National 5 Physics at Leith Academy

**Thermodynamics**

**March 2018**

**Specific heat capacity**

If you put a 1 kg block of metal under a hot sun, it will heat up very quickly. If you put a 1 kg block of stone in the sun, it will take longer to warm up.

This is because different materials need different quantities of heat to raise their temperature.

The **specific heat capacity** of a substance is the amount of heat energy needed to change the temperature of 1 kg of the substance by 1°C. Each substance has a different value of specific heat capacity.

*Eh* =

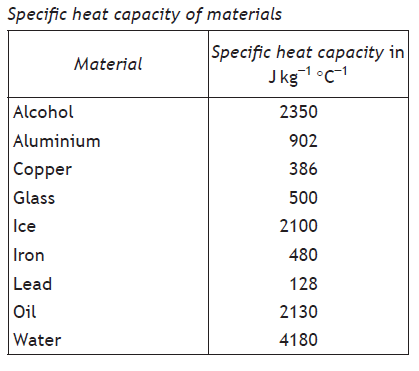
*c* =

*m* =

*T =*

What does each letter stand for?

What is the correct unit?



**Example 1**  
How much heat energy is needed to heat 0.5 kg of water from 20 °C to 60 °C?

**Solution**: the change in temperature needs to be calculated first.

Now find the specific heat capacity of water from the table above: 4180

Now use the formula:

**Example 2**24 000 J of energy is supplied to a 2 kg block of steel. Calculate the change in temperature.

**Example 3**  
If 30 000 J of energy is supplied to a 4.5 kg block of copper, what will the final temperature be if its initial temperature was 25 oC?

PROBLEM PRACTICE

N5 D&S page 60 questions 2-15

**An experiment to find the specific heat capacity of aluminium**

1. Draw a labelled diagram of the equipment here

2. Complete these measurements as you do the experiment

Initial temperature of block = \_\_\_\_\_ Final temperature of block = \_\_\_\_\_\_\_\_

Current supplied to heater = \_\_\_\_\_\_ Voltage across heater = \_\_\_\_\_\_\_\_

Time heater is on = \_\_\_\_\_\_ mass of block = 1.0 kg

3. Use your measurements to make these calculations

Power of heater P = I x V = \_\_\_\_\_\_\_\_\_\_\_\_\_\_

Energy supplied to block E = P x t = \_\_\_\_\_\_\_\_\_\_\_\_\_\_

Temperature rise of block T = \_\_\_\_\_\_\_\_\_\_\_\_\_\_

The amount of energy needed to raise 1 kg of a material by 1 oC is called the **specific heat capacity** of the material.

c = E\_\_

m x T

So the specific heat capacity of aluminium is \_\_\_\_\_\_\_\_\_ J kg-1 oC-1

**Temperature and heat**

What's wrong with these sentences? Are they all wrong?

*The water in the kettle is at a high heat. A kettle produces a lot of temperature.*

*The heat of the coffee is 85 oC. An insulated mug stops the coffee losing temperature.*

The words *heat* and *temperature* are often confused.

Heat is a form of energy. It is caused by the movement of particles in a substance. The faster they move, the more kinetic energy they have. This increases the heat energy in the substance.

Temperature tells us how hot a substance is. **It is a measure of the average kinetic energy of the particles in the substance.**

Heat energy is measured in joules (J). Temperature is measured in degrees Celsius (oC)

**Conservation of energy and heat transfer**

You’ve already learnt an important principle in physics:

*Energy cannot be created or destroyed. It is always conserved.*

This applies to all types of energy, including heat energy. In fact, we used this idea in the experiment to find the specific heat capacity of aluminium.

We used P = I x V and E = P x t to work out the total amount of \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ energy.

We assumed that all of this energy was then converted into \_\_\_\_\_ energy to warm up the block.

**Example 1**  
A 2000 W kettle contains 1.5 kg of water at 20 oC. It is switched on for 2 minutes.

a) Calculate the electrical energy used by the kettle.

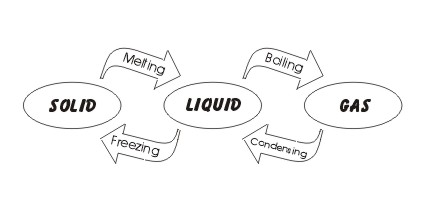
b) If all the electrical energy is converted to heat energy, calculate the final temperature of the water.

**Example 2**  
A 12.0 V heater draws a current of 3.0 A. It is placed in a beaker containing 0.8 kg of oil and switched on for 900 seconds.

a) Calculate the power of the heater.

b) Calculate the electrical energy supplied by the heater.

c) Calculate the temperature rise of the oil.

**Latent heat**

There are three states of matter: solid, liquid and gas.

Substances can change state – for example, solid ice can melt to become liquid water.

Changes of state involve latent heat energy. (Latent means ‘hidden’.)

Whenever a substance changes state, **latent heat energy** is required.

When solids melt or liquids boil – energy needs to put in.

When gases condense or liquids freeze – energy is given out.

Latent heat is the term used to describe energy that causes a change of state **without** change of temperature.

**Specific latent heat**

Specific latent heat is the quantity of energy needed to change the state of 1 kg of a substance.

There is no change in temperature during a change in state.

We can calculate the energy using the formula:

*Eh* =

*m* =

*l =*

What does each letter stand for?

What is the correct unit?

The amount of heat energy required to change 1 kg of ice into water (or water into ice) is **NOT** the same as the energy required to change 1 kg of water into steam (or steam into water).



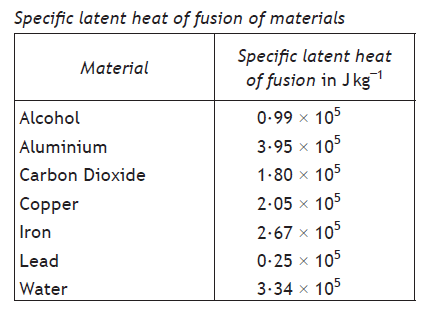
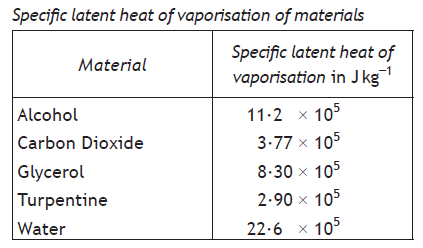
It takes 334,00 J of heat energy to turn 1 kg of ice at 0 oC into liquid water at 0 oC.

This is called the **specific latent of fusion**. This applies to solid🡪liquid and liquid🡪solid changes.



It takes 2,260,000 J of heat energy to turn 1 kg of water at 100 oC into steam at 100 oC.

This is the **specific latent of vaporisation**. This applies to liquid🡪gas and gas🡪liquid changes.



**Example 1**   
800 g of water at 0 oC is placed in a freezer. Calculate the heat energy that must be removed from the water to change it all into ice at 0 oC.

Solution: Find the specific latent heat of fusion of water from the table. Remember to convert the mass to kg.

**Example 2**  
Water in a kettle is brought to the boil at 100 °C and then heated for a further 2 minutes. The kettle is 240,000 J.

1. Calculate the mass of water converted to steam during this time.
2. Why would it take a longer time, in practice, to convert this mass of water to steam?

Solution:

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N5 D&S page 62 questions 2-14

**Heating and cooling curves**  
Imagine removing a block of ice from a freezer at -15 oC and heating it.

To begin with, the solid ice will warm up:

When it reaches 0 oC, it will melt into water at 0 oC:

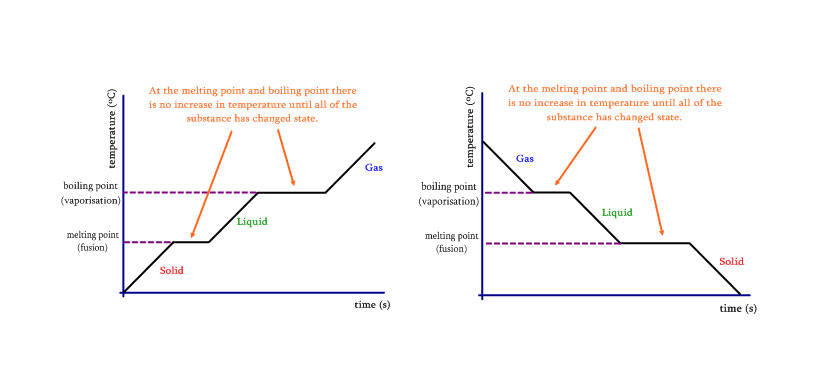
The liquid water will then heat up until it reaches 100 oC:

The water will then turn into steam at 100 oC:

The graph of the change in temperature against time is made up of slopes and horizontal lines.

The slopes show where the **temperature** is changing:

The horizontal lines show where the **state** is changing:



**Example**  
Calculate the total energy required to change 0.5 kg of ice at -15 °C into steam at 100 °C.

Hint: you need to do five calculations: energy to heat up the ice ()

energy to melt the ice ()

energy to heat the water ()

energy to turn the water into steam ()

then add them together

**Pressure**

If someone stands on your foot wearing wellingtons, it’s not too bad.



If they are wearing a stiletto heel, they might make a hole in your foot.

Although the force applied is the same, the area is different. We measure this effect using the idea of **pressure**.

Pressure is defined as the force per unit area:

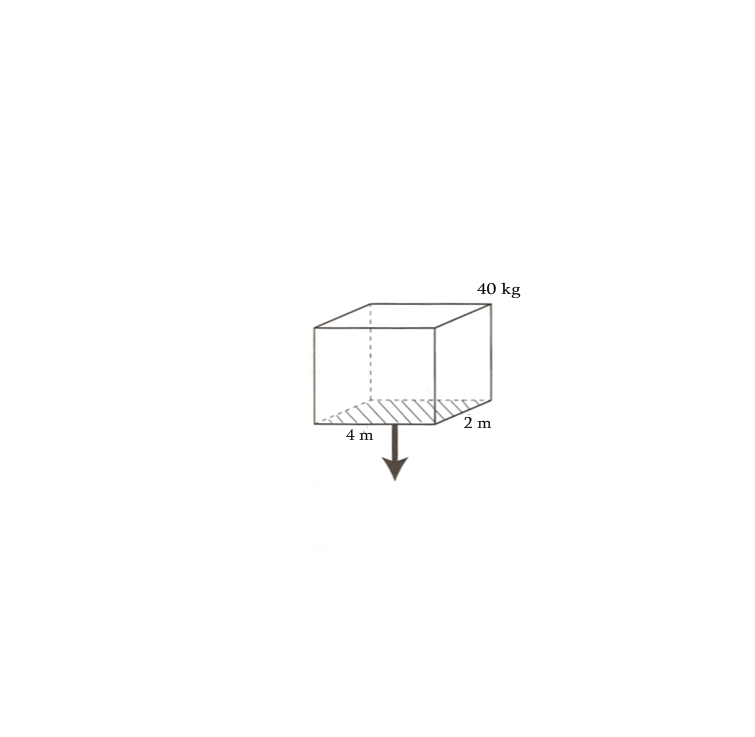
*p* =

*F* =

*A* =

What does each letter stand for?

What is the correct unit?

Note: 1 Pa = 1 N m-2

**Example**   
Calculate the pressure exerted by a 40 kg mass sitting on a bench. The base of the mass measures 4 m × 2 m.

Solution: the area of the block is

The force acting is the weight of the 40 kg mass

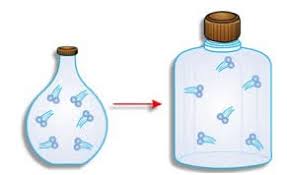
The pressure is:

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N5 E&E page 66 questions 1-15

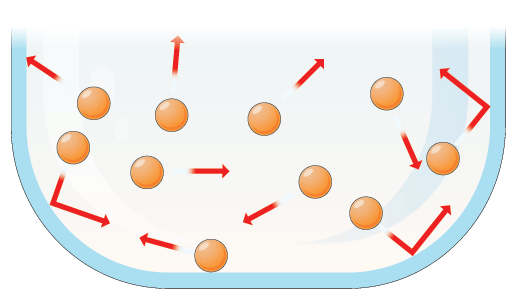
**Gases and the Gas Laws**

Gases are made up of tiny particles – atoms or molecules – that are widely separated and moving at speed.

The Gas Laws look at the relationships between three aspects of gases – pressure, volume and temperature.

The **volume** of a gas is the volume of the container it is in – usually measured in cm3 or m3.

These two bottles contain the same mass of gas – count the particles – but have different volumes.



The **pressure** of a gas is caused by the moving particles hitting against the sides of the container. This applies a force over the area of the container – so we have a pressure. Pressure is measured in pascals (Pa).



The **temperature** of a gas is a measure of the average speed of the particles. The faster the particles are moving, the higher the temperature of the gas.

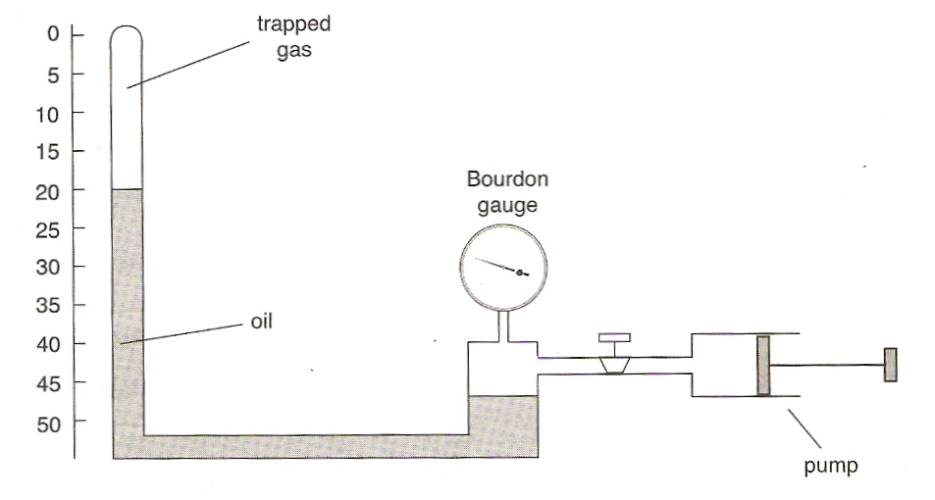
**Boyle’s Law**

**You may be asked about this experiment in an exam – learn the details.**

**Aim:** To find a relationship between pressure and volume for a fixed mass of gas at constant temperature.

**Procedure: T**he pump is used to increase the pressure (measured on the Bourdon gauge). The oil moves up the tube, compressing the gas into a smaller volume (measured on the scale).

The pressure is then gradually reduced in steps, taking measurements of the volume each time.

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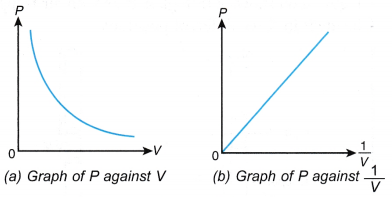
**Results**

|  |  |  |  |
| --- | --- | --- | --- |
| **pressure (kPa)** | **volume (cm3)** | **p x V** | **1/V** |
|  |  |  |  |
|  |  |  |  |
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**Analysis**

What do you notice about the values of p x V?

If we draw a graph of p against V, we get something like (a):



But a graph of p against 1/V looks like (b).

**Conclusion:** From graph (b) and from the final column of the table above:

*k is a constant*

*means ‘proportional to’*

**Using Boyle’s Law**

For a sample of gas, the value of is always the same. This means we can write:

The ‘1’ values are before you change the gas. The ‘2’ values are afterwards.

**Example 1**

A container holds 0.2 m3 of hydrogen gas at a pressure of 200 × 105Pa. The volume of the container box is reduced to 0.08 m3. Calculate the new pressure.

Solution:

**Example 2**  
200 cm3 of gas is expanded to 600 cm3 at a constant temperature. If the initial pressure was   
1.2 x 105 Pa, calculate the final pressure.

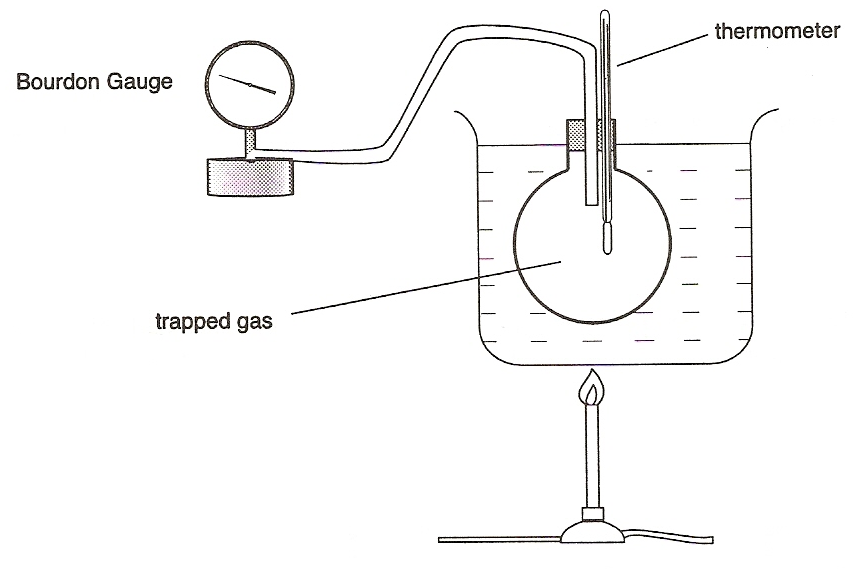
**Example 3**  
58 cm3 of gas at a pressure of 2.5 x 105 Pa is allowed to expand until the pressure reaches  
 2.0 x 105 Pa. Calculate the new volume.

PROBLEM PRACTICE

N5 E&E page 72 questions 4-9

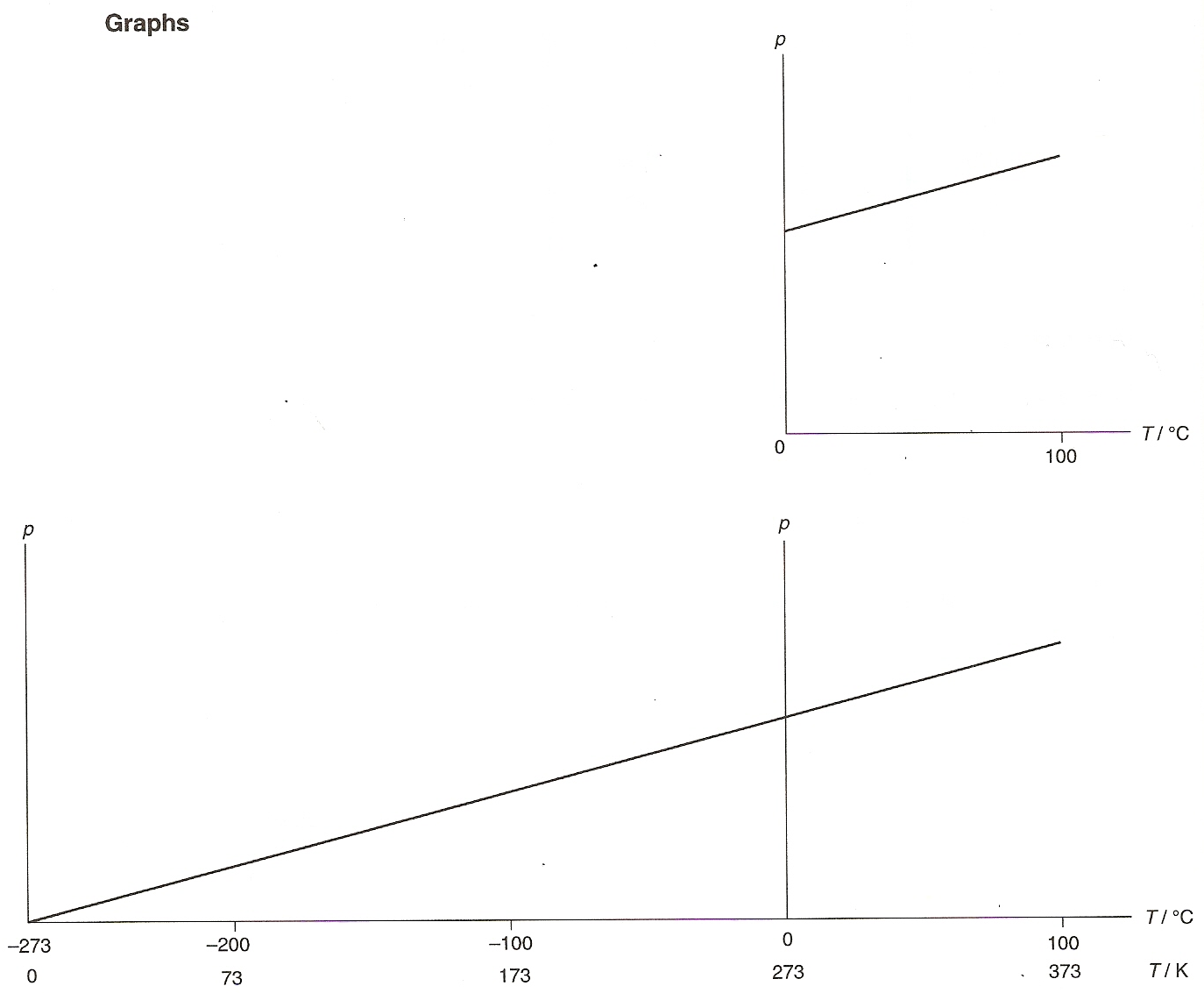
**The Pressure-Temperature Law (or the Gay-Lussac Law)**

**You may be asked about this experiment in an exam – learn the details.**

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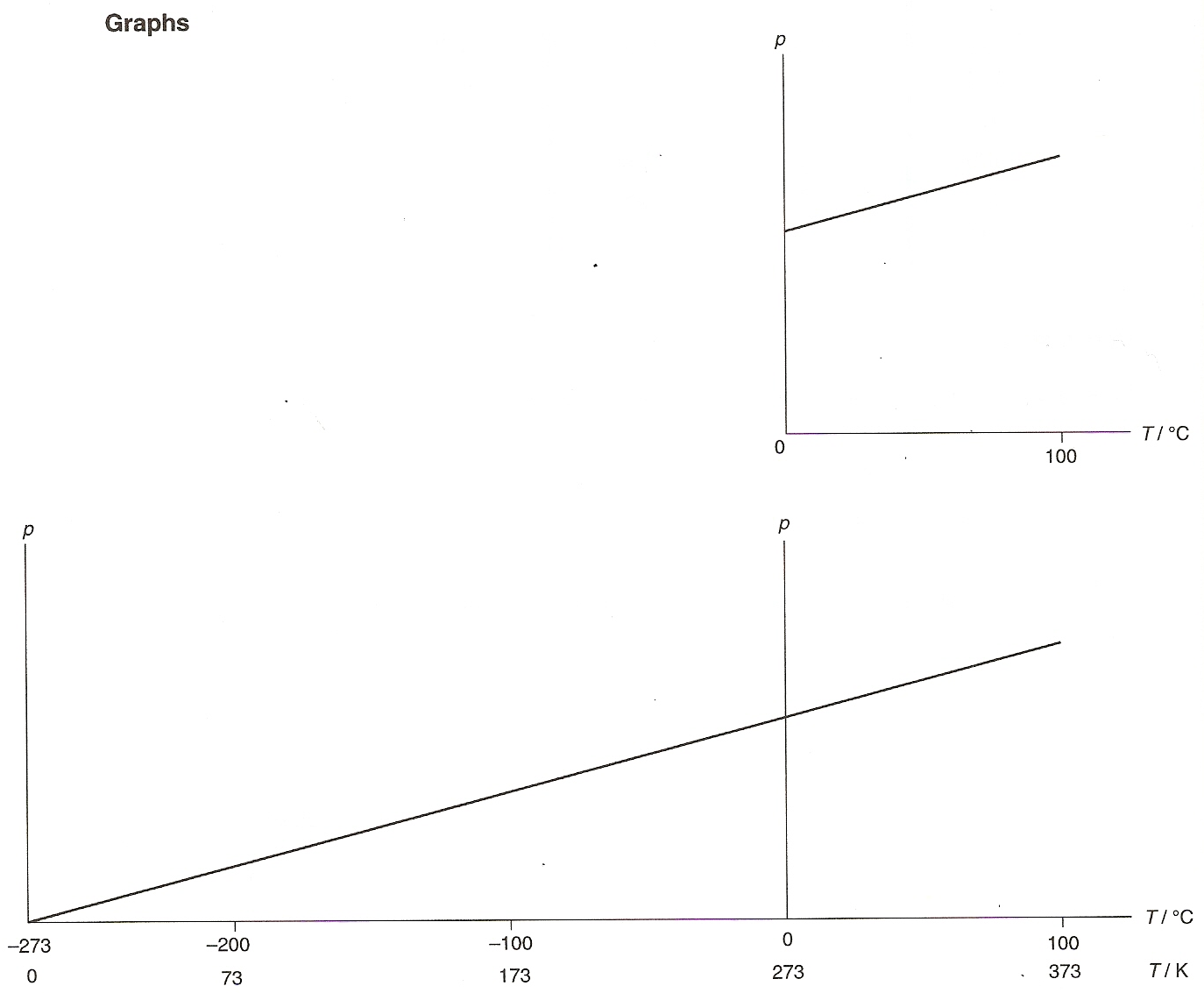
**Object:** To find a relationship between **pressure** and **temperature** for a fixed mass of gas at constant volume.

**Procedure:** In the apparatus opposite, the water is heated. This heats the gas in the flask. Pressure readings (on the Bourdon gauge) are recorded at different temperatures, as measured by the thermometer.

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**Typical results:**

|  |  |
| --- | --- |
| **T ()** | **P ()** |
| 20 | 1.01 |
| 30 | 1.04 |
| 40 | 1.08 |
| 50 | 1.11 |
| 60 | 1.15 |
| 70 | 1.18 |

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**Conclusion**The graph of p against T (°C) is a straight line but it does not go through the origin. If we draw the line ‘backwards’ until it meets the temperature axis, it cuts it at -273 oC.

If we start our temperature scale at -273 oC – and call it **zero Kelvin** – we have a straight line through the origin. So long as we measure temperature in Kelvin, we can write:

*means ‘proportional to’*

*k is a constant*

*provided V is constant and a fixed mass of gas*

We usually write this as:

*provided T is measured in Kelvin*

**Example 1**An empty aerosol can contains 250 cm3ofgas at a temperature of 20 °C and a pressure of 1.5 × 10**5** Pa. For safety reasons, the can is designed to burst when the pressure inside the can reaches 3.0 × 10**5** Pa. Find the maximum temperature it can be safely exposed to.

Solution  
The temperature needs to be converted to Kelvin:

Now use the Pressure Law:

**Example 2**  
A sealed container is heated from 20 °C to 80 °C. If the initial pressure of the gas inside was   
160 kPa, calculate the final pressure.

PROBLEM PRACTICE

N5 E&E page 73 questions 10-14

**More on absolute zero and the Kelvin scale**What does ‘absolute zero’ actually mean?

At 0 degrees Kelvin, the pressure of a gas is zero. Pressure is caused by particles moving and hitting into the sides of the container. If the pressure is zero, this means the particles must have stopped moving.

Because the particles can’t move any less than ‘not moving’, zero Kelvin (or -273 oC) is the **lowest possible temperature**.

This doesn’t mean it’s just the lowest temperature we can get down to – it is the lowest temperature that there can be.

**Converting between oC and K**

To convert oC to K, **ADD** 273. So 20 oC = 293 K

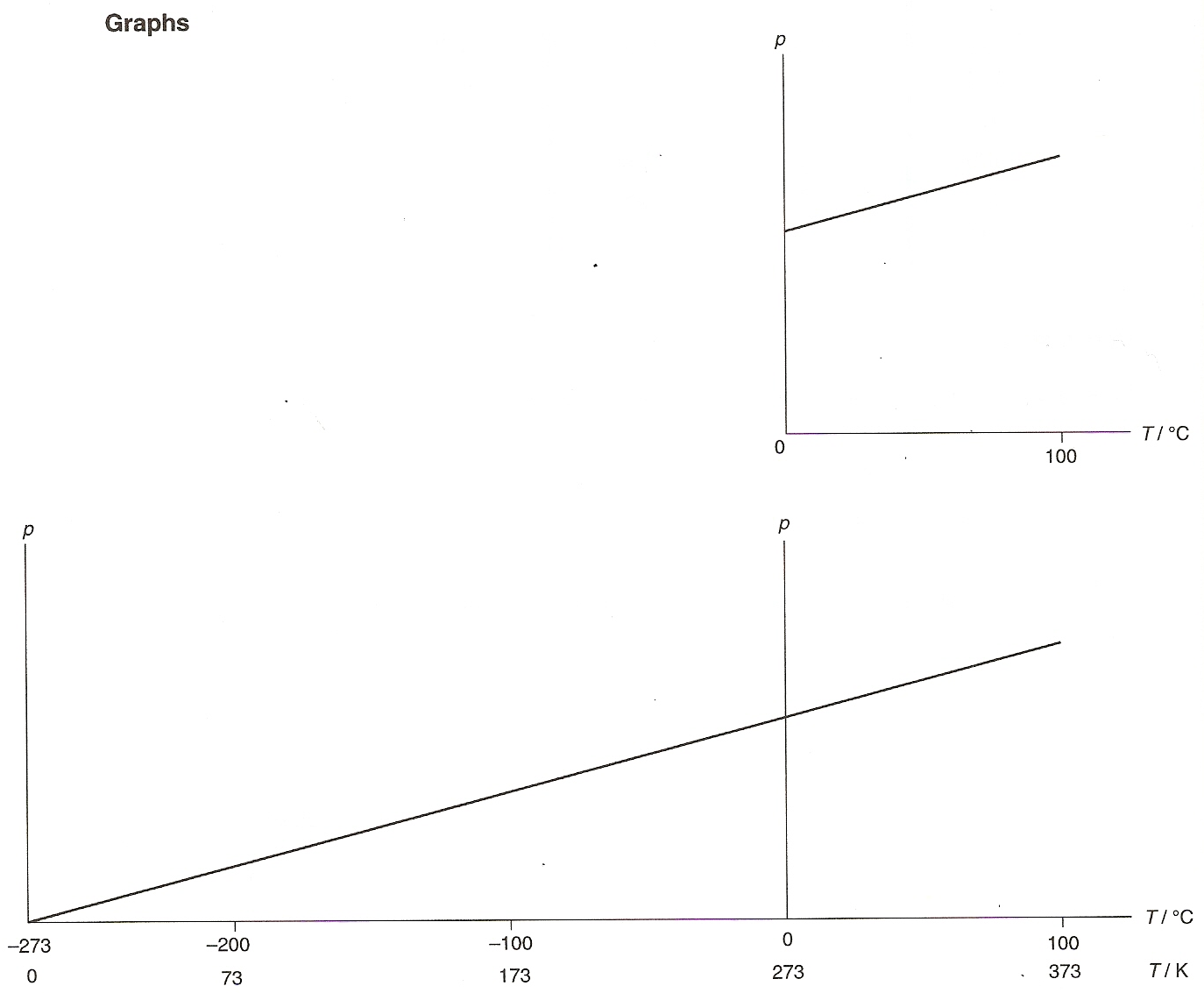
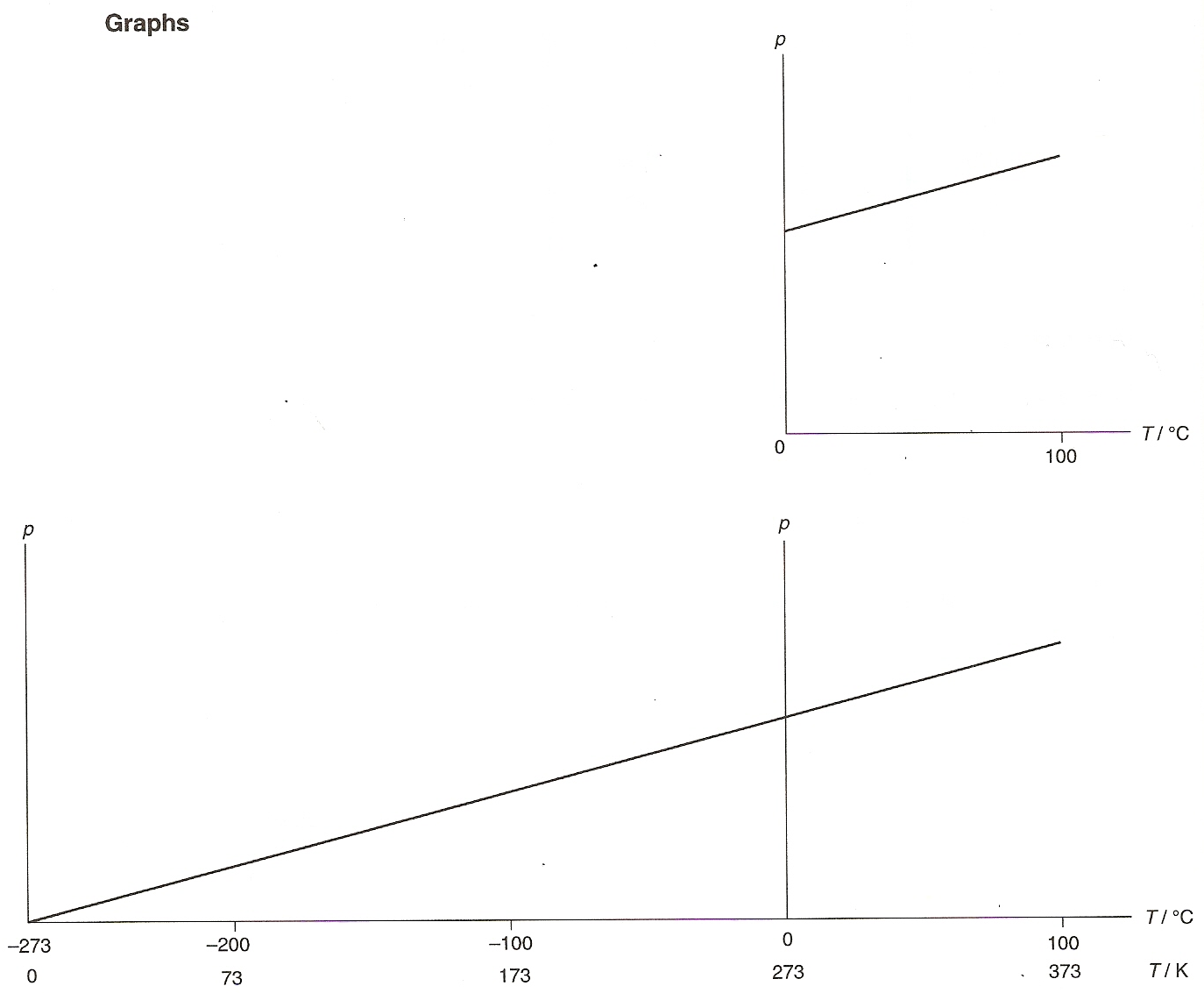
To convert K to oC, **SUBTRACT** 273. So 400 K = 137 oC.

Convert these degrees Celsius temperatures to Kelvin:

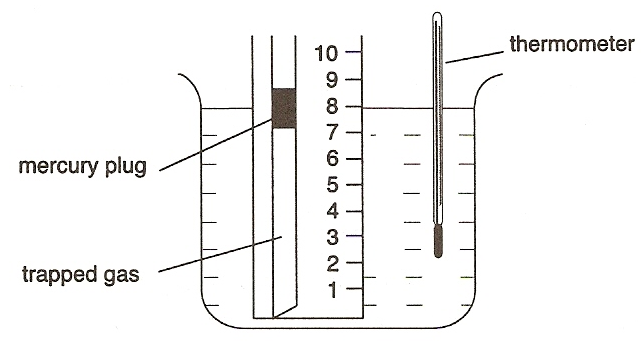
0 oC 30 oC -196 oC 850 oC -6 oC 4156 oC

Convert these Kelvin temperatures to degrees Celsius:

0 K 250 K 300 K 99 K 274 K 4156 K

**Charles’ Law – the link between volume and temperature**

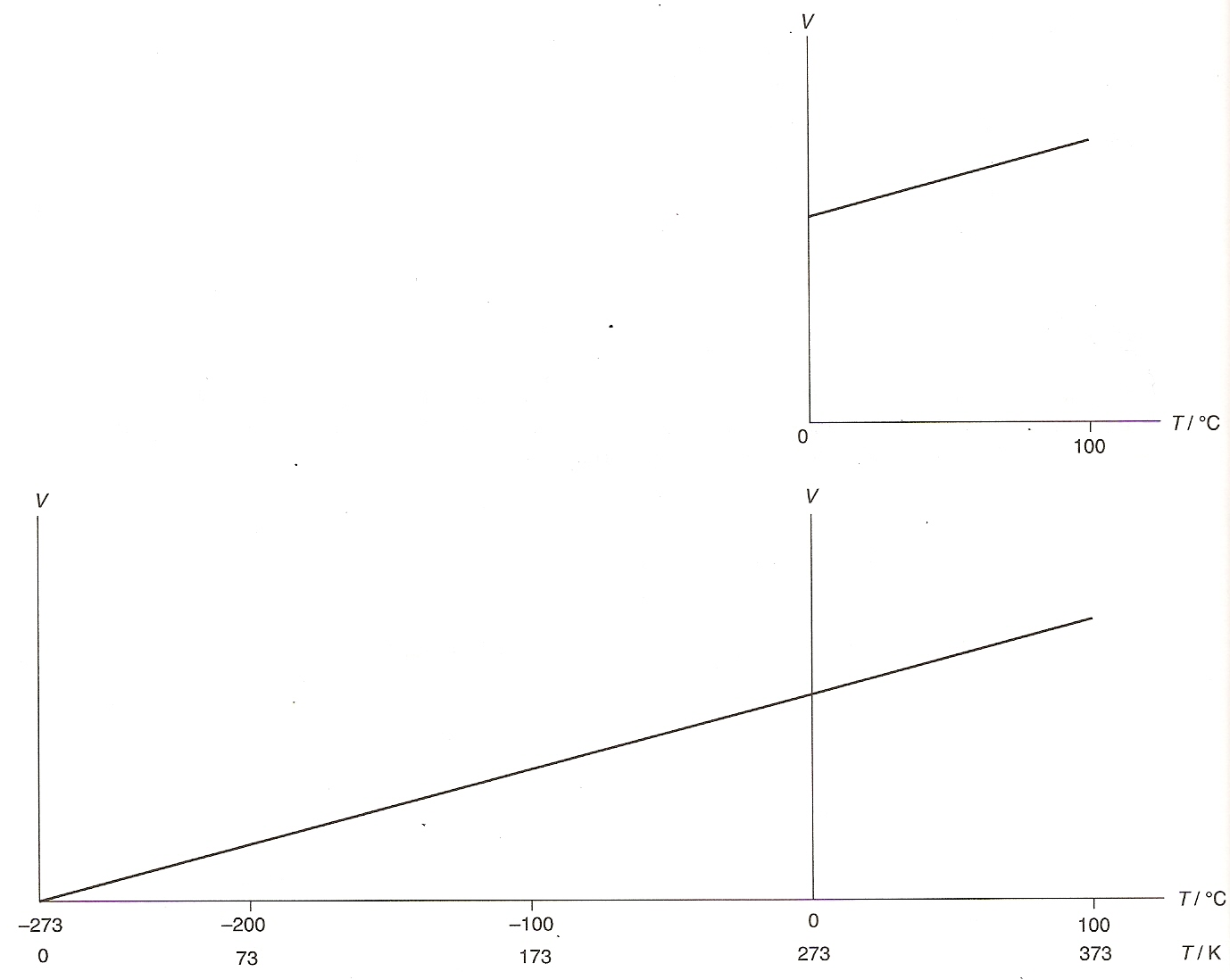
**You may be asked about this experiment in an exam – learn the details.**



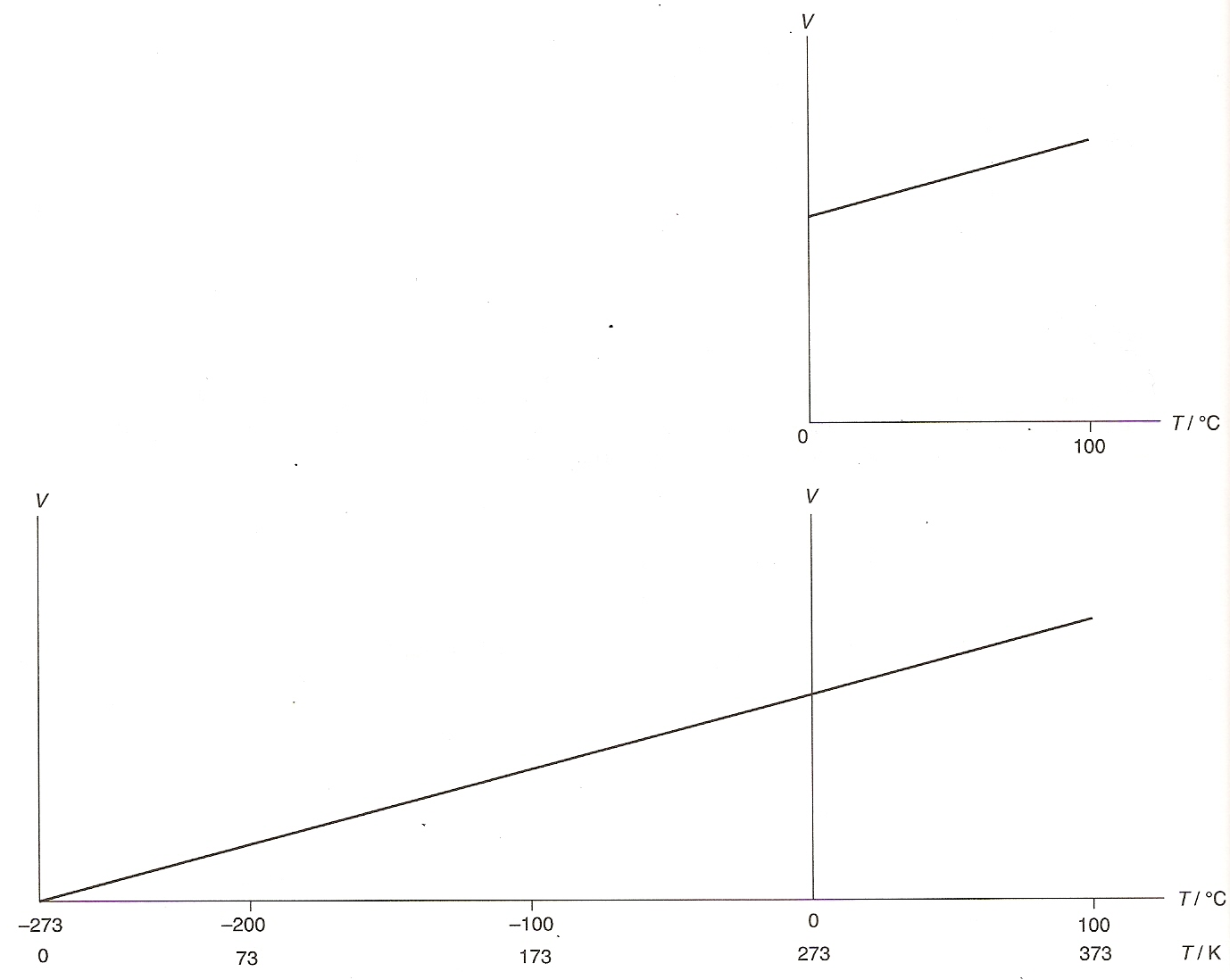
**Object:** To find a relationship between volume and temperature for a fixed mass of gas at constant pressure.

**Procedure:** In the apparatus opposite, the temperature of the water is increased, as measured on the thermometer. When heated, the gas expands and pushes the mercury plug up the tube. The linear scale gives a measure of the volume of the trapped gas.

**Typical results:**

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|  |  |
| --- | --- |
| **T ()** | **V ()** |
| 20 | 1.01 |
| 30 | 1.04 |
| 40 | 1.08 |
| 50 | 1.11 |
| 60 | 1.15 |



**Conclusion**The graph of V against T (°C) is a straight line but it does not go through the origin. If we draw the line ‘backwards’ until it meets the temperature axis, it cuts it at -273 oC.

If we start our temperature scale at -273 oC – and call it zero Kelvin – we have a straight line through the origin. So long as we measure temperature in Kelvin, we can write:

*means ‘proportional to’*

*k is a constant*

*provided p is constant and a fixed mass of gas*

We usually write this as:

*provided T is measured in degrees Kelvin*

**Example 1**  
A syringe contains 50 cm3of air trapped air at a temperature of 20 °C. The syringe is placed in boiling water at 100 oC. Calculate the new volume of the trapped air if the pressure remains constant

Solution: the temperatures need to be converted to Kelvin first.

Now use Charles’ Law

**Example 2**  
A fixed mass of air in a balloon, held at a constant pressure, is cooled from 100 °C. If the volume decreases from 2.0 litres to 1.5 litres calculate the final temperature of trapped air.

PROBLEM PRACTICE

N5 E&E page 74 questions 15-17

**The General Gas Equation**

The three gas laws can be combined into a single equation. We can use this if pressure, volume and temperature are all changing.

*k is a constant*

Or:

**Example**  
Helium in a sealed container was heated from 350 K to 400 K. If the gas was allowed to expand during heating from 50 cm3 to 120 cm3 and the initial pressure 4.2 x 105 Pa, what was the pressure after the container was heated?

Solution: the temperature is already in Kelvin so does not need to be converted.

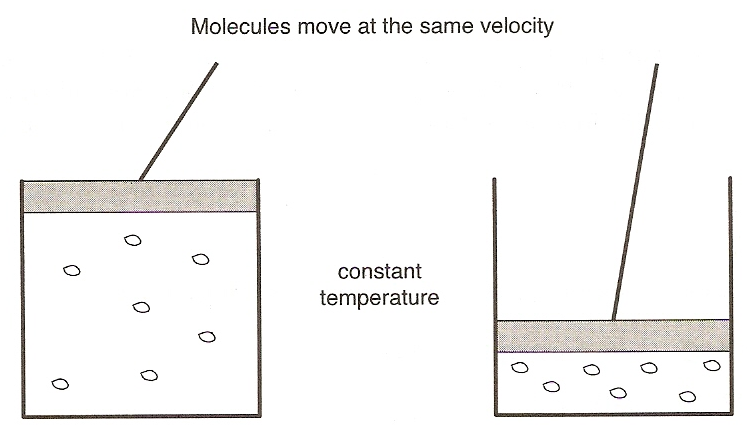
Use the General Gas Equation.

PROBLEM PRACTICE

N5 E&E page 74 qn 18

**Kinetic theory**

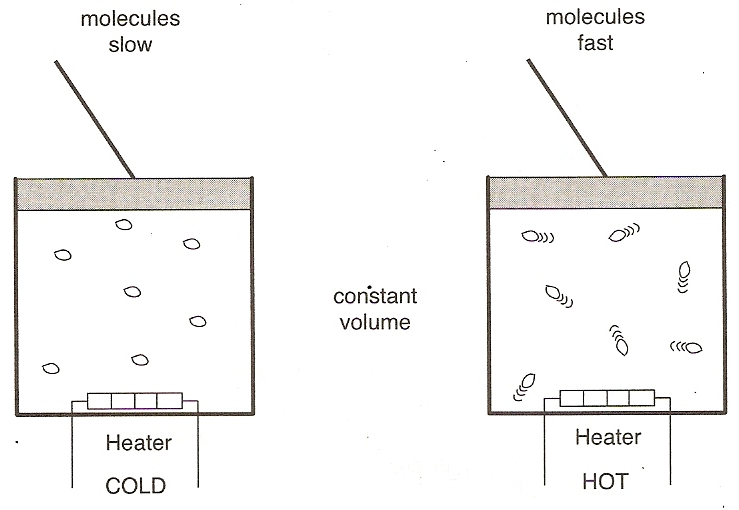
We can explain the gas laws by thinking about how the particles move.

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**Boyle’s Law (P and V *with T constant*)**

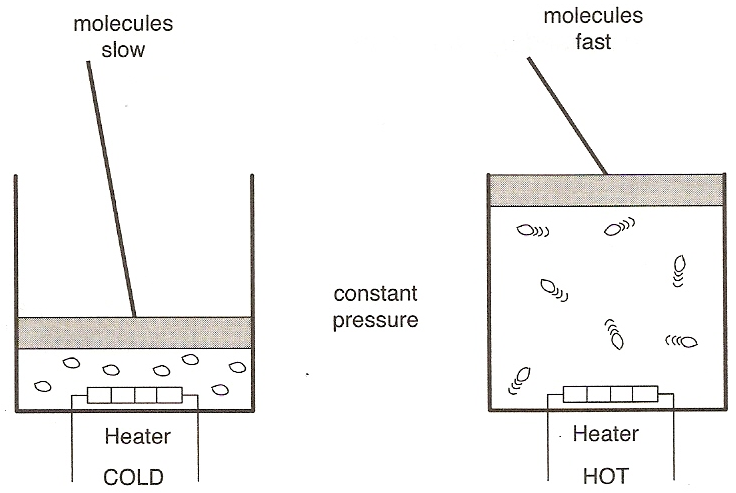
When a fixed mass of gas is compressed in a sealed container:

* the volume decreases
* the molecules are moving with the same velocity so they make more collisions per second with the container walls
* the force applied to walls increases and so the pressure increases.

**Pressure Law (P and T *with V constant*)**

When a fixed mass of is heated in a sealed container:

* the temperature increases
* the average Ek of the molecules increases so the molecules move faster
* they hit the walls harder and more often
* the force applied to walls increases, so the pressure increases

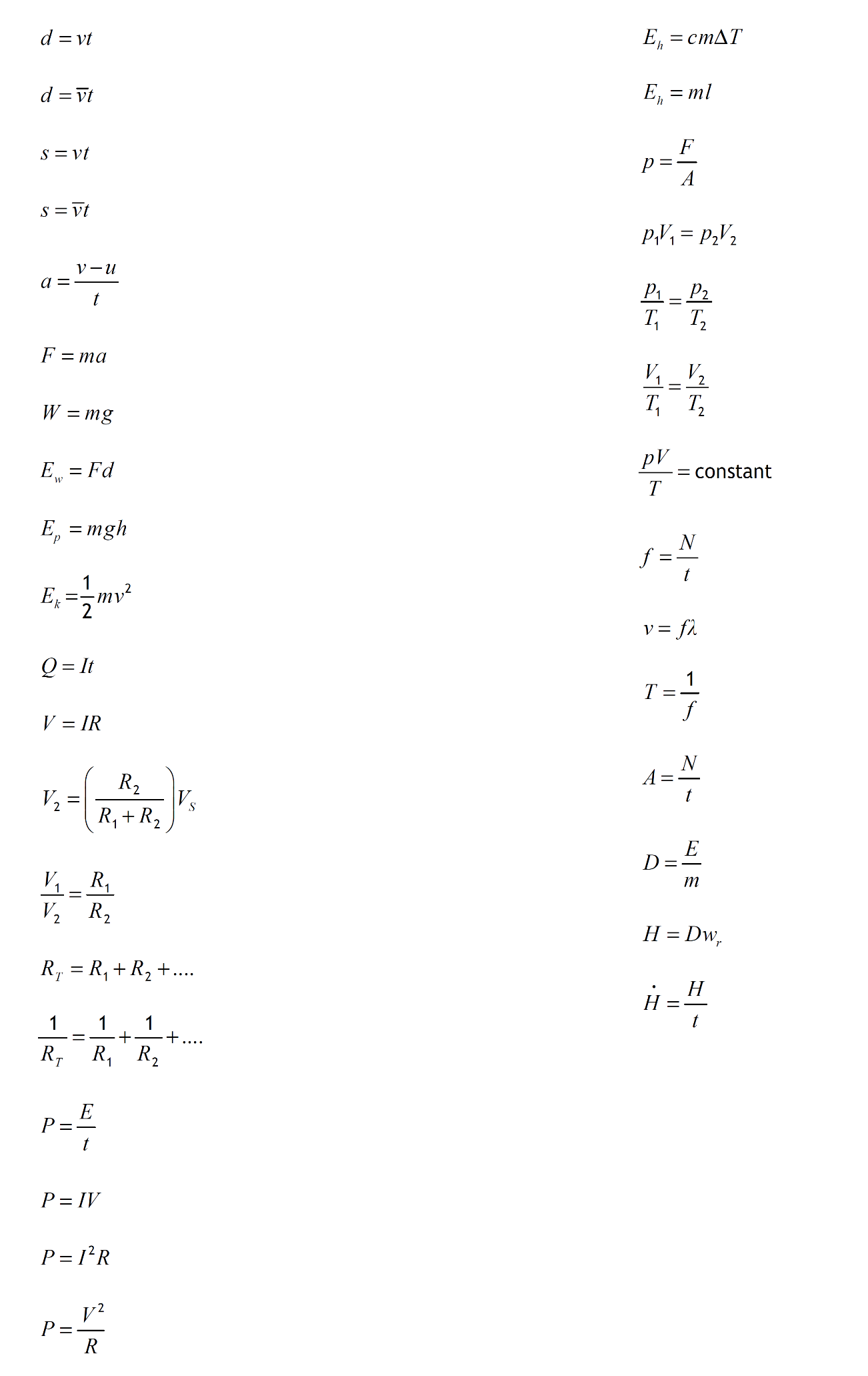
**Charles’ Law (V and T *with P constant*)**

When a fixed mass of gas is heated in a sealed container,

* the temperature increases
* the average Ek of the molecules increases the molecules move faster
* the gas must expand to keep the pressure the same
* the volume increases.

Use kinetic theory to explain why the pressure of a gas falls if its volume increases.

**Formula sheet for National 5**

By the end of the course, you must know what each letter stands for and what its unit is.

Formulas for this unit