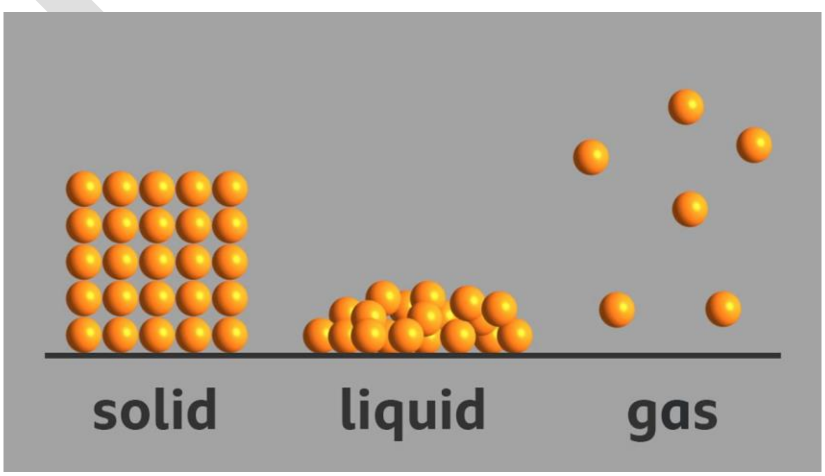
Edexcel IGCSE

Physics

CODE: (4PH13)

Unit 5

Solid, liquid and gases



5.1 Density and pressure

Density

Solids, liquids and gases have different properties and characteristics. One such characteristic is density. Solids are often very dense - that is, they have a high mass for a certain volume. Liquids are often less dense than solids, and gases have very low densities.

The density (p) of a material can be calculated if you know the mass (m) of a certain volume (V) of the material, using this equation:

$$\text{density, } \rho = \frac{\text{mass, } m}{\text{volume, } V}$$

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

Pressure and sold

Drawing pins and sharp knives are easier to use due to their small points, which concentrate force into a smaller area. Pressure is defined as force per unit area, measured in newtons (N) and square meters (m). 1 Pa is equivalent to 1 N/m^2.

Pressure (p), force (F) and area (A) are linked by the following equation:

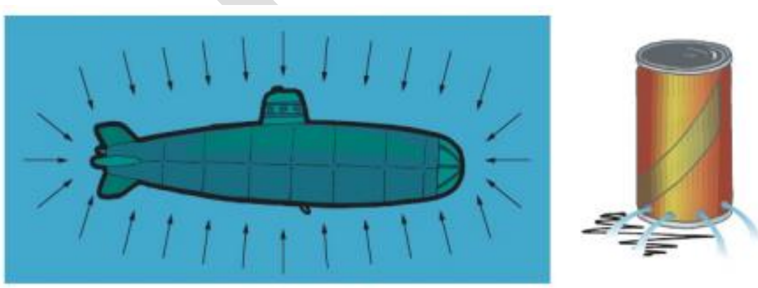
$$\text{pressure, } p \text{ (pascals)} = \frac{\text{force, } F \text{ (newtons)}}{\text{area, } A \text{ (square metres)}}$$

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

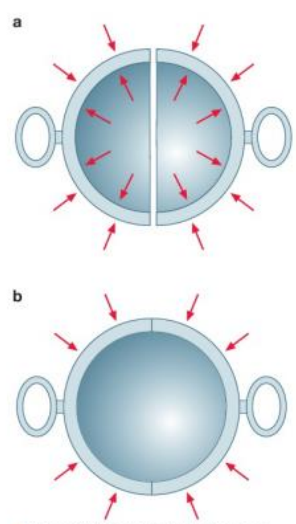
Pressure in liquid and gases

The submersible, as depicted in Figure 18.1, has a robust hull to withstand seawater pressure, demonstrating that pressure in liquids acts equally in all directions, as demonstrated by a punched can.

Gases also exert pressure on things around them. The pressure exerted by the atmosphere on your body is about 100 000 Pa (although the pressure varies slightly from day to day). However, the pressure inside our bodies is similar, so we do not notice the pressure of the air.



▲ Figure 18.6 Pressure in liquids acts equally in all directions. A can of water with holes can be used to demonstrate this.



▲ Figure 18.8 **a** When the hemispheres are full of air, the forces are the same inside and outside. **b** When the air is taken out, there is only a force on the outside of the hemispheres.

Pressure and depth

The volume of this water (V) is found by multiplying the area of its base (A) by the height (h) of the column. We can work out the mass (m) of the water by multiplying the volume (A x h) by the density (p).

mass of water, m = (Axh) x *p*

The force (F) on the bottom of the water column is equal to the weight of this volume of water, which is the mass, m (A x h x p), multiplied by the gravitational field strength (g)

F= (A x h x *p*) x g

As we are concerned with the pressure on the base of the column, we divide the force by the area:

$$F = \frac{A \times h \times \rho \times g}{A}$$

The area of the column therefore does not matter, and we can calculate the pressure difference between two points in a liquid using the equation:

pressure difference, p (Pa) = height, h (m) x density, p (kg/m^3) x gravitational field strength, g (N/kg)

p=h x *p* x g

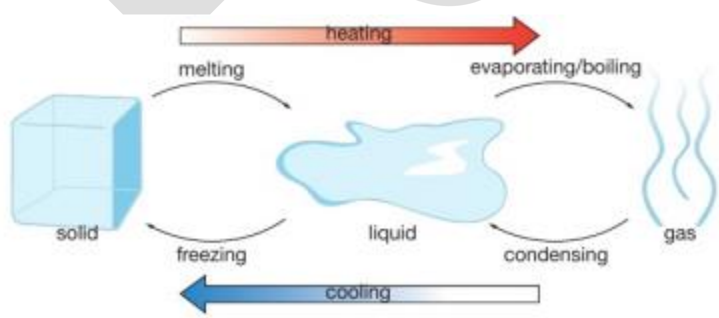
Be careful not to muddle the symbol for pressure, *p*, with the symbol for density, p.

5.2 Solid liquid and gases

The states of matter

Substance properties depend on chemical composition, and they exist in solid, liquid, and gas states. Common everyday substances include water, ice, water, and steam, while others are found in only one state.

Substances can change state by the processes of melting, evaporation, boiling, freezing and condensing.



▲ Figure 19.2 Changes of state

Solids

Solids have a rigid shape and dense particles, with high densities due to tightly packed particles. Strong forces hold them together, giving solid objects a definite shape and strength. However, particles can move and vibrate, with increased kinetic energy observed as the temperature of the substance increases.

Liquids

Liquids, unlike gases, have no definite shape but stick together, occupying the lowest part of containers. They have greater densities due to their close-packed particles.

Gases

Gases have low densities and no definite shape, with small forces holding them together. They can be compressed or randomly moved, with collisions causing pressure. Solids and liquids are difficult to compress due to their close-packed particles.

Summary of the properties of solid, liquid and gases

Property	Solids	Liquids	Gases
definite shape	yes	no	no
can be easily compressed	no	no	yes
relative density	high	high	low
can flow (fluid)	no	yes	yes
expands to fill all available space	no	no	yes

The particles (molecules) in a solid (Figure 19.3a):

■Are tightly packed
■Are held in a fixed pattern or crystal structure by strong forces between them
■Vibrate around their fixed positions in the structure.

The particles (molecules) in a liquid (Figure 19.3b):

■Are tightly packed (still very close together, like in solids)
■Are not held in fixed positions but are still bound together by strong forces between them
■Move at random with no fixed positions.

The particles (molecules) in a gas (Figure 19.3c):

■Are very spread out
■Have no fixed positions and the forces between them are very weak
■Move with a rapid, random motion.

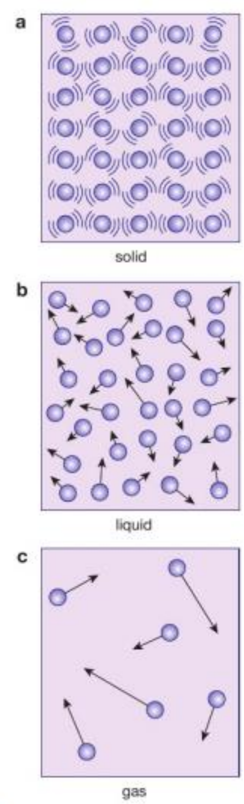


Figure 19.3 The different arrangements of the particles in **a** solids; **b** liquids and **c** gases (not drawn to scale)

Measuring heat energy

We define the specific heat capacity (s.h.c.), c, of a substance as the amount of energy required to increase the temperature of 1 kilogram of that substance by 1 °C. The unit of s.h.c. is J/kg °C.

We use the following equation to work out how much energy is needed to change the temperature of an object by a given amount:

change in thermal energy, ΔQ (joules) = mass, m (kilograms) × specific heat capacity, c × change in temperature, $\Delta\theta$ (°C)

$$\Delta Q = m \times c \times \Delta\theta$$

The energy involved in change of state

When you supply energy to a substance you would expect its temperature to rise, and this is generally true.

The gas law

The text focuses on the properties of gases, specifically the movement of particles. Gases are composed of moving molecules, which are spread out and random. When they collide with a container, they exert pressure, resulting in pressure.

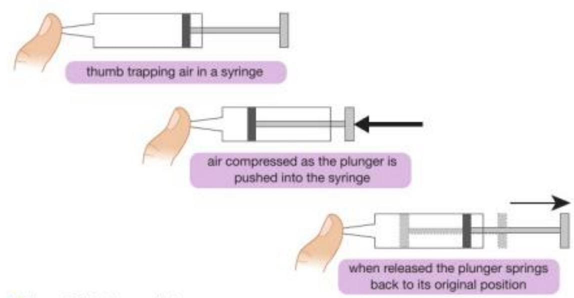
Boyles' law

Robert Boyle discovered that air is squashy and can be squeezed into a cylinder, returning to its original volume upon release, a concept like bicycle pump usage.

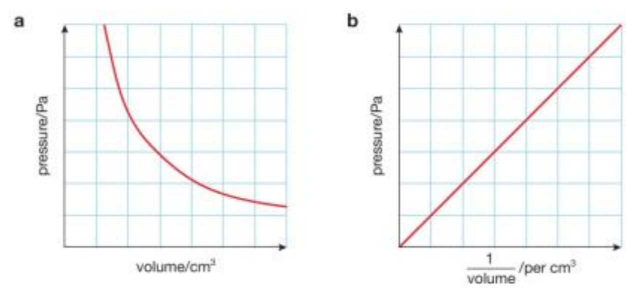
Boyle's experiment examined the relationship between gas volume and pressure, using the concept of pressure in N/m^2. He ensured the trapped gas remained at the same temperature by increasing pressure and recording the new volume.

Boyle noticed that when he doubled the pressure, the volume of the gas halved. If we plot pressure (p), against $\frac{1}{\text{volume}}$ $\left(\frac{1}{V}\right)$, as in Figure 19.9b, we can see from the straight line passing through the origin that p is proportional to $\frac{1}{V}$. This discovery, called Boyle's law, is expressed in the equation:

$$p_1V_1 = p_2V_2$$



▲ Figure 19.7 Air is squashy!



▲ Figure 19.9 **a** Graph to show how the pressure of a gas at constant temperature varies with the volume; **b** Graph of pressure against $\frac{1}{\text{volume}}$

Absolute zero

Boyle took care to conduct his experiment at constant temperature. He was aware that temperature also influenced the pressure of a gas. Figure 19.10 shows an experiment to investigate how the pressure of a gas depends on its temperature.

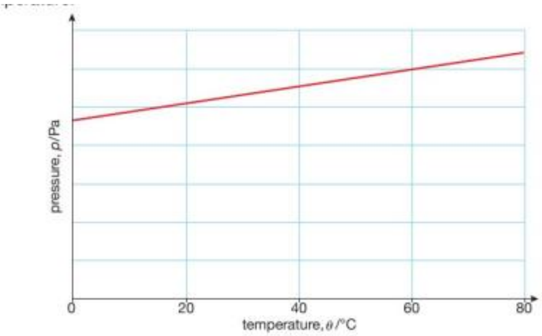
The experiment shows that gas pressure increases with temperature, while cooling decreases. The graph in Figure 19.11 and Figure 19.12 illustrates the effects of cooling on gas pressure.

The graph of pressure against temperature, using the absolute or Kelvin temperature scale, demonstrates that the pressure of a gas is directly proportional to its Kelvin temperature, as shown in Figure 19.13.

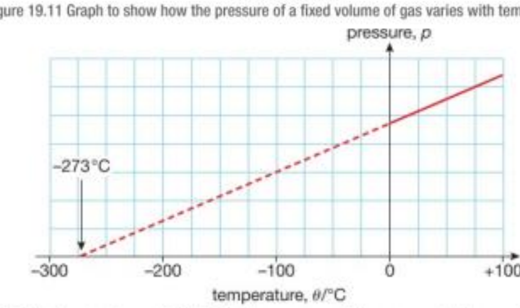
For a fixed mass of gas at a constant volume:

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

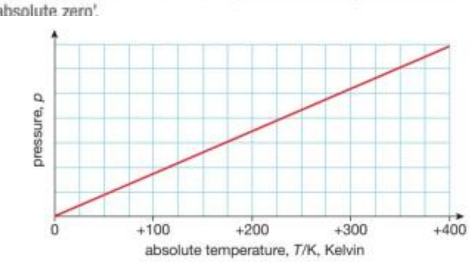
NB T must be measured in Kelvin.



▲ Figure 19.11 Graph to show how the pressure of a fixed volume of gas varies with temperature



▲ Figure 19.12 At a temperature of –273 °C, the pressure of the gas would be zero. This temperature is known as 'absolute zero'.



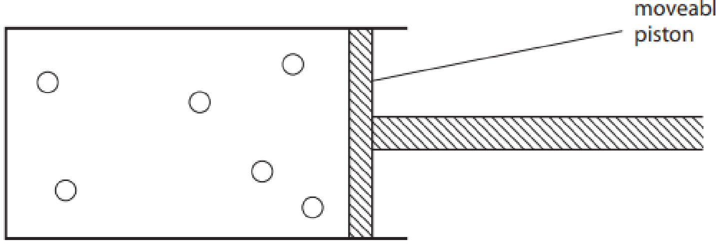
▲ Figure 19.13 Graph of pressure against absolute temperature for a fixed amount of gas at constant volume

Revision questions

1) A diver works in the sea on a day when the atmospheric pressure is 101 kPa and the density of the seawater is 1028 kg/m^3

(a) The diver uses compressed air to breathe under water. 1700 litres of air from the atmosphere is compressed into a 12-litre gas cylinder.
The compressed air quickly cools to its original temperature.
Calculate the pressure of the air in the cylinder.
(b) (i) State the equation linking pressure difference, depth, density and g.
(ii) Calculate the increase in pressure when the diver descends from the surface to a depth of 11m
(iii) Calculate the total pressure on the diver at a depth of 11m. Assume that the atmospheric pressure remains at 101kPa.
(c) As the diver breathes out, bubbles of gas are released and rise to the surface.
The bubbles increase in volume as they rise.
Explain this increase in volume

2) The diagram shows some gas particles in a container. The piston can be moved in or out to change the volume of the gas.



(a) Add arrows to the diagram to show the random motion of the gas particles.
(b) Explain how the motion of the gas particles produces a pressure inside the container.
(c) State what would happen to the pressure if you pushed the piston into the container without changing the temperature.
(d) When the gas in the container is heated, the piston moves outwards. Place ticks against the three correct statements.

Statement	Tick (✓)
the gas particles get bigger	
the mass of the gas particles stays the same	
the gas particles move faster	
the average distance between the gas particles increases	
the temperature of the gas decreases	

(3) All gases above absolute zero exert a pressure on the walls of their container.
(a) (i) State the value of absolute zero in ◦C.
(ii) Explain, in terms of its molecules, how a gas exerts a pressure on the walls of its container
(b) A pressure switch is used in a washing machine to control the flow of water. The water pushes on a flexible container and compresses some trapped air. When the pressure of this trapped air reaches 104 kPa,

the pressure switch turns the water off. The pressure of the trapped air is given by this relationship

$$\text{pressure of the trapped air} = \text{atmospheric pressure} + \text{pressure difference caused by water}$$

(i) State the equation linking pressure difference, height, density and g.
(ii) Calculate the height of water in the machine when the pressure of the trapped air reaches 104 kPa and the switch operates.

[atmospheric pressure = 100 kPa, density of water = 1000 kg/m^3]

(4) A student wants to calculate the pressure he exerts on the floor when he stands on one foot. He records these measurements.

My weight	650 ....
Area of the floor in contact with my foot	270 cm^2

(a) (i) Complete the table by adding the unit for weight.
(ii) Which piece of equipment should the student use to measure his weight?
(b) Suggest how the student measured the area of the floor in contact with his foot.
c) (i) State the equation linking pressure, force and area.
(ii) Calculate the pressure that the student's foot exerts on the floor.

(5) A student places a pile of coins on a table, as shown in photograph A.

Photograph **A**

There are 8 coins in the pile.
The weight of each coin is 0.036 N.
The area of each coin is 0.0013 m^2.
(a) (i) State the equation linking pressure, force and area.

(ii) Calculate the pressure on the table caused by the pile of coins.
(b) The student then spreads the 8 coins out on the table as shown in photograph B.

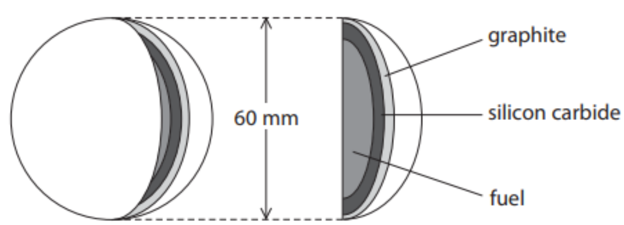
Photograph **B**

(i) Describe how this affects the total force from the coins on the table
(ii) Explain how this affects the pressure on the table caused by the coins.

(6) The photograph shows a car tyre that needs to be inflated.

The tyre exerts a pressure on the road of 270 kPa.
The area of the tyre touching the road is 0.016 m^2 .
(a) (i) State the equation linking pressure, force and area
(ii) Calculate the force exerted on the road by the tyre. Give the unit.
(b) Use ideas about molecules to explain why the air inside the tyre exerts pressure
(c) Air is pumped into the tyre to inflate it.
This increases the temperature and the pressure of the air in the tyre.
Use ideas about molecules to explain why the air pressure in the tyre increases

(7) (a) The diagram shows the fuel used in some nuclear reactors.
The fuel is contained inside spheres.
The silicon carbide layer of each sphere is designed to contain the fission products for at least one million years

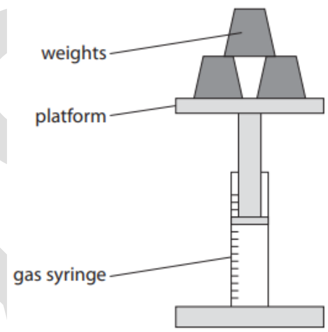


section through a fuel sphere

(i) Give the name of a fuel that could be used.

(ii) Explain what is meant by the term fission products.
(iii) Explain why it is important to contain these fission products for such a long time
(iv) The graphite layer in every fuel sphere acts as a moderator. What is the function of the moderator in a nuclear reactor?
(v) The nuclear reactor also contains boron control rods. Explain why it is dangerous to remove most of the control rods from the reactor
(b) The reactor is cooled with helium gas. The gas enters the reactor at 500 °C.
(i) What is this temperature in kelvin?
(ii) Helium gas enters the reactor at a pressure of 8.40 MPa and leaves the reactor at a temperature of 1170 K. Calculate the pressure of the helium gas as it leaves the reactor. [assume the volume of the gas does not change]

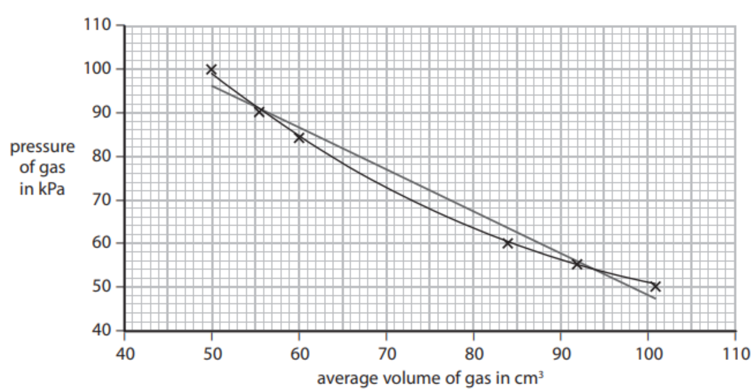
(8) A student uses this apparatus to investigate the pressure and volume inside a sealed gas syringe.



She takes readings of the volume as she increases the pressure (loading) and as she decreases the pressure (unloading). These are her results.

Pressure in kPa	Volume of gas in cm^3		
	loading	unloading	average (mean)
100	50	50	50
90	56	55	55.5
84	60	60	60
55	90		92
60	85	83	84
50	101	101	101

(a) (i) Complete the table by filling in the missing value.
(ii) Suggest why the student takes readings for increasing the pressure and for decreasing the pressure
(b) The student plots this graph.



(i) Suggest a reason why the axes do not start from the origin (0,0)
(ii) The student has drawn both a straight line of best fit and a curve of best fit. Discuss which line is correct for this investigation.
(iii) Suggest a way that the student could make this experiment valid (a fair test)
(iv) Suggest two ways in which the student could improve the quality of her data