Physics 052

L6

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CH 13: Fluid Mechanics

Things can float in air as well as in water. A balloon filled with helium pulls up on the string, but a balloon filled with air drifts down to the floor. What makes the difference ?! ::

What are we going to talk about today?

Ch13: Fluid Mechanics

- 13.0 Introduction: Fluid, density and pressure.
- 13.1 Archimedes' principle.
- 13.2 The equation of Continuity
- 13.3 Bernoulli's Equation

Archimedes
Greek Mathematician, Physicist, and Engineer (c. 287–212 BC)

Fluid

$$\overbrace{\hspace{10em}}$$

Fluids statics — fluids at rest

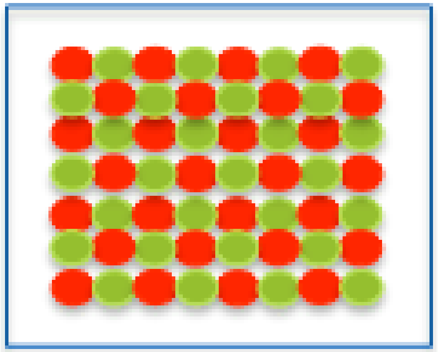
Fluids dynamics — fluids in motion

13.0 Introduction: Fluid, density and pressure.

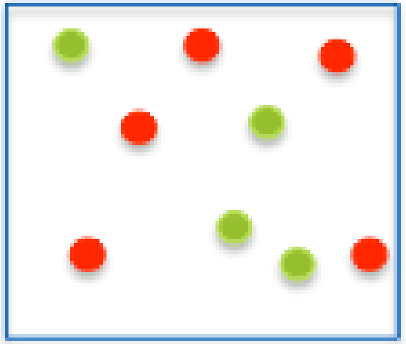
Density is defined as the mass per unit volume.

$$\boxed{\rho = \frac{m}{V}}$$

- Density is a scalar quantity.
- The dimension of density is $[\rho] = \frac{M}{L^3}$
- The S.I unit of density is the (Kg/m^3).



High Density



Low Density

Densities of various substances

Substance	Density (Kg/m^3)
Water	1×10^3
Aluminum	2.70×10^3
Titanium	4.54×10^3
Zinc	7.13×10^3
Tin	7.31×10^3
Iron	7.87×10^3
Nickel	8.90×10^3
Copper	8.96×10^3
Silver	10.50×10^3
Lead	11.35×10^3
Mercury	13.55×10^3
Gold	19.30×10^3

For more about density
Click Here

Checkpoint 1:

In a machine shop, two cams are produced, one of aluminium and one of iron. Both cams have the same mass. Which cam is larger?

(a) The aluminum cam is larger.

(b) The iron cam is larger.

(c) Both cams have the same size.

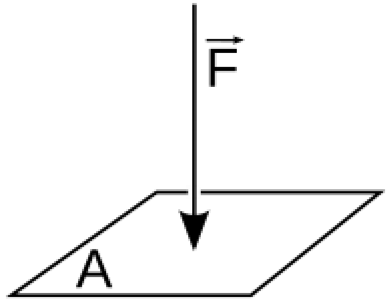
13.0 Introduction: Fluid, density and pressure.

The pressure exerted on an object depends on:

1. The force exerted on the object. In fact, pressure is directly proportional to force $P \propto F$.
2. The area over which the force is applied. In fact, pressure is inversely proportional to area $P \propto \frac{1}{A}$.

Therefore we can defined pressure as the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Or Mathematically:

$$\boxed{P = \frac{F}{A}}$$



- Pressure is a scalar quantity.
- The dimension of pressure is $[P] = \frac{M}{LT^2}$
- The S.I unit of pressure is the pascal (Pa), where $(1\ \text{Pa} = 1\frac{kg}{ms^2} = 1\frac{N}{m^2})$.

13.0 Introduction: Fluid, density and pressure.

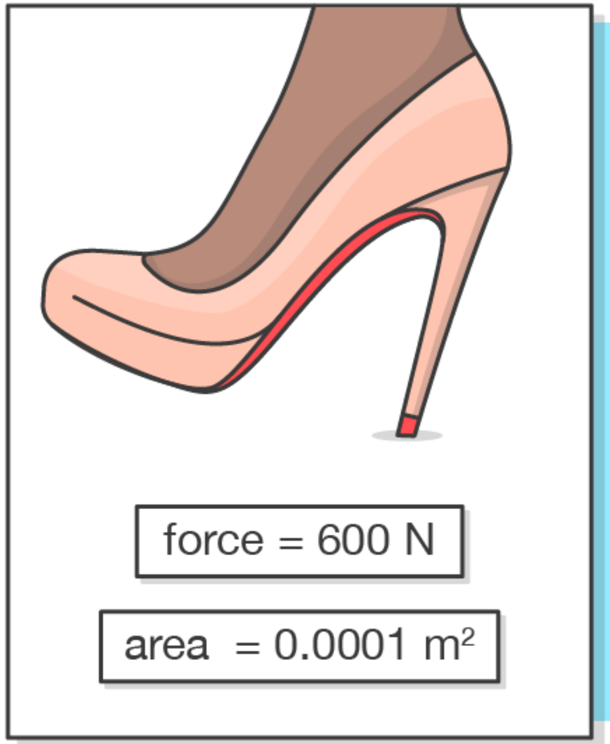
Why lying on a bed of nails doesn't hurt ?

https://www.youtube.com/watch?v=zIz4WAJ6JRU

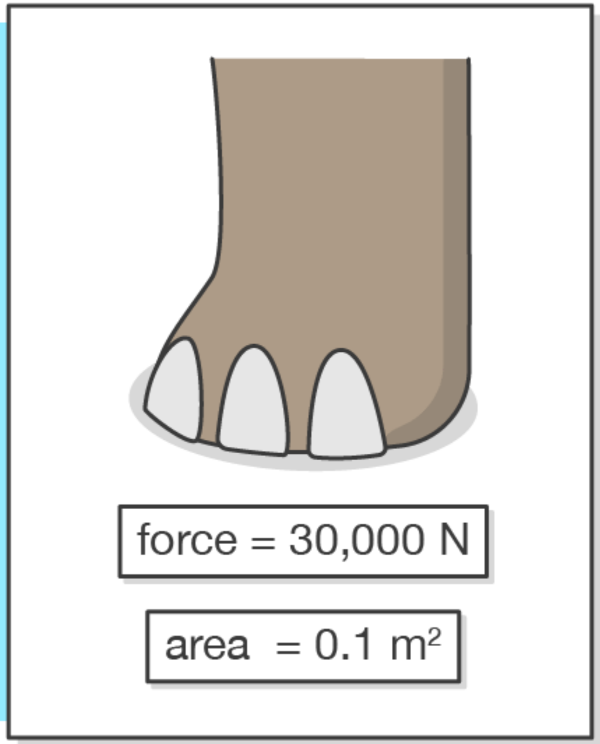
When there's plenty of nails, the pressure any single nail exerts on the skin is quite small, resulting in no pain and no cuts. Resting an entire body on a single nail, however, would be a different story!!

Checkpoint 2:

Which exerts more pressure: a person in a stiletto heel or an elephant?



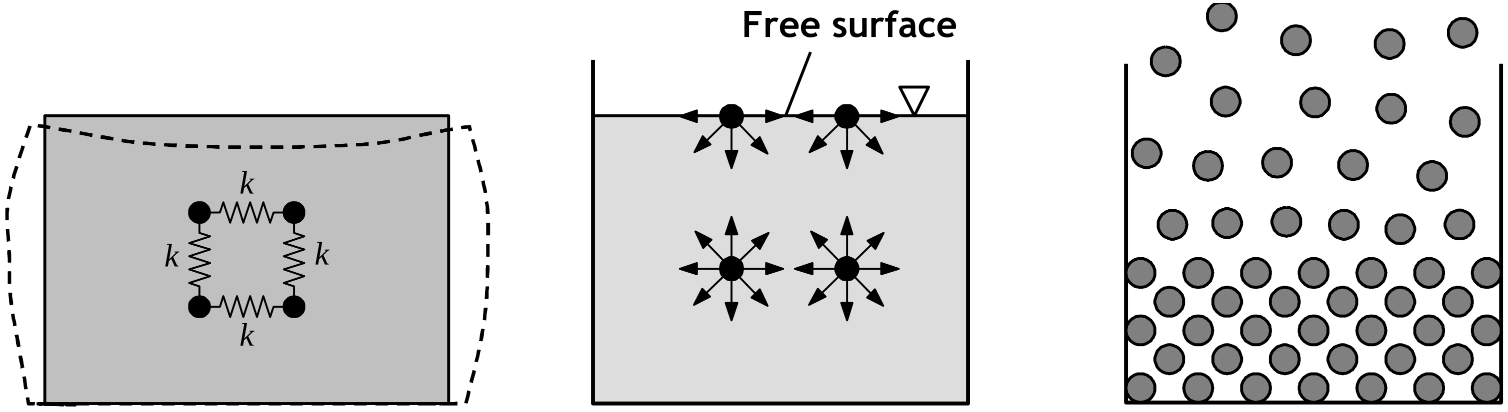
(a)



(b)

13.0 Introduction: Fluid, density and pressure.

Matter is normally classified as being in one of three states: solid, liquid, or gas. From everyday experience we know that a solid has a definite volume and shape, a liquid has a definite volume but no definite shape, and an unconfined gas has neither a definite volume nor a definite shape.



(a) Solid (b) Liquid (c) Gas

What is a Fluid?

A Fluid is a substance can flow. It is a collection of molecules that are randomly arranged and held together by weak cohesive forces and by forces exerted by the walls of a container. Both liquids and gases are fluids.

13.0 Introduction: Fluid, density and pressure.

Fluid

$$\overbrace{\hspace{10em}}$$

Fluids statics

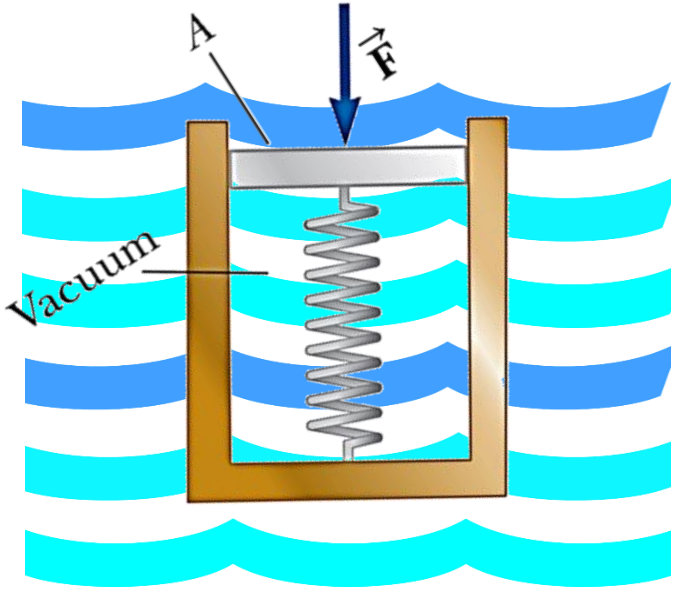
fluids at rest

Fluids dynamics

fluids in motion

13.0 Introduction: Fluid, density and pressure.

The pressure P in a fluid can be measured with the device consists of an evacuated cylinder that encloses a light piston connected to a spring. As the device is submerged in a fluid, the fluid presses on the top of the piston and compresses the spring until the inward force exerted by the fluid is balanced by the outward force exerted by the spring. The fluid pressure can be measured directly if the spring is calibrated in advance.



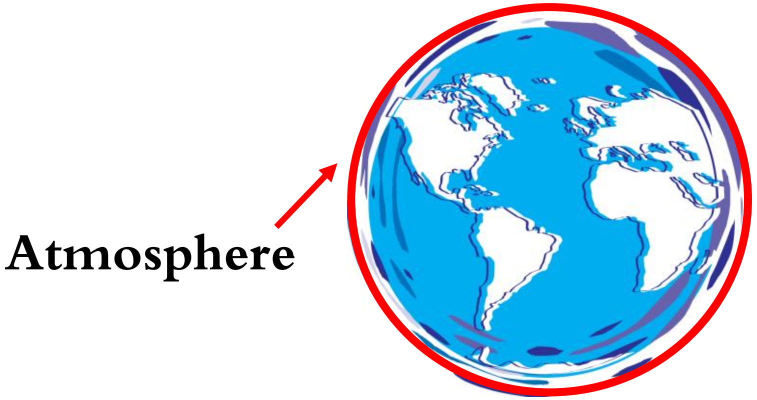
If F is the magnitude of the force exerted on the piston and A is the surface area of the piston, the pressure P of the fluid at the level to which the device has been submerged is defined as:

$$\boxed{P = \frac{F}{A}}$$

Not that: The force exerted by a static fluid on an object is always perpendicular to the surfaces of the object.

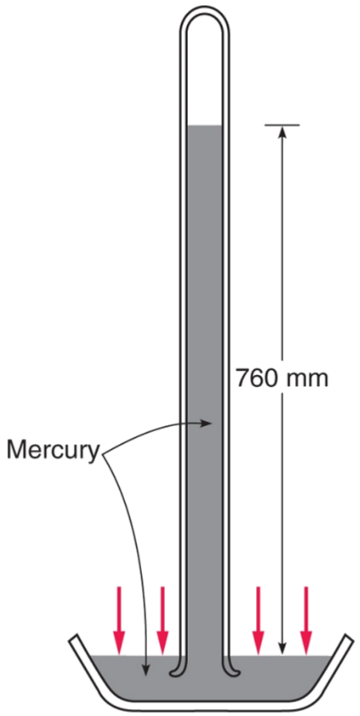
13.0 Introduction: Fluid, density and pressure.

Atmospheric pressure knows as the pressure of the layer of air that surrounds the earth. At sea level, the atmospheric pressure is 1 atm which equal to $100\ kPa = 14.7\,\frac{IP}{in^2} = 760\ mm$Hg, but it decreases with altitude.



How is atmospheric pressure measured?

Torricelli invented the barometer, a device for measuring atmospheric pressure. He filled a tube with mercury (Hg) and inverted it into an open container of mercury. Air pressure acting on the mercury in the dish can supported a column of mercury 760 mm in height.



Two teams of horses try, but fail, to separate Otto von Guericke's evacuated metal hemispheres. For more Click Here

13.0 Introduction: Fluid, density and pressure.

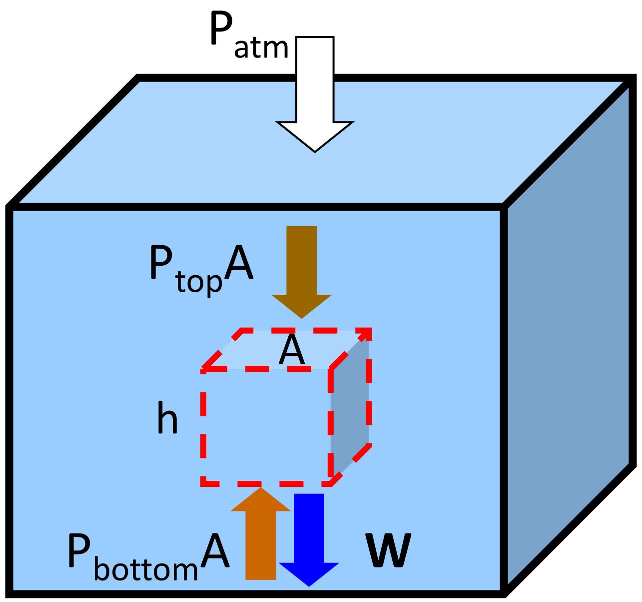
If you poke two holes in a bucket, top and bottom, why the water flow faster out of the bottom hole than the top one?!

13.0 Introduction: Fluid, density and pressure.

To obtain a relation for the variation of pressure with depth, consider a rectangular fluid element of height h and a cross–sectional area A, The pressure exerted by the liquid on the bottom face of the parcel is P_{bottom}, and the pressure on the top face is P_{top}. Therefore, the upward force exerted by the outside fluid on the bottom of the parcel has a magnitude $P_{bottom}A$, and the downward force exerted on the top has a magnitude $P_{top}A$. The mass of liquid in the parcel is $M = \rho V = \rho hV$; therefore, the weight of the liquid in the parcel is $Mg = \rho hAg$. Because the parcel is at rest and remains at rest, it can be modeled as a particle in equilibrium.

$$\sum F = 0, \text{ therefore } P_{bottom}A - P_{top}A - W = 0$$

$$\boxed{P_{bottom} = P_{top} + \rho hg}$$

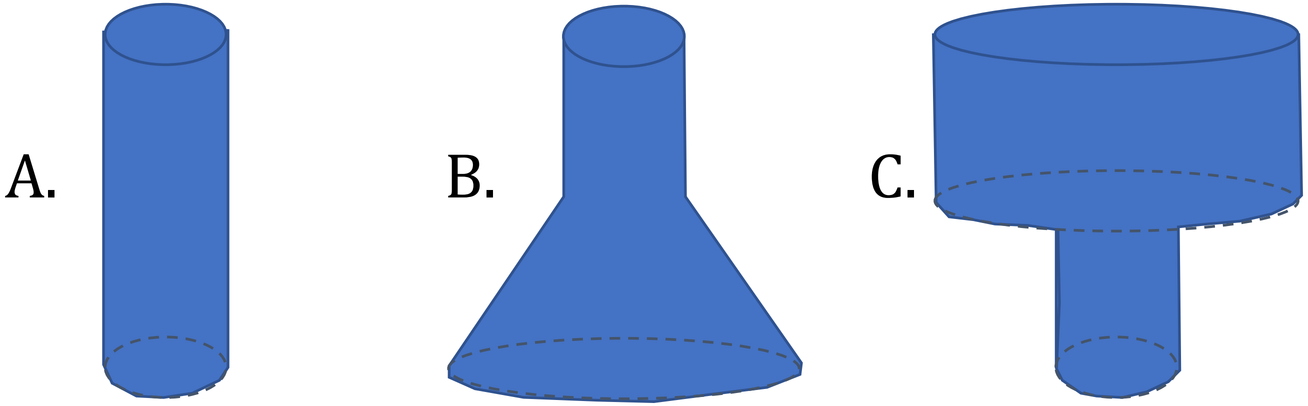


If the liquid is open to the atmosphere and P_{top} is the pressure at the surface of the liquid, then P_{top} is atmospheric pressure P_{atm}.

Checkpoint 3:

Consider the three open containers with height h filled with water. How do the pressures at the bottoms compare ?

1. $P_A = P_B = P_C$
2. $P_A < P_B = P_C$
3. $P_A < P_B < P_C$
4. $P_B < P_A < P_C$
5. Not enough information



Checkpoint 4:

The three open containers with height are now filled with oil, water and honey respectively. How do the pressures at the bottoms compare ?

(where $\rho_{oil} = 9.5 \times 10^2 \frac{kg}{m^3}, \rho_{water} = 10^3 \frac{kg}{m^3}, \rho_{honey} = 1.4 \times 10^3 \frac{kg}{m^3}$)

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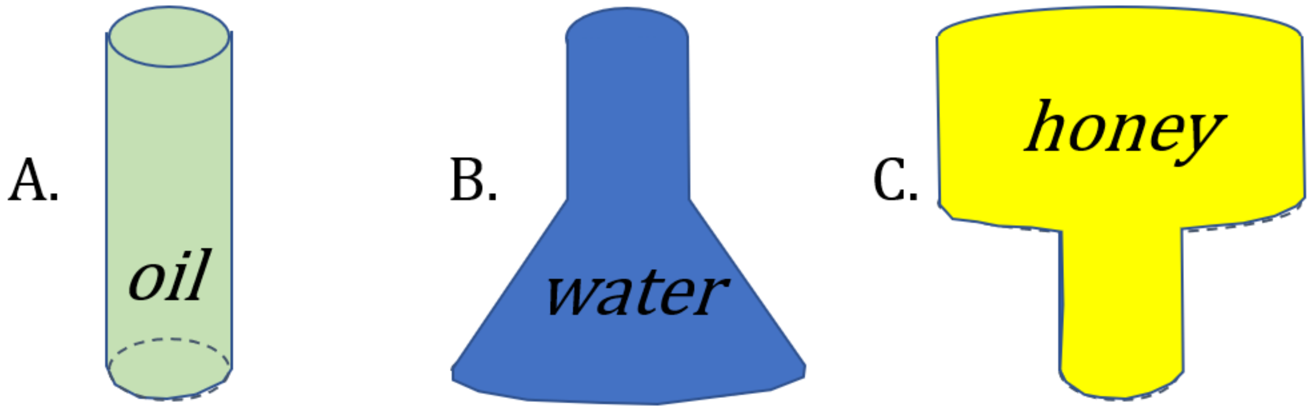
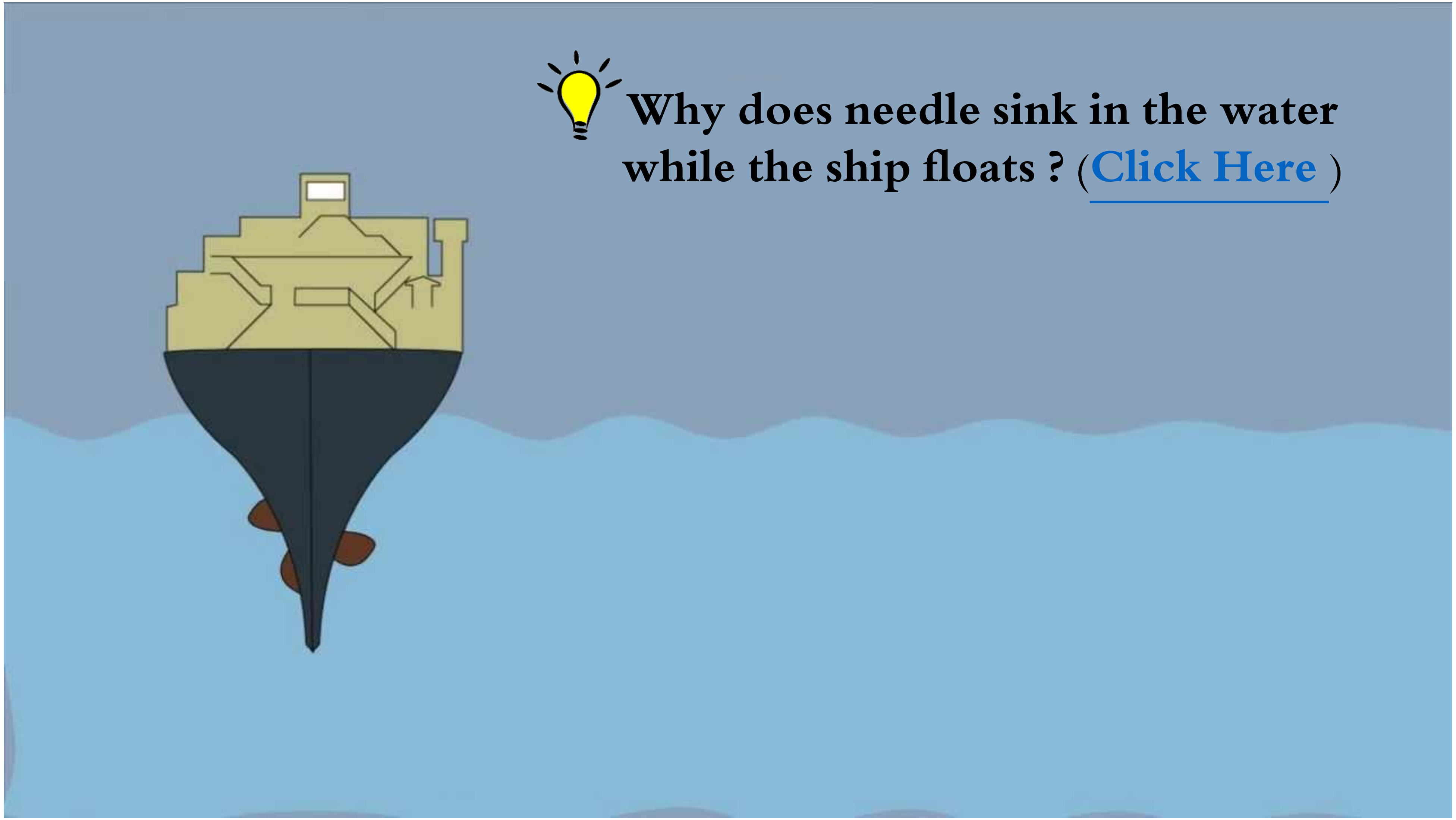


13.1 Archimedes' principle.



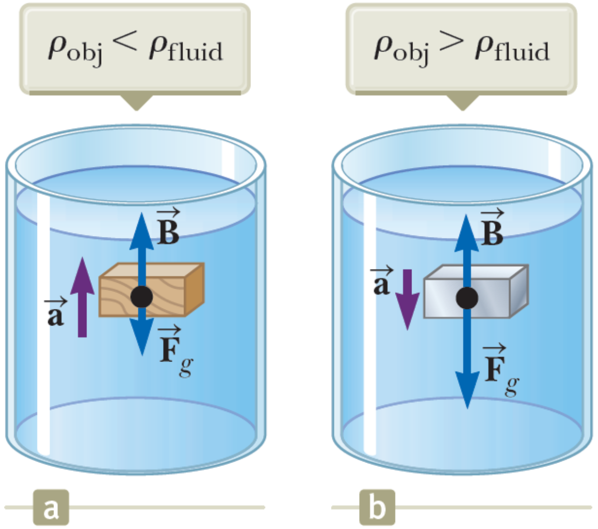
13.1 Archimedes' principle.

:: Archimedes' principle states that the buoyant force on the object is equal to the weight of the displaced fluid:

- A submerged object pushes aside, or displaces, a volume of fluid equal to its own volume.
- A partially submerged object displaces a volume equal to the volume of the part of the object that is submerged.

Consider an object of volume V_o and density ρ_o completely submerged in a fluid of density ρ_{fluid}. The fluid displaced by the solid has a mass $m_{fluid} = \rho_{fluid} V_{fluid}$, then it weighs of displaced fluid is $W_{fluid} = m_{fluid} g = \rho_{fluid} V_{fluid} g$. The buoyant force is then:

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

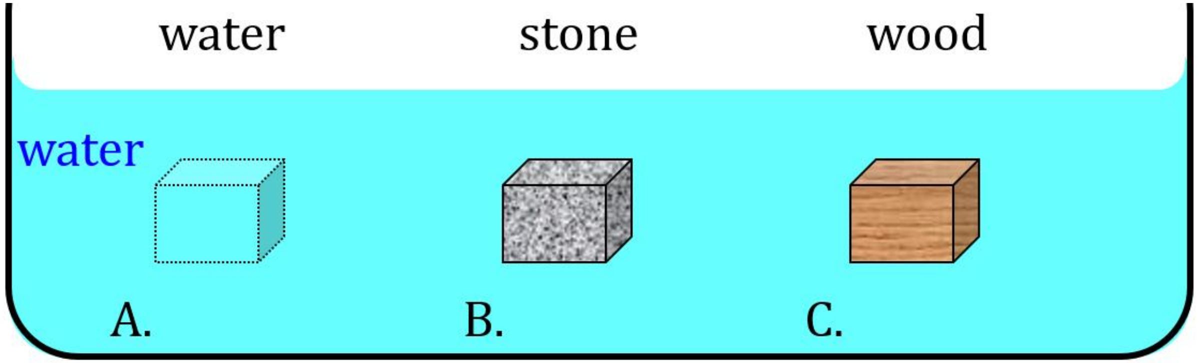


(a) A totally submerged object that is less denser than the fluid in which it is submerged experiences a net upward force and rises to the surface after it is released [Fig.(a)].

(b) (b) A totally submerged object that is denser than the fluid experiences a net downward force and sinks [Fig.(b)].

Checkpoint 5:

Which of the three cubes of length l shown below has the largest buoyant force ?

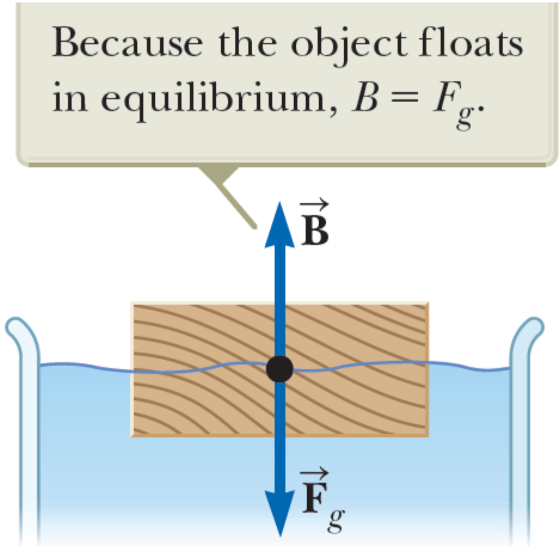


13.1 Archimedes' principle.

Partially submerged solid

If an object of volume is not completely immersed in a fluid, the displaced volume is equal to the submerged volume of the solid (volume of the part of the solid below the top surface of the fluid) . Then a quantity without unit called submerged fraction is defined by the ratio of the submerged volume and the total volume of the solid $V_{fluid\,(sub)}/V_o$. By equating the buoyant force and the weight of the object $B = F_g$, we get:

$$\rho_{fluid} V_{fluid(sub)} g = \rho_o V_o g$$



The submerged fraction is then equal to the ratio of the density of the solid to the density of the fluid:

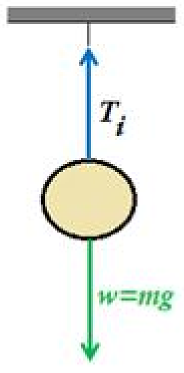
$$\frac{V_{fluid(sub)}}{V_o} = \frac{\rho_o}{\rho_{fluid}}$$

13.1 Archimedes' principle.

Example 13.1, P 316:

A piece of metal of unknown volume is suspended from a string. Before submersion, the tension in the string is T_i . When the metal is submerged in water the tension is T_f. The water density is ρ_{fluid}.

(a) calculate the weight of object ? (Ans: $w = T_i$)



13.1 Archimedes' principle.

Example 13.1, P 316:

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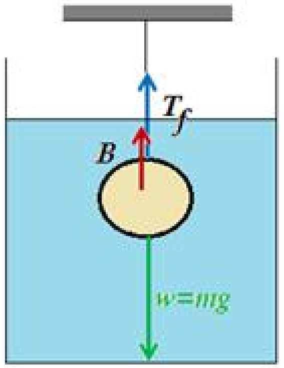
(b) Calculate the buoyant force ? (Ans: $B = T_i - T_f$)



(b)

Example 13.1, P 316:

A piece of metal of unknown volume is suspended from a string. Before submersion, the tension in the string is T_i . When the metal is submerged in water the tension is T_f. The water density is ρ_{fluid}

(c) calculate the volume of the piece of metal (Ans: $V_o = \frac{T_i - T_f}{\rho_{fluid} g}$)

13.1 Archimedes' principle.

Example 13.1, P 316:

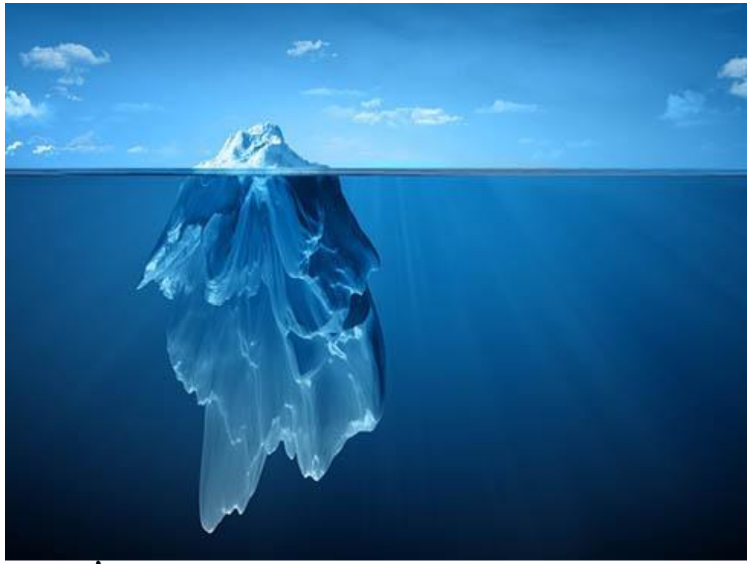
(d) If $T_i = 10\ N$ and $T_f = 8\ N$. what is the density of the metal?

(Ans: $\rho_o = \frac{\rho_{fluid} T_i}{T_i - T_f} = 5000\ \frac{kg}{m^3}$)

13.1 Archimedes' principle.

Example 13.2, P 316: :

The density of ice is 920 Kg/m^3 while that of sea water is 1025 Kg/m^3. What fraction of an iceberg is submerged? (Ans: $\frac{V_{f(sub)}}{V_o} = 0.898$)



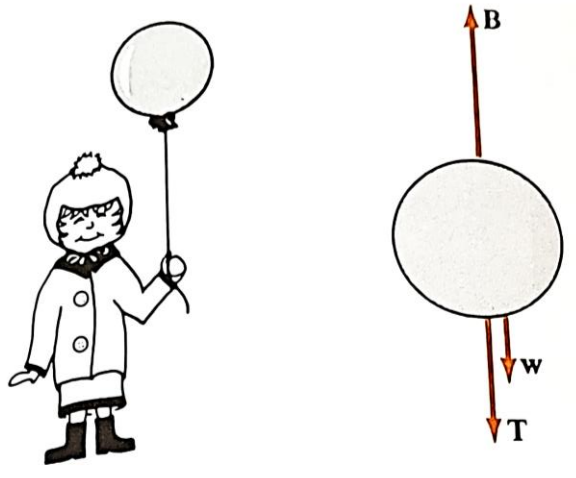
Sinking of the Titanic

13.1 Archimedes' principle.

Example 13.3, P 316: :

A child holds a helium–filled rubber balloon with a volume of 10 litres = 0.01 m^3 in air at 0° C (Fig. 13.20). Neglect the weight of the rubber and string and the buoyant force of the air on the child.

(a) How great a force must she exert to keep the balloon from rising? ($Ans: T = 0.109\ N$)



(a) (b)

13.1 Archimedes' principle.

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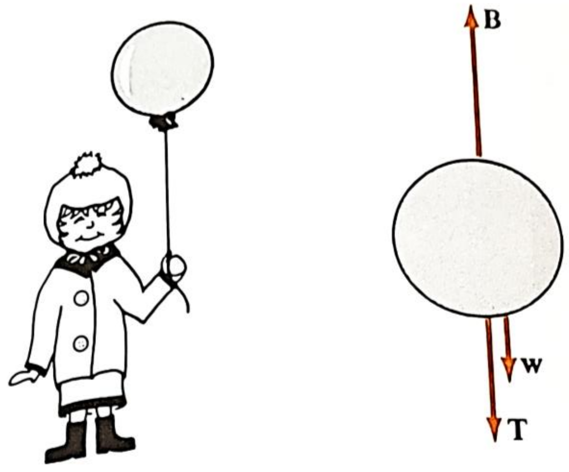


(a) (b)

Example 13.3, P 316: :

A child holds a helium–filled rubber balloon with a volume of 10 litres = 0.01 m^3 in air at 0° C (Fig. 13.20). Neglect the weight of the rubber and string and the buoyant force of the air on the child.

(b) How many such balloons would it take to lift a 20–kg child? $(Ans: 1800)$

13.2 The equation of Continuity

Fluid

Fluids statics
fluids at rest

Fluids dynamics
fluids in motion

13.2 The equation of Continuity

The flow rate: is the volume of the fluid flowing past a point in a channel per unit time: $Q = \frac{\Delta V}{\Delta t}$

The S.I unit of the flow rate is the m^3/s .

For an incompressible fluid ($\rho = \text{const.}$) the volume of fluid that passes any section of the tube per second is unchanged. The fluid that enters one end of the channel such as a pipe or an artery at the flow rate Q_1, must leave the other end at a rate Q_1 which is the same. Thus the equation of continuity can be written as $Q_1 = Q_2$.

The speed of water spraying from the end of a garden hose increases as the size of the opening is decreased with the thumb.

13.2 The equation of Continuity

Consider a section of the tube with cross–sectional area as the figure. and suppose that the fluid on this section has the same velocity. In the time Δt the fluid moves the distance $\Delta x = v\Delta t$ and the volume of the fluid crossing the tube is $\Delta V = A\Delta x = Av\Delta t$. The flow rate is then :

$$Q = Av$$

The flow rate equals the cross–sectional area times the velocity of the fluid.

For a channel whose cross section changes from A_1 to A_2 , this result together with $Q_1 = Q_2$ gives another form of the continuity equation:

$$\boxed{A_1 v_1 = A_2 v_2}$$

13.2 The equation of Continuity

Example 13.4 P 319:

A water pipe leading up to a hose a radius of 1 cm. Water leaves the hose at a rate of 3 litres per minute. ($\mathbf{1}L = \mathbf{0.001}m^3$) **and** ($\mathbf{1}\ \mathrm{min} = \mathbf{60}s$)

a) **Find the velocity of the water in the pipe.** (**Ans:** $v_1 = 0.159\ \frac{m}{s}$)

13.2 The equation of Continuity

Example 13.4 P 319:

A water pipe leading up to a hose a radius of 1 cm. Water leaves the hose at a rate of 3 litres per minute. ($1L = 0.001m^3$) and ($1\ \text{min} = 60s$)

b) The hose has a radius of 0.5 cm. What is the velocity of the water in the hose? (Ans: $v_2 = 0.636\ \frac{m}{s}$)

13.3 Bernoulli's Equation

Bernoulli's equation can be used for the following conditions :

1– The fluid is incompressible, then its density remains constant.

2– The fluid is non–viscous (no mechanical energy is lost).

3– The flow is streamline, not turbulent.

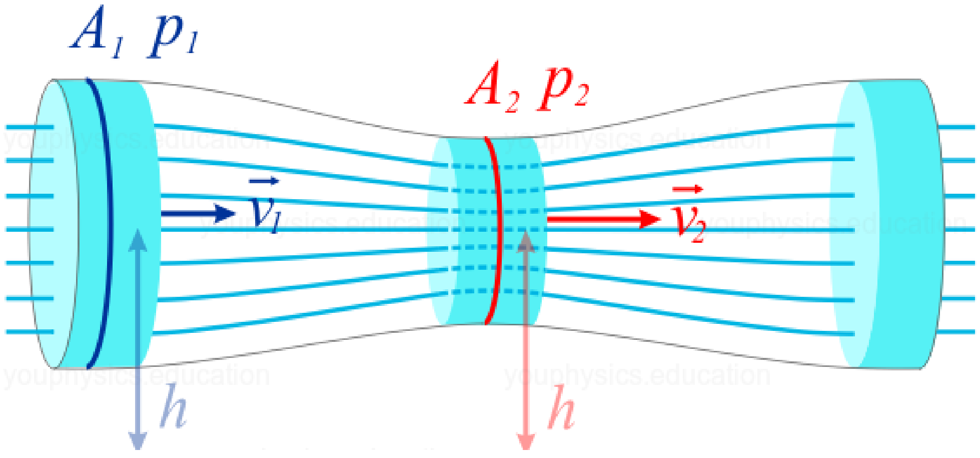
4– The velocity of the fluid at any point does not change during the period of observation. (This is called the steady–state assumption.)

If the above conditions are satisfied, then Bernoulli's equation states that the pressure plus the kinetic energy per unit volume is constant everywhere in the fluid.

$$\boxed{P + \frac{1}{2}\rho v^2 = const.}$$

or

$$\boxed{P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2}$$



Example:

Calculate the pressure in the hose whose absolute pressure is $1.01\ x\ 105\ N.m^{-2}$ if the speed of the water in hose increases from $1.96\ m.s^{-1}$ to $25.5\ m.s^{-1}$. Assume that the flow is frictionless and density $103\ kg.m^{-4}$ (Ans: $P_1 = 4.24\ \times 10^5 \frac{N}{m^2}$)

Name: **Section**

- ## Homework 6

Ch13: 13.1, 13.7, 13.10, 13.34

Final Answers : 13.10[12 m/s], 13.34[(a) 8m/s, (b) 2.73×10^5Pa]