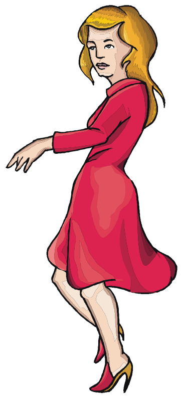
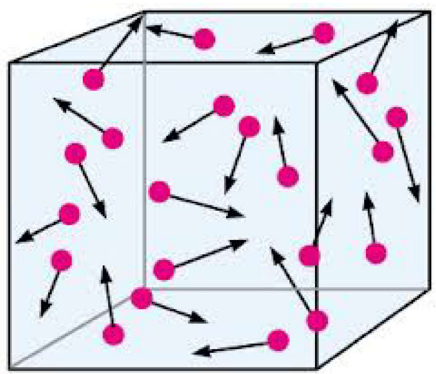
National 5 Physics

"PROPERTIES OF MATTER"



'Pressure, Force and Area'

'Gas Laws and The Kinetic Model'



Name: ____________________

This section of the "Properties of Matter" unit initially defines 'pressure' as 'the force exerted per m^2 of surface area (at right-angles, 90°, to the surface)'. It then explains how to solve problems involving 'pressure', 'force' and 'area' using the equation F = p A.

The 'kinetic model' is introduced to describe how a gas exerts pressure on a surface.

This is followed by an explanation of the 'kelvin temperature scale' in terms of the 'absolute zero' of temperature. Conversion between temperatures in 'kelvin' and 'degrees Celsius' is also explained.

The laws linking 'gas pressure to gas volume', 'gas pressure to kelvin temperature' and 'gas volume to kelvin temperature' are then explained qualitatively in terms of the 'kinetic model'. Descriptions of experiments to verify the 'pressure-volume (Boyle's) law', 'pressure-temperature (Gay-Lussac's) law' and 'volume-temperature (Charles') law' are included.

The section ends by showing how to use appropriate relationships to solve problems involving the 'volume', 'pressure' and 'kelvin temperature' of a fixed mass of gas - based on the 'general gas equation:

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

By the end of this section, you should be able to:

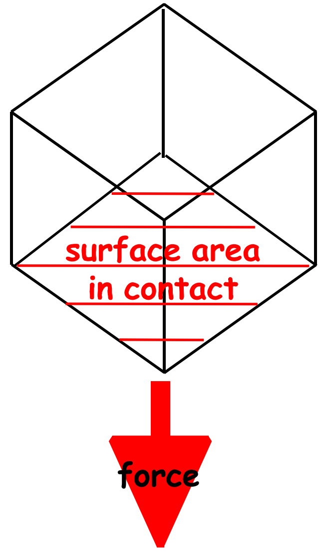
- ☐ define 'pressure' as 'the force (at right-angles to a surface) per unit area exerted on the surface
- ☐ state that the 'pascal' ('Pa') is a unit of pressure
- ☐ solve problems involving 'pressure', 'force' and "area' using the equation F = p A
- ☐ explain, using the 'kinetic model', how the pressure exerted by a gas on a surface arises
- ☐ understand the meaning of 'the absolute zero of temperature' in terms of 'particle movement'
- ☐ convert temperatures from 'degrees Celsius' to 'kelvin' (and vice versa)
- ☐ understand qualitatively the laws linking 'gas pressure to gas volume', 'gas pressure to kelvin temperature' and 'gas volume to kelvin temperature' in terms of the 'kinetic model'
- ☐ describe experiments to verify these gas laws
- ☐ solve problems involving the 'volume', 'pressure' and 'kelvin temperature' of a fixed mass of gas - based on the 'general gas equation'

Pressure on Solid Surfaces

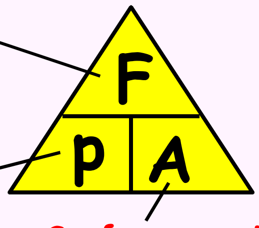
An object sitting on a flat, horizontal, solid surface exerts a **downward force** on the surface due to the object's **weight**. This **downward force** is spread out over the entire **surface area** in contact.

Pressure is defined as **the force exerted per m^2 of surface area (at right-angles, 90°, to the surface)**.

Unit $N\,m^{-2}$ or Pa (pascals). $1\,N\,m^{-2} = 1$ Pa.



$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

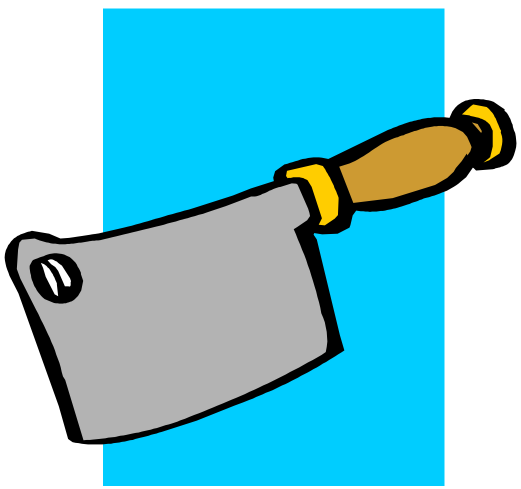


F =

p =

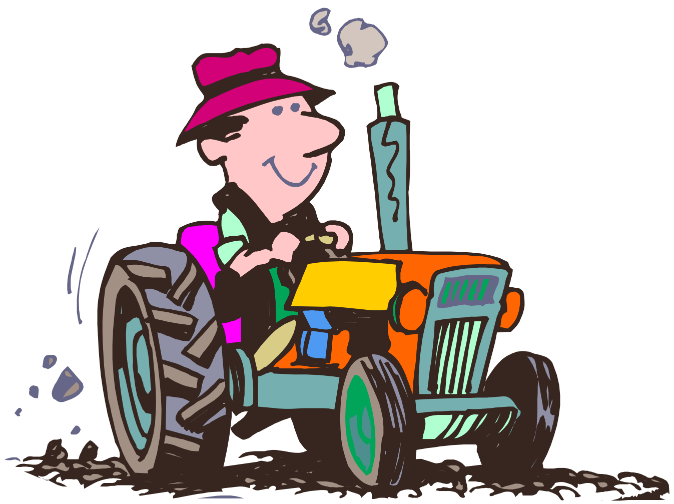
A =

Small surface area: High Pressure



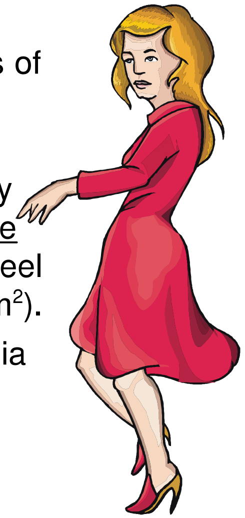
A meat cleaver or knife has a small, sharp edge (small surface area) so that a high pressure is applied to meat being cut - this makes the cutting easy.

Large surface area: Low Pressure



Tractor tyres have a large surface area so that the weight (downward force) of the tractor acting on the soil exerts a low pressure on the soil - so the tractor does not sink.

Example



Virginia the vandal has a mass of 65 kg.

Her favourite hobby is vandalising linoleum floors by applying all her weight on one heel of her stiletto shoe. The heel has an area of 1 cm^2 (0.0001 m^2).

Calculate the **pressure** Virginia exerts on a floor when she does this.

Force = weight = mg

= 65 × 9.8

= 637 N

Area = 1 cm^2 = 0.0001 m^2

$$P = \frac{F}{A} = \frac{637}{0.0001} = \underline{\underline{6\,370\,000\text{ Pa}}}$$

Calculate the pressure acting on a floor when a force of 1 050 N acts on an area of 1.5 m^2.	Calculate the pressure acting on a wall when a force of 1 000 N acts on an area of 2.5 m^2.	Calculate the force acting on a surface of area 14 m^2 when the pressure exerted is 10 Pa.	Calculate the force acting on a surface of area 12 m^2 when the pressure exerted is 2.5 Pa.
Calculate the pressure acting on a door when a force of 750 N acts on an area of 0.5 m^2.	Calculate the pressure acting on a window when a force of 350 N acts on an area of 0.25 m^2.	Calculate the area of surface a 24 N force acts on if the pressure exerted by the force is 48 Pa.	Calculate the area of surface a 200 N force acts on if the pressure exerted by the force is 125 Pa.

Hannah stands on only one heel of her stiletto cowboy boots. Hannah's mass is 55 kg and the area of the stiletto heel is 0.0001 m^2.

(a) Calculate Hannah's weight.

(b) Calculate the pressure Hannah exerts on the floor.

Shaun stands on one foot. His mass is 70 kg and the area of his shoe sole in contact with the ground is 0.045 m^2.

(a) Calculate Shaun's weight.

(b) Calculate the pressure Shaun exerts on the floor.

Gregor's football boot studs have a total contact area of 0.0024 m^2 with a football pitch. Gregor has a mass of 68 kg.

(a) Calculate Gregor's weight.

(b) Calculate the pressure Gregor exerts on the football pitch.

Stephanie stands on only one heel of her stiletto winkle picker shoes. If Stephanie's mass is 60 kg and the area of the stiletto heel is 0.00015 m^2:

(a) Calculate Stephanie's weight.

(b) Calculate the pressure Stephanie exerts on the floor.

Paul stands on both feet. His mass is 65 kg and the total area of his shoe soles in contact with the ground is 0.09 m^2.

(a) Calculate Paul's weight.

(b) Calculate the pressure Paul exerts on the floor.

The wheels of Tasman's roller hockey boots have a total contact area of 0.005 m^2 with a pitch. If Tasman has a mass of 52 kg:

(a) Calculate Tasman's weight.

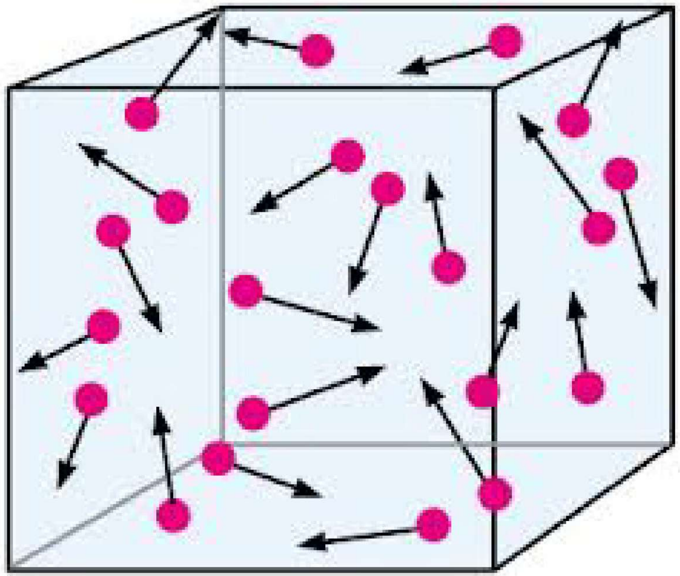
(b) Calculate the pressure Tasman exerts on the pitch.

NOTES

THE KINETIC MODEL OF A GAS

Gases are made up of tiny particles. The particles have kinetic energy - they move around, colliding with one another and with the inside walls of their container.

When the gas particles hit the inside walls of their container, they exert a pressure on the inside walls.



If temperature increases, the kinetic energy of the gas particles increases - they hit the inside walls of their container more times every second and with greater force. As a result, the pressure the gas particles exert on the inside walls increases.

If temperature decreases, the kinetic energy of the gas particles decreases - they hit the inside walls of their container less times every second and with less force. As a result, the pressure the gas particles exert on the inside walls decreases.

THE KELVIN TEMPERATURE SCALE

If the temperature of a gas is decreased to -273 °C, the gas particles stop moving. They no longer collide with the inside walls of their container, so exert zero pressure on the inside walls.

Using this idea, Scottish physicist Lord Kelvin devised a new temperature scale - the kelvin scale.

The zero on the kelvin scale corresponds to -273 °C, the temperature at which gas particles stop moving.

A temperature change of 1 K
= a temperature change of 1 °C.

Note that the kelvin temperature unit (K) does NOT have a degree sign.

- To change from °C to K, add 273 to the °C temperature.
- To change from K to °C, subtract 273 from the K temperature.

Change the following temperatures from °C to K:

(a) -273 °C (b) -50 °C (c) 0 °C (d) 20 °C

(e) 50 °C (f) 75 °C (g) 100 °C (h) 500 °C

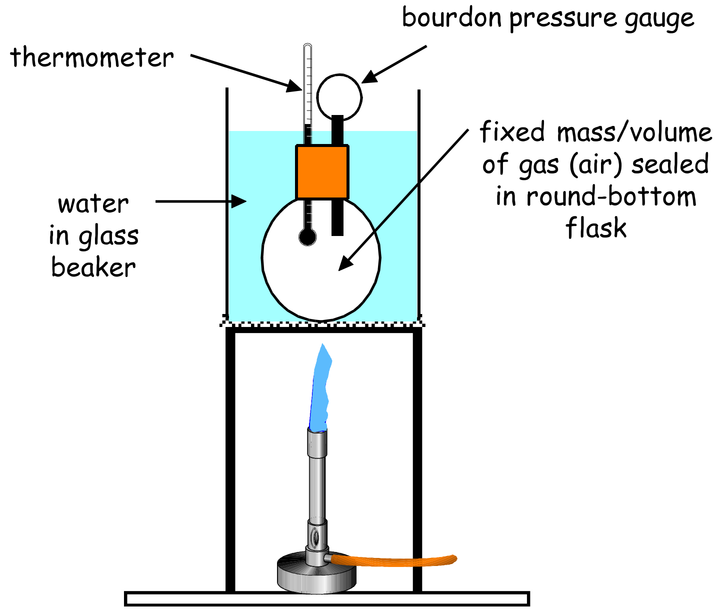
Change the following temperatures from K to °C:

(a) 0 K (b) 20 K (c) 75 K (d) 100 K

(e) 200 K (f) 273 K (g) 300 K (h) 500 K

Pressure and Temperature of a Fixed Mass of Gas at Constant Volume

An experiment can be performed to find out how the pressure a fixed mass of gas exerts on the walls of its container depends on the gas temperature (measured in K). The volume of the gas is kept constant.



- The water is heated slowly. This increases the temperature of the fixed mass/volume of air in the round-bottom flask. This changes the pressure of the air. (Alternatively, the water is heated to its boiling point, then is left to cool slowly.)
- At regular intervals, the pressure of the fixed mass/volume of air is read from the bourdon pressure gauge and its temperature (in K) is read from the thermometer.

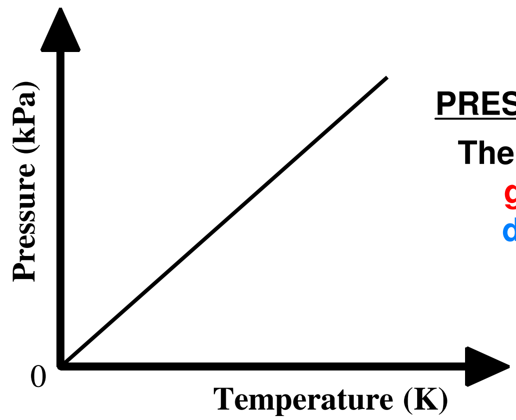
Readings from a typical experiment are shown in the table.

- Calculate values for the third row of the table.

Pressure (kPa)	**110**	**120**	**130**	**139**
Temperature (K)	**298**	**323**	**348**	**373**
$\frac{\textbf{Pressure (kPa)}}{\textbf{Temperature (K)}}$				

$$\frac{\textbf{Pressure}}{\textbf{Temperature (in K)}} = \_\_\_\_\_\_\_\_\_ \textbf{ value}$$

The data in the table can be shown on a line graph:



PRESSURE - TEMPERATURE LAW

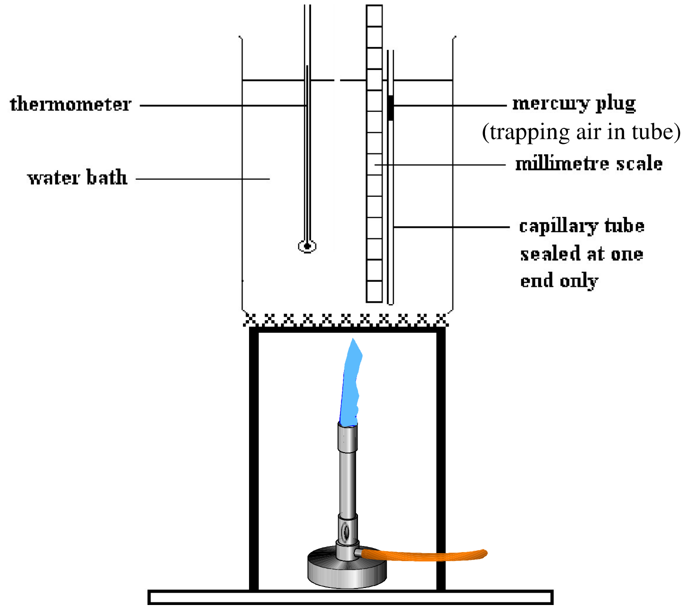
The pressure of a fixed mass of gas at constant volume is directly proportional to its temperature in kelvin.

PRESSURE - TEMPERATURE LAW IN TERMS OF PARTICLE MOVEMENT

If the **temperature** of a sealed container full of gas is **increased** (and the **volume** stays the same), the **kinetic energy** and hence **speed** of the gas particles **increases**. The gas particles therefore hit the walls of the container **more times every second** and with **more force** - so the **pressure increases**.

Volume and Temperature of a Fixed Mass of Gas at Constant Pressure

An experiment can be performed to find out how the volume of a fixed mass of gas depends on the gas temperature (measured in K). The pressure of the gas is kept constant.



- A fixed mass of air is trapped in the glass capillary tube by a small plug of mercury which is free to move up and down the tube.
- The water is heated slowly. This increases the temperature of the the fixed mass of trapped air in the capillary tube. This changes the volume of the air. (Alternatively, the water is heated to its boiling point, then is left to cool slowly.)
- At regular intervals, the length of the column of trapped air is read from the length scale and its temperature (in K) is read from the thermometer.

The length of the column of trapped air is taken to represent the volume, since the length of trapped air is directly proportional to its volume in the capillary tube which has a uniform cross-sectional area.

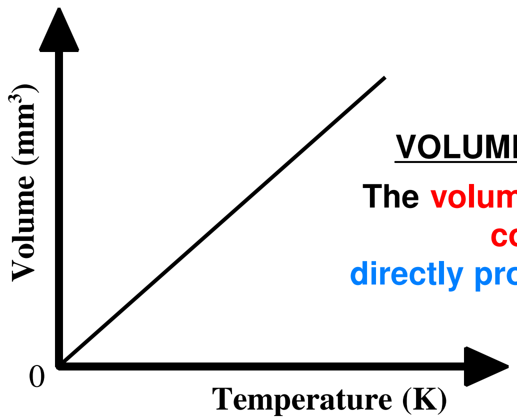
Readings from a typical experiment are shown in the table.

- Calculate values for the third row of the table.

Volume (mm^3)	**64.0**	**69.0**	**73.5**	**78.0**
Temperature (K)	**298**	**323**	**348**	**373**
$\frac{\textbf{Volume (mm}^3\textbf{)}}{\textbf{Temperature (K)}}$				

$$\frac{\text{Volume}}{\text{Temperature (in K)}} = \_\_\_\_\_\_\_\_\_ \text{ value}$$

The data in the table can be shown on a line graph:



VOLUME - TEMPERATURE LAW

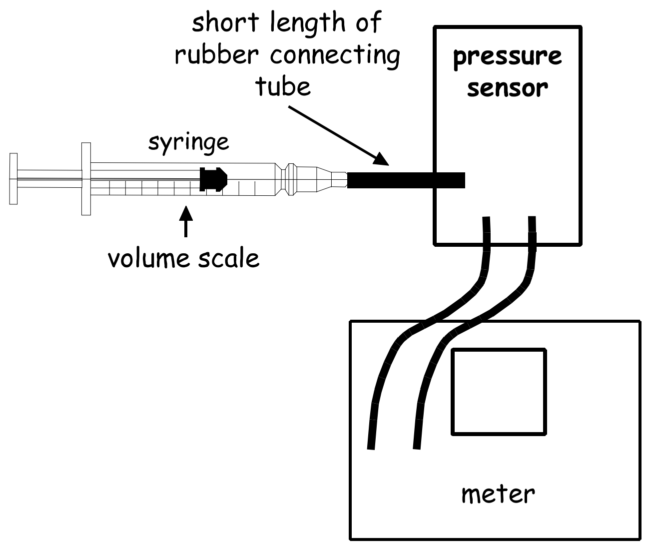
The volume of a fixed mass of gas at constant pressure is directly proportional to its temperature in kelvin.

VOLUME - TEMPERATURE LAW IN TERMS OF PARTICLE MOVEMENT

If the **temperature** of a sealed container full of gas is **increased** (and the **pressure** stays the same), the **kinetic energy** and hence **speed** of the gas particles **increases**. The gas particles therefore hit the walls of the container **more times every second** and with **more force** - so the walls of the container are pushed outwards **(volume increases)**.

Pressure and Volume of a Fixed Mass of Gas at Constant Temperature

An experiment can be performed to find out how the pressure a fixed mass of gas exerts on the walls of its container depends on the volume of the container. The temperature of the gas is kept constant.



- The plunger of the syringe is pushed in and held in position several times. This compresses the trapped air in the syringe, increasing the pressure on it.
- Each time the plunger is pushed in and held, the temperature of the trapped air is allowed to stabilise for 1 minute, then the volume of trapped air is read from the volume scale on the syringe and the pressure of the trapped air is read from the meter connected to the pressure sensor.

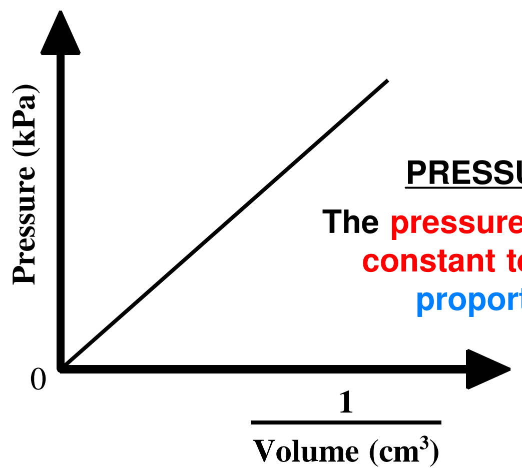
Readings from a typical experiment are shown in the table.

- *Calculate values for the third row of the table.*

Pressure (kPa)	**100**	**150**	**200**	**250**
Volume (cm^3)	**24**	**16**	**12**	**9.6**
Pressure x Volume				

Pressure x Volume = _ _ _ _ _ _ _ _ _ value

The data in the table can be shown on a line graph:



PRESSURE - VOLUME LAW

The pressure of a fixed mass of gas at constant temperature is inversely proportional to its volume.

PRESSURE - VOLUME LAW IN TERMS OF PARTICLE MOVEMENT

If the **volume** of a sealed container full of gas is **decreased** (and the **temperature** stays the same), the gas particles continue to travel with the same **speed** but hit the walls of the container **more times every second** with the **same force** - so the **pressure increases**.

THE GENERAL GAS EQUATION

The **gas law experiments** give us three equations:

Pressure (p) x Volume (V) = constant

$$\frac{\text{Pressure (p)}}{\text{Temperature (T) in kelvin}} = \text{constant}$$

$$\frac{\text{Volume (V)}}{\text{Temperature (T) in kelvin}} = \text{constant}$$

These can be combined into one equation which can be applied to all gases - the **general gas equation**:

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

- p_1, V_1 and T_1 refer to the **initial** conditions of a gas.
- p_2, V_2 and T_2 refer to the **final** conditions of a gas.

When using the "general gas equation", all temperatures must be in kelvin.

Example 1

A cylinder contains 0.2 m^3 of nitrogen gas at a pressure of 300 kPa. Without any change in temperature, the volume is increased to 0.3 m^3. What will be the new pressure of the nitrogen gas at this volume?

Temperature does not change, so miss it out of "general gas equation":

$$p_1 V_1 = p_2 V_2$$
$$300 \times 0.2 = p_2 \times 0.3$$
$$60 = 0.3\, p_2$$
$$p_2 = \frac{60}{0.3}$$
$$= 200 \text{ kPa}$$

(Use the same unit given in the question).

A fixed mass of gas is kept at *constant temperature*.

Its initial pressure is 100 kPa when its volume is 60 cm^3.

What will be the *volume* of the gas
when its pressure is increased to 150 kPa?

A fixed mass of gas is kept at *constant temperature*.

Its initial pressure is 300 kPa when its volume is 50 cm^3.

What will be the *pressure* of the gas
when its volume is increased to 200 cm^3?

A fixed mass of gas is kept at *constant temperature*.

Its initial pressure is 120 kPa when its volume is 20 cm^3.

What will be the *volume* of the gas
when its pressure is decreased to 100 kPa?

A fixed mass of gas is kept at *constant temperature*.

Its initial pressure is 150 kPa when its volume is 90 cm^3.

What will be the *pressure* of the gas
when its volume is decreased to 30 cm^3?

Example 2

Carbon dioxide gas is sealed in a container. Its pressure is 150 kPa and its temperature is 25 °C.
What will be the new pressure of the carbon dioxide gas when it is heated to a temperature of 70 °C? The volume remains constant.

25 °C = 25 + 273 = 298 K and 70 °C = 70 + 273 = 343 K

Volume does not change, so miss it out of "general gas equation":

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

$$\frac{150}{298} = \frac{p_2}{343}$$

$$298\ p_2 = 150 \times 343$$

$$p_2 = \frac{150 \times 343}{298} = \underline{\underline{173\ \text{kPa}}}$$

(Use the same unit given in the question).

A fixed mass of gas is kept at *constant* *volume*.

Its initial pressure is 180 kPa
when its temperature is 27 °C.

What will be the *pressure* of the gas
when its temperature is increased to 57 °C?

A fixed mass of gas is kept at *constant* *volume*.

Its initial pressure is 200 kPa
when its temperature is 47 °C.

What will be the *temperature* of the gas (in kelvin)
when its pressure is increased to 300 kPa?

A fixed mass of gas is kept at *constant* *volume*.

Its initial pressure is 210 kPa
when its temperature is 87 °C.

What will be the *pressure* of the gas
when its temperature is increased to 27 °C?

A fixed mass of gas is kept at *constant* *volume*.

Its initial pressure is 720 kPa
when its temperature is 327 °C.

What will be the *temperature* of the gas (in kelvin)
when its pressure is decreased to 480 kPa?

Example 3

1.50 m^3 of helium gas is sealed in a weather balloon at a temperature of 20 °C. The temperature of the helium gas increases, causing the volume to increase to 1.75 m^3. The pressure remains constant. Calculate the new temperature of the weather balloon.

$20\ °C = 20 + 273 = 293\ K$

Pressure does not change, so miss it out of "general gas equation":

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{1.50}{293} = \frac{1.75}{T_2}$$

$$1.50\, T_2 = 293 \times 1.75$$

$$T_2 = \frac{293 \times 1.75}{1.50} = \underline{\underline{342\ K}}$$

A fixed mass of gas is kept at *constant pressure*.

Its initial volume is 4 cm^3
when its temperature is 7 ^oC.

What will be the *volume* of the gas
when its temperature is increased to 77 ^oC?

A fixed mass of gas is kept at *constant pressure*.

Its initial volume is 900 cm^3
when its temperature is 97 ^oC.

What will be the *temperature* of the gas (in kelvin)
when its volume is increased to 1350 cm^3?

A fixed mass of gas is kept at *constant pressure*.

Its initial volume is 735 cm^3
when its temperature is 147 ^oC.

What will be the *volume* of the gas
when its temperature is decreased to 37 ^oC?

A fixed mass of gas is kept at *constant pressure*.

Its initial volume is 125 cm^3
when its temperature is 67 ^oC.

What will be the *temperature* of the gas (in kelvin)
when its volume is decreased to 100 cm^3?

Sometimes more than one quantity for a gas (pressure, volume and kelvin temperature) will change at the same time.
In this situation, the "general gas equation" can still be used.

In each case below, use the "general gas equation" to calculate the missing quantity:

p_1 = 800 kPa V_1 = 100 cm^3 T_1 = 300 K
p_2 = ? kPa V_2 = 50 cm^3 T_2 = 600 K

p_1 = 400 kPa V_1 = 15 cm^3 T_1 = 800 K
p_2 = 200 kPa V_2 = ? cm^3 T_2 = 300 K

p_1 = 900 kPa V_1 = 50 cm^3 T_1 = 450 K
p_2 = 500 kPa V_2 = 45 cm^3 T_2 = ? K

Notes

Notes