Physics 042

L6

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CH 14: 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?

Ch14: Fluid Mechanics

- 14.0 Introduction: Pressure, density and fluid
- 14.1 Pressure
- 14.2 Variation of Pressure with Depth
- 14.3 Pressure Measurements

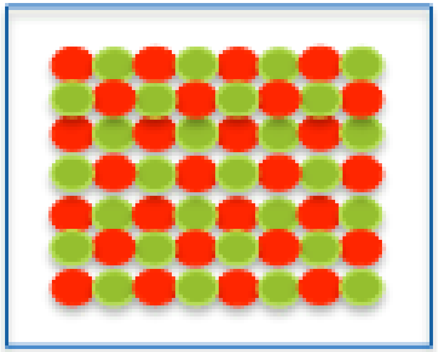
Archimedes
Greek Mathematician, Physicist, and Engineer (c. 287–212 BC)

14.0 Introduction: Pressure, density and fluid

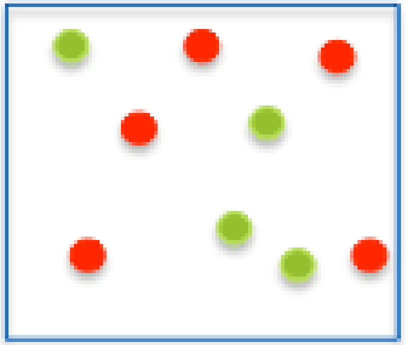
Density is defined as the mass per unit volume.

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

- 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

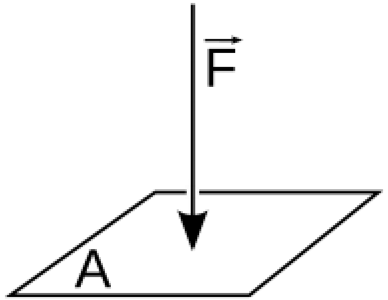
14.0 Introduction: Pressure, density and fluid

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:

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



- 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 ($1\ \text{Pa} = 1\frac{kg}{ms^2} = 1\frac{N}{m^2}$).

14.0 Introduction: Pressure, density and fluid

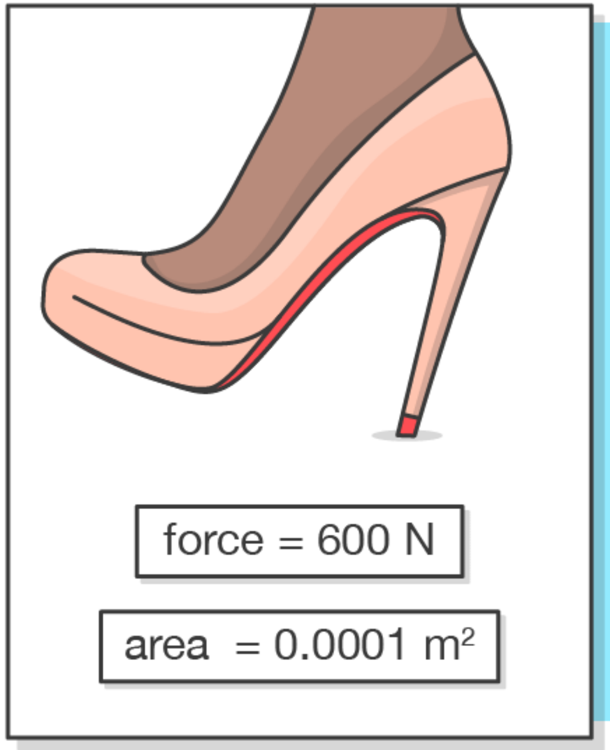
Why lying on a bed of nails doesn't hurt ?

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

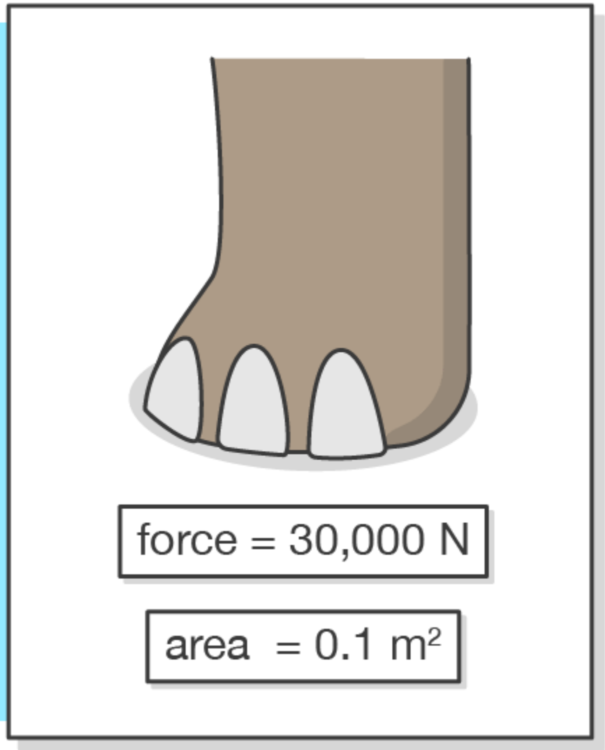
When there's plenty of nails, the pressure any single nail exerts on the skin is quite small, resulting in no pain and no cuts. Resting an entire body on a single nail, however, would be a different story!!

Checkpoint 2:

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



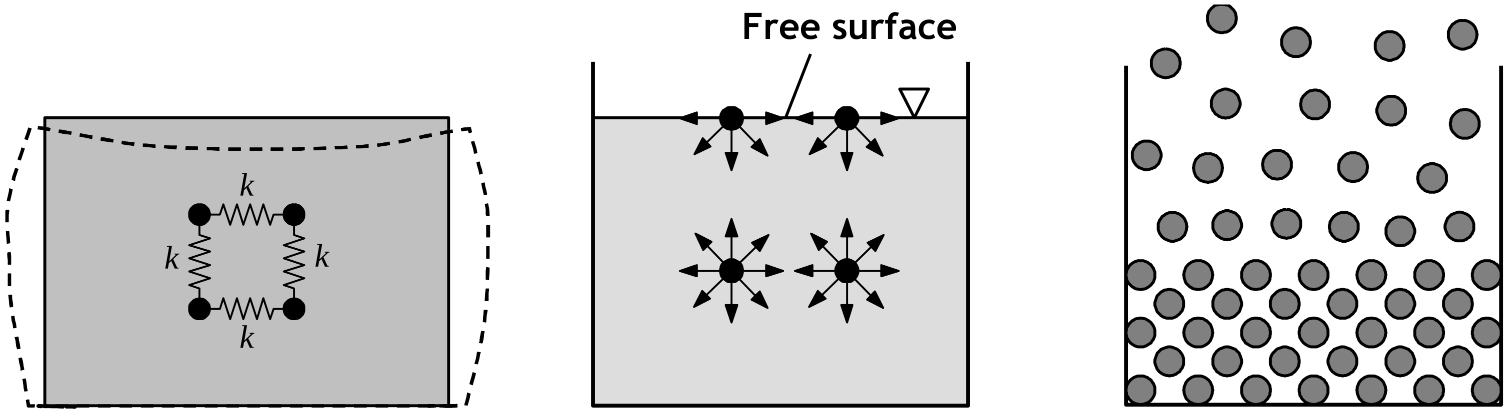
(a)



(b)

14.0 Introduction: Pressure, density and fluid

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.



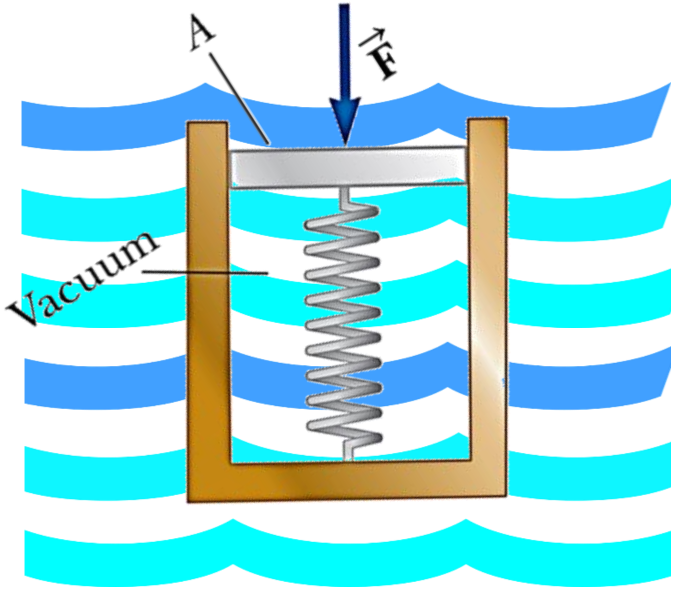
(a) Solid (b) Liquid (c) Gas

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.

14.1 Pressure (Liquid and Gas)

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:

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

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

14.2 Variation of Pressure with Depth

The pressure exerted on the piston extends uniformly throughout the fluid, causing it to push outward with equal force per unit area on the walls and bottom of the cylinder. [Fig. (a)]

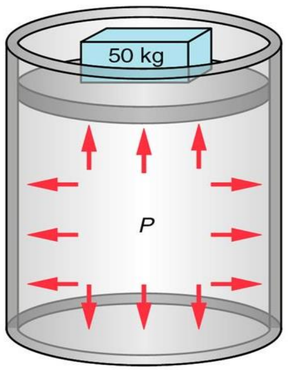


Figure (a) What happens inside a fluid when pressure is exerted on it?

Pascal's Principle:

Any change in the pressure of a fluid is transmitted uniformly in all directions throughout the fluid.

What technology uses Pascal's principle?

One of the most important technological applications of Pascal's principle is found in a hydraulic system, which is an enclosed fluid system used to exert forces. The most common hydraulic systems are those one that can lift cars easily , which named : (Hydraulic Jack) [Fig. (b)]

Figure (b) : A hydraulic jack can easily lift a car

14.2 Variation of Pressure with Depth

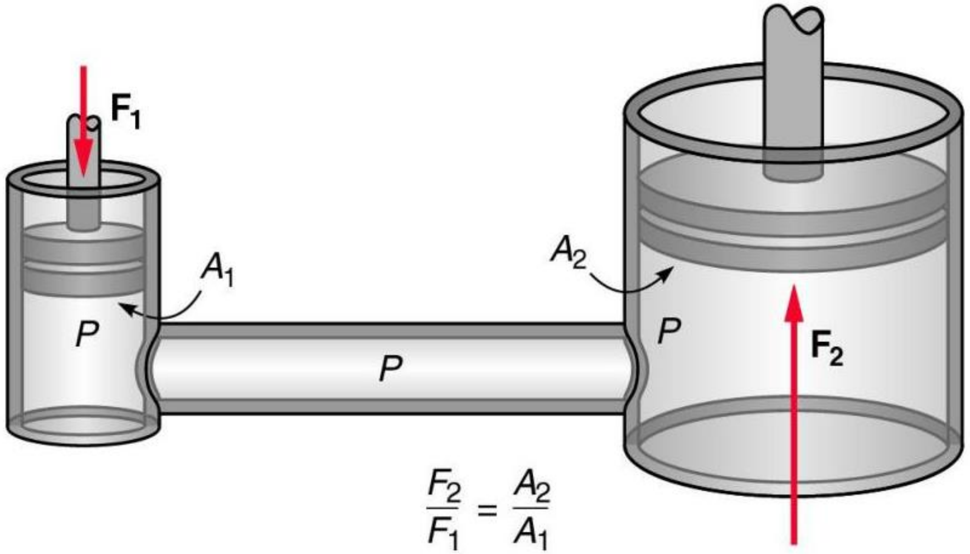
Hydraulic Jack :

When an input force $\vec{F}_1$ is applied to the small piston (with area A_1) in a hydraulic system, the piston pushes against the fluid sealed in the system.

- The pressure produced by the small piston is transmitted through the fluid to the large piston.
- The pressure on both pistons is the same $P_{in} = P_{out}$
- Because the output pressure acts on a much larger area A_2, the output force is larger $\vec{F}_2$

$$P_{in} = P_{out}$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{or} \quad \frac{F_2}{F_1} = \frac{A_2}{A_1}$$



Exercise 1:

A force of $10\ N$ is applied to a circular piston with an area of $2cm^2$ in a hydraulic jack. The output piston for the jack has an area of $100cm^2$.

(a) What is the pressure in the fluid?

Exercise 1:

A force of $10\ N$ is applied to a circular piston with an area of $2cm^2$ in a hydraulic jack. The output piston for the jack has an area of $100cm^2$.

(b) What is the force exerted on the output piston by the fluid?

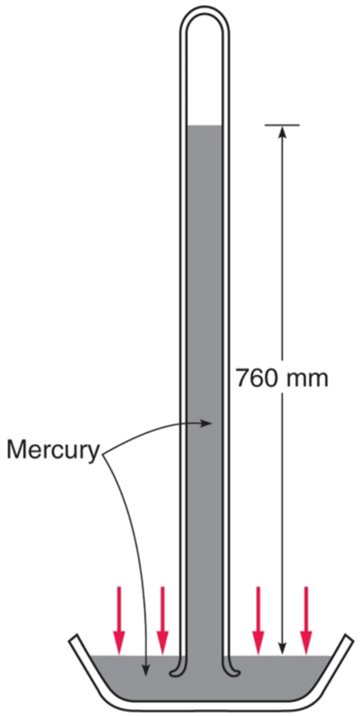
14.2 Variation of Pressure with Depth

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.

Atmosphere

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

14.2 Variation of Pressure with Depth

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?!

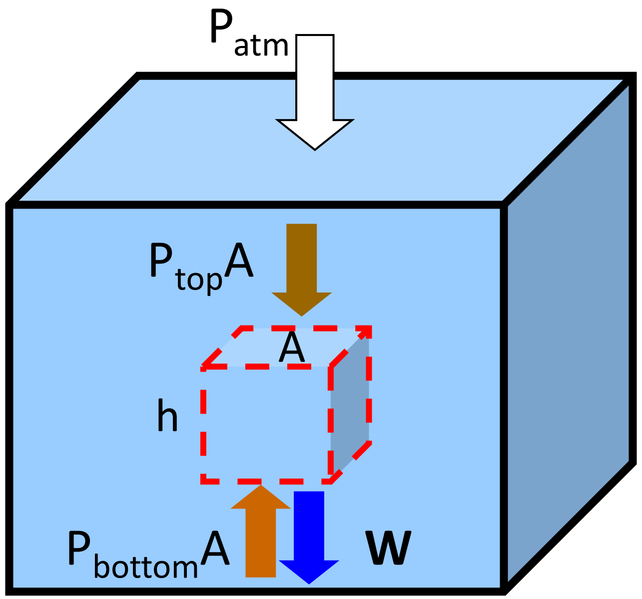
14.2 Variation of Pressure with Depth

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.

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

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

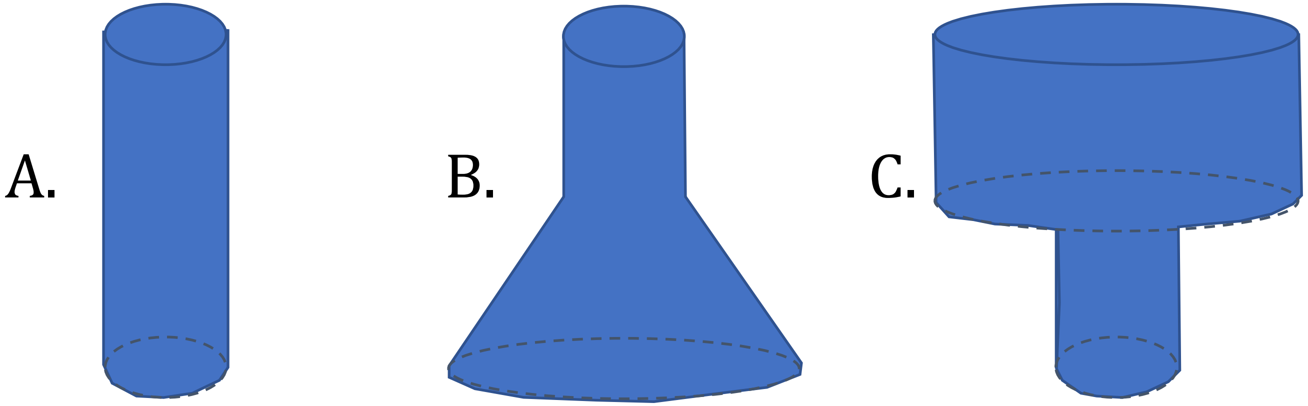
If the liquid is open to the atmosphere and P_{top} is the pressure at the surface of the liquid, then P_{top} is atmospheric pressure P_{atm}.



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



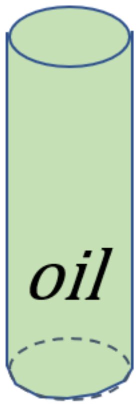
Checkpoint 4:

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

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

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

A.



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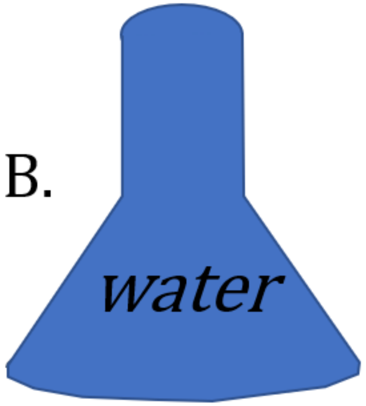
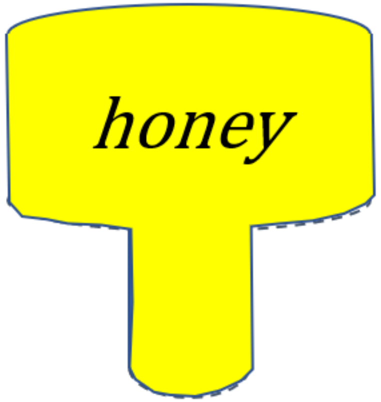


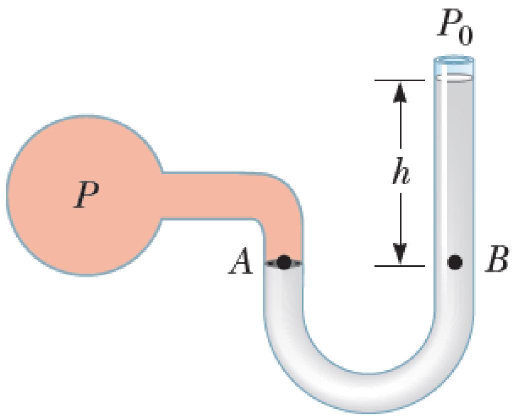
C.



14.3 Pressure Measurements

- **Manometer:**

A device for measuring the pressure of a gas contained in a vessel is the open tube manometer illustrated in Fig. One end of a U–shaped tube containing a liquid is open to the atmosphere, and the other end is connected to a container of gas at pressure P. In an equilibrium situation, the pressures at points A and B must be the same ($P_A = P_B$), and the pressure at A is the unknown pressure of the gas. Therefore, equating the unknown pressure P to the pressure at point B, we see that.



Devices for measuring pressure, an open-tube manometer.

$$P_A = P_0 + \rho h g$$

Again, we can calibrate the height h to the pressure P.