Phases of matter

Content

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Density

- In daily life, very often we hear people say that iron is "heavier" than wood. This cannot really be true since a large log clearly weighs more than an iron nail. What we should say is that iron is more **dense** than wood.
- Density of a substance is defined as its **mass per unit volume of a substance.**
- It tells us about how concentrated the matter is.

$$\boxed{\textbf{Density} = \frac{\textbf{mass}}{\textbf{volume}}}$$

- The symbol for density is ρ "rho".
- The S.I. unit for density is the kgm^{-3}
- Density is constant for a given material.
- For water, the density, ρ = 1 g/ml = 1 kg/l = 1 gcm^{-3} = 1000 kgm^{-3}

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Density & Temperature

- Densities of solids and liquids vary **slightly** with temperature while density of gases vary enormously.
- As substances get bigger when they are heated, ***the increase in volume causes a reduction in density.***
- The solid form of most substances is **denser** than the liquid phase, thus, a block of most solids will sink in its liquid phase.
- However, a block of ice floats in liquid water because ice is *less* dense !

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Densities of common substances in kg/m^3

Air	1.3
Cork	250
Wood	750
Petrol	800
Ice	920
Water	1000
Glass	2500
Aluminium	2700
Steel	7800
Lead	11300
Mercury	13600
Gold	19300
Platinum	21500

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Example 1

- A cube of copper has a mass of 240g. Each side of the cube is 3.0cm long. Calculate the density of copper in gcm^{-3} and in $kgm^{-3.}$

- The density of steel is 7850 $kgm^{-3.}$ Calculate the mass of the steel sphere of radius 0.15m.

- Calculate the mass of steel having the same volume as 5400 kg of aluminium, given that, the density of aluminium is 2700 kgm^{-3} and that of steel is 7800 $kgm^{-3.}$

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States of Matter

- Matter comes in a variety of states usually : **solid, liquid, gas**
- The molecules of solids has definite volume and shape. They are locked in a rigid structure and can only vibrate. Adding thermal energy will cause the vibrations to increase. A solid is incompressible.
- A liquid has definite volume but no definite shape. If you pour a litre of juice into several glasses, the shape of the juice has changed but the total volume hasn't. A liquid is virtually incompressible
- A gas has neither definite shape nor definite volume. If a container of CO_2 is opened, it will diffuse throughout the room. A gas is easily compressed.

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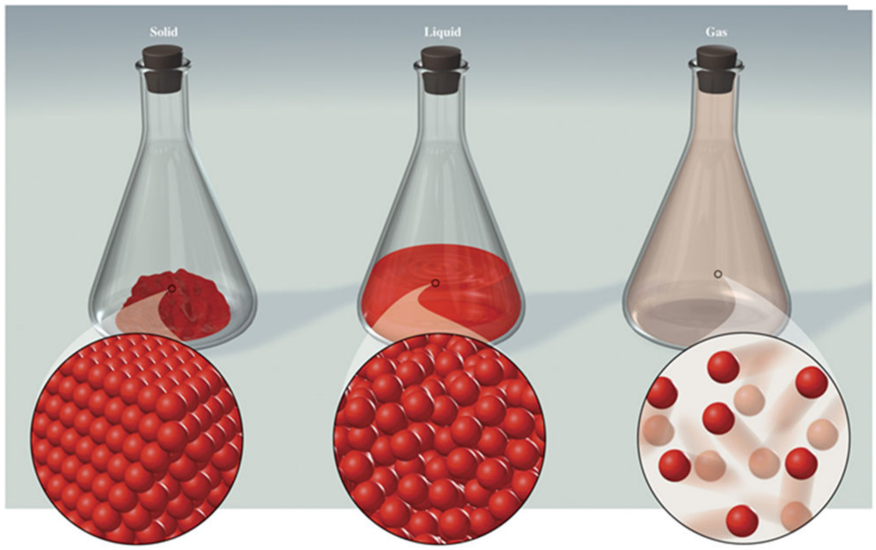
States of Matter



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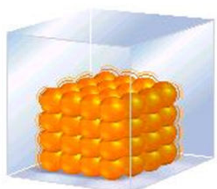
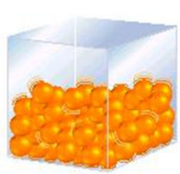
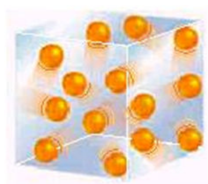
Kinetic model of matter

Kinetic model of matter states that:

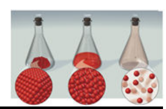
- Matter is made up of a large number of particles such as atoms and molecules.
- Particles are in constant motion.
- Particles repel and attract each other. (intermolecular forces)
- Particles have KE and PE (internal energy).

State of Matter	Structure and Characteristic	Motion of Molecules
Solid   Solid	1.) Atoms or molecules are very closely packed. (a) Crystalline solid - atoms or molecules which are compactly arranged in a regular and orderly lattice structure. Crystals have high density (b) Non-crystalline solid – atoms or molecules which are arranged in a more random way. The density is high but generally lower than many crystalline solid. 2.) Has a fixed shape and volume. They are not easily compressed or stretched by mechanical means. 3.) A typical inter-atomic separation in a crystalline solid is about $3x10^{-10}$ m	1.) Atoms and molecules are locked in and constrained by attractive and repulsive intermolecular forces. They vibrate about their equilibrium positions continually as long as temperature is above absolute zero. 2.) All molecular motion ceases at zero Kelvin. As temperature rises, molecular motion and kinetic energy increases. 3.) When solids are stretched, atoms/molecules move further apart but are opposed by attractive forces. When solids are compressed, atoms/molecules move closer together but are opposed by repulsive forces. 4.) At melting point, kinetic energy is high enough to enable atoms/molecules to escape from their fixed positions and exchange places with their neighbours. Bonds are broken and lattice structure collapsed.

Liquid   Liquid	1.) Atoms or molecules are only slightly further apart than in solids. Density remains high. 2.) Volume is nearly constant but has variable shape. They are not easily compressed by mechanical means. 3.) Evaporation occurs at the surface of a liquid. 4.) Atomic or molecular separation in a liquid is about the same as that of solid. The difference between liquid is about the same as that of solid.	1.) Atoms or molecules vibrate but in addition, have random and restricted translation motion. 2.) Attractive forces between atoms or molecules are weaker. This allows for greater mobility which in turn explains why liquid can take the shape of any container. Attractive forces manifest themselves as surface tension and viscosity of a liquid. 3.) Kinetic energy of atoms or molecules varies. Those with higher speeds are energetic enough to overcome the forces of attraction and escape from the surface. Atoms or molecules left behind have lower kinetic energy. This explains why evaporation causes cooling in liquid. 4.) There is no structure in a liquid because atoms or molecules move randomly and translationally.

Gas  	1.) Atoms or molecules are very far apart. Densities of gases are very low. 2.) Gases do not have fixed volume or shape. They are highly compressible. 3.) Atomic or molecular separations at standard temperature and pressure (s.t.p) are on average about 30 $\times 10^{-10}$ m . It is about 10 times of solids / liquids.	1.) Atoms or molecules move randomly at very high speed. The average kinetic energy is directly proportional to temperature. 2.) Atoms or molecules will occupy any available space in a container. Intermolecular forces between them are negligible except during random collisions with each other. Large repulsive forces are exerted during collisions.

States of Matter



Comparison of Characteristics of the 3 Phases of Matter:

Category	Solid	Liquid	Gas
Spacing of particles	Closely packed ($\sim 10^{-10}$ m) **(Not for water)**	Slightly further apart than in solid ($\sim 10^{-10}$ m) **(Not for water)**	Far apart ($\sim 10^{-9}$ m)
Order of particles	Long range of order (regular pattern)	Short range of order (in clusters)	Disorder
Motion of particles	Vibrational	Translational but restricted	Free & Random
Density	High	Considerably High	Low
Compressibility	Not compressible	Almost incompressible	Easily compressible
Volume & Shape	Fixed & Definite	Fixed volume Takes shape of container	Not fixed

Intermolecular Spacing

- 1 molar mass of any substance is defined as the mass of 1 mole of substance.
- 1 mole of substance is the amount of N_A particles of the substance, where N_A is the Avogadro constant. (6.023×10^{23} particles per mol)

- In other words, 1 mole of any substance will have 6.023×10^{23} particles.
- 1 molar mass will then be the mass of that 6.023×10^{23} particles of a particular substance.

- The intermolecular spacing is estimated to be:

$$d = [M / (p.N_A)]^{1/3}$$

Where;
M = molar mass of substance
p = density of substance
N_A = Avogadro constant

Example 1

- Calculate the intermolecular spacing of water, given molar mass of water 0.018kg mol^{-1} and its density is 1000kgm^{-3}

- Estimate the spacing between adjacent atoms of copper, given molar mass of copper 0.064kg mol^{-1} and its density is 8000kgm^{-3}

Example 2

(a) (i) Define *density*. [1]

(ii) One cubic centimetre of water has mass one gram. Determine the density of water in terms of SI units. [2]

(iii) The mass of a water molecule is 3.0×10^{-26} kg. Estimate the mean distance between two adjacent molecules in water. [3]

(iv) Calculate the density of steam. The mean distance between two adjacent molecules is 3.7×10^{-9} m. [2]

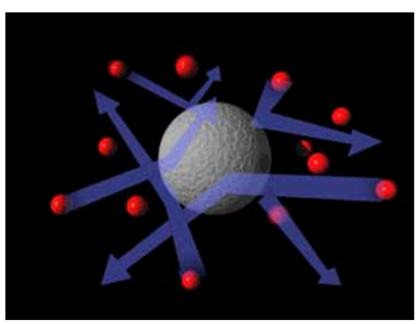
The densities of water and steam are 1.0×10^3 kg m^{-3} and 6.1×10^{-1} kg m^{-3} respectively.

What is the ratio: $\dfrac{\text{average separation of steam molecules}}{\text{average separation of water molecules}}$?

A 12 **B** 40 **C** 250 **D** 1600

Brownian Motion

- The early evidence to support the Kinetic Theory of matter comes from Brownian Motion Experiment.
- Is the random movement of particles of matter.



Brownian Motion

- The phenomenon was discovered in 1827 by the British botanist Robert Brown. He was investigating pollen grains in water, and noticed that they wouldn't sit still under his microscope. At first he thought the pollen was moving because it was alive. But even hundred-year old pollen grains danced around. When he looked at non-living particles, they moved too, so he knew there had to be some other explanation. Further experiments by Brown concluded that the atoms or molecules that make up a liquid or gas are in constant and random motion.
- Brownian Motion is the random motion of suspended particles when they are in a fluid. (liquid/gas)
- The cause of Brownian Motion is due to the continual bombardment of fast moving liquid or gas molecules on the tiny particles.

Robert Brown

Robert Brown (1773–1858)

Born	21 December 1773 Montrose, Scotland
Died	10 June 1858 London
Nationality	Scottish
Fields	Botany
Known for	Brownian motion
Author abbreviation (botany)	R.Br.

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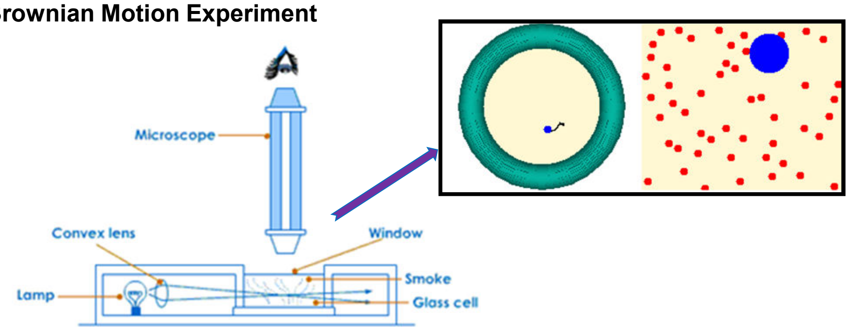
Brownian Motion

Brownian Motion Experiment



- **Observation:**

1.) Bright specks of smoke particles are seen dancing about in an erratic or random manner.

2.) The smoke particles do not often collide with each other but rather appear to be knocked about by some other invisible particles in the smoke cell.

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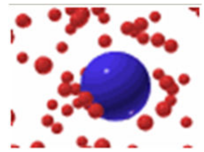
Brownian Motion



Brownian Motion Experiment

- **Conclusion:**

1.) The motion of the smoke particles is evidence that air molecules are also moving, which explains why the tiny smoke particles are being knocked about by "invisible" particles.

2.) This random motion of smoke particles, which demonstrate that air molecules move randomly in all directions with a range of speeds and kinetic energies is known as Brownian motion.

3.) By placing tiny graphite particles onto water in the glass cell and then repeating the experiment, a similar random motion of the graphite particles can be observed.

4.) This shows that water molecules, like air molecules also move about in a random manner with different speeds and directions.

http://www.worsleyschool.net/science/files/brownian/motion2.html

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Example 3

- Pollen grains are suspended in a liquid and are illuminated strongly. When observed under a microscope they are seen to be in continuous random motion. What is the reason for this?

A convection currents in the liquid

B evaporation of the liquid

C molecules of the liquid colliding with the pollen grains

D pollen grains colliding with each other

Example 4

- In an experiment to demonstrate Brownian motion, smoke particles in a container are illuminated by a strong light source and observed through a microscope. The particles are seen as small specks of light that are in motion. What causes the Brownian motion?

A collisions between the smoke particles and air molecules

B collisions between the smoke particles and the walls of the container

C convection currents within the air as it is warmed by the light source

D kinetic energy gained by the smoke particles on absorption of light

Example 5

- Particles of dust, suspended in water, are viewed through a microscope. The particles can be seen to move irregularly. This movement is due to

A convection currents in the water.

B evaporation of the water near the dust particles.

C gravitational forces acting on the particles of dust.

D water molecules hitting the dust particles in a random way.

SOLIDS

CRYSTALLINE	AMORPHOUS (NON-CRYSTALLINE)	POLYMERS
- Has a regular geometric shape. - Molecules are arranged in a definite and regular 3-dimensional pattern. - This orderly 3-D pattern repeats itself in all directions in the solid over large distance. (long range order) - Basic repeating unit is unit cell. - Has high & definite melting point. - Gives a clean surface after cleavage with knife rather than an irregular breakage. - E.g: All metals (copper, nickel, quartz, aluminium), diamond, rock salt, & sugar etc.	- Molecules are arranged in a regular manner up to a small region only. (short range order) - No regular shape or well defined planes / patterns. - No definite melting point as amorphous solids melt gradually over a temperature range. - Does not give a clean surface after cleavage with knife. They undergo a irregular breakage. - They have tendency to flow like liquid though very slowly. This tendency is illustrated by the fact that glass panes in the window of old historical buildings are found to be thicker at the bottom than at the top. - E.g: Glass, ceramic, wax, toffee etc.	- Materials consisting of long chain of carbon bonded to hydrogen and other atoms. - Made from smaller basic identical units called monomers. - The simplest polymer is polythene. This is made by the process called **polymerization**, whereby a monomer double bond is opened out to make a polymer, with side bonds. - Some are crystalline polymers (long chain of molecules arranged parallel to each other), some are amorphous polymers (long chain of molecules cross-linking each other). - E.g: raw & vulcanized rubber, plastics (nylon, polyethylene, polyprophylene, polymethyl-methacrylate, polystyrene, ABS, PVC) etc.

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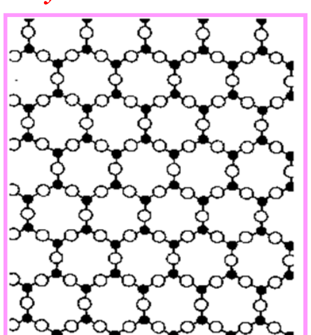
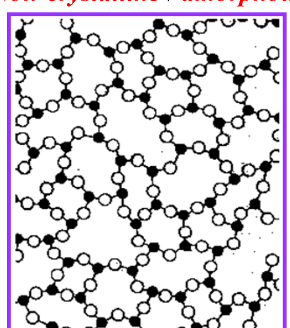
Crystalline and non-crystalline solids

Crystalline



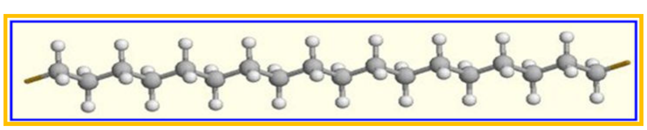
molecular arrangement in a crystal

Non-crystalline / amorphous



molecular arrangement in a glass

- *Polymer*



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Pressure in SOLIDS

•Pressure is defined as ***normal force per unit area***

Pressure = Force/Area.

•The S.I. unit for pressure is the Pascal, which is Newton per square meter:

$1\ Pa = 1\ N/m^2$.

•Two blocks may have the same weight but have different areas hence exert different pressures. The larger the force and the smaller the area, the greater is the pressure exerted.

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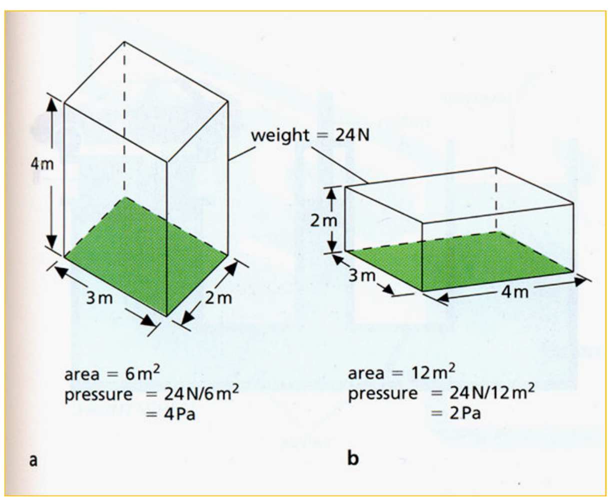
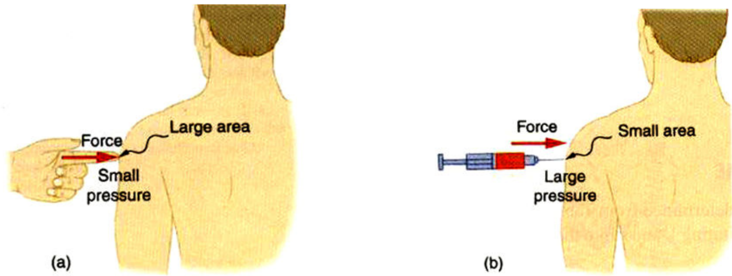
Pressure in SOLIDS

- The greater the area a force is applied, the smaller the pressure.



Pressure in SOLIDS



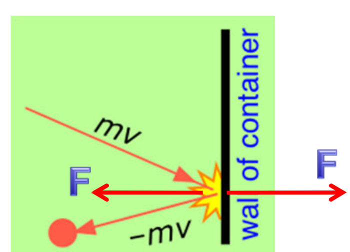
Typical pressure values

- Foot pressure - 20 kPa
- Tyre pressure - 200 kPa
- Thumb pressure on thumb tack - 1000 kPa
- High heels - 2000 kPa

Pressure in GAS

- Kinetic model of gas can use to explain the pressure exerted by the air molecules inside a container.
- Based on kinetic model theory of gases, air molecules inside a container are in a state of random motion.
- When a molecule hits the wall of a container, this is what happens:

a.) When a molecule collides with the wall of a container, the molecule will experience a change in momentum due to the force that the wall exerts on the molecule.
b.) Based on Newton 2nd Law, the force that the wall exerts on the molecule will be equal to the rate of change of momentum of the molecule.
c.) At the same time, the molecule will also exert a force on the wall which is equal and opposite to the force exerted by the wall on the molecule. (Newton 3rd Law.)
d.) Considering numerous collisions take place between the molecules and the wall, the change in momentum of air molecules is found to be the cause of the force acting on the container walls.



The force acting per unit area of the container wall is the pressure that the gas exerted on the wall.

Pressure in LIQUIDS

Based on experiment, the following are the properties of pressure in liquids.

a.) The pressure in a liquid increases with the depth below its surface.

b.) The pressure in a liquid is equal in all directions at the same depth.

c.) The pressure is proportional to the density of the liquid.

d.) The liquid pressure depends only on the height of the particular liquid and **not on the shape or width of the tube !**

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Pressure in LIQUIDS

- Air pressure is lower up the mountains than at sea level.
- Water pressure is much lower at the surface than down deep.
- Pressure depends on fluid density and depth and is given by: $p = h\rho g$

How to proof:

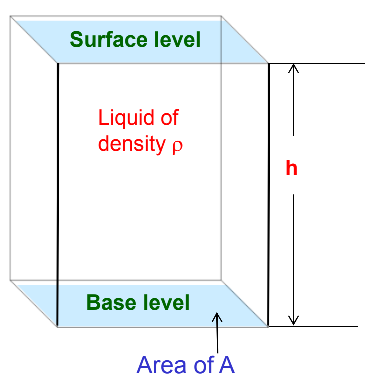
Consider a column of liquid of height h and base area A. Volume of liquid is given by V = Ah

Weight of liquid column, w =mg, = (ρV)g, = ρ(Ah)g

Thus, pressure at the base of liquid column is:

$P = F/A = W/A = \rho(Ah)g/A$

$$\boxed{P = h_{water}\rho_{water}\, g}$$



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Example 6

1. Why does an ideal gas exert pressure on its container?

A The molecules of the gas collide continually with each other.

B The molecules of the gas collide continually with the walls of the container.

C The molecules of the gas collide inelastically with the walls of the container.

D The weight of the molecules exerts a force on the walls of the container.

2. The formula for hydrostatic pressure is p = ρ gh.

Which equation, or principle of physics, is used in the derivation of this formula?

A density = mass ÷ volume

B potential energy = mgh

C atmospheric pressure decreases with height

D density increases with depth

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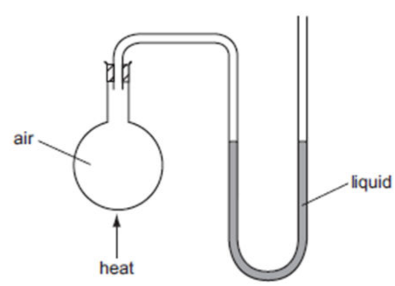
Example 7

The diagram shows a flask connected to a U-tube containing liquid. The flask contains air at atmospheric pressure.



The flask is now gently heated and the liquid level in the right-hand side of the U-tube rises through a distance h. The density of the liquid is ρ.

What is the increase in pressure of the heated air in the flask?

A $h\rho$ **B** $\frac{1}{2}h\rho g$ **C** $h\rho g$ **D** $2h\rho g$

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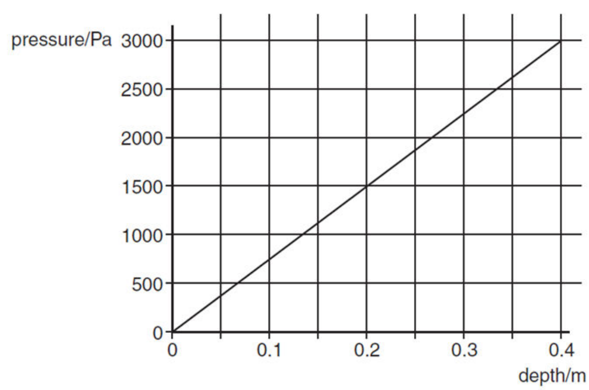
Example 8

- At a depth of 20 cm in a liquid of density 1800 kgm^{-3}, the pressure due to the liquid is *p*. Another liquid has a density of 1200 kgm^{-3}. What is the pressure due to this liquid at a depth of 60 cm?

A $\frac{p}{2}$ **B** $\frac{3p}{2}$ **C** $2p$ **D** $3p$

Example 9

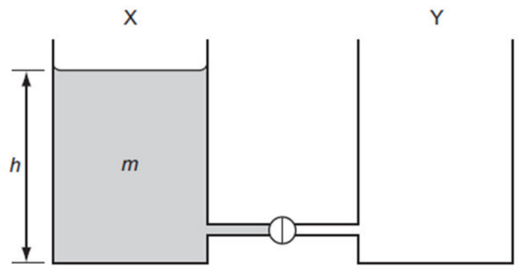
- The graph shows how the pressure exerted by a liquid varies with depth below the surface



What is the density of the liquid?

Example 10

The diagram shows two identical vessels X and Y connected by a short pipe with a tap.



Initially, X is filled with water of mass m to a depth h, and Y is empty.

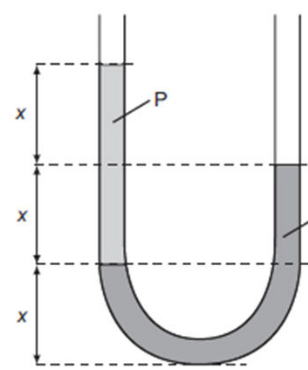
When the tap is opened, water flows from X to Y until the depths of water in both vessels are equal.

How much potential energy is lost by the water during this process? (g = acceleration of free fall)

A 0 **B** $\frac{mgh}{4}$ **C** $\frac{mgh}{2}$ **D** mgh

Example 11

The diagram shows two liquids, labelled P and Q, which do **not** mix. The liquids are in equilibrium in an open U-tube.



What is the ratio $\frac{\text{density of P}}{\text{density of Q}}$?

A $\frac{1}{2}$ **B** $\frac{2}{3}$ **C** $\frac{3}{2}$ **D** 2

Example 12

Liquids X and Y are stored in large open tanks. Liquids X and Y have densities of $800\,kg\,m^{-3}$ and $1200\,kg\,m^{-3}$ respectively.

At what depths are the pressures equal?

	depth in liquid X	depth in liquid Y
A	8 m	12 m
B	10 m	10 m
C	15 m	10 m
D	18 m	8 m

Upthrust – (Due to Pressure Difference)

- When a rock is immersed in water, it appears to weigh less than on land. It is easier to lift a rock under water than out of water. This is due to the existence of an **upthrust or buoyancy force.**

- Assuming a cylinder is placed into the pool of water;
  - The pressure at the bottom of the cylinder is greater than the pressure at the top of the cylinder
  - This means that there is a greater force acting upwards on the base of the cylinder than there is acting downwards

- The difference in these forces is the ***upthrust or buoyancy force***

$$F_{upthrust} = F_{up} - F_{down} \;;\; F = PA$$
$$= (P_{up}A) - (P_{down}A)$$
$$= (h_{up}\rho_{water}gA) - (h_{down}\rho_{water}gA) = \rho gA(h_{up} - h_{down})$$
$$= \rho_{water}gA(H) \;;\; H = \text{height of object}$$
$$F_{upthrust} = \rho_{water}gA(H) = \rho_{water}gV = m_{water}g \text{ (weight of water displaced)}$$

- The **upthrust** value is equals to the **weight of the liquid displaced by the immersed object**. This is also known as **Archimedes Principle.**

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Change of Phase: Melting…

- The process of changing a solid to liquid is called **melting**.
- The change in the state of matter takes place at a certain temperature.
- When heat is supplied to a solid, its temperature will rise until it reaches melting point.
- The temperature at which a solid changes and becomes liquid is it **melting point**.
- As an example, the melting point for ice is 0 °C. This means that at 0 °C, the ice is starting to melt and becomes water.

- At this temperature, solid will melt to become liquid at constant temperature.
- Heat is supplied is used to break the bonds that hold the particles in the lattice (fixed position). Hence, its shape changes.
- No increment in the average random K.E of all particles because the temperature is constant.
- P.E of the molecules increases. (Molecules have greater freedom of movement, hence can flow)

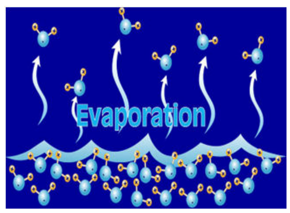
Change of Phase: Boiling…

- The process of changing a liquid to vapour/steam is called **boiling.**
- The change in the state of matter takes place at a certain temperature.
- When heat is supplied to a liquid, its temperature will rise until it reaches boiling point.
- The temperature at which a liquid changes and becomes vapour is it boiling point.
- As an example, the boiling point for water is 100 °C. This means that at 100 °C, the water is starting to boil and becomes steam.

- At this temperature, liquid will boil to become vapor/steam at constant temperature.
- Heat is supplied is used to separate the molecules. The molecules are now further apart (large increase in volume, hence density reduces) with negligible intermolecular forces of attraction between them.
- No increment in the average random K.E of all particles because the temperature is constant
- P.E of the molecules increases. (Molecules can move freely without any intermolecular forces between them)

Change of Phase: Evaporation…

- Like boiling, it is a change of state from liquid to vapour.
- The difference is that evaporation an occur at any temperature and only at the surface of the liquid.
- At the liquid surface, the more energetic molecules are able to overcome the intermolecular forces of other molecules and escape into the atmosphere. This leaves behind a liquid with less energetic molecules.
- A liquid with slower moving molecules is cooler as the temperature is directly proportional to the average kinetic energy of the molecules.
- This explains why the temperature of a liquid falls as evaporation occurs.



Change of Phase

Difference between melting, boiling & evaporation:

MELTING	BOILING	EVAPORATION
1. Occurs at a fixed temperature	1. Occurs at a fixed temperature	1. Occurs at a any temperature
2. Absorb heat from outside	2. Absorb heat from outside	2. Causes cooling of the liquid
3. Takes place throughout the solid	3. Takes place throughout the liquid	3. Takes place only on the surface of the liquid
4. Temperature remains constant during melting	4. Temperature remains constant during boiling	4. Temperature may change

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Example 13

- For a given liquid at atmospheric pressure, which process can occur at any temperature?

  A.) boiling
  B.) evaporation
  C.) melting
  D.) solidification

- Which statement applies to the boiling but not to the evaporation of a liquid?

  A.) All the bonds between molecules in the liquid are broken.
  B.) At normal atmospheric pressure, the process occurs at one temperature only.
  C.) Energy must be provided for the process to happen.
  D.) The separation of the molecules increases greatly.

Example 14

- Below are four short paragraphs describing the molecules in a beaker of water at 50°. Which paragraph correctly describes the molecules?

A.) The molecules all travel at the same speed. This speed is not large enough for any of the molecules to leave the surface of the water. There are attractive forces between the molecules.

B.) The molecules have a range of speeds. Some molecules travel sufficiently fast to leave the surface of the water. There are no forces between the molecules.

C.) The molecules have a range of speeds. Some molecules travel sufficiently fast to leave the surface of the water. There are attractive forces between the molecules.

D.) The molecules have a range of speeds. The fastest molecules are unable to leave the surface of the water. There are attractive forces between the molecules.