Higher Physics – Unit 1

1.5 – Density and Pressure

Density

The **density** of a substance is the **mass per unit volume**.

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

density ($kg\ m^{-3}$)

mass (kg)

volume (m^3)

The **more mass** in a **given volume**, the **greater** the **density**.

Density has the symbol, ρ (rho).

Example 1

A rectangular block of metal measures 20 cm x 15 cm x 10 cm and has a mass of 12 kg.

Calculate the density of the metal.

$$V = 0.2 \times 0.15 \times 0.1$$
$$= 0.003 \text{ m}^3$$
$$m = 12 \text{ kg}$$
$$\rho = ?$$

$$\rho = \frac{m}{V}$$
$$= \frac{12}{0.003}$$
$$\rho = 4{,}000 \text{ kg m}^{-3}$$

Measuring Density of Air

Aim

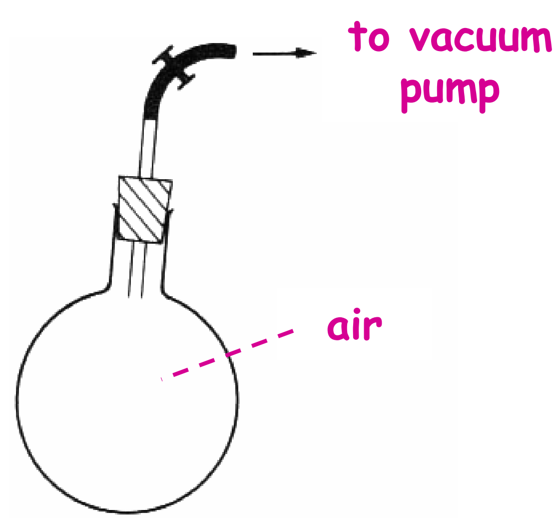
To measure and compare the value for the density of air.

Method

A round bottomed flask is weighed with air inside it.

The air is evacuated using a vacuum pump and is reweighed.

The volume of the flask is measured by filling it with water and emptying into a measuring cylinder.



Results

mass of flask + air = ________ g

mass of flask (no air) = ________ g

mass of air extracted = ________ g

= ________ kg

volume of air in flask = ________ ml

= ________ litres

= ________ m^3

** 1000 litres = 1 m^3 **

$$\rho_{air} = \frac{m}{V}$$

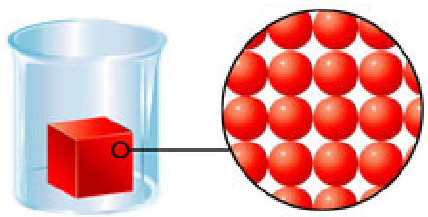
ρ_{air} = ____________

ρ_{air} = ____________ $kg\,m^{-3}$

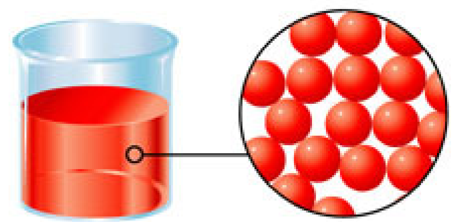
** Must Be Able To Describe How To Measure Density of Air **

Molecule Separation

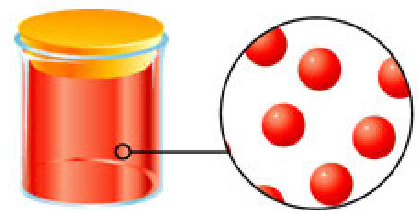
The molecule separation for each of the three states of matter is considered.



solid



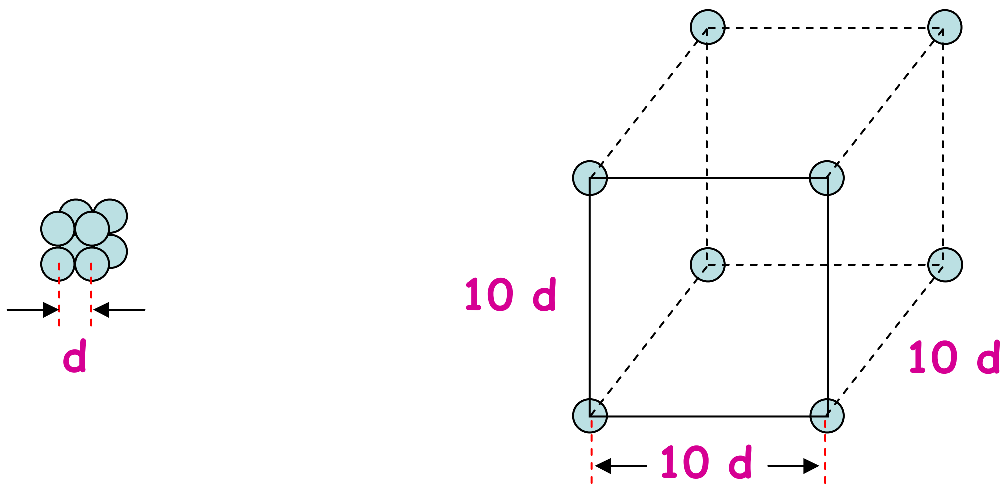
liquid



gas

The volume occupied by a substance in its solid form is approximately equal to the volume occupied when in liquid form.

The **volume** of a **gas** however is **1000 times greater** than the volume of the same mass of the solid or liquid form of that substance.



As the mass is contained in a **volume** which is **1000 times greater**, the **density** is **1000 times smaller**.

$$\rho = \frac{m}{1000\,V}$$

The **densities** of **gases** are **smaller** than the densities of solids and liquids by a **factor of 1000**.

Summary

	Separation	Volume	Density
Solid	1	1	1
Liquid	1	1	1
Gas	10	1000	1/1000

Pressure

The **pressure** is defined as the **force per unit area**.

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

pressure (Pa)

force (N)

area (m^2)

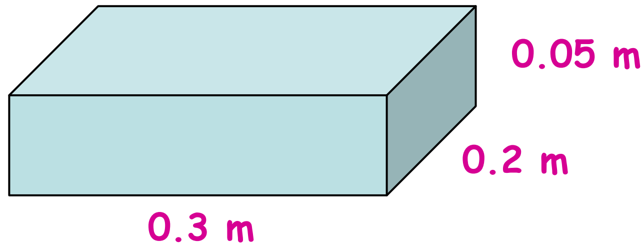
The unit of pressure is the **Pascal** (Pa).

Alternative units for pressure are: **$N\ m^{-2}$**.

$$1\,Pa = 1\,N\,m^{-2}$$

Example 1

A 3 kg block has dimensions as shown.



Calculate the pressure the box exerts on the surface of a desk.

Weight of Box

$$W = m\,g$$
$$= 3 \times 9.8$$
$$W = 29.4\,\text{N}$$

Area of Base

$$A = l \times b$$
$$= 0.3 \times 0.2$$
$$A = 0.06\,\text{m}^2$$

Pressure on Desk

$$P = \frac{F}{A}$$
$$= \frac{29.4}{0.06}$$
$$P = 490\,\text{Pa}$$

Worksheet – Density and Pressure

Q1 - Q20

Pressure in Fluids

Fluid is a general term which describes **liquids and gases**.

Any equations that apply to liquids at rest equally apply to gases at rest.

Atmospheric Pressure

At the Earth's surface, the **air exerts pressure** in all directions.

This is caused by **air molecules** which move at high speeds in random directions. When they **collide** with surfaces they **exert a force**.

The **force** exerted by the atmosphere is 1×10^5 N per m^2.

This force is known as the **atmospheric pressure**:

$$1.01 \times 10^5 \text{ Pa}$$

At **high altitudes** there is **less atmospheric pressure** because there are **fewer air molecules** and **less weight pushing down** from above.

Pressure in Liquids

At the surface of a liquid the pressure is the same as atmospheric pressure.

Beneath the surface, the **pressure** in fluids **varies directly** with the **depth** and the **density** of the liquid.

$$P = \rho g h$$

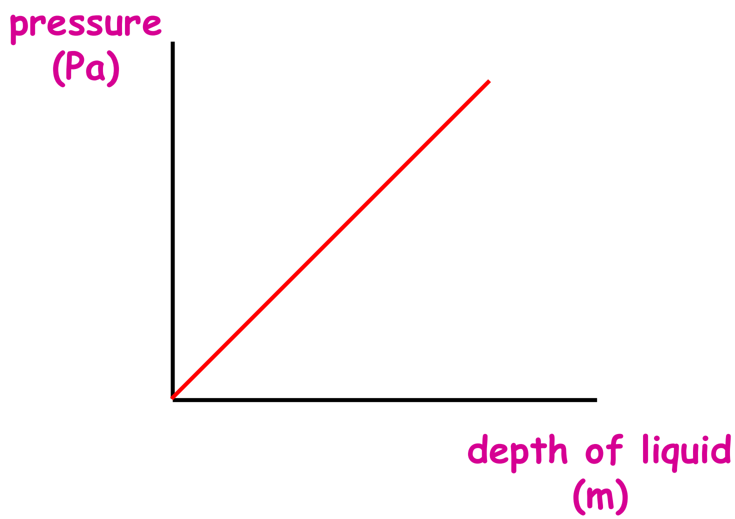
pressure (Pa)

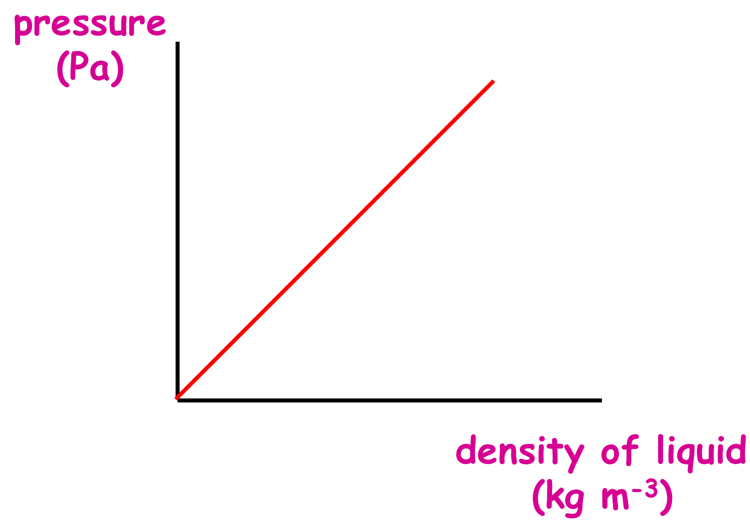
density ($kg\ m^{-3}$)

gravitational field strength ($N\ kg^{-1}$)

depth (m)

Graph of Relationship





Example 1

An object at 6 m is placed in a liquid with a density of 800 kg m^{-3}.

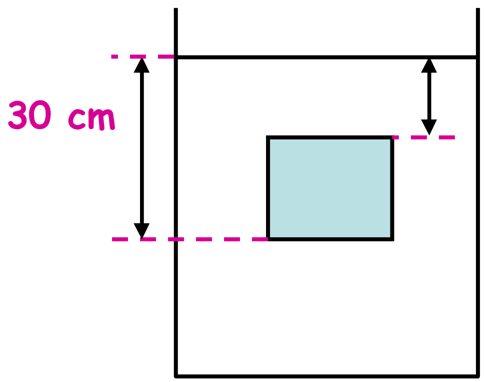
Calculate the pressure due to the liquid.

$$h = 6\,m$$
$$\rho = 800\,kg\,m^{-3}$$
$$g = 9.8\,N\,kg^{-1}$$
$$P = ?$$

$$P = \rho g h$$
$$= 800 \times 9.8 \times 6$$
$$= 47{,}040$$
$$P = 4.7 \times 10^4\ Pa$$

Example 2

A cube with sides 12 cm is submerged in water to a depth of 30 cm.



The density of fresh water is 1×10^3 kg m^{-3}.

(a) Calculate the pressure at the **bottom** surface of the cube due to the water.

$$h = 30\text{ cm} = 0.3\text{ m}$$

$$\rho = 1 \times 10^3 \text{ kg m}^{-3}$$

$$g = 9.8 \text{ N kg}^{-1}$$

$$P = ?$$

$$P = \rho g h = (1 \times 10^3) \times 9.8 \times 0.3$$

$$P = 2{,}940 \text{ Pa}$$

(b) Calculate the pressure at the **top** surface of the cube due to the water.

$$h = 30 - 12$$
$$= 18 \text{ cm}$$
$$= 0.18 \text{ m}$$

$$\rho = 1 \times 10^3 \text{ kg m}^{-3}$$

$$g = 9.8 \text{ N kg}^{-1}$$

$$P = ?$$

$$P = \rho g h$$
$$= (1 \times 10^3) \times 9.8 \times 0.18$$
$$P = 1{,}764 \text{ Pa}$$

(c) Calculate the force acting on the **bottom** surface of the cube.

$$P = 2{,}940 \text{ Pa}$$

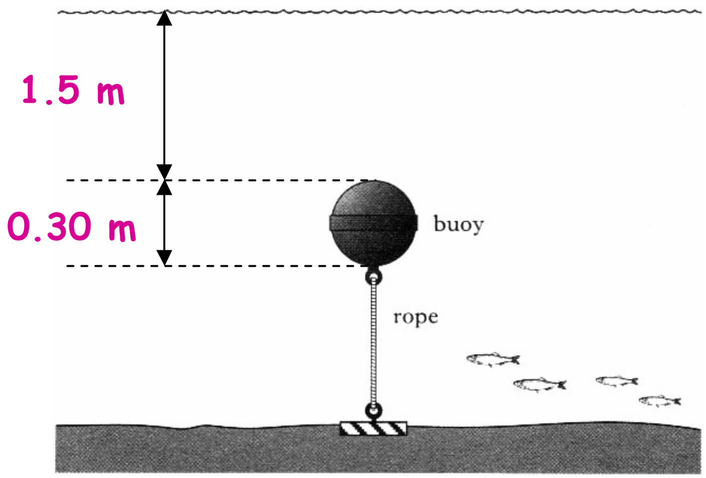
$$A = 0.12 \times 0.12$$
$$= 0.0144 \text{ m}^2$$

$$F = ?$$

$$F = P A$$
$$= 2940 \times 0.0144$$
$$F = 42.3 \text{ N}$$

Example 3 – (Atmospheric Pressure)

A mooring buoy is tethered to the bottom of a sea water loch by a vertical cable as shown.



The density of sea water is $1.02\times10^{3}\ kg\ m^{-3}$.

(a) Calculate the total pressure on the **top** of the buoy.

$h = 1.5\ m$

$\rho = 1.02\times10^{3}\ kg\ m^{-3}$

$g = 9.8\ N\ kg^{-1}$

$P = ?$

$P = \rho g h$

$= (1.02\times10^{3})\times9.8\times1.5$

$P = 14{,}994\ Pa$

This pressure is only due to the sea water.

To find the **total pressure**, we need to **add** the **atmospheric pressure** from the air above.

$$P_{total} = 14{,}994 + \left(1.01 \times 10^5\right)$$
$$= 115{,}994 \text{ Pa}$$
$$= 1.16 \times 10^5 \text{ Pa}$$

(b) Calculate the total pressure on the **bottom** of the buoy.

$h = 1.8 \text{ m}$

$\rho = 1.02 \times 10^3 \text{ kg m}^{-3}$

$g = 9.8 \text{ N kg}^{-1}$

$P = ?$

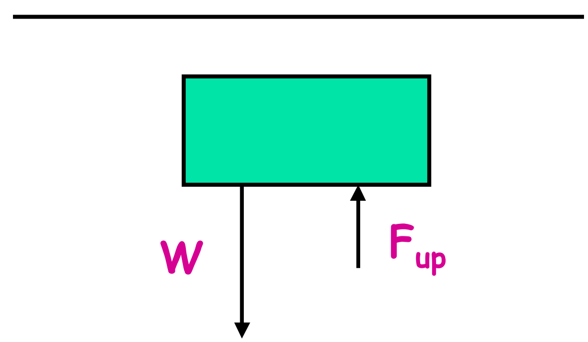
$$P = \rho g h$$
$$= \left(1.02 \times 10^3\right) \times 9.8 \times 1.8$$
$$P = 17{,}992.8 \text{ Pa}$$

$$P_{total} = 17{,}992.8 + \left(1.01 \times 10^5\right)$$
$$= 118{,}992.8 \text{ Pa}$$
$$= 1.19 \times 10^5 \text{ Pa}$$

Buoyancy (Upthrust)

When an object is submerged in a liquid, it appears to lose wight.

It's **weight** stays the **same**, but the object experiences a **buoyancy force** or **upthrust**.



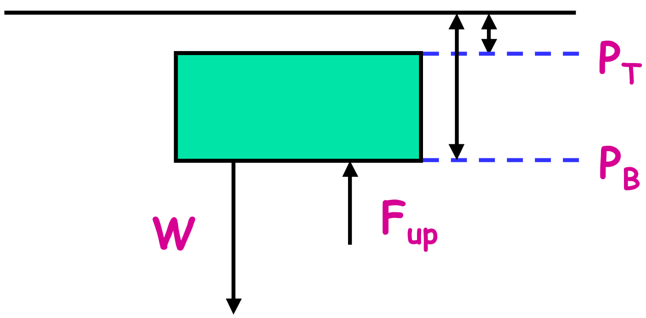
Explaining Buoyancy Force

Pressure varies with depth $(P = \rho g h)$

P_B greater than P_T.

From $F = P \times A$: F_B greater than F_T.

Unbalanced force upwards is buoyancy.



Sink, Float or Rise?

weight > upthrust => SINK

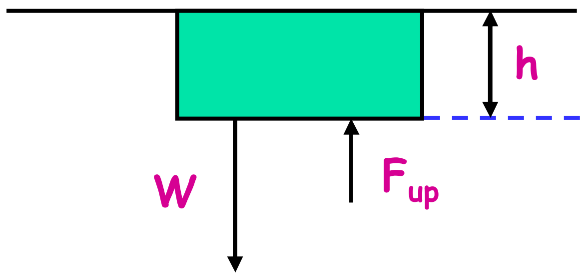
weight = upthrust => FLOAT

weight < upthrust => RISE

Maximum Buoyancy

The **MAXIMUM BUOYANCY** is achieved **just before** the object becomes **fully submerged**.

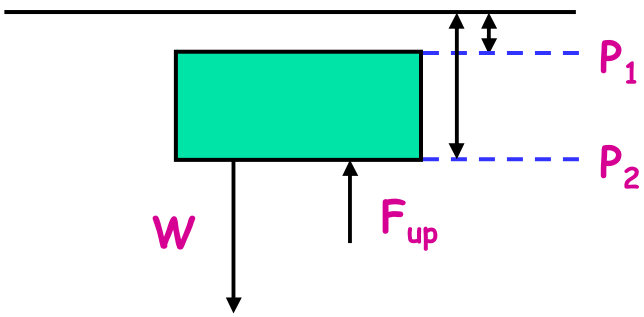
After that the pressure on the top surface would cause a downward force cancelling out any further increase in F_{up}.

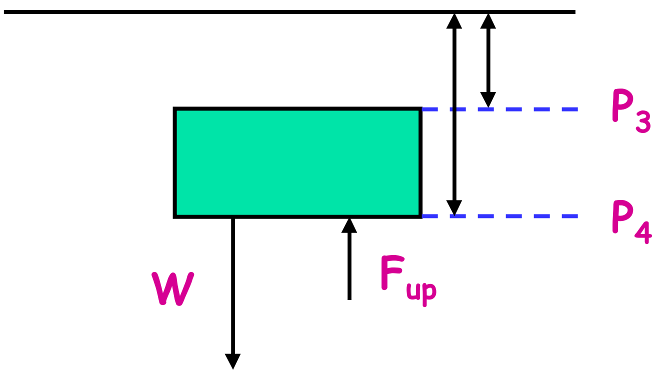


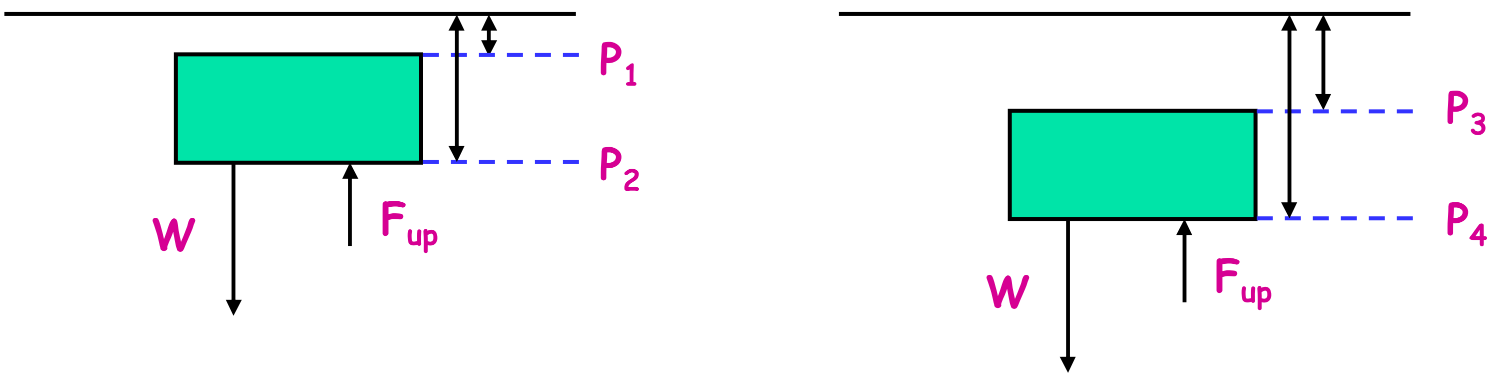
Size of Upthrust (Submerged)

The **size of the upthrust** depends on the **pressure difference** between the top and bottom surface.

It does **NOT** depend on the **depth** .







Note

- P_1 less than P_3
- P_2 less than P_4
- However, the pressure difference in both situations is the same:

$$P_2 - P_1 = P_4 - P_3$$

- From F= PxA, the upthrust on each object is equal.

Worksheet – Pressure in Liquids and Buoyancy

Q1 – Q13