Pressure

Learning Outcomes

(a) define the term pressure in terms of force and area

(b) recall and apply the relationship *pressure* = *force* / *area* to new situations or to solve related problems

(c) describe and explain the transmission of pressure in hydraulic systems with particular reference to the hydraulic press

(d) recall and apply the relationship *pressure due to a liquid column* = *height of column* × *density of the liquid* × *gravitational field strength* to new situations or to solve related problems

(e) describe how the height of a liquid column may be used to measure the atmospheric pressure

(f) describe the use of a manometer in the measurement of pressure difference

Pressure

- Pressure is defined as force acting on unit area where the force acts perpendicular to the surface.

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

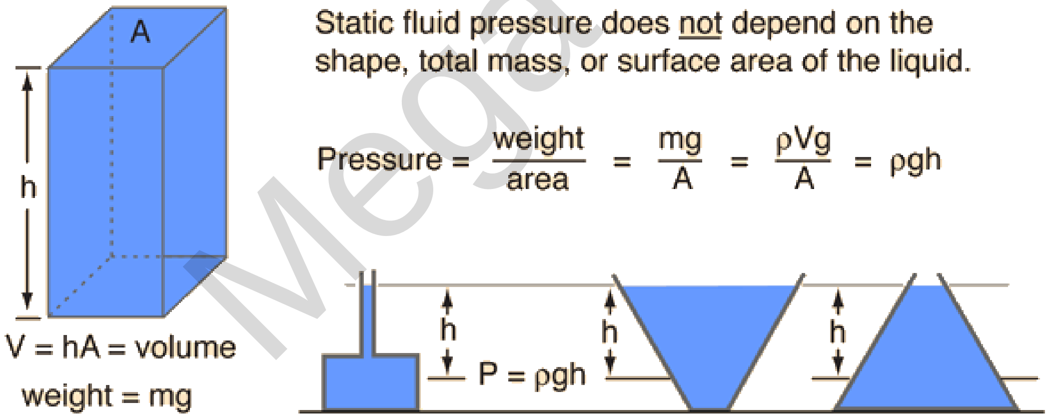
- It is a **scalar** quantity
- **Unit**: Pa, N/m^2

Examples

Assignment 7 Qns 1 and 2

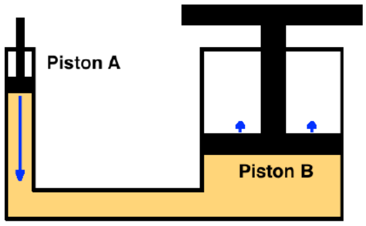
Pressure in a fluid (liquid)

- A fluid can exert a pressure in **any direction**. (divers experience the same water pressure on all parts of their body)
- At any point in a fluid at rest, the pressure is the **same** in all directions at a given depth.



Examples
Assignment 7 Qns 3 and 4

Hydraulic systems



hydraulic lift system

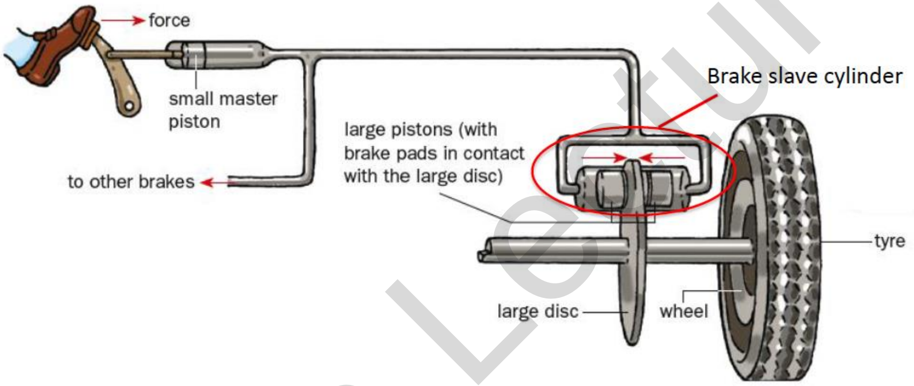
How is pressure transmitted in a hydraulic press?

- It is based on **Pascal's theory** that when pressure is applied to a fluid in an enclosed system, the pressure throughout the fluid is constant.
- This works for **incompressible** liquids
- Make use of P = F/A to calculate the force on piston B

Presence of air reduces stiffness or slows the response of the system. It may also require **greater power** to be delivered to the system as energy is used to compress the air bubbles

- Principle of conservation of energy applies in hydraulic systems:
  work done on piston A = work done by fluid to move piston B.

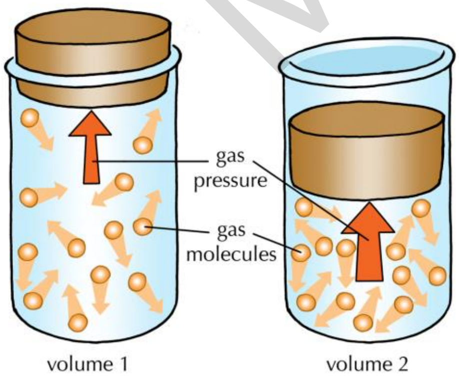
Applications of hydraulic systems



Example
Assignment 7 Qn 5 & 11

Gas pressure

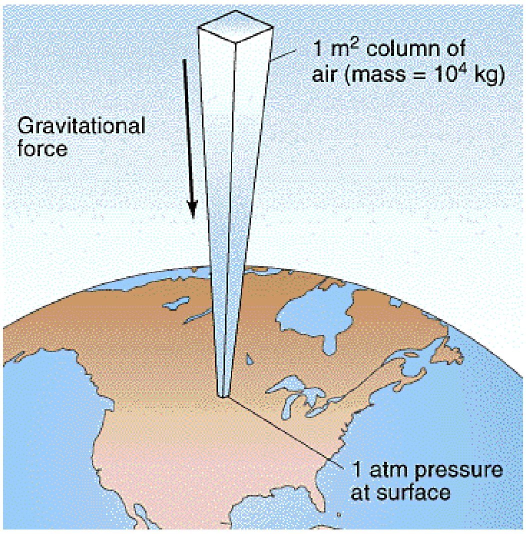
- By the **definition** of pressure, gas pressure is the **average force per unit area** exerted by gas particles when they collide with the walls of the container.



When the volume of the gas decreases, the frequency of collision **between particles and the wall** increases, therefore average force exerted on the wall increases. As a result, pressure increases.

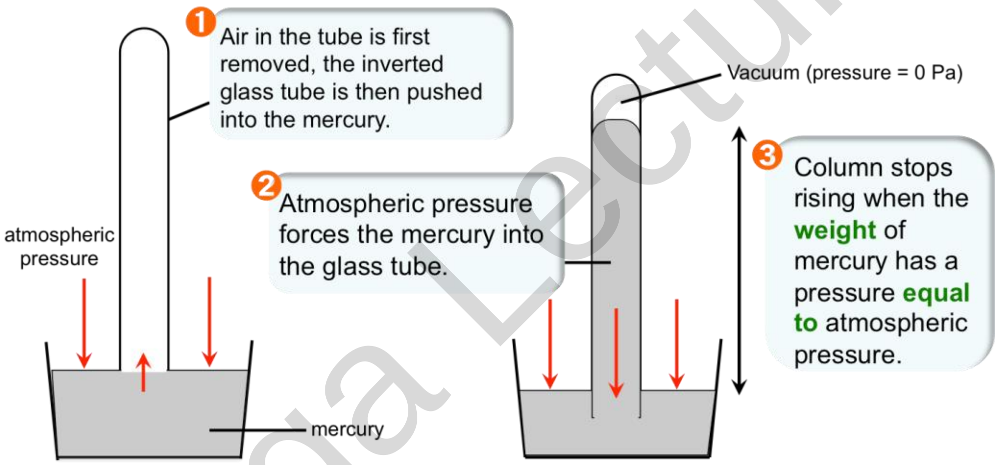
Extension: When a gas is compressed, it undergoes a change of state. Pressurised carbon dioxide is used to decaffeinate coffee beans because caffeine dissolves in carbon dioxide.

Atmospheric Pressure



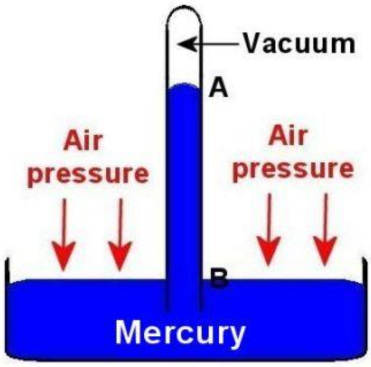
If the height of the atmosphere is 8.5 km, what is the average pressure due to the atmosphere at sea level? (average density of air, ρ = 1.225 kg/m^3, g = 9.81 N/kg)

Measuring atmospheric pressure (barometer)

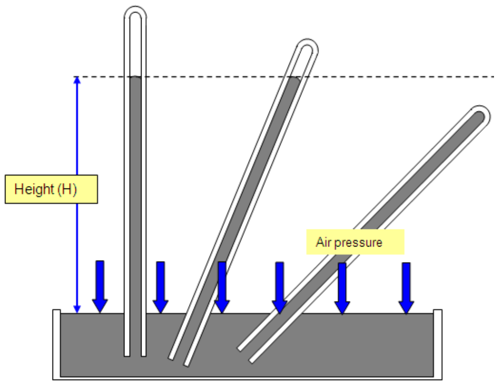


- In reality, a perfect vacuum cannot exist, so there will be a little air trapped above the mercury in the glass tube.
- What happens if the barometer is brought to a mountaintop?
  Answer: The weight of the atmosphere pressing down on the mountaintop is smaller compared to the atmospheric pressure pressing down on Earth at sea level. Therefore, on the mountaintop, less mercury will flow into the glass tube and the height of the mercury column decreases.

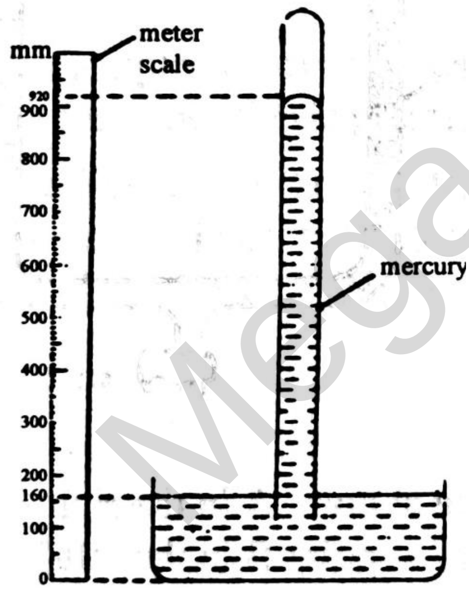
Units of pressure	Corresponding atmospheric pressure
Pa or N/m^2	1.01325×10^5 Pa or N/m^2
cmHg, mmHg (mmHg is also known as torr)	76 cmHg or 760 mmHg
atm	1 atm
bar	1.01325 bar



- The pressure at B is equal to the atmospheric pressure
- The atmospheric pressure can be calculated if the height h of the mercury barometer is known. h is usually about 76 cm.
- Density of mercury = 13600 kg/m^3
- Therefore, $P_{atm} = h\rho g$
  $= 0.76 \text{ m} \times 13600 \times 10$
  $= \mathbf{1.03 \times 10^5 \text{ Pa}}$
- **Atmospheric pressure** is usually expressed as **76 cmHg**. (Hg = chemical symbol of mercury)



The height of the liquid column is independent of its inclination



(a) State the atmospheric pressure shown by the barometer.

(b) When air was introduced into the barometer tube, the difference between the mercury levels in the barometer tube and the reservoir became 746 mm. Deduce the pressure of the air above the mercury in the barometer tube.

c) After the air was introduced, the barometer tube is lowered so that its lower end is immersed **more deeply** in the reservoir. By considering the air above the mercury in the barometer tube, explain briefly why the difference in mercury levels in the tube and reservoir is now **less than** 746 mm.

Example

If mercury (ρ_m = 13 600 kg m^{-3}) in a barometer is replaced with water (ρ_w = 1000 kg m^{-3}), determine the height of the water column. The height of a mercury column is 760 mm at sea level.

Example

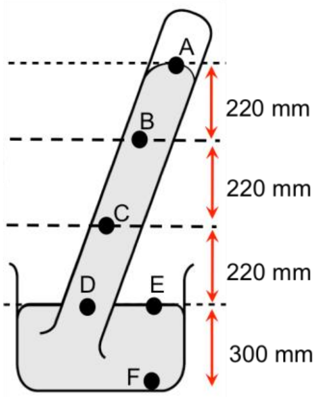
In a simple barometer that measures atmospheric pressure, the mercury column is measured at 760 mm at sea level. Some air is then introduced into the vacuum at the top of the mercury column.

(a) Explain how this will affect the mercury column.

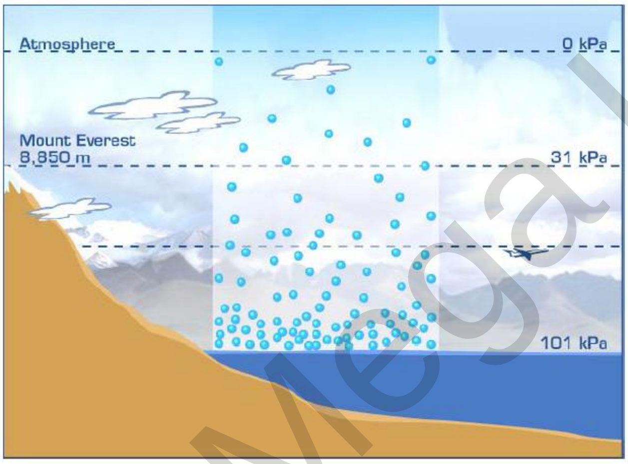
(b) Determine the pressure due to the trapped air, given that the height of the mercury column is now 500 mm. Atmospheric pressure is 760 mm Hg.

Example

What are the pressures in mm Hg at the points (A to F) indicated on the mercury barometer?

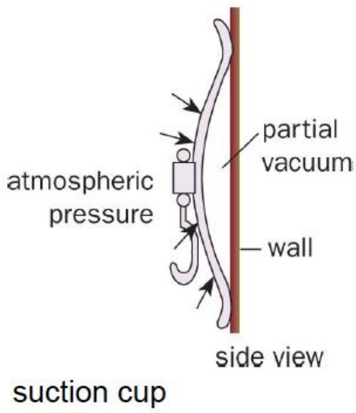


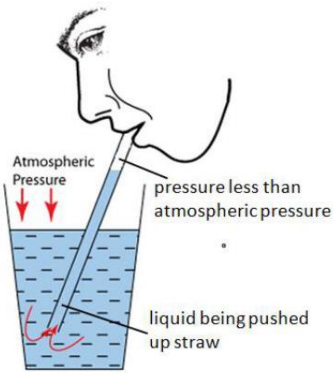
Assignment 7 Qns 6 to 9



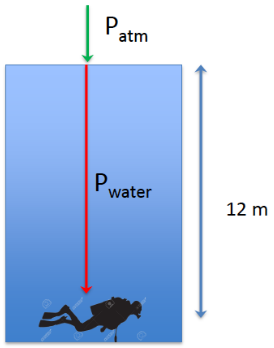
Why does atmospheric pressure decrease with height?

Explain the following scenarios using pressure concepts.



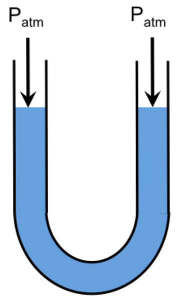


Example

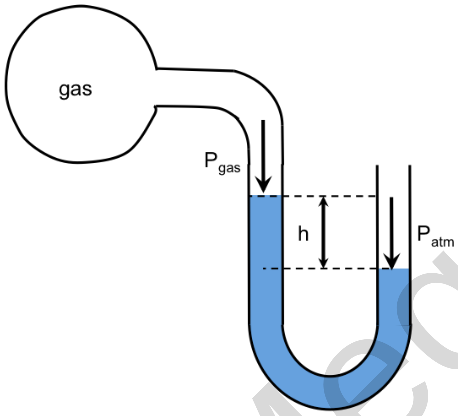


What is the total pressure on a scuba diver when she is 12 m below the surface of the ocean? Assume standard atmospheric conditions.
(P_{atm} = 1.0 ×10^5 Pa, density of sea water = 1.03 ×10^3 kg/m^3)

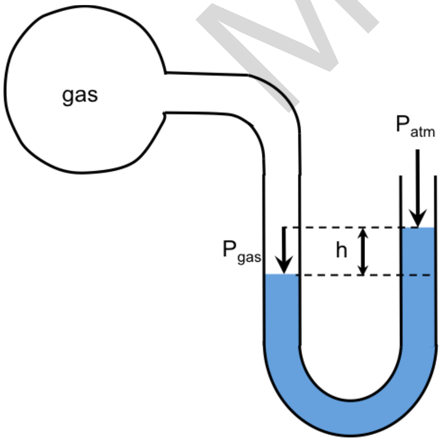
Manometer
Measuring pressure difference using a **manometer**



Since both ends of the tube are exposed to the surroundings, the pressure on the surface of the liquid is equal in both ends of the tube.

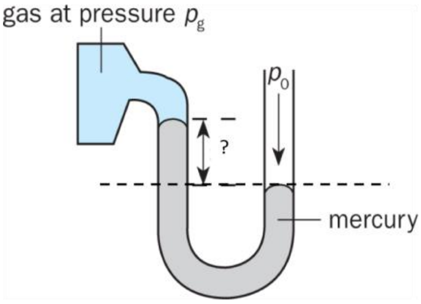


$P_{gas} < P_{atm}$
Pressure difference = $P_{atm} - P_{gas} = \rho gh$



$P_{gas} > P_{atm}$
Pressure difference = $P_{gas} - P_{atm} = \rho gh$

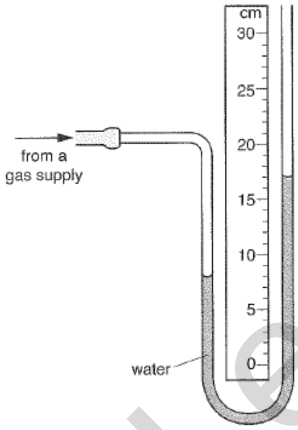
Example



The pressure p_g of a gas in a container is measured using a manometer and found to be 56 cm Hg. Determine the height difference between the two arms, given that the atmospheric pressure p_0 is 76 cm Hg.

Assignment 7 Qn 10

Example
A water manometer is connected to a laboratory gas supply, as shown in the figure.



Before the gas supply is connected, the water is at the same level on the two sides of the manometer.

(a) Explain why
  (i) the water level moves down on the left side of the manometer when the gas supply is connected.
  (ii) the water levels finally remain constant at the levels shown.

(b) Calculate the pressure difference being measured by the manometer in the figure. The gravitational field strength g is 10 N/kg and the density of water is 1000 kg/m^3.

(c) Suggest how the manometer can be changed to measure greater pressure differences using a tube of the same length.

Example

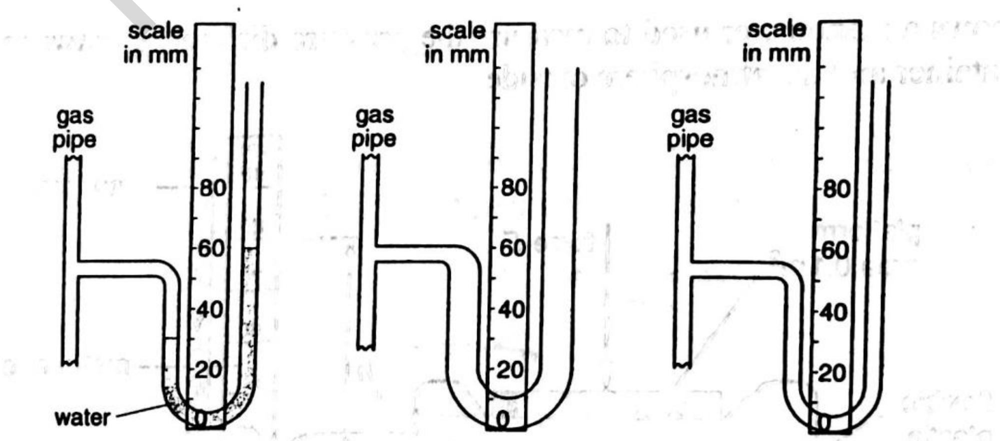


Fig 1.1 Fig 1.2 Fig 1.3

(a) State whether the pressure inside the gas pipe in Fig 1.1 is larger than or smaller than atmospheric pressure.

(b) The density of water is 1000 kg/m^3 and the gravitational field strength is 10 N/kg. Calculate the pressure difference between the gas inside the pipe and atmospheric pressure in Fig 1.1.

(c) The manometers shown in Fig 1.2 and 1.3 are connected to the same gas pipe at the same pressure as shown in Fig 1.1.
On Fig 1.2 and 1.3, draw the levels of the liquid in each manometer if
(i) the manometer in Fig 1.2 contains water and has tubes with twice the diameter of the tubes in Fig 1.1.
(ii) the manometer in Fig 1.3 contains a liquid with density half that of water.

Extension

How does an aneroid barometer work?

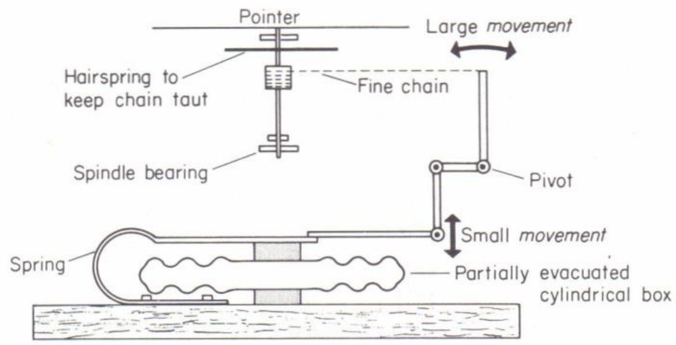


Fig. 10.14. Aneroid barometer movement