Energy and Properties of Matter
Summary Notes

Conservation of Energy

The Principle of Conservation of Energy

Energy can be changed from one form into another but *it cannot be created or destroyed*. Energy *is always conserved*.

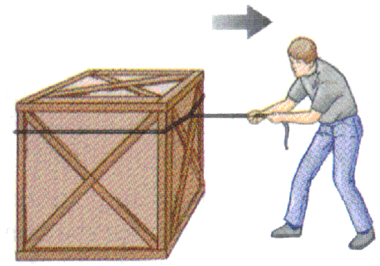
As energy transforms from one form into another, some energy may be lost. For example in a light bulb the main energy change is electrical into light however some of the energy is lost in the form of heat.

Transformations

- Light bulb — electrical energy ⟶ light + (heat)
- Cooker — electrical energy ⟶ heat + (light)

Work Done

When an object is moved from one place to another, energy has to be transformed to do this.



To pull this box along the ground the person transfers his chemical energy into work done.

The amount of energy transferred (work done) will depend on:

- The force applied to the box.
- The distance the box has been pulled from its original position (displacement)

Work done has the symbol E_w and is measured in joules, J

Force has the symbol F and is measured in Newtons, N.

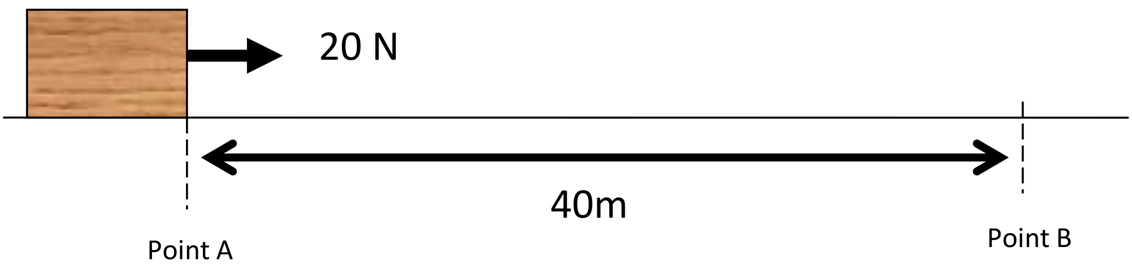
Distance has the symbol d and is measured in metres, m.

Work done = force x distance (or displacement) $E_w = F \times d$

Carry out calculation using $E_w = F \times d$

Example

Calculate the work done in pulling the 2 kg box from point A to B.



$E_w = ?$

$F = 20$ N

$d = 40$ m

$E_w = F \times d$

$E_w = 20 \times 40$

$E_w = 800$J

Gravitational Potential Energy

Gravitational potential energy is the work done against gravity.

The 2 kg box has to be lifted up 20 m onto the shelf above it. The work done against gravity can be calculated using **$E_w = F \times d$.**

Where, F = weight of the box = m x g = 2 x 9.8 =**20 N** *(rounded)*

d = the height = **20 m**

E_w = the change in gravitational potential energy, E_p

Therefore an equation more relevant to the problem can be written:

Change in Potential energy = mass x gravitational field strength x height

$$E_p = m \times g \times h$$

$$= 2 \times 9.8 \times 20$$

$$= 400\ \text{J}$$ *(rounded)*

Kinetic Energy

Kinetic energy is the energy an object has because it is moving. Kinetic energy has the symbol E_k and is measured in joules, J.

The kinetic energy an object has depends on the mass and velocity of the object they are related as follows:

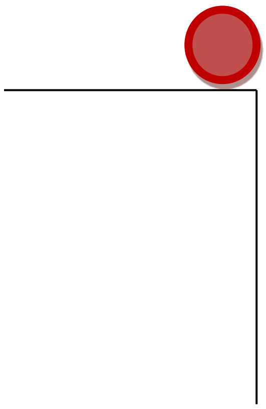
kinetic energy = ½ x mass x velocity²

$$E_k = \frac{1}{2} \times m \times v^2$$

Joules, **J** → E_k; kilograms, **kg** → m; metres per second, **m/s** → v

Calculations involving energy transformations using the Principle of Conservation of Energy

As an object falls from a height its gravitational potential energy is transformed into other forms. If there are no energy losses all the gravitational potential energy would be converted into kinetic energy.



As the balls falls all its $\mathbf{E_p}$ is transformed into $\mathbf{E_k}$

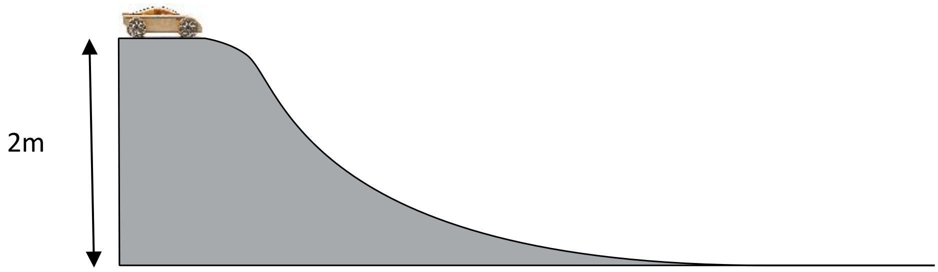
Therefore $\quad E_p = E_k$

$$E_p = m \times g \times h$$

Carry the answer for Ep and use in the Ek equation and you can calculate v the speed it hits the ground.

Example

A model car has a mass of 0.5 kg, it starts from rest and is allowed to roll down a slope.



(a) Calculate the amount of gravitational potential energy it loses as it runs down the slope.
(b) Ignoring any energy loses state its gain in kinetic energy as it runs down to the bottom of the slope.
(c) Calculate the speed of the model car at the bottom of the slope.

Solutions

(a) E_p = m x g x h
= 0.5 x 9.8 x 2
= **9.8 J**

(b) E_k = 9.8 J, since all potential energy is converted into kinetic energy as no energy is lost.

$$E_k = \frac{1}{2}mv^2$$

$$9.8 = 0.5x0.5xv^2$$

$$9.8 = 0.25v^2$$

(c) $$\frac{9.8}{0.25} = v^2$$

$$\sqrt{39.2} = v$$

$$v = 6.3ms^{-1}$$

Power

Power has the symbol P and is measured in units of watts, W. Power is the number of joules of energy transformed per second.

Power Equation

Power can be calculated using the following equation:

seconds, **s**

$$P = E / t$$

Power (W)

Energy (J)

Example

A passenger lift has a power of 12000W. It is used for a period of 1 minute. How much energy does it use?

P = 12000W

t = 60 s

E = ?

P = E / t

12000 = E / 60

E= 720 000J

Gas Laws and the Kinetic Model

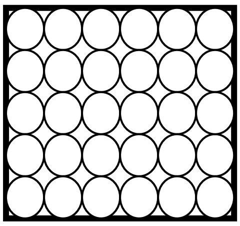
<u>The Three States of Matter</u>

Kinetic - movement

Matter - what everything is made up of (particles)

A kinetic model of matter explains how the *particles* which make up solids, liquids and gases are arranged and how they move around.

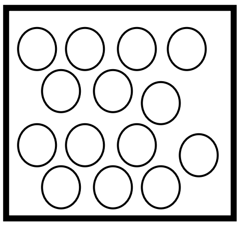
The diagrams below show how the particles in solids, liquids and gases are arranged.



SOLID

Arranged: Particles very close together.

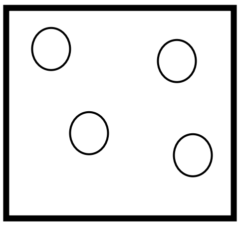
Move: particles vibrate in the one spot.



LIQUID

Arranged: Particles close together.

Move: particles swap places with their nearest neighbouring particles.



GAS

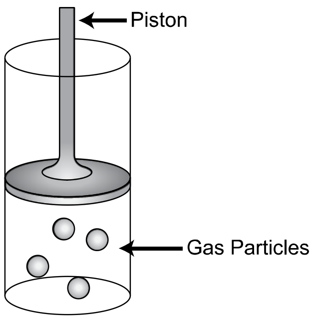
Arranged: Particles far apart.

Move: particles move very fast randomly around in all directions.

Kinetic Theory of Gases

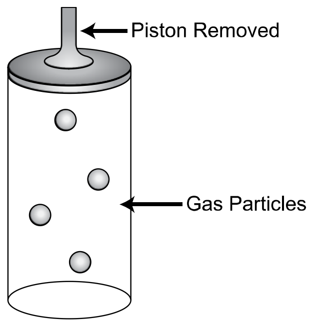
Pressure varies with Volume

A gas half fills a glass tube and is held in position with a tightly fitting piston.



The gas particles are moving around very fast in all directions. The gas particles are colliding with each other and with the sides of the glass tube, thus creating a *pressure* inside.

What would happen if the piston was moved to the end of the glass tube?



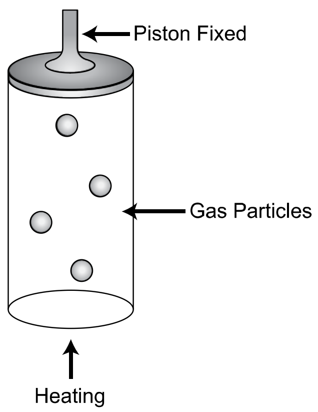
The gas particles will move to fill up the whole of the glass tube

How will this affect the **pressure** inside the glass tube?

The pressure will be reduced since there is more space for the particles to move around. Therefore the particles will collide less often with each other and they will collide less often with the sides of the container.

As the volume increases the pressure decreases.

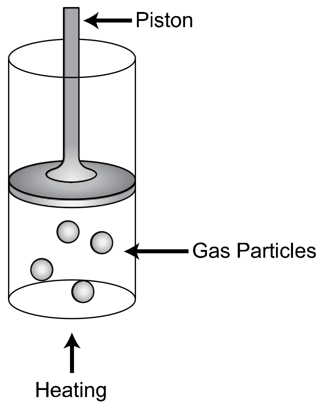
Pressure varies with Temperature



As the gas inside the glass tube is heated the gas particles gain more kinetic energy. This causes them to collide more often with each other and the walls of the container, causing an increase in pressure

As the temperature increases the pressure increases.

Volume varies with Temperature



As the gas inside the glass tube is heated the gas particles gain more kinetic energy. This causes them to collide more often with each other and the walls of the container, causing an increase in pressure on the glass tube and the piston.

As the piston is not fixed the pressure will *force the piston upwards* increasing the volume the gas takes up within the glass tube.

As the temperature increases the volume increases.

Applications of the kinetic model of a gas

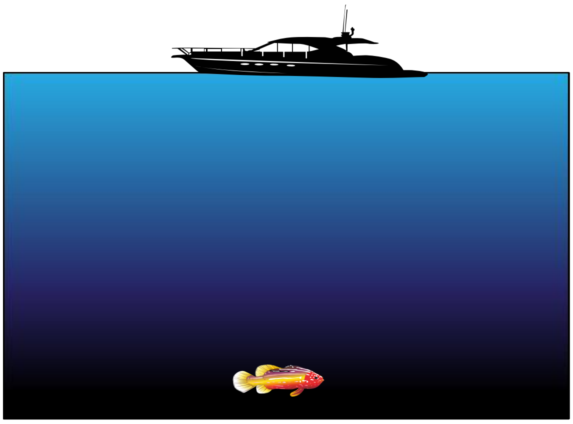
Example 1

As pressure increases, volume decreases and vice versa for a fixed mass of gas.

In deep water the pressure on a body is less nearer the surface of the water than it is close to the sea bed.

This is due to the increase in the amount of water on top of the body. The greater the volumes of water on top of the body, the greater the pressure the body feels.

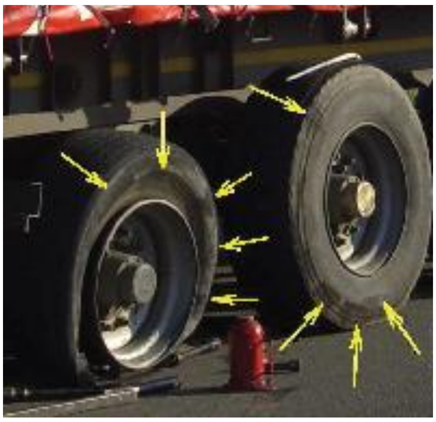
When a fish adapted to life in deep water is brought to the surface, the pressure on it decreases. Therefore, its volume of gas in the fish's body increases, causing their air bladders, cells and membranes to 'pop', ending their lives.



Example 2

As pressure increases, temperature increases and vice versa for a fixed mass of gas.

In summer time when the outside temperature is hotter than normal, a car tyre may explode.



This happens as the gas particles are exposed to an increase in temperature. This causes them to gain more kinetic energy and causes the pressure of the air inside the tyre to increase.

Example 3

As temperature increases, volume increases and vice versa for a fixed mass of gas.

A football inflated inside then taken outside on a cold winter's day will shrink slightly.

This happens since the air inside the ball is exposed to a colder temperature, causing the kinetic energy of the particles of air to decrease. Therefore, the particles of the air collide less often with the walls of the ball and the pressure inside the ball decreases. Therefore the ball shrinks.

Pressure

Pressure can be described as the force exerted on a surface per one metre squared.

The greater the force on 1 m^2, the greater the pressure exerted on the surface and vice versa.

$$\textbf{pressure} = \frac{\textbf{force}}{\textbf{area}} \qquad P = \frac{F}{A}$$

Newtons, **N** (F)

metre squared, **m^2** (A)

Newtons per metre squared, **N/m^2** (P)

Pressure is measured in units of Newtons per metre squared, N/m^2 or Pascals, Pa.

Remember: when calculating the total pressure at a depth in water, you must take into account the pressure due to the atmosphere = 1×10^5 Pa.

Example 1

A box has a weight of 650 N and has dimensions 0.5m by 2m, what pressure is exerted on the floor?

F = 650 N

A = (0.5 x 2) m^2 = 1 m^2

P = ?

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

$$P = \frac{650}{1}$$

P = 650 Pa

Example 2

A girl has a mass of 40kg, her shoes have dimensions 0.25 m by 0.1 m, what pressure does she exert on the with one foot?

F = W = m x g = 40 x 9.8 = 392 N

A = 0.25 x 0.1 = 0.025 m^2

P = ?

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

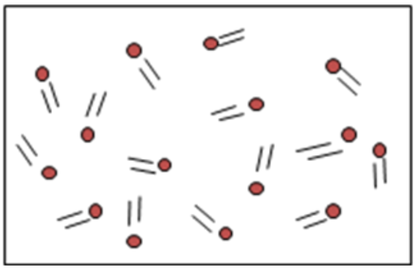
$$P = \frac{392}{0.025}$$

P = 16 000 Pa

Think: when is the *pressure* of the girl on the floor at *its greatest?* when standing one foot or two feet.

Kinetic Theory of Gases

The kinetic theory of gases is used to explain the behaviour of gases using a model. The model considers a gas to be composed of a large number of very small particles that are widely spaced. The particles are moving at random in all directions with a range of speeds. No energy is lost when the particles collide with the walls of the container and each other.



Volume

The volume of a gas is taken as the volume of the container. The volume occupied by the gas particles themselves is considered so small as to be negligible.

Temperature

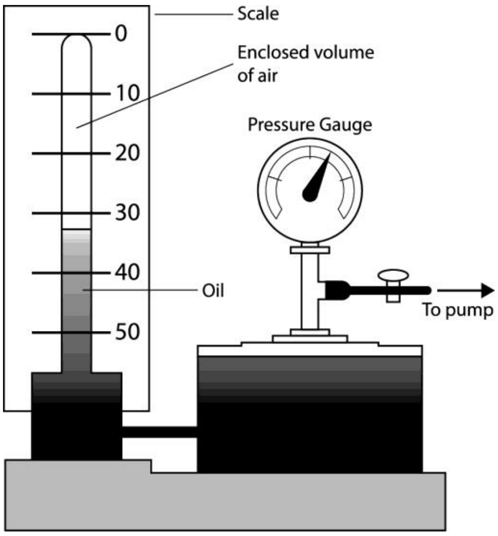
The temperature of a substance is a measure of the mean kinetic energy of its particles. The faster the particles move, the greater their kinetic energy and the higher the temperature.

Pressure

The pressure of a gas is caused by the particles colliding with the walls of the container. The more frequent these collisions or the more violent these collisions, the greater will be the pressure.

Relationship between Pressure and Volume of a Gas (Boyles Law)

Consider an experiment to determine the relationship between pressure and volume of a fixed mass and fixed volume of gas.



- As the pump varies the pressure, the volume of the enclosed gas is measured
- It is found that as the pressure increases, the volume decreases

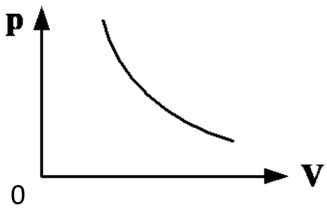
The mass of gas in the tube remains the same.

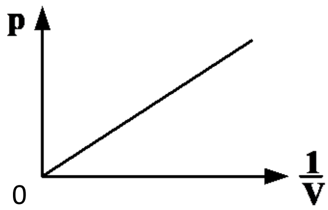
A reading for volume of enclosed air is taken from the tube, along with the corresponding pressure from the pressure gauge. Air is then pumped into the apparatus above the oil and a further set of readings of volume of air and pressure can be taken. More air is then pumped into the apparatus again and the process is repeated to get a set of volume and corresponding pressure readings.

Boyle's law states that for a fixed mass of gas at a constant temperature, the pressure of a gas is inversely proportional to its volume:

$p \propto \frac{1}{V}$	$p \times V = \text{constant}$	$p_1 V_1 = p_2 V_2$

Graph





Example

The pressure of a gas enclosed in a cylinder by a piston changes from 80 kPa to 200 kPa.

If there is no change in temperature and the initial volume was 25 litres, calculate the new volume.

p_1 = 80 kPa — **$p_1 V_1 = p_2 V_2$**

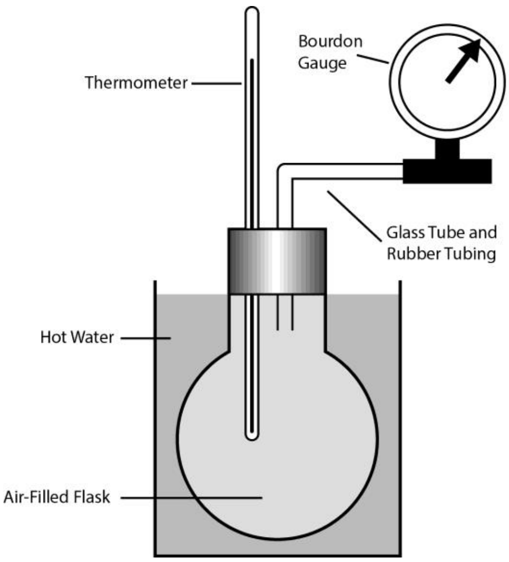
V_1 = 25 litres — $80 \times 25 = 200 \times V_2$

p_2 = 200 kPa — **<u>V_2 = 10 litres</u>**

V_2 = ?

Relationship between Pressure and Temperature of a Gas (Gay-Lussac's Law)

Consider an experiment to determine the relationship between pressure and temperature of a fixed mass and fixed volume of gas.

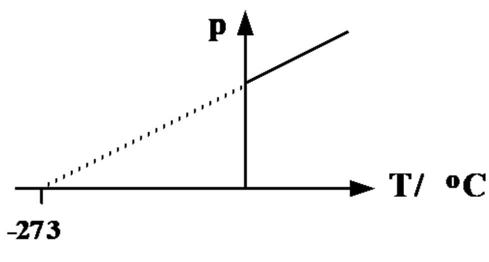


- As the water is heated, the pressure of the gas is measured
- It is found that as the temperature increases, the pressure increases

The flask containing a fixed mass of gas is submerged in a water bath and the temperature slowly increased using an immersion heater. This in turn raises the temperature of the gas within the flask. Readings of the temperature of the gas can be read from the thermometer and corresponding pressure from the bourdon pressure gauge. The results are taken at regular intervals as the temperature of the air in the flask increases.

The volume of the gas remains constant.

If a graph is drawn of pressure against temperature in degrees celsius for a fixed mass of gas at a constant volume, the graph is a straight line which does not pass through the origin. When the graph is extended until the pressure reaches zero, it crosses the temperature axis at -273 ^{o}C. This is true for all gases:



Kelvin Temperature Scale

The temperature $-273^{o}C$ is called **absolute zero** and is the zero on the Kelvin temperature scale. At a temperature of absolute zero, 0 K, all particle motion stops and this is therefore the lowest possible temperature.

One division on the kelvin temperature scale is the same size as one division on the celsius temperature scale, i.e. temperature **differences** are the same in kelvin as in degrees Celsius e.g. a temperature increase of 10°C is the same as a temperature increase of 10 K.

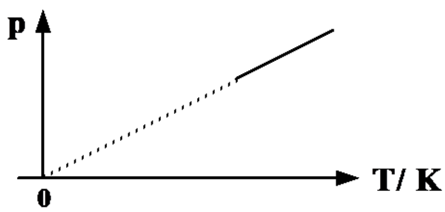
Note: the unit of the kelvin scale is the kelvin, K, **not** degrees kelvin, °K!

Converting temperatures between °C and K

Converting °C to K add 273

Converting K to °C subtract 273

If the graph of pressure against temperature is drawn using the kelvin temperature scale, zero on the graph is the zero on the kelvin temperature scale and the graph now goes through the origin:



Gay Lussac's law states that for a fixed mass of gas at a constant volume, the pressure of a gas is directly proportional to its temperature measured in kelvin (K):

$$p \propto T \qquad \frac{p}{T} = \text{constant} \qquad \frac{p_1}{T_1} = \frac{p_2}{T_2}$$

Example

Hydrogen in a sealed container at 27 °C has a pressure of 1.8×10^5 Pa. If it is heated to a temperature of 77 °C, what will be its new pressure?

$p_1 = 1.8 \times 10^5$ Pa

$T_1 = 27$ °C $= 300$ K

$p_2 = ?$

$T_2 = 77$ °C $= 350$ K

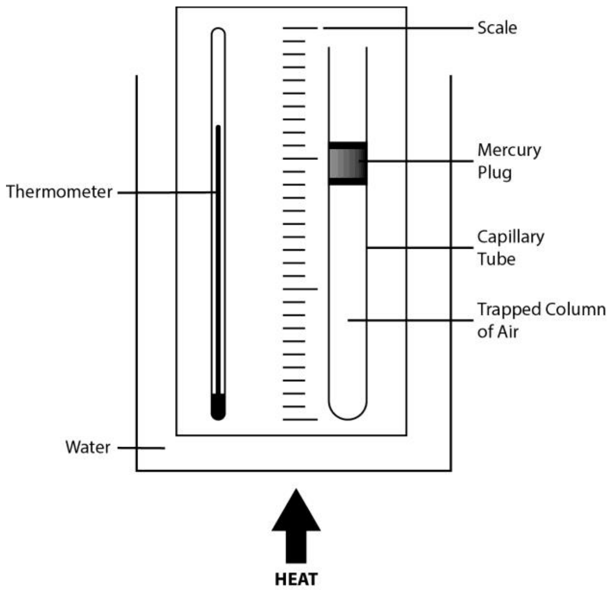
$$\mathbf{p_1 / T_1 = p_2 / T_2}$$

$$1.8 \times 10^5 / 300 = p_2 / 350$$

$$\underline{\mathbf{p_2 = 2.1 \times 10^5\ Pa}}$$

Relationship between Volume and Temperature of a Gas (Charles' law)

Consider an experiment to determine the relationship between volume and temperature of a fixed mass of gas at a constant pressure.



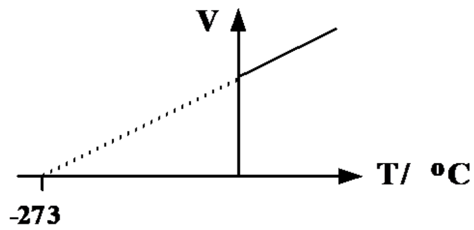
- As the water is heated, the volume of the gas is measured
- It is found that as the temperature increases, the volume increases

A fixed mass of gas is trapped in a glass tube by a mercury plug which is free to move up and down the tube. This keeps the pressure of the trapped gas constant.

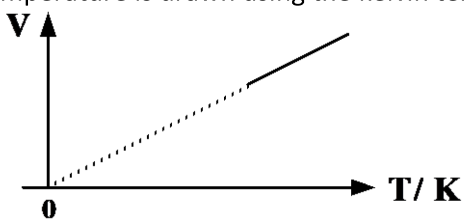
As the water is heated the trapped gas expands and pushes the mercury up the tube. Readings of the volume of trapped air and the corresponding temperature can be taken at regular intervals as the temperature changes (usually increasing).

The length of this trapped gas is taken as a measure of its volume (since the length of the gas is proportional to volume in a tube with a uniform cross section).

If a graph is drawn of volume against temperature, in degrees celsius, for a fixed mass of gas at a constant pressure, the graph is a straight line which does not pass through the origin. When the graph is extended until the volume reaches zero, again it crosses the temperature axis at -273 °C. This is true for all gases



If the graph of volume against temperature is drawn using the kelvin temperature scale, the graph now goes through the origin:



Charles' law states that for a fixed mass of gas at a constant pressure, the volume of a gas is directly proportional to its temperature measured in kelvin (K):

$V \alpha T$	$\frac{V}{T}$ = constant	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Example

400 cm^3 of air is at a temperature of 20 °C. At what temperature will the volume be 500 cm^3 if the air pressure does not change?

V_1 = 400 cm^3

T_1 = 20 °C = 293 K

V_2 = 500 cm^3

T_2 = ?

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

$$\frac{400}{293} = \frac{500}{T_2}$$

T_2 = 366 K = 93 °C

Note: convert back to the temperature scale used in the question

Combined Gas Equation

By combining the above three relationships, the following relationship for the pressure, volume and temperature of a fixed mass of gas is true for all gases.

$$\frac{p \times V}{T} = \text{constant}$$

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

Example

A balloon contains 1.5 m^3 of helium at a pressure of 100 kPa and at a temperature of 27 °C. If the pressure is increased to 250 kPa at a temperature of 127 °C, calculate the new volume of the balloon.

p1 = 100 kPa

V1 = 1.5 m3

T1 = 27 °C = 300 K

p2 = 250 kPa

V2 = ?

T2 = 127 °C = 400 K

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

$$\frac{100 \times 1.5}{300} = \frac{250 \times V_2}{400}$$

V_2 = <u>0.8 m^3</u>

Gas Laws and the Kinetic Theory of Gases

Pressure - Volume (constant mass and temperature)

Consider a volume V of gas at a pressure p. If the volume of the container is reduced without a change in temperature, the particles of the gas will hit the walls of the container more often (but not any harder as their average kinetic energy has not changed). This will produce a larger force on the container walls. The area of the container walls will also reduce with reduced volume. As volume decreases, then the force increases and area decreases resulting in, from the definition of pressure, an increase in pressure i.e. volume decreases hence pressure increases and vice versa.

Pressure - Temperature (constant mass and volume)

Consider a gas at a pressure p and temperature T. If the temperature of the gas is increased, the kinetic energy and hence speed of the particles of the gas increases. The particles collide with the container walls more violently and more often. This will produce a larger force on the container walls. As temperature increases, then the force increases resulting in, from the definition of pressure, an increase in pressure,

i.e. temperature increases hence pressure increases and vice versa.

Volume - Temperature (constant mass and pressure)

Consider a volume V of gas at a temperature T. If the temperature of the gas is increased, the kinetic energy and hence speed of the particles of the gas increases. If the volume was to remain constant, an increase in pressure would result as explained above. If the pressure is to remain constant, then the volume of the gas must increase to increase the area of the container walls that the increased force is acting on, i.e. volume decreases hence pressure increases and vice versa.

Heat Energy

Heat and temperature are often confused. Heat is a form of energy and is measured in Joules (J).

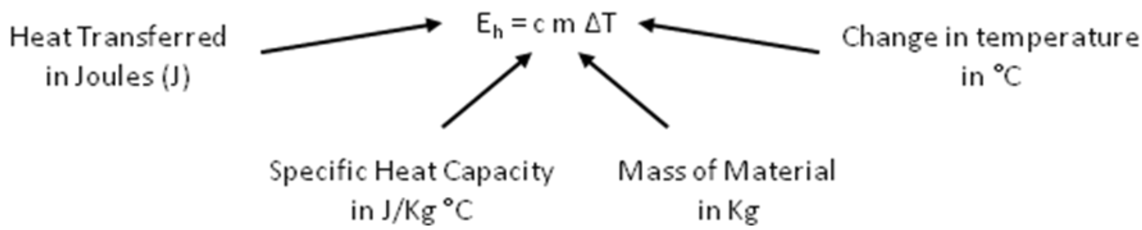
If a substance gains heat, its temperature can increase. If a substance loses heat, its temperature can decrease.

The temperature of a substance is a measure of the average kinetic energy of the particles in that substance.

Specific heat capacity

The same mass of different materials needs different quantities of heat energy to change their temperature by one degree Celsius. The ability of different substances to store different amounts of heat energy is known as the specific heat capacity of that substance. The **specific heat capacity** of a substance is defined as the amount of heat energy required to change the temperature of 1 kg of a substance by 1 °C.

Specific heat capacity is calculated using the formula:



The unit for specific heat capacity is the joule per kilogram degree Celsius ($Jkg^{-1}\ °C^{-1}$).

Example

When a kettle containing 2 kg of water (specific heat capacity 4180 J/kg °C) cools from 40 °C to 20 °C, calculate the heat given out by the water.

Solution

$c = 4180$ J/kg °C
$m = 2$ kg
$T_2 = 40$ °C
$T_1 = 20$ °C
} $\Delta T = 40 - 20$
$E_h = ?$

$E_h = cm\Delta T$
$= 4180 \times 2 \times 20$
$= \underline{167200 \text{ J}}$

Conservation of Energy (Heat)

Energy can be changed from one form to another. The principle of conservation of energy states that no energy is lost during this process. Therefore the total amount of energy before transformation is the same as the total amount of energy after transformation.

Heat energy can be produced from electrical energy in devices and appliances containing a heater:

Some of the heat energy supplied by the heater will be "lost" to the surroundings. However, heat lost to the surroundings can ignored in some heat problems

Therefore, the energy supplied by the heater = energy absorbed by the material

Example 1

A kettle heats 0.8 kg of water (c_{water}= 4180 J/KgºC) and raises its temperature from 16 ºC to 100 ºC. If it takes 2 minutes to reach the final temperature, calculate the power rating of the kettle.

Solution

Step 1

c = 4180 J/KgºC
m = 0.8 kg
ΔT = 84 ºC
E_h = ?

E_h = c m ΔT
= 4180 x 0.8 x 84
= 282240 J
= **280896J**

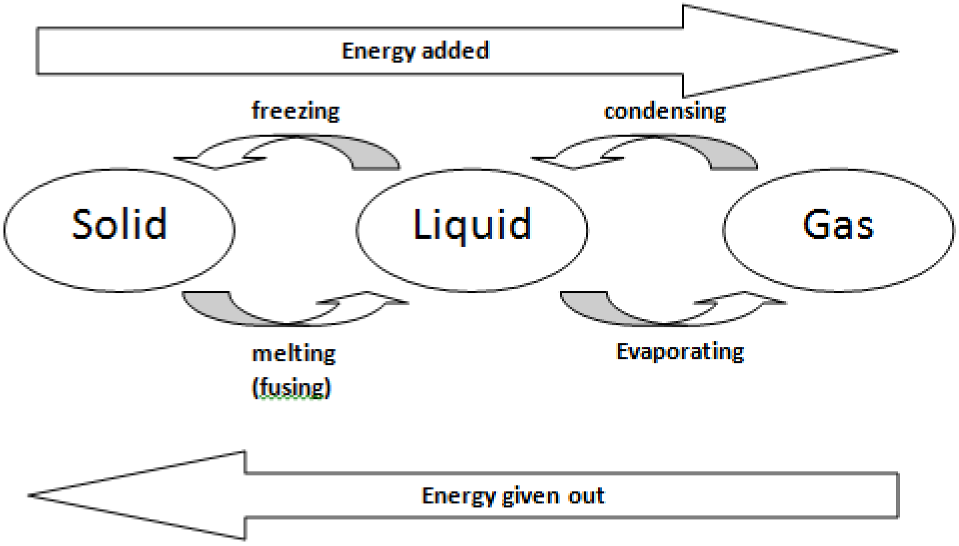
Step 2

P = ?
t = 2 mins = 120 s
E = 282240 J

P = E / t
= 280896 / 120
= 2341 W

Latent Heat

Changes of State



During a change of state, energy is either added or given out as shown in the diagram above

During a change of state, there is no change in temperature until the change of state of state is complete.

Specific Latent Heat

The specific latent heat of a substance is the energy involved in changing the state of 1 kg of the substance without any temperature change. Specific latent heat of a substance is calculated using the formula:

heat transferred — $E_h = m\,l$ — specific latent heat

mass of material

The specific latent heat of vaporisation is the heat energy required to change 1 kg of liquid to vapour without temperature change.

The specific latent heat of fusion is the heat energy required to change 1 kg of a solid to liquid without change in temperature.

The unit for specific latent heat is the joule per kilogram, Jkg^{-1}.