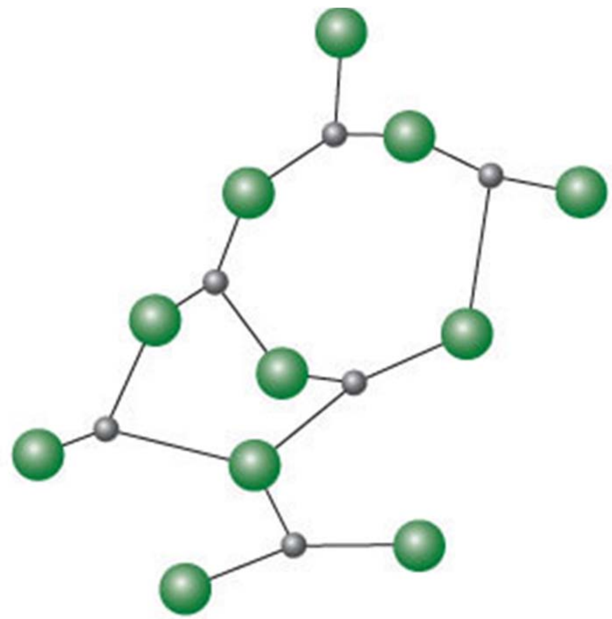
- Atoms have an ordered structure
- This example is salt
  - Gray spheres represent Na^+ ions
  - Green spheres represent Cl^- ions



(a)

Amorphous Solid

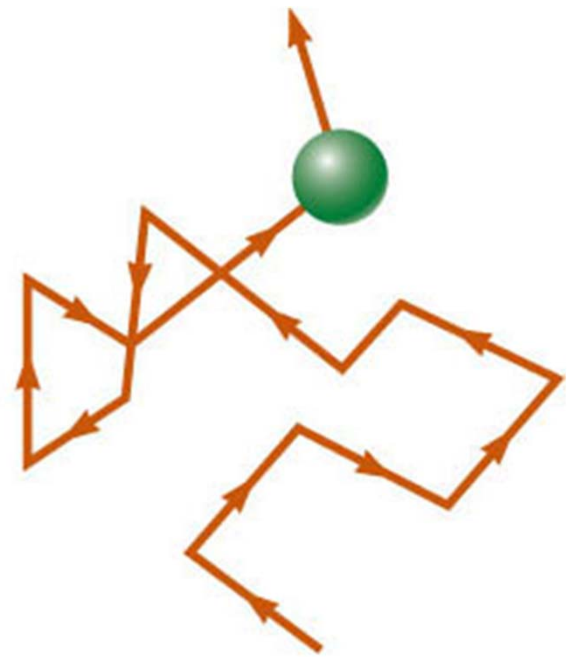
- Atoms are arranged almost randomly
- Examples include glass



(b)

Liquid

- Has a definite volume
- No definite shape
- Exists at a higher temperature than solids
- The molecules "wander" through the liquid in a random fashion
  - The intermolecular forces are not strong enough to keep the molecules in a fixed position



(c)

Gas

- Has no definite volume
- Has no definite shape
- Molecules are in constant random motion
- The molecules exert only weak forces on each other
- Average distance between molecules is large compared to the size of the molecules

Plasma

- Gas heated to a very high temperature
- Many of the electrons are freed from the nucleus
- Result is a collection of free, electrically charged ions
- Plasmas exist inside stars

Types of Matter

- Normal matter
  - About 5% of total matter
- Dark matter
  - Affects the motion of stars in galaxies
  - May be as much at 25% of total matter
- Dark energy
  - Accounts for acceleration of the expansion of the universe
  - May be as much as 70% of all matter

Deformation of Solids

- All objects are deformable
- It is possible to change the shape or size (or both) of an object through the application of external forces
- When the forces are removed, the object tends to its original shape
  - An object undergoing this type of deformation exhibits *elastic behavior*

Elastic Properties

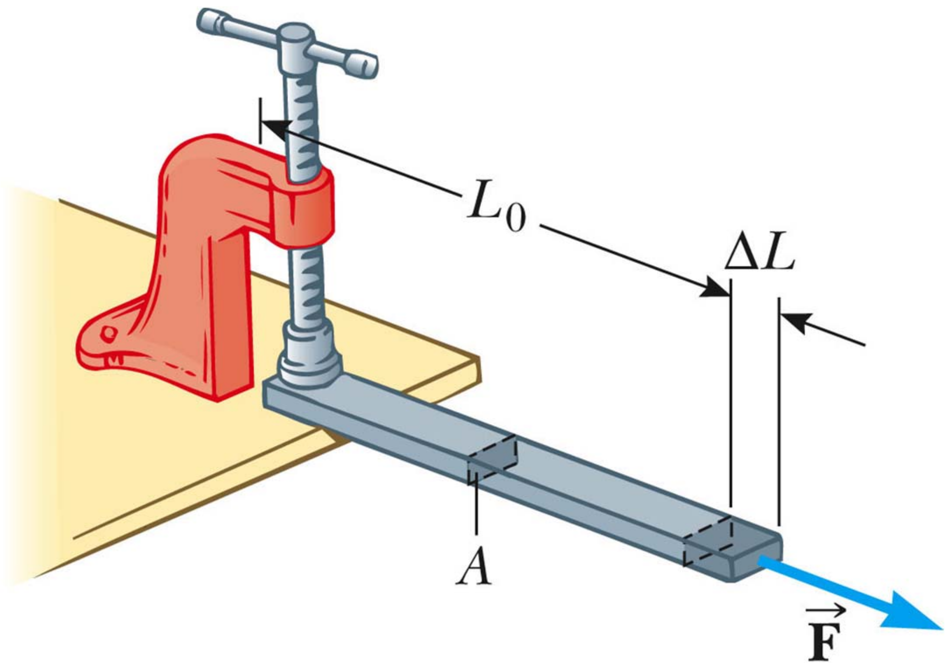
- *Stress* is the force per unit area(F/A) causing the deformation
- *Strain* is a measure of the amount of deformation ($\Delta L/L$)
- The *elastic modulus Y* is the constant of proportionality between stress and strain
  - For sufficiently small stresses, the stress is directly proportional to the strain
  - The constant of proportionality depends on the material being deformed and the nature of the deformation

Elastic Modulus

- The elastic modulus can be thought of as the stiffness of the material
  - A material with a large elastic modulus is very stiff and difficult to deform
    - Analogous to the spring constant
  - $\text{stress} = \text{Elastic modulus} \times \text{strain}$

Young's Modulus: Elasticity in Length

- Tensile stress is the ratio of the external force to the cross-sectional area
  - Tensile is because the bar is under tension
- The elastic modulus is called *Young's modulus*



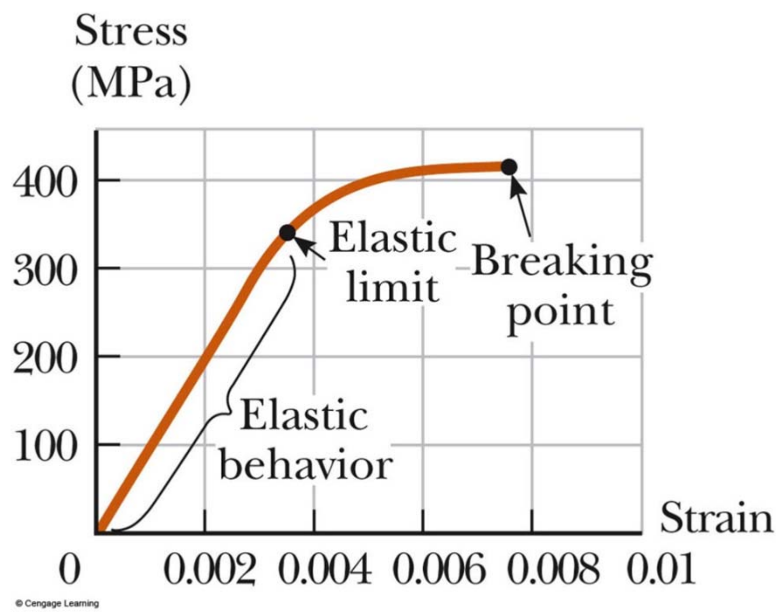
Young's Modulus, cont.

- SI units of stress are Pascals, Pa
  - 1 Pa = 1 N/m^2
- The tensile strain is the ratio of the change in length to the original length
  - Strain is dimensionless

$$\frac{F}{A} = Y \frac{\Delta L}{L_o}$$

Young’s Modulus, final

- Young’s modulus applies to a stress of either tension or compression
- It is possible to exceed the *elastic limit* of the material
  - No longer directly proportional
  - Ordinarily does not return to its original length

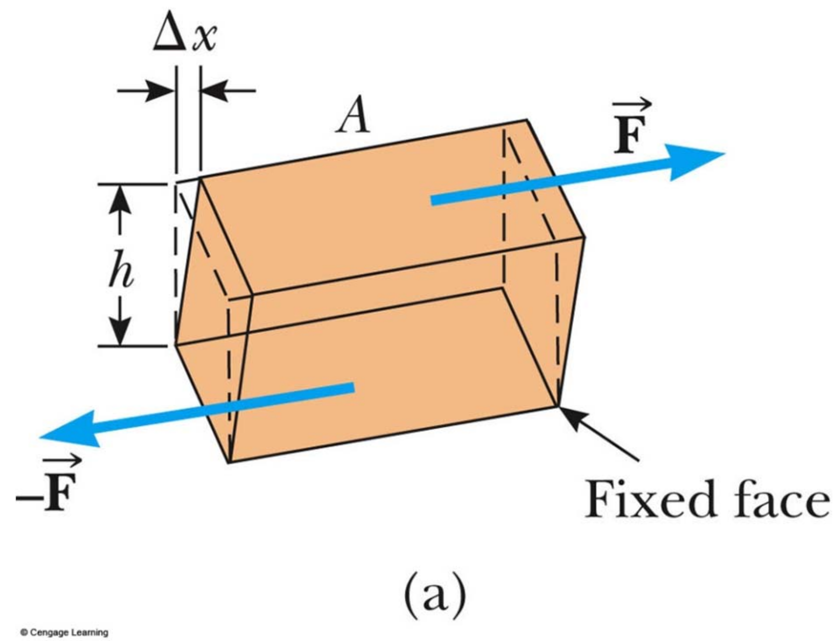


Breaking

- If stress continues, it surpasses its *ultimate strength*
  - The ultimate strength is the greatest stress the object can withstand without breaking
- The **breaking point**
  - For a brittle material, the breaking point is just beyond its ultimate strength
  - For a ductile material, after passing the ultimate strength the material thins and stretches at a lower stress level before breaking

Shear Modulus: Elasticity of Shape

- Forces may be parallel to one of the object's faces
- The stress is called a *shear stress*
- The *shear strain* is the ratio of the horizontal displacement and the height of the object
- The shear modulus is S



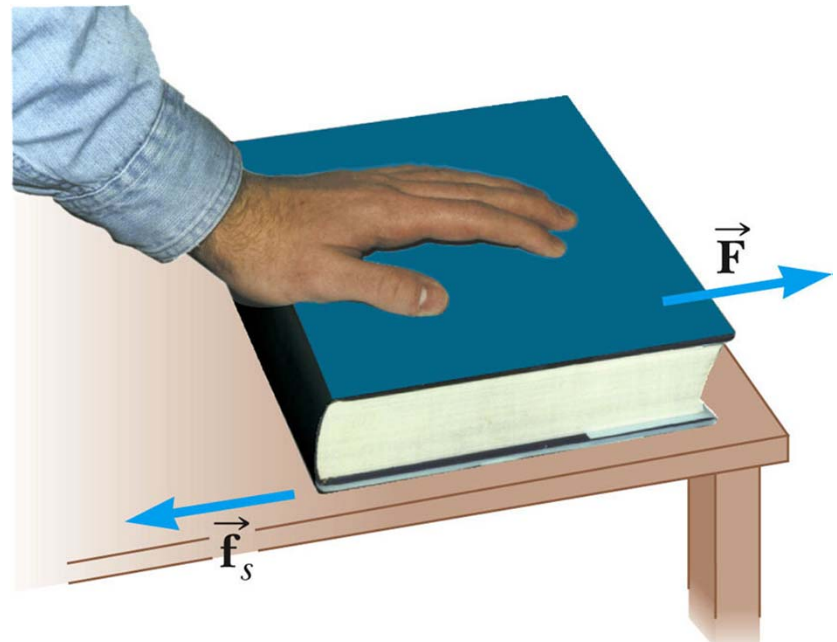
Shear Modulus, Equations

- $$\text{shear stress} = \frac{F}{A}$$

  $$\text{shear strain} = \frac{\Delta x}{h}$$

  $$\frac{F}{A} = S\frac{\Delta x}{h}$$

- S is the shear modulus
- A material having a large shear modulus is difficult to bend



(b)

Shear Modulus, final

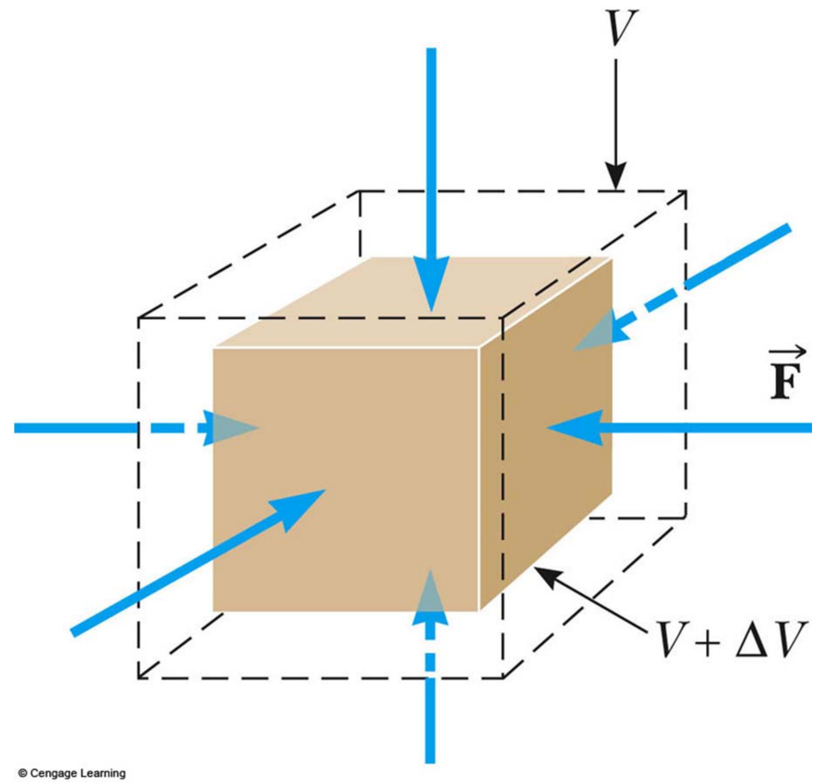
- There is no volume change in this type of deformation
- Remember the force is parallel to the cross-sectional area
    - In tensile stress, the force is perpendicular to the cross-sectional area

Bulk Modulus: Volume Elasticity

- Bulk modulus characterizes the response of an object to uniform squeezing
  - Suppose the forces are perpendicular to, and act on, all the surfaces
    - Example: when an object is immersed in a fluid
- The object undergoes a change in volume without a change in shape

Bulk Modulus, cont.

- Volume stress, ΔP, is the ratio of the force to the surface area
  - This is also called the pressure when dealing with fluids
- The volume strain is equal to the ratio of the change in volume to the original volume



Bulk Modulus, final

$$\Delta P = -B\frac{\Delta V}{V}$$

- A material with a large bulk modulus is difficult to compress
- The negative sign is included since an increase in pressure will produce a decrease in volume
  - B is always positive
- The *compressibility* is the reciprocal of the bulk modulus

Notes on Moduli

- Solids have Young’s, Bulk, and Shear moduli
- Liquids have only bulk moduli, they will not undergo a shearing or tensile stress
  - The liquid would flow instead

Elastic Modulus

Values for the Elastic Modulus

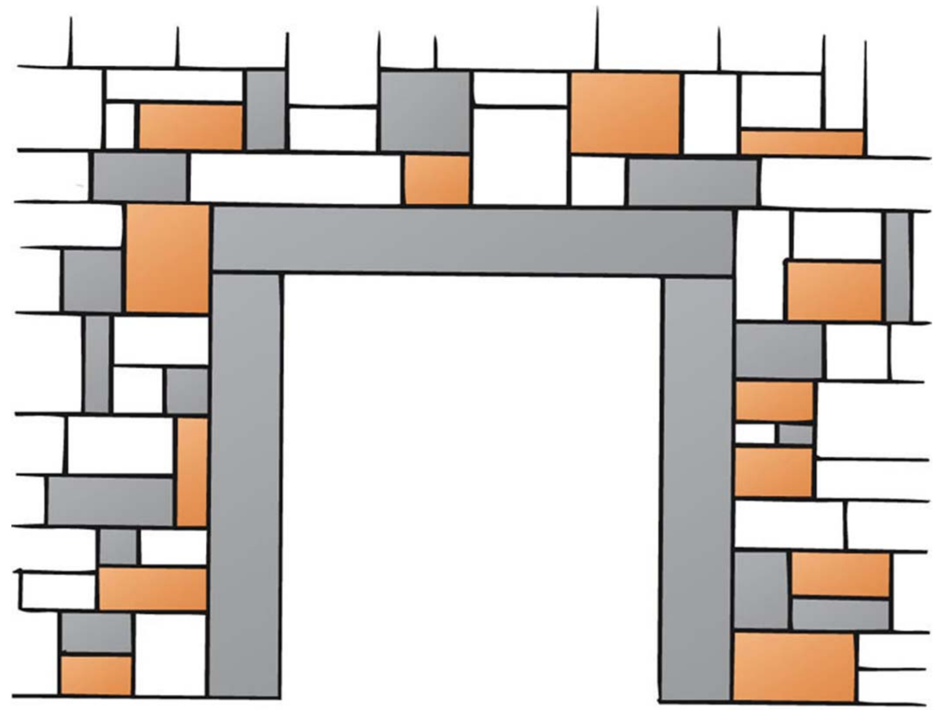
Substance	Young's Modulus (Pa)	Shear Modulus (Pa)	Bulk Modulus (Pa)
Aluminum	7.0×10^{10}	2.5×10^{10}	7.0×10^{10}
Bone	1.8×10^{10}	8.0×10^{10}	—
Brass	9.1×10^{10}	3.5×10^{10}	6.1×10^{10}
Copper	11×10^{10}	4.2×10^{10}	14×10^{10}
Steel	20×10^{10}	8.4×10^{10}	16×10^{10}
Tugsten	35×10^{10}	14×10^{10}	20×10^{10}
Glass	$6.5–7.8 \times 10^{10}$	$2.6–3.2 \times 10^{10}$	$5.0–5.5 \times 10^{10}$
Quartz	5.6×10^{10}	2.6×10^{10}	2.7×10^{10}
Rib Cartilage	1.2×10^{7}	—	—
Rubber	0.1×10^{7}	—	—
Tendon	2×10^{7}	—	—
Water	—	—	0.21×10^{10}
Mercury	—	—	2.8×10^{10}

Ultimate Strength of Materials

- The *ultimate strength* of a material is the maximum force per unit area the material can withstand before it breaks or factures
- Some materials are stronger in compression than in tension

Post and Beam Arches

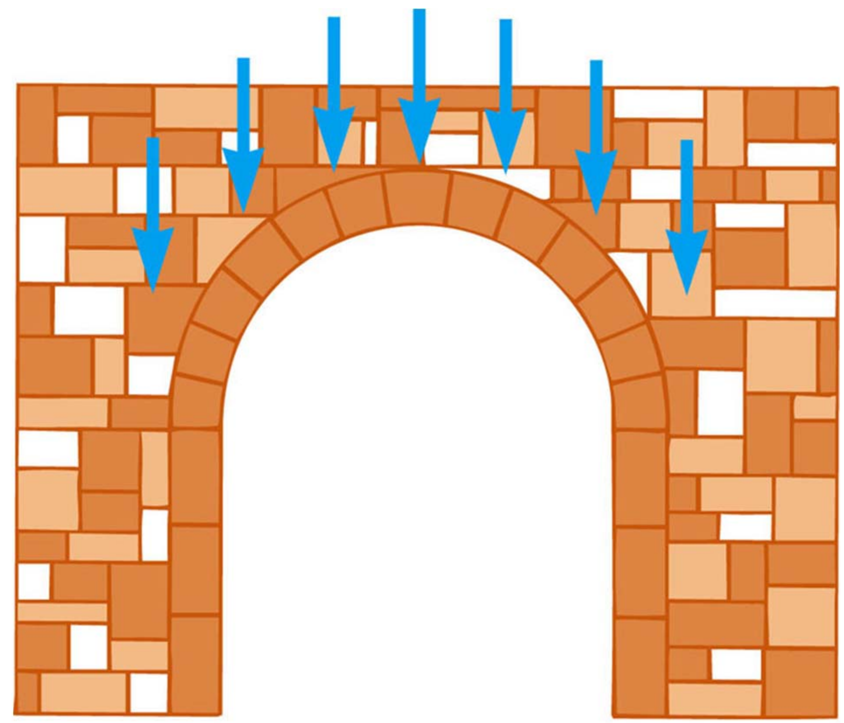
- A horizontal beam is supported by two columns
- Used in Greek temples
- Columns are closely spaced
  - Limited length of available stones
  - Low ultimate tensile strength of sagging stone beams



Post and beam
(a)

Semicircular Arch

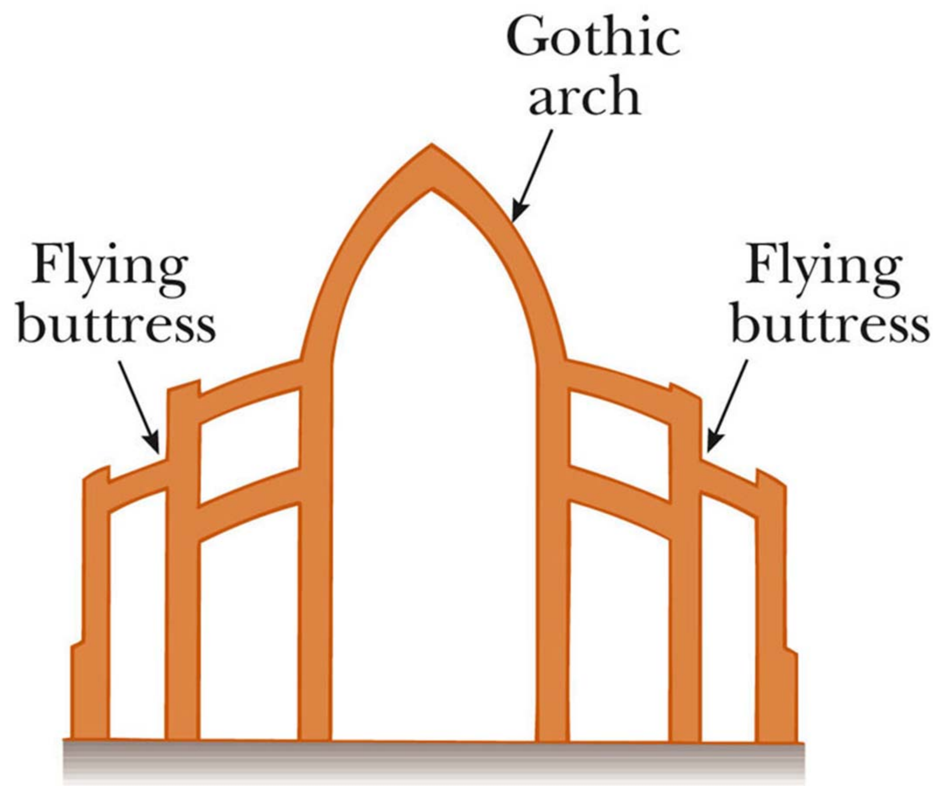
- Developed by the Romans
- Allows a wide roof span on narrow supporting columns
- Stability depends upon the compression of the wedge-shaped stones



Semicircular arch (Roman)
(b)

Gothic Arch

- First used in Europe in the 12th century
- Extremely high
- The flying buttresses are needed to prevent the spreading of the arch supported by the tall, narrow columns



Pointed arch (Gothic)
(c)

Sample Problem 9.1

Problem A vertical steel beam in a building supports a load of 6.0×10^4 N. **(a)** If the length of the beam is 4.0 m and its cross-sectional area is 8.0×10^{-3} m^2, find the distance the beam is compressed along its length. **(b)** What maximum load in newtons could the steel beam support before failing?

Example 1

A 20 cm long rod with a diameter of 0.25 cm is loaded with a mass of 500 kg. If the length of the rod increases to 20.75 cm, determine the (a) stress and strain at this load, and (c) the modulus of elasticity.

Sample Problem 9.2

Problem A defensive lineman of mass $M = 125$ kg makes a flying tackle at $v_i = 4.00$ m/s on a stationary quarterback of mass $m = 85.0$ kg, and the lineman's helmet makes solid contact with the quarterback's femur. (a) What is the speed v_f of the two athletes immediately after contact? Assume a linear inelastic collision. (b) If the collision lasts for 0.100 s, estimate the average force exerted on the quarterback's femur. (c) If the cross-sectional area of the quarterback's femur is 5.00×10^{-4} m^2, calculate the shear stress exerted on the bone in the collision.

Strategy The solution proceeds in three well-define steps. In part (a), use conservation of linear momentun to calculate the final speed of the system consisting of th quarterback and the lineman. Second, the speed founc in part (a) can be used in the impulse-momentum theo rem to obtain an estimate of the average force exertec on the femur. Third, dividing the average force by th cross-sectional area of the femur gives the desired esti mate of the shear stress.

Sample Problem 9.3

Problem A solid lead sphere of volume $0.50\ m^3$, dropped in the ocean, sinks to a depth of 2.0×10^3 m (about 1 mile), where the pressure increases by 2.0×10^7 Pa. Lead has a bulk modulus of 4.2×10^{10} Pa. What is the change in volume of the sphere?

TABLE 9.2

Ultimate Strength of Materials

Material	Tensile Strength (N/m^2)	Compressive Strength (N/m^2)
Iron	1.7×10^8	5.5×10^8
Steel	5.0×10^8	5.0×10^8
Aluminum	2.0×10^8	2.0×10^8
Bone	1.2×10^8	1.5×10^8
Marble	—	8.0×10^7
Brick	1×10^6	3.5×10^7
Concrete	2×10^6	2×10^7

Density

- The density of a substance of uniform composition is defined as its mass per unit volume:

$$\rho \equiv \frac{m}{V}$$

- Units are kg/m^3 (SI) or g/cm^3 (cgs)
- $1\ g/cm^3 = 1000\ kg/m^3$

Density, cont.

- The densities of most liquids and solids vary slightly with changes in temperature and pressure
- Densities of gases vary greatly with changes in temperature and pressure
- The higher normal densities of solids and liquids compared to gases implies that the average spacing between molecules in a gas is about 10 times greater than the solid or liquid

TABLE 9.3

Densities of Some Common Substances

Substance	ρ (kg/m^3)[a]	Substance	ρ (kg/m^3)[a]
Ice	0.917×10^3	Water	1.00×10^3
Aluminum	2.70×10^3	Glycerin	1.26×10^3
Iron	7.86×10^3	Ethyl alcohol	0.806×10^3
Copper	8.92×10^3	Benzene	0.879×10^3
Silver	10.5×10^3	Mercury	13.6×10^3
Lead	11.3×10^3	Air	1.29
Gold	19.3×10^3	Oxygen	1.43
Platinum	21.4×10^3	Hydrogen	8.99×10^{-2}
Uranium	18.7×10^3	Helium	1.79×10^{-1}

[a]All values are at standard atmospheric temperature and pressure (STP), defined as 0°C (273 K) and 1 atm (1.013×10^5 Pa). To convert to grams per cubic centimeter, multiply by 10^{-3}.

Example 2

- $P = F/A$

- A water bed is 2.00 m on a side and 30 cm deep. Find the pressure that the water bed exerts on the floor.

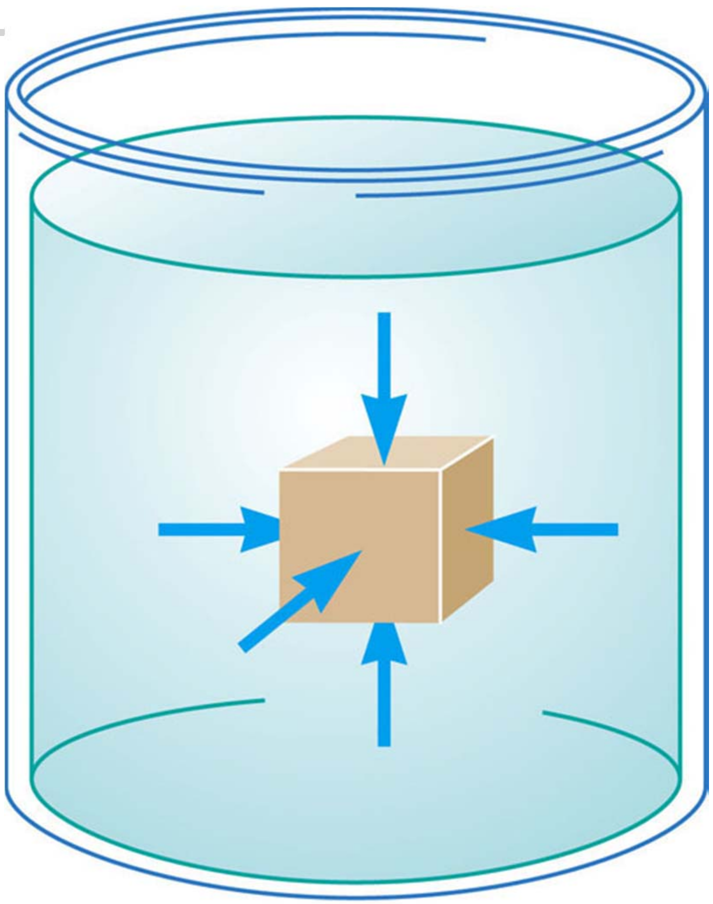
Specific Gravity

- The *specific gravity* of a substance is the ratio of its density to the density of water at 4° C
  - The density of water at 4° C is 1000 kg/m^3
- Specific gravity is a unitless ratio

Pressure

- The force exerted by a fluid on a submerged object at any point is perpendicular to the surface of the object

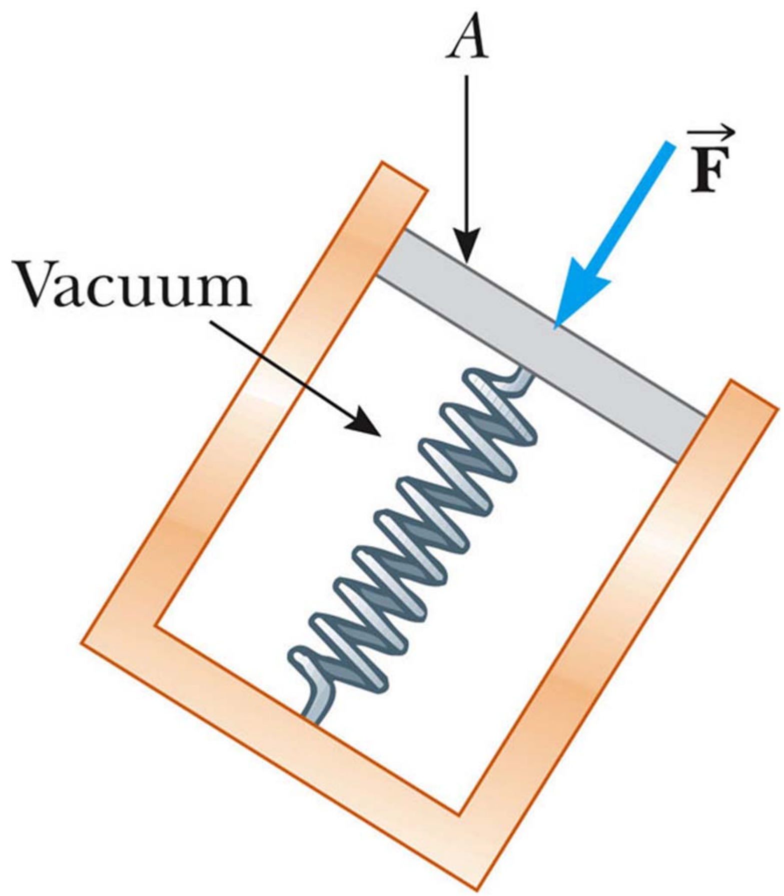
$$P \equiv \frac{F}{A} \text{ in } Pa = \frac{N}{m^2}$$



(a)

Measuring Pressure

- The spring is calibrated by a known force
- The force the fluid exerts on the piston is then measured



(b)

Variation of Pressure with Depth

- If a fluid is at rest in a container, all portions of the fluid must be in static equilibrium
- All points at the same depth must be at the same pressure
  - Otherwise, the fluid would not be in equilibrium
  - The fluid would flow from the higher pressure region to the lower pressure region

Pressure and Depth

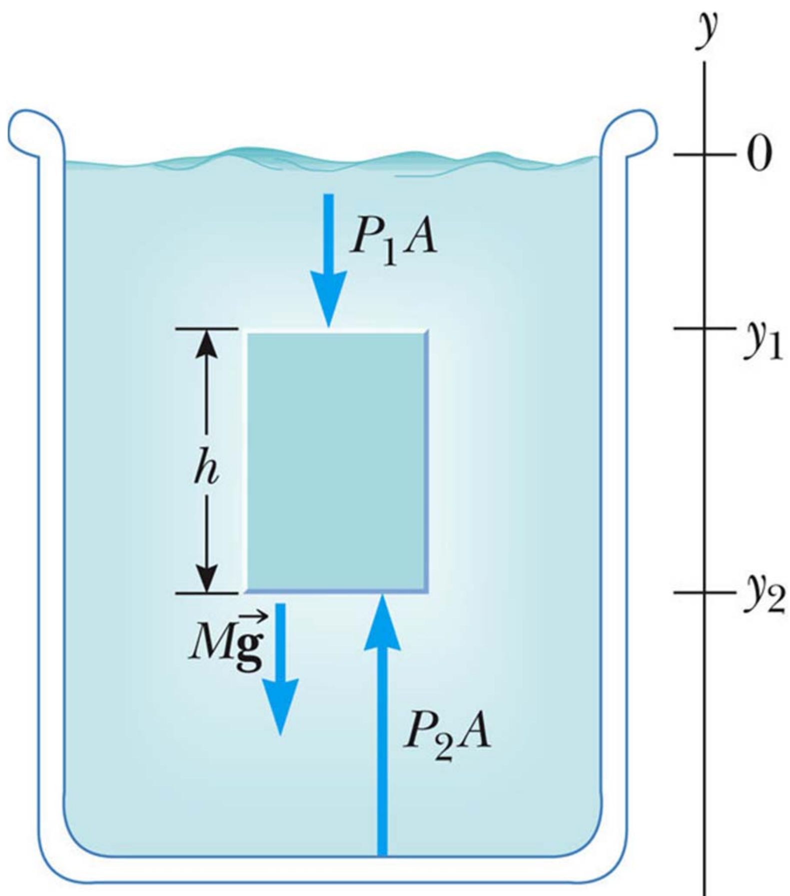
- Examine the darker region, assumed to be a fluid
  - It has a cross-sectional area A
  - Extends to a depth h below the surface
- Three external forces act on the region:

$$P_2A - P_1A - Mg = 0$$

$$M = \rho V = \rho A(y_1 - y_2) = \rho Ah$$

$$P_2A - P_1A - \rho Ahg = 0$$

$$P_2 = P_1 - \rho gh$$



(b)

Pressure and Depth equation

- $$P = P_o + \rho g h$$
- P_o is atmospheric pressure
  - 1.013×10^5 Pa = 14.7 lb/in.^{2} (psi)

  ρgh - hydrostatic pressure or gauge pressure

  P = absolute pressure
- The pressure does not depend upon the shape of the container

Example 3

- Calculate the absolute pressure at the bottom of a fresh-water lake at depth of 27.5 m. Assume the density of the water is 1000 kg/m^3 and the air above is at a pressure of 101.3 kPa.
- (b) What force is exerted by the water on the window of underwater vehicle at this depth if the window is circular and has a diameter of 35 cm

Sample Problems 9.5, 9.6, 9.7

Problem In a huge oil tanker, salt water has flooded an oil tank to a depth of 5.00 m. On top of the water is a layer of oil 8.00 m deep, as in the cross-sectional view of the tank in Figure 9.13. The oil has a density of 0.700 g/cm^3. Find the pressure at the bottom of the tank. (Take 1 025 kg/m^3 as the density of salt water.)

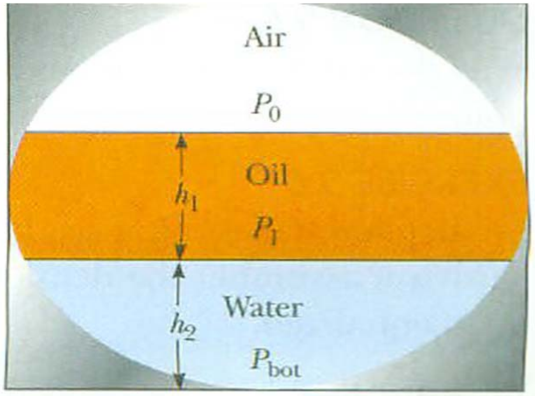


FIGURE 9.13 (Example 9.5)

Pascal’s Principle

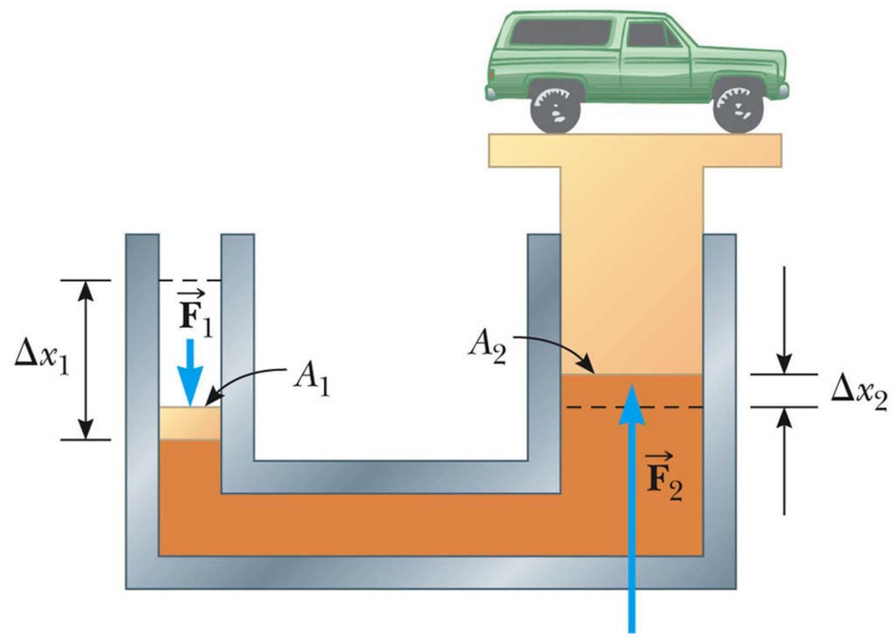
- A change in pressure applied to an enclosed fluid is transmitted undimished to every point of the fluid and to the walls of the container.
  - First recognized by Blaise Pascal, a French scientist (1623 – 1662)

Pascal's Principle, cont

- The hydraulic press is an important application of Pascal's Principle

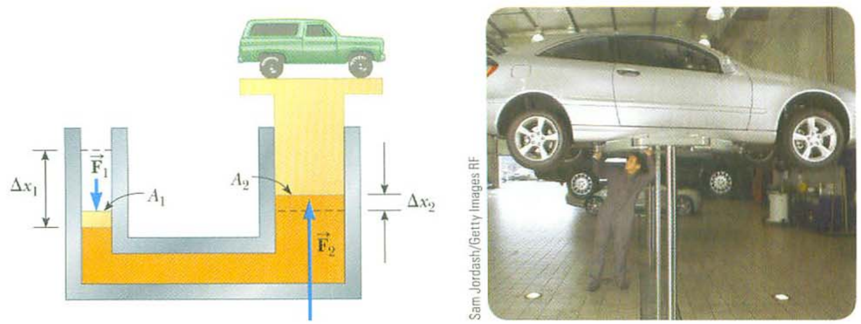
$$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

- Also used in hydraulic brakes, forklifts, car lifts, etc.



(a)

Problem Estimate the net force exerted on your eardrum due to the water above when you are swimming at the bottom of a pool that is 5.0 m deep.



(a) (b)

FIGURE 9.14 (a) Diagram of a hydraulic press (Example 9.7). Because the pressure is the same at

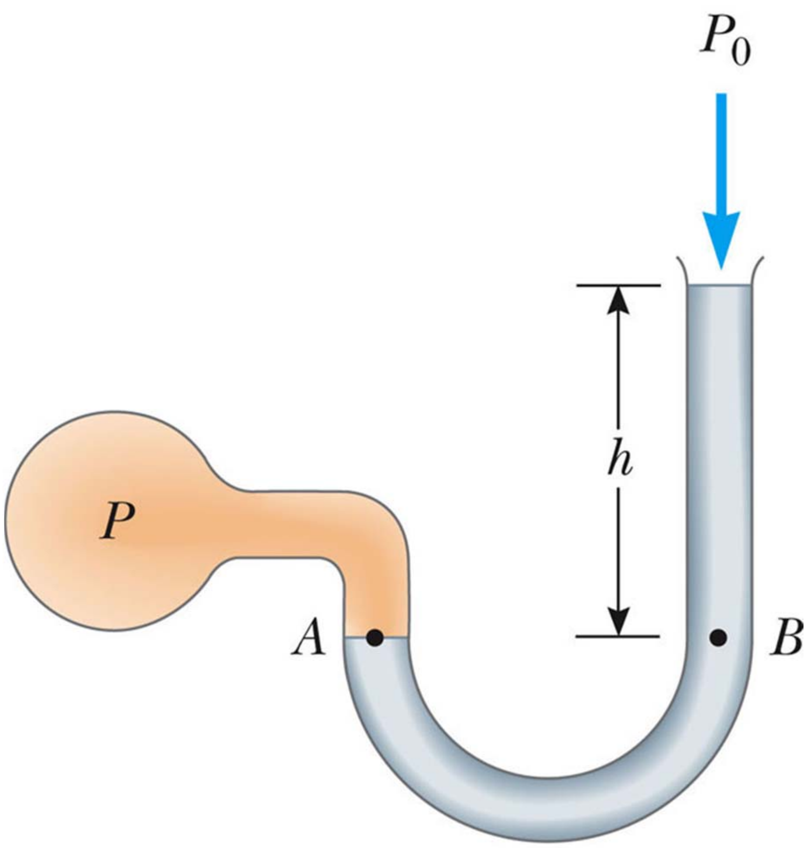
Problem In a car lift used in a service station, compressed air exerts a force on a small piston of circular cross section having a radius of $r_1 = 5.00$ cm. This pressure is transmitted by an incompressible liquid to a second piston of radius $r_2 = 15.0$ cm. **(a)** What force must the compressed air exert on the small piston in order to lift a car weighing 13 300 N? Neglect the weights of the pistons. **(b)** What air pressure will produce a force of that magnitude? **(c)** Show that the work done by the input and output pistons is the same.

Absolute vs. Gauge Pressure

- The pressure P is called the ***absolute*** pressure
  - Remember, $P = P_o + \rho gh$
- $P - P_o = \rho gh$ is the ***gauge*** pressure

Pressure Measurements: Manometer

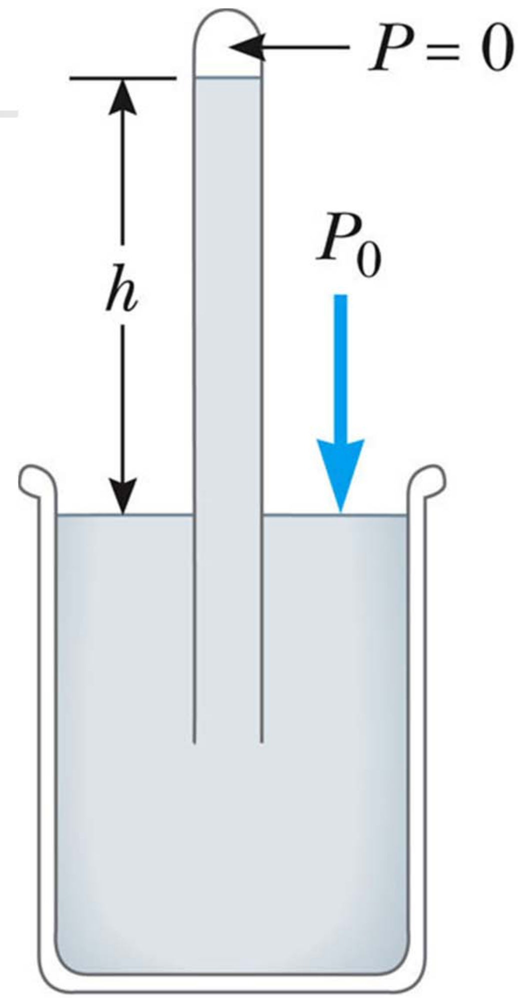
- One end of the U-shaped tube is open to the atmosphere
- The other end is connected to the pressure to be measured
- If P in the system is greater than atmospheric pressure, h is positive
  - If less, then h is negative



(a)

Pressure Measurements: Barometer

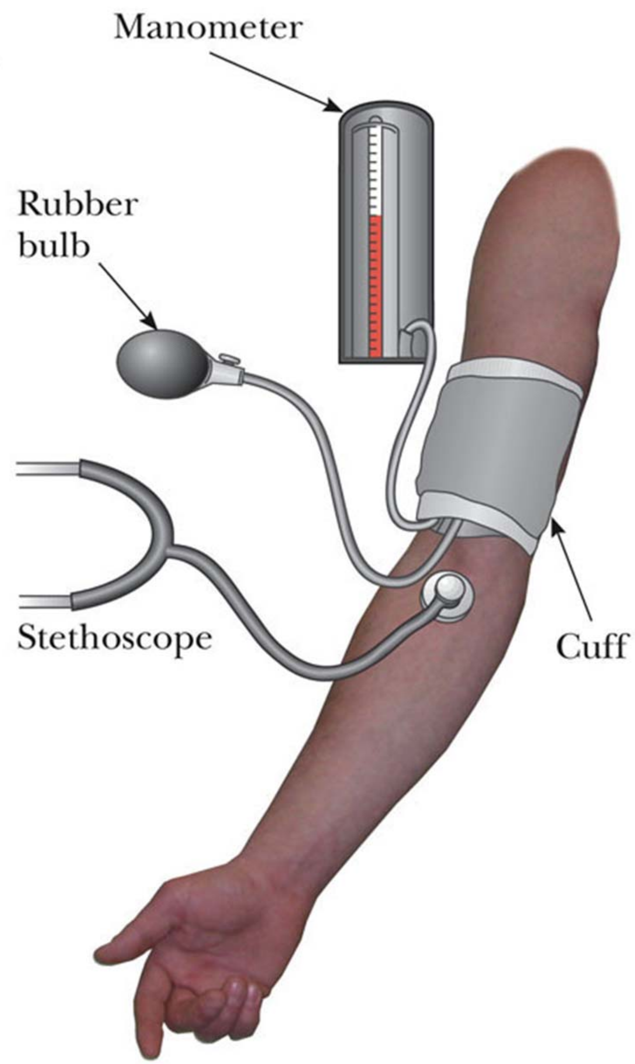
- Invented by Torricelli (1608 – 1647)
- A long closed tube is filled with mercury and inverted in a dish of mercury
- Measures atmospheric pressure as ρgh



(b)

Blood Pressure

- Blood pressure is measured with a special type of manometer called a *sphygmomano-meter*
- Pressure is measured in mm of mercury



Pressure Values in Various Units

- One atmosphere of pressure is defined as the pressure equivalent to a column of mercury exactly 0.76 m tall at 0^{o} C where g = 9.806 65 m/s^2
- One atmosphere (1 atm) =
  - 76.0 cm of mercury
  - 1.013×10^5 Pa
  - 14.7 lb/in^2

Archimedes

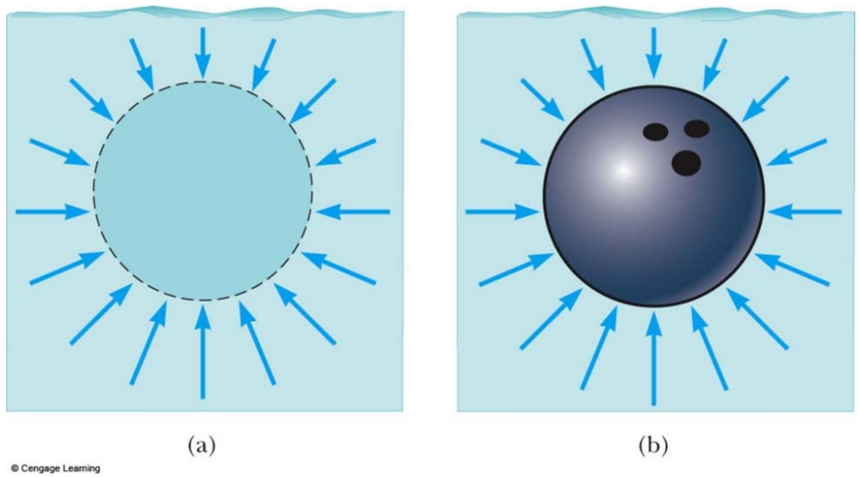
- 287 – 212 BC
- Greek mathematician, physicist, and engineer
- Buoyant force
- Inventor

Archimedes' Principle

- Any object completely or partially submerged in a fluid is buoyed up by a force whose magnitude is equal to the weight of the fluid displaced by the object

Buoyant Force

- The upward force is called the *buoyant force*
- The physical cause of the buoyant force is the pressure difference between the top and the bottom of the object



Buoyant Force, cont.

- The magnitude of the buoyant force always equals the weight of the displaced fluid

$$B = \rho_{fluid} V_{fluid} g = w_{fluid}$$

- The buoyant force is the same for a totally submerged object of any size, shape, or density

Buoyant Force, final

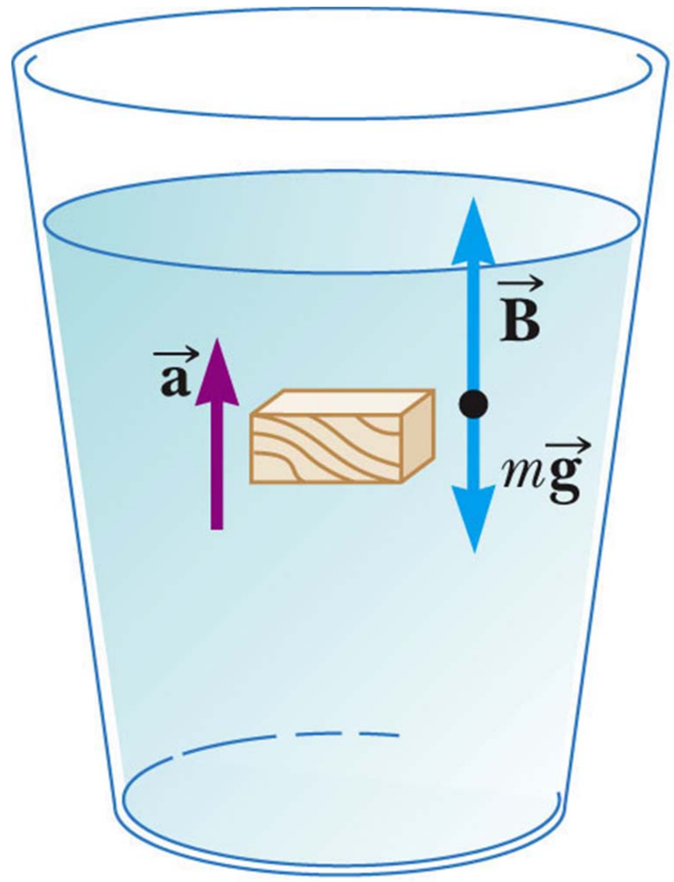
- The buoyant force is exerted by the fluid
- Whether an object sinks or floats depends on the relationship between the buoyant force and the weight

Archimedes' Principle: Totally Submerged Object

- The upward buoyant force is $B=\rho_{fluid}g_{obj}V$
- The downward gravitational force is $w=mg=\rho_{obj}g_{obj}V$
- The net force is $B-w=(\rho_{fluid}-\rho_{obj})g_{obj}V$

Totally Submerged Object

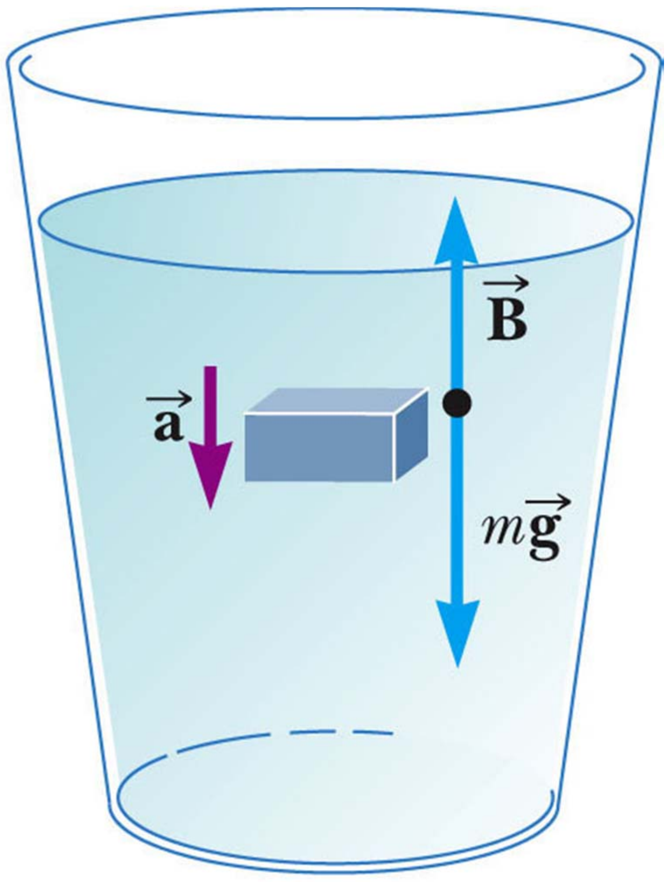
- The object is less dense than the fluid
- The object experiences a net upward force



(a)

Totally Submerged Object, 2

- The object is more dense than the fluid
- The net force is downward
- The object accelerates downward



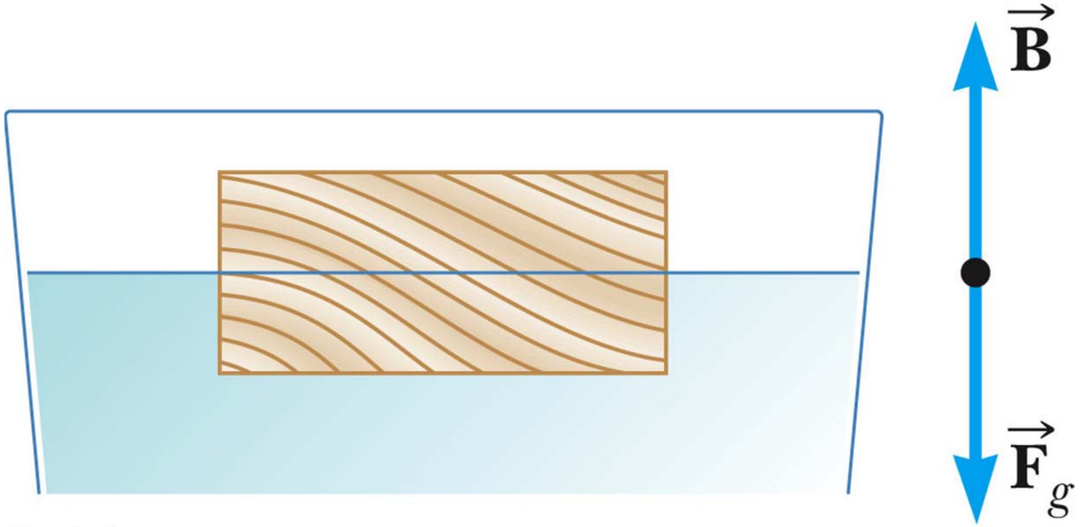
(b)

Archimedes' Principle: Floating Object

- The object is in static equilibrium
- The upward buoyant force is balanced by the downward force of gravity
- Volume of the fluid displaced corresponds to the volume of the object beneath the fluid level

Archimedes' Principle: Floating Object, cont

- The forces balance
- $$\frac{\rho_{obj}}{\rho_{fluid}} = \frac{V_{fluid}}{V_{obj}}$$
  - Neglects the buoyant force of the air

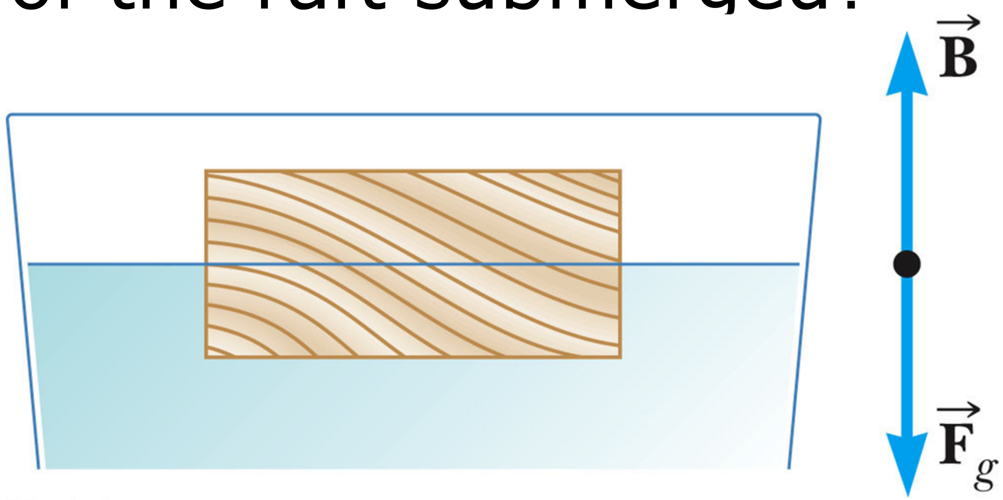


Example 4

- A sample of unknown material appears to weigh 320 N in air and 250 N in fresh water ($\rho = 1000\ kg/m^3$). What are (a) the volume and (b) the density of this material?

Example 5

- A raft is constructed from wood having a density 600 kg/m^3. Its surface area is 5.7 m^2 and its volume is 0.6 m^3. when the raft is placed in fresh water to what depth *h* is the bottom of the raft submerged?



Fluids in Motion: Streamline Flow

- Streamline flow
  - Every particle that passes a particular point moves exactly along the smooth path followed by particles that passed the point earlier
  - Also called laminar flow
- Streamline is the path
  - Different streamlines cannot cross each other
  - The streamline at any point coincides with the direction of fluid velocity at that point

Streamline Flow, Example

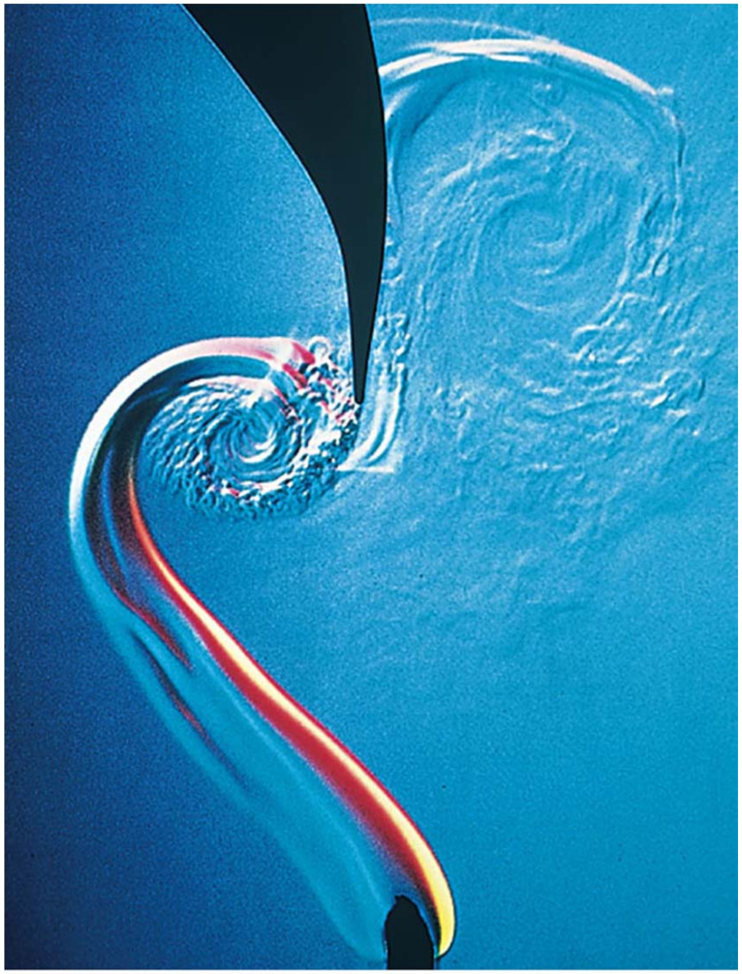
Streamline flow shown around an auto in a wind tunnel

Fluids in Motion: Turbulent Flow

- The flow becomes irregular
  - Exceeds a certain velocity
  - Any condition that causes abrupt changes in velocity
- Eddy currents are a characteristic of turbulent flow

Turbulent Flow, Example

- The rotating blade (dark area) forms a vortex in heated air
  - The wick of the burner is at the bottom
- Turbulent air flow occurs on both sides of the blade

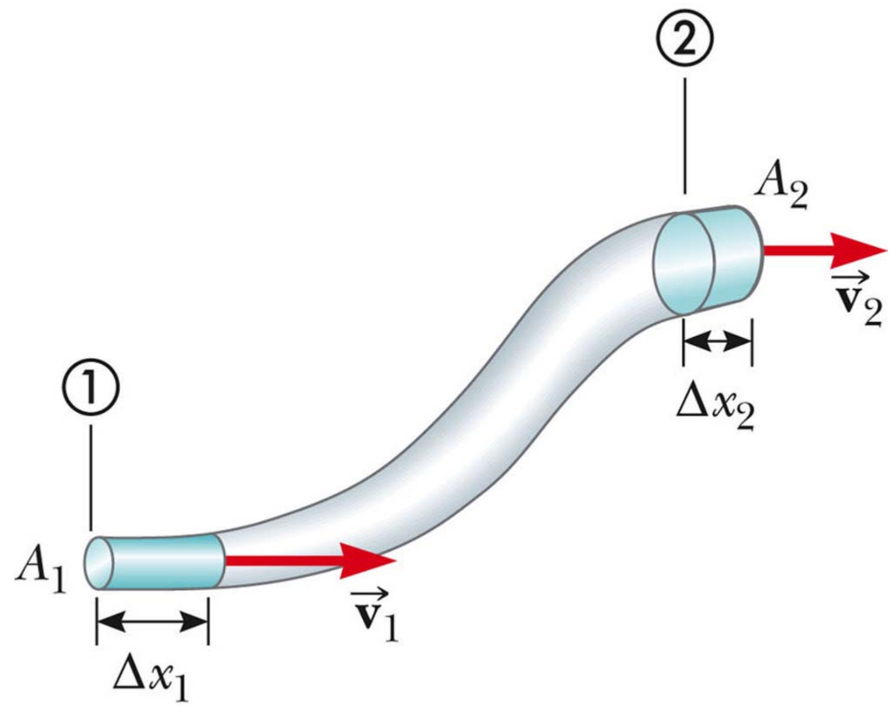


Characteristics of an Ideal Fluid

- The fluid is nonviscous
  - There is no internal friction between adjacent layers
- The fluid is incompressible
  - Its density is constant
- The fluid motion is steady
  - Its velocity, density, and pressure do not change in time
- The fluid moves without turbulence
  - No eddy currents are present
  - The elements have zero angular velocity about its center

Equation of Continuity

- $A_1v_1 = A_2v_2$
- The product of the cross-sectional area of a pipe and the fluid speed is a constant
  - Speed is high where the pipe is narrow and speed is low where the pipe has a large diameter
- Av is called the *flow rate*



(a)

Equation of Continuity, cont

- The equation is a consequence of conservation of mass and a steady flow
- $A\,v = \text{constant}$ $\qquad A_1 v_1 = A_2 v_2$
  - This is equivalent to the fact that the volume of fluid that enters one end of the tube in a given time interval equals the volume of fluid leaving the tube in the same interval
    - Assumes the fluid is incompressible and there are no leaks

Daniel Bernoulli

- 1700 – 1782
- Swiss physicist and mathematician
- Wrote *Hydrodynamica*
- Also did work that was the beginning of the kinetic theory of gases

Bernoulli's Equation

- Relates pressure to fluid speed and elevation
- Bernoulli's equation is a consequence of Conservation of Energy applied to an ideal fluid
- Assumes the fluid is incompressible and nonviscous, and flows in a nonturbulent, steady-state manner

Bernoulli's Equation, cont.

- States that the sum of the pressure, kinetic energy per unit volume, and the potential energy per unit volume has the same value at all points along a streamline

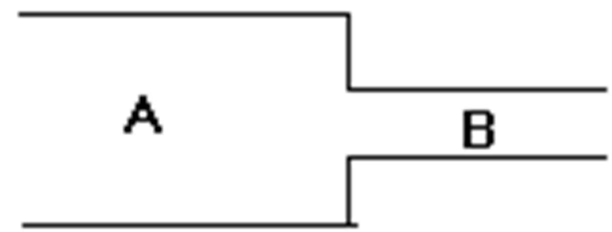
$$P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$

Example 1

If wind blows at 30 m/s over the roof having an area of 175 m^2, what is the upward force exerted on the roof?

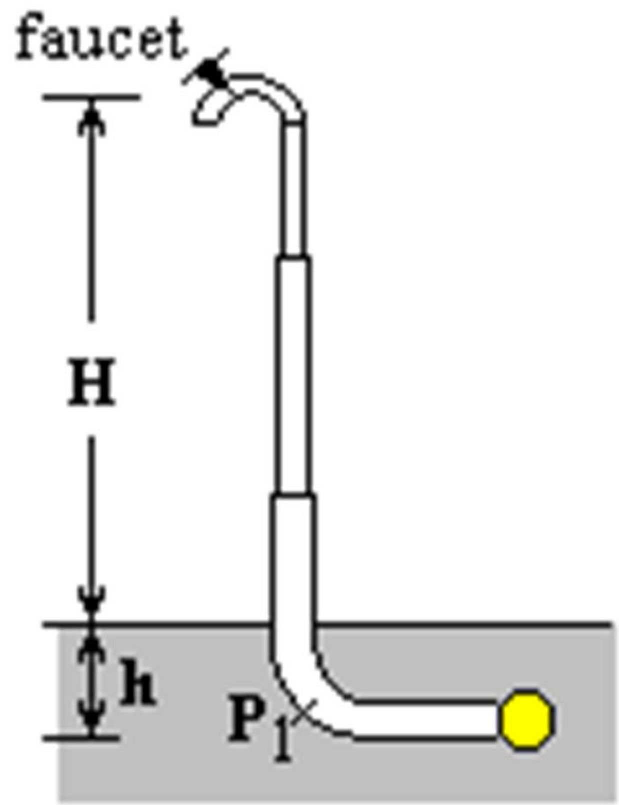
Example 2

- Water (density = 1000 kg/m^3) flows through a horizontal tapered pipe. The radius of pipe A is 12 cm and the radius of the pipe B is 7 cm. a. If the speed of the water in the pipe A is 2.2 m/s what is the speed of the water in the pipe B. b) What is the pressure difference between pipe A and pipe B?



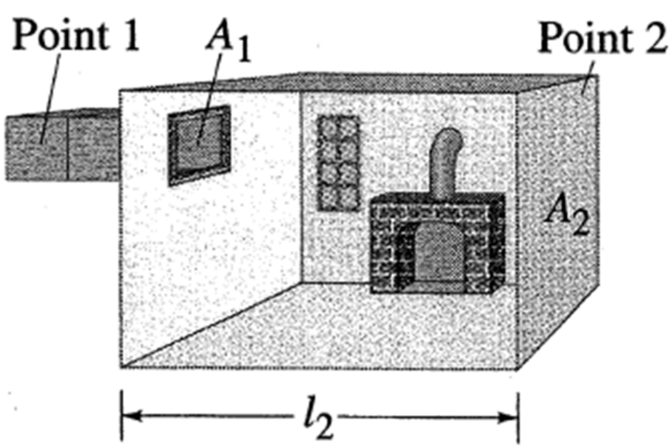
Example 3

A water line enters a house h= 2 m below ground. A smaller diameter pipe carries water to a faucet 4 m above the ground, on the second floor. Water flows at 2 m/s in the main line and at 7 m/s on the second floor. If the pressure in the main line is 2 x 10^5 Pa, then the pressure on the second floor is:



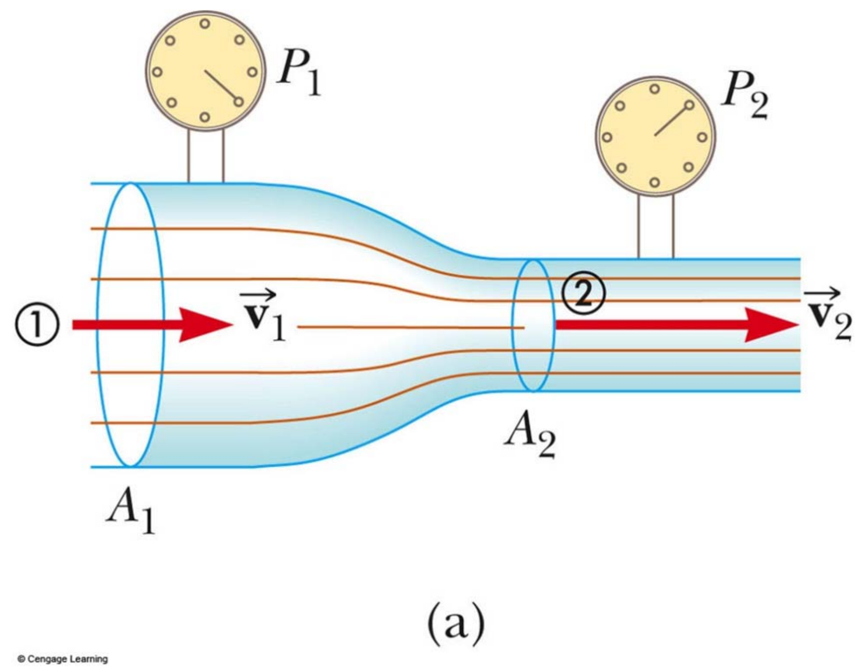
Example 4

How large must a heating duct be if air moving 3 m/s along it can replenish the air every 15 min in a room of 300-m^3 volume?



Applications of Bernoulli's Principle: Measuring Speed

- Shows fluid flowing through a horizontal constricted pipe
- Speed changes as diameter changes
- Can be used to measure the speed of the fluid flow
- Swiftly moving fluids exert less pressure than do slowly moving fluids



Applications of Bernoulli's Principle: Venturi Tube

- The height is higher in the constricted area of the tube
- This indicates that the pressure is lower

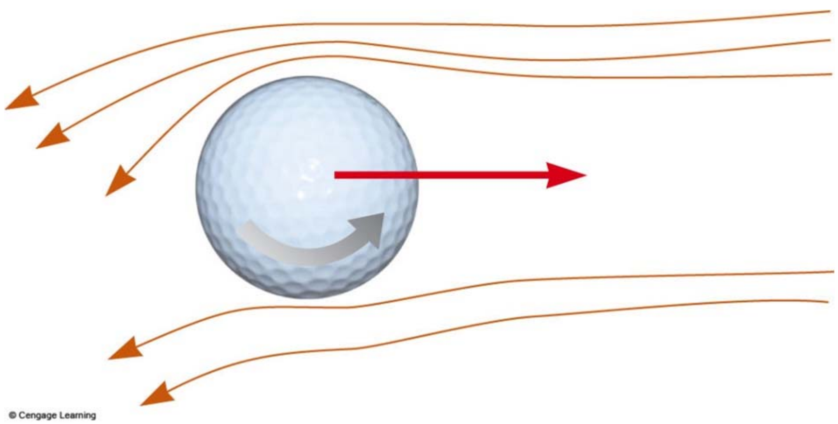
(b)

An Object Moving Through a Fluid

- Many common phenomena can be explained by Bernoulli's equation
  - At least partially
- In general, an object moving through a fluid is acted upon by a net upward force as the result of any effect that causes the fluid to change its direction as it flows past the object
- Swiftly moving fluids exert less pressure than do slowing moving fluids

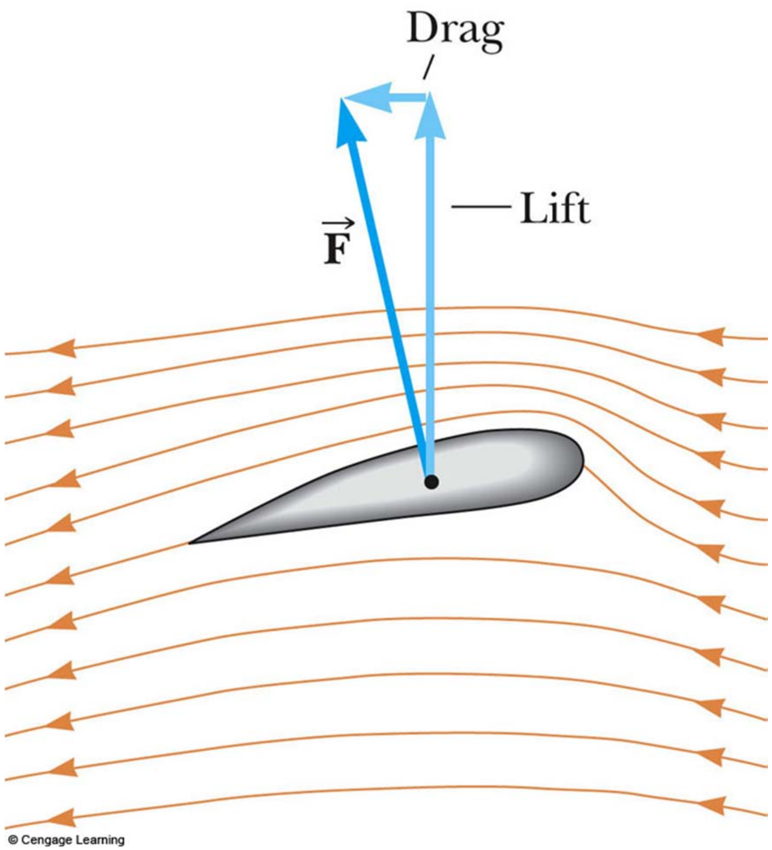
Application – Golf Ball

- The dimples in the golf ball help move air along its surface
- The ball pushes the air down
- Newton's Third Law tells us the air must push up on the ball
- The spinning ball travels farther than if it were not spinning



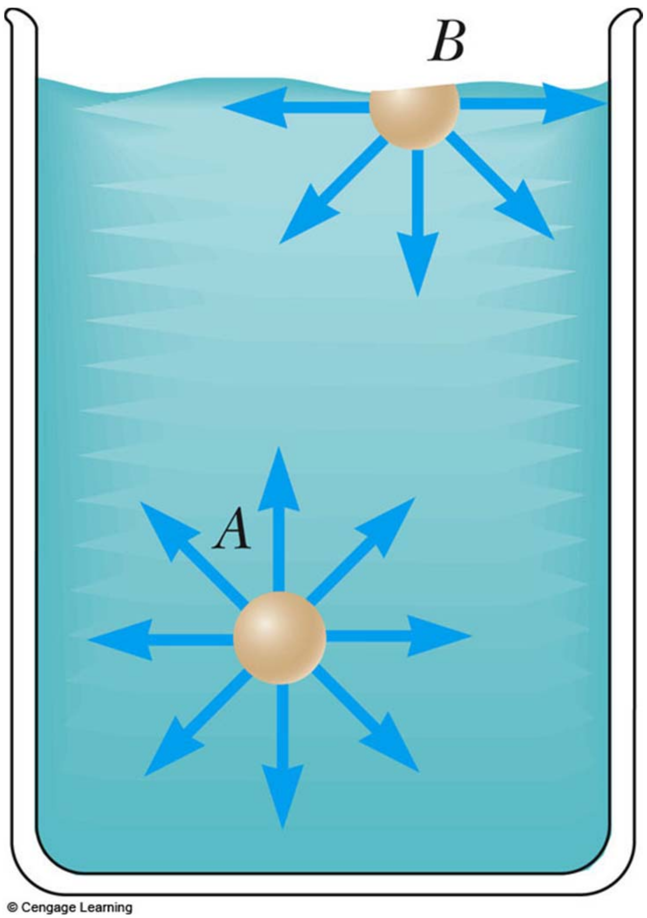
Application – Airplane Wing

- The air speed above the wing is greater than the speed below
- The air pressure above the wing is less than the air pressure below
- There is a net upward force
  - Called *lift*
- Other factors are also involved



Surface Tension

- Net force on molecule A is zero
  - Pulled equally in all directions
- Net force on B is not zero
  - No molecules above to act on it
  - Pulled toward the interior of the fluid

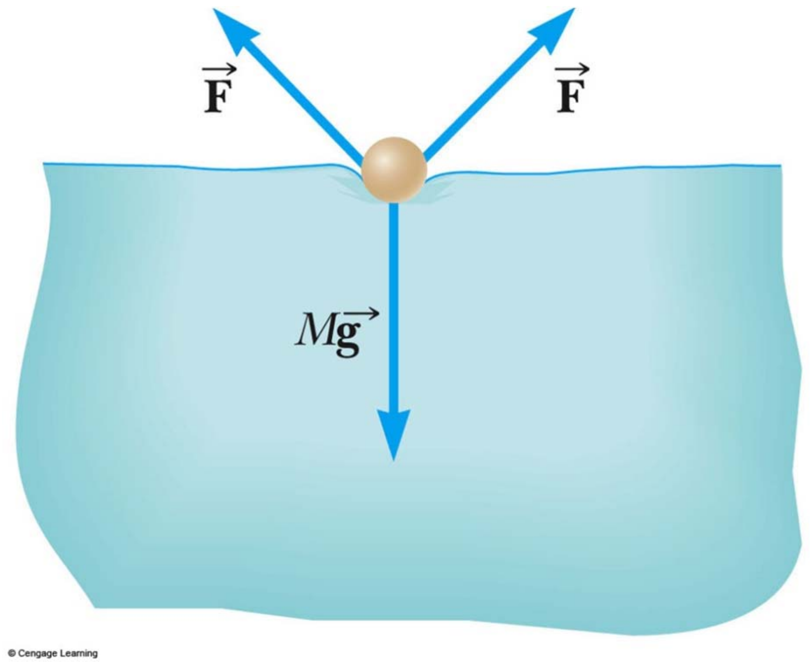


Surface Tension, cont

- The net effect of this pull on all the surface molecules is to make the surface of the liquid contract
- Makes the surface area of the liquid as small as possible
  - Example: Water droplets take on a spherical shape since a sphere has the smallest surface area for a given volume

Surface Tension on a Needle

- Surface tension allows the needle to float, even though the density of the steel in the needle is much higher than the density of the water
- The needle actually rests in a small depression in the liquid surface
- The vertical components of the force balance the weight



Surface Tension, Equation

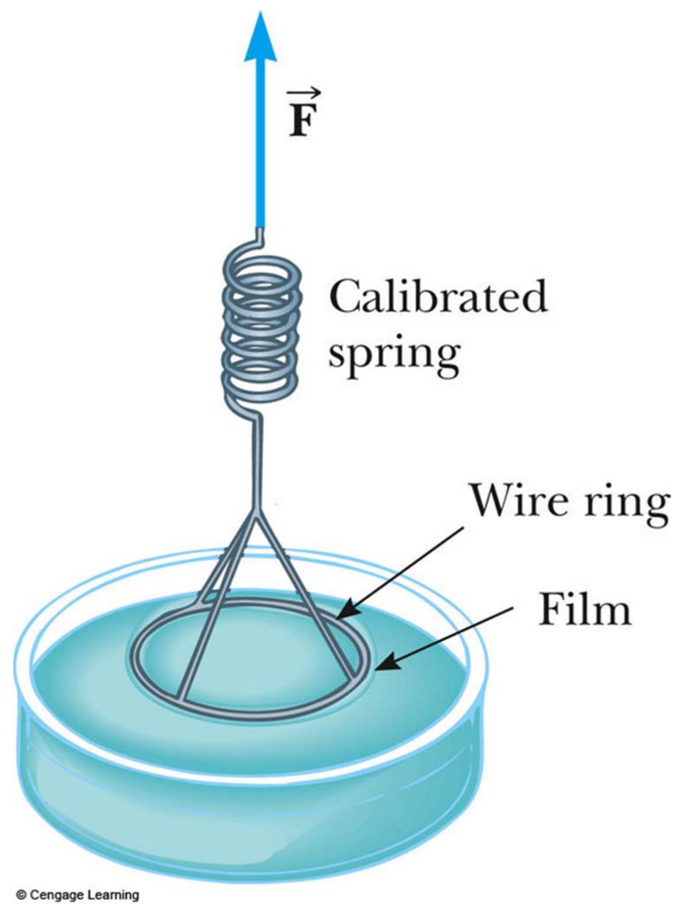
- The surface tension is defined as the ratio of the magnitude of the surface tension force to the length along which the force acts:

$$\gamma = \frac{F}{L}$$

- SI units are N/m
- In terms of energy, any equilibrium configuration of an object is one in which the energy is a minimum

Measuring Surface Tension

- The force is measured just as the ring breaks free from the film
- $\gamma = \dfrac{F}{2L}$
  - The 2L is due to the force being exerted on the inside and outside of the ring



Final Notes About Surface Tension

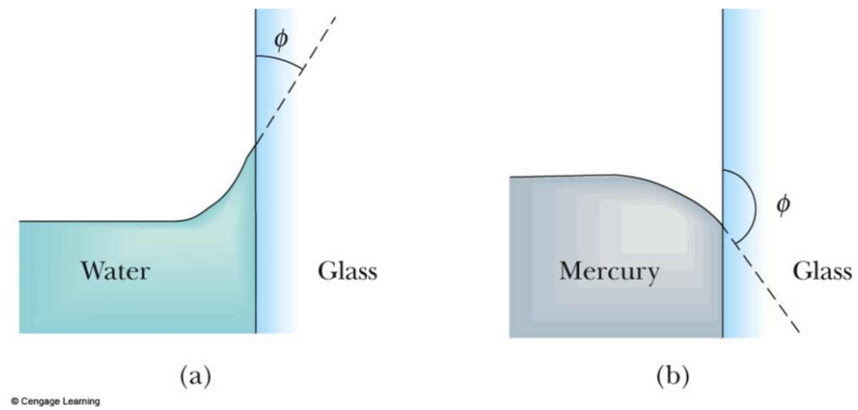
- The surface tension of liquids decreases with increasing temperature
- Surface tension can be decreased by adding ingredients called *surfactants* to a liquid
  - Detergent is an example

A Closer Look at the Surface of Liquids

- *Cohesive forces* are forces between like molecules
- *Adhesive forces* are forces between unlike molecules
- The shape of the surface depends upon the relative size of the cohesive and adhesive forces

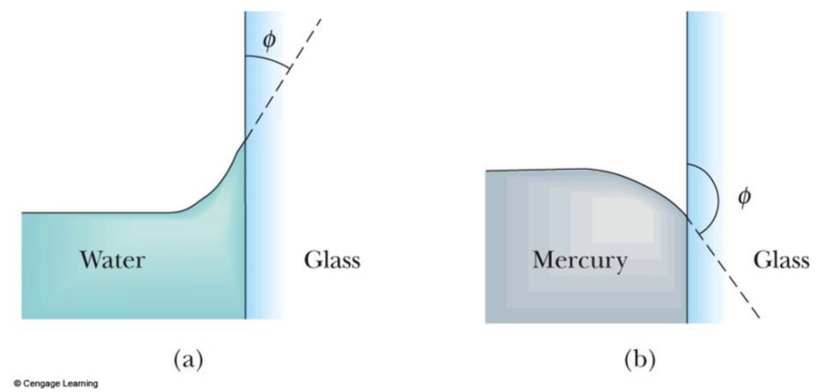
Liquids in Contact with a Solid Surface – Case 1

- The adhesive forces are greater than the cohesive forces
- The liquid clings to the walls of the container
- The liquid "wets" the surface

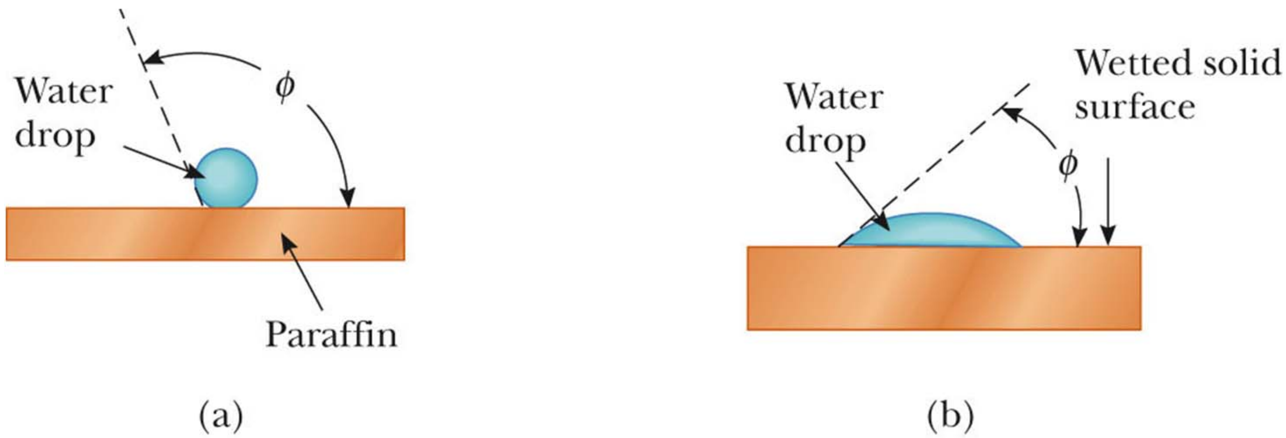


Liquids in Contact with a Solid Surface – Case 2

- Cohesive forces are greater than the adhesive forces
- The liquid curves downward
- The liquid does not "wet" the surface



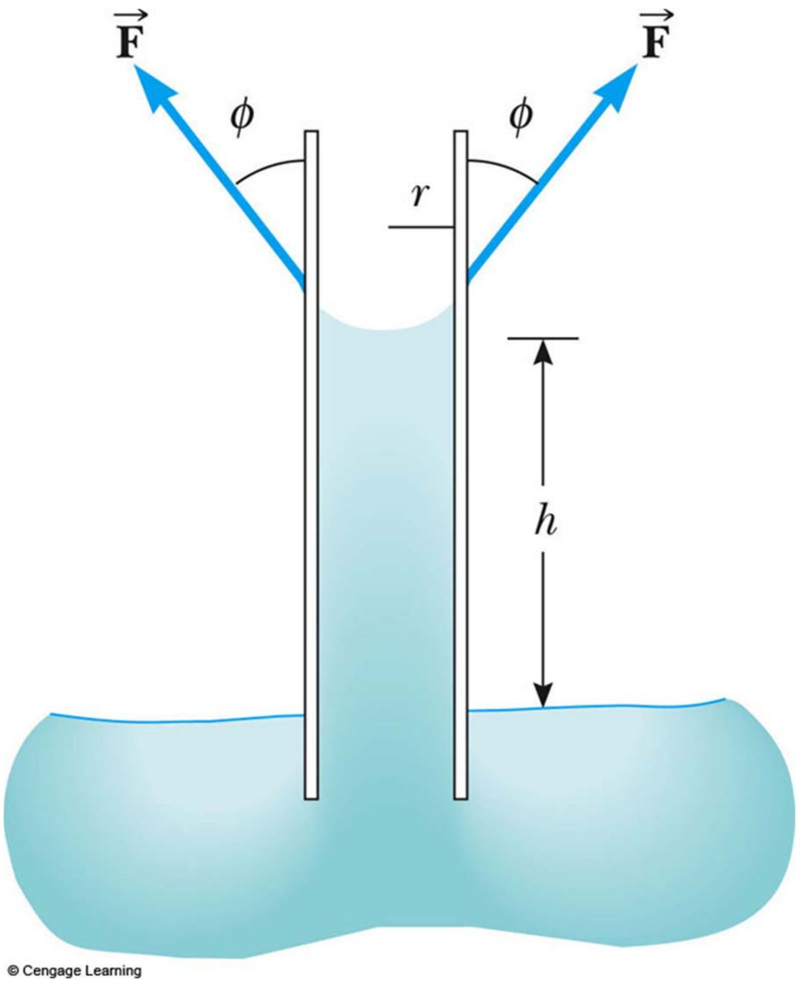
Contact Angle



- In a, Φ > 90° and cohesive forces are greater than adhesive forces
- In b, Φ < 90° and adhesive forces are greater than cohesive forces

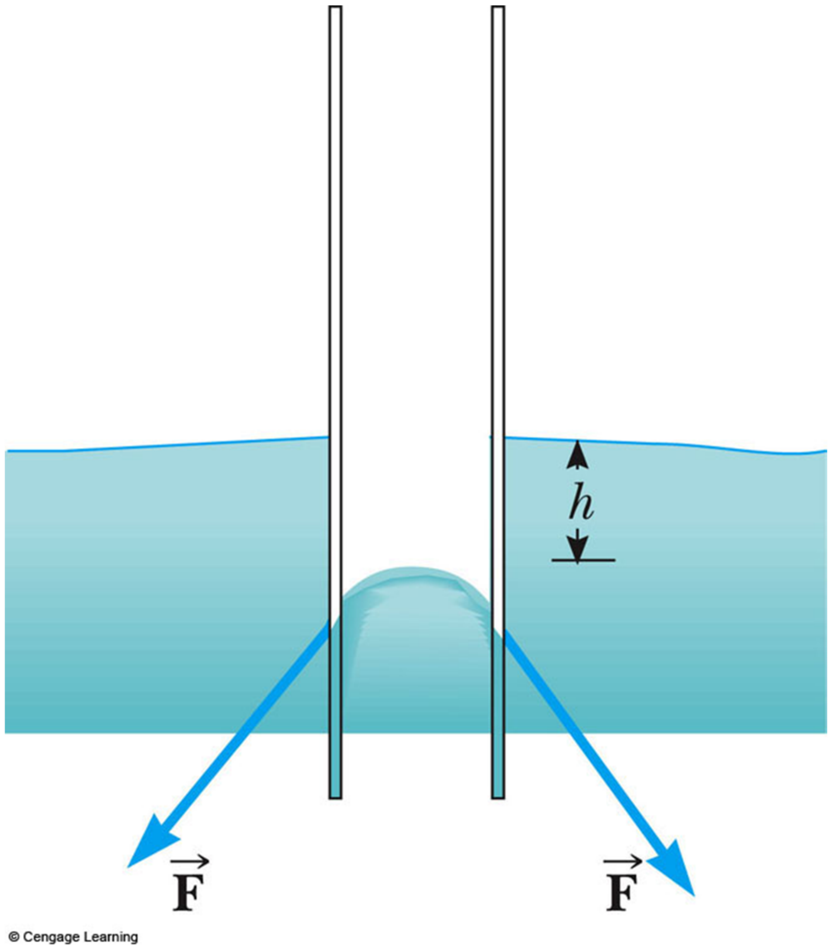
Capillary Action

- Capillary action is the result of surface tension and adhesive forces
- The liquid rises in the tube when adhesive forces are greater than cohesive forces
- At the point of contact between the liquid and the solid, the upward forces are as shown in the diagram



Capillary Action, cont.

- Here, the cohesive forces are greater than the adhesive forces
- The level of the fluid in the tube will be below the surface of the surrounding fluid



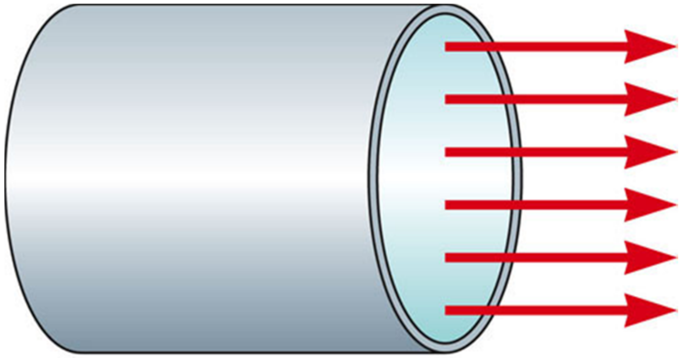
Capillary Action, final

- The height to which the fluid is drawn into the tube is given by:

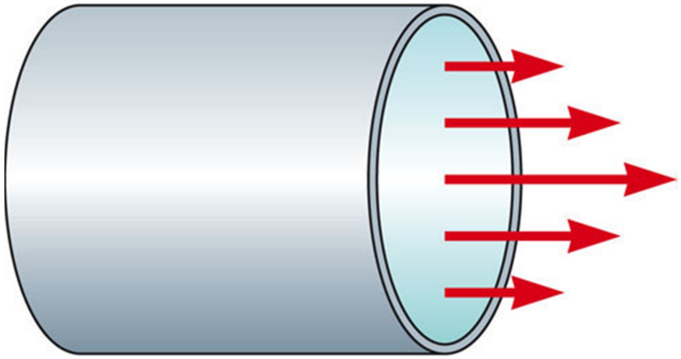
$$h = \frac{2\gamma}{\rho g r}\cos\phi$$

Viscous Fluid Flow

- Viscosity refers to friction between the layers
- Layers in a viscous fluid have different velocities
- The velocity is greatest at the center
- Cohesive forces between the fluid and the walls slow down the fluid on the outside



(a)



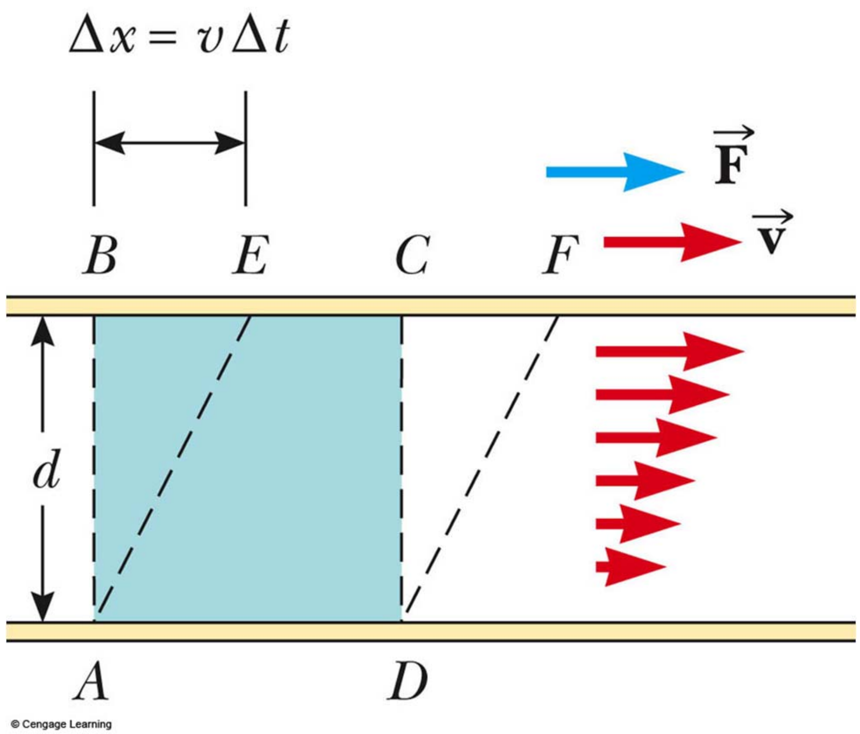
(b)

Coefficient of Viscosity

- Assume a fluid between two solid surfaces
- A force is required to move the upper surface

$$F = \eta \frac{Av}{d}$$

- η is the coefficient
- SI units are $N \cdot s/m^2$
- cgs units are Poise
  - 1 Poise = 0.1 $N \cdot s/m^2$



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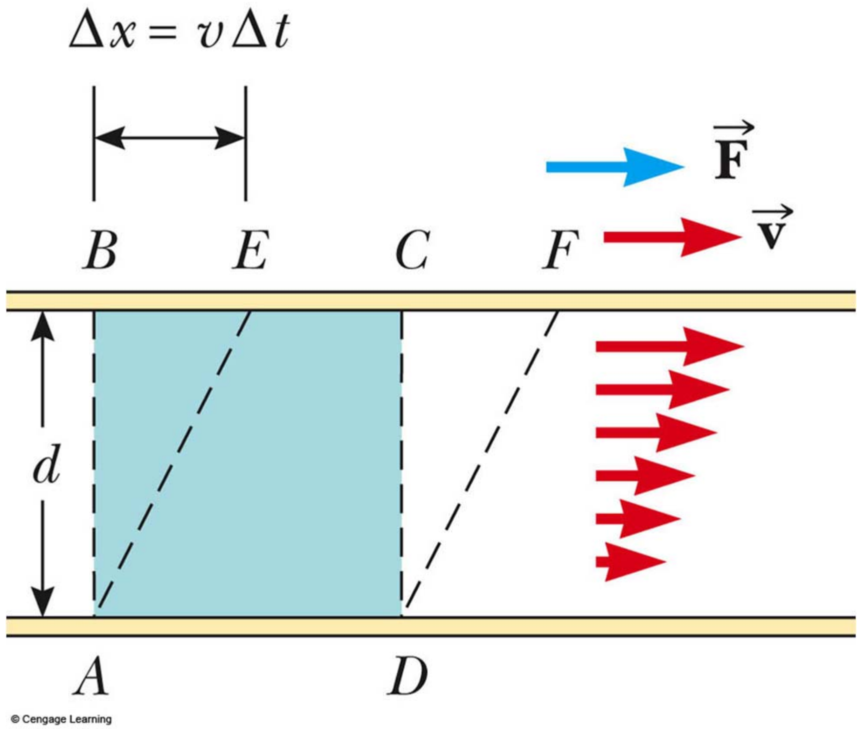
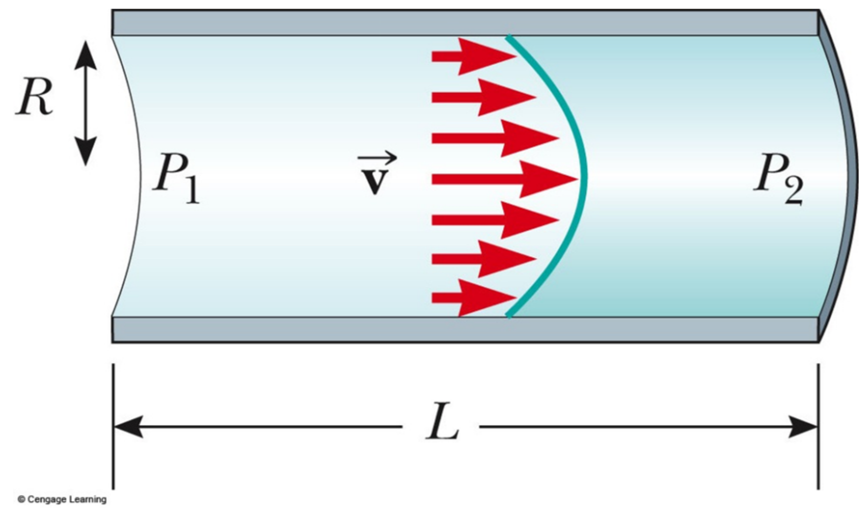


Poiseuille's Law

- Gives the *rate of flow* of a fluid in a tube with pressure differences



$$Rate\ of\ flow = $$

$$\frac{\Delta V}{\Delta t} = \frac{\pi R^4 (P_1 - P_2)}{8 \eta L}$$

Reynold's Number

- At sufficiently high velocity, a fluid flow can change from streamline to turbulent flow
  - The onset of turbulence can be found by a factor called the Reynold's Number, RN

$$RN = \frac{\rho v d}{\eta}$$

  - If RN = 2000 or below, flow is streamline
  - If 2000 <RN<3000, the flow is unstable
  - If RN = 3000 or above, the flow is turbulent