Gleniffer High School

National 5

Electricity and Energy

Summary Notes

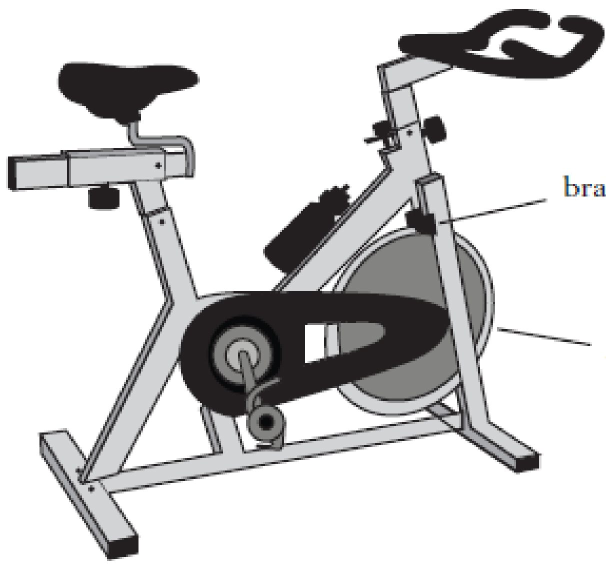
Name:____________________

Principle of Conservation of Energy

Energy cannot be created or destroyed, but it can be changed from one type into another type. All forms of energy are measured in the same unit –the **joule (J)**.

Machines can be used to change one type of energy into another type of energy. For example, an electrical motor will change electrical energy into kinetic energy. However, not all the electrical energy which is supplied to the motor will be changed into the final useful form of energy. Some electrical energy will be changed into heat energy due to friction and some electrical energy will be changed into sound energy. This makes the machine inefficient.

In this machine there will be friction between the wheel and the brake.



Efficiency is measured by expressing the useful energy output as a percentage of the total energy input.

Formula for efficiency

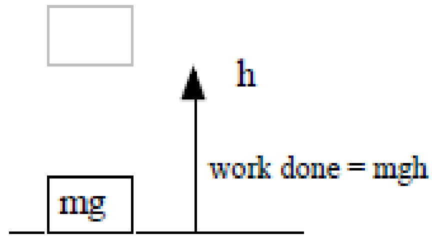
$$\% \text{ Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times \frac{100}{1}$$

Power is the rate of energy transfer. This means the above equation can also be applied to power rather than energy.

Gravitational Potential Energy

An object which is raised up to a high position is said to have gravitational potential energy.
The work done against gravity to raise it equals the energy transformed into potential energy.

Imagine a mass of m kg lifted through a height of h metres:



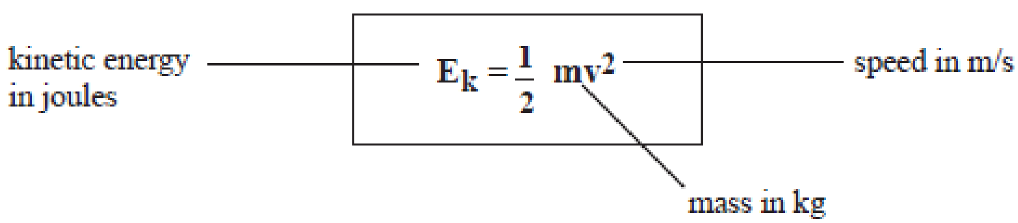
Force needed = weight of m kg = mg newtons
Work done = force x distance = mg x h
potential energy = **mgh joules**

$$E_p = mgh$$

where,
E_p is gravitational potential energy measured in joules (J)
m is mass measured in kilograms (kg)
g is gravitational field strength, which has a value of $9.8Nkg^{-1}$ on planet Earth
h is the height measured in metres (m)

Kinetic Energy

Kinetic Energy is the energy associated with a moving object. It is measured in joules and has the symbol E_k.
The kinetic energy of a moving object depends on the mass of the object and on the square of its speed.



Notes

The unit of kinetic energy is the **joule** which is normally written as a **J.**
The unit for speed is **metres per second** which is normally written as $\mathbf{ms^{-1}}$.

<u>REMEMBER</u>

THE PRINCIPLE OF CONSERVATION OF ENERGY STATES THAT, THE TOTAL ENERGY REMAINS CONSTANT DURING ENERGY CHANGES. ENERGY CANNOT BE CREATED OR DESTROYED BUT IS CHANGED INTO ONE OF ITS MANY TYPES.

Example One

A student lifts a textbook of mass 0.35kg, 0.9m from the floor to her desk.
a) What is the value of the gravitational potential energy gained by the textbook?
b) The textbook falls off the desk, with what speed will it hit the floor?

a)

E_p = ? m = 0.35kg g = 9.8Nkg^{-1} h = 0.9m

$$E_p = mgh$$
$$E_p = 0.35 \text{ x } 9.8 \text{ x } 0.9$$
$$E_p = 3.087$$
$$E_p = 3.1\text{J}$$

b) By applying the principle of conservation of energy, the gravitational potential energy lost by the textbook will be equal to the kinetic energy that it gains.

$$E_p \text{ lost} = E_k \text{ gained}$$

E_k gained = 3.1J m = 0.35kg v = ?

$$E_k = 0.5 \text{ x m x } v^2$$
$$3.1 = 0.5 \text{ x } 0.35 \text{ x } v^2$$
$$3.1 = 0.175 \text{ x } v^2$$
$$v^2 = 17.7$$
$$v = 4.2\text{ms}^{-1}$$

Example Two

A 400W electric motor is to be used to lift a 190kg crate on to the back of a van. The crate must be 1.6m above the ground before it can be loaded onto the van. If the motor operates for 8 seconds, can the crate be placed on the back of the van?

Firstly calculate the energy supplied by the electric motor.

P = 400W t = 8s E = ?

$$E = P \text{ x } t$$
$$E = 400 \text{ x } 8$$
$$E = 3200\text{J}$$

Assume all the energy supplied is changed into gravitational potential energy. (This is very unlikely as the motor will be making heat energy and sound energy.)

$$E \text{ supplied} = E_p \text{ gained}$$

E_p = 3200J m = 190kg g = 9.8Nkg^{-1} h = ?

$$E_p = m\ g\ h$$
$$3200 = 190 \text{ x } 9.8 \text{ x h}$$
$$3200 = 1862 \text{ x h}$$
$$h = 1.7\text{m}$$

As 1.7m is greater than 1.6m the crate will be able to go on the back of the van.

Work

The work done is a measure of the energy transformed. It is equal to the force multiplied by the distance the force moves. The force and distance must be measured in the **same direction**.

Work is measured in the same units as energy: joules. The symbol for work is E_w.

The equation for calculating work done is…

$$\mathbf{E_w = F \times d}$$

where,

E_w is the work done (or energy transferred) measured in joules (J)

F is the force measured in newtons (N)

d is the distance in metres (m)

Example

A dog pulls a 4 kg sledge for a distance of 15 m using a force of 30 N.
How much work does the dog do?

$F = 30\ N \qquad Ew = F \times d$

$d = 15\ m \qquad\quad = 30 \times 15$

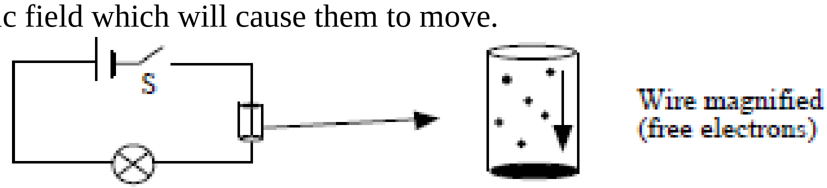
$\qquad\qquad\qquad\quad = 450\ J$

Work done is 450 J. (Note that the mass was not required.)

Electric Current

Materials can be divided into two main groups – conductors and insulators. In a conductor the electrons are free to move through the structure, but in an insulator the electrons are not free to move through the structure.

In the following circuit, when switch, S, is closed the free electrons in the wire (a conductor) will experience an electric field which will cause them to move.



This flow of electrons is known as an electric current. Electric current depends on the number of electrons passing a point in a circuit in a second.

$$\mathbf{I = \frac{Q}{t}} \quad \text{or} \quad \mathbf{Q = I\,t}$$

where,

I is the current measured in amperes (A)

Q is the charge measured in coulombs (C)

t is the time measured in seconds (s)

Example

Calculate the electric current in a circuit if 3 C of charge pass a point in a circuit in a time of 1 minute.

Ensure that all quantities are stated with the correct units.

$I = ? \qquad Q = 3\ C \qquad t = 1\ min = 60\ s$

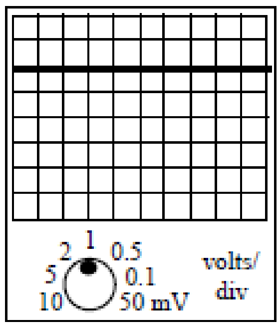
$$I = \frac{Q}{t} = \frac{3}{60} = 0.05\ A$$

Alternating Current (a.c.) and Direct Current (d.c.)

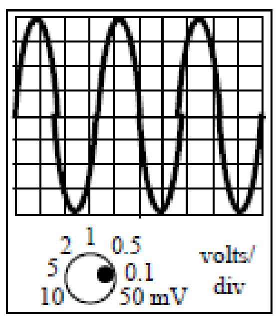
All power supplies can be grouped into two categories depending on the way they supply energy to the charges in a circuit.
A d.c. supply produces a flow of charge in one direction only. The symbol for a d.c. supply is shown below:-

An a.c. supply produces a flow of charge in a circuit that regularly reverses direction. The symbol for an a.c. supply is shown below:-

A CRO can be used to display the voltage from both types of supply.
A d.c. supply would produce a horizontal trace.



Whereas, an a.c. supply would produce a trace that shows alternating peaks and troughs.

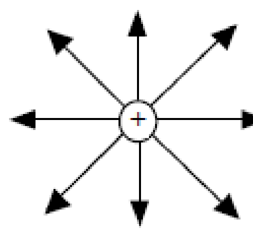


Electric Fields

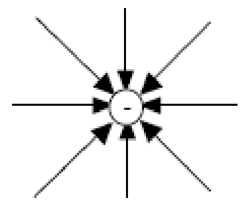
In an electric field, a charged particle will experience a force. We use lines of force to show the strength and direction of the force. The closer the field lines the stronger the force. Field lines are continuous - they start on positive and finish on negative charge. The direction is taken as the same as the force on a **positive** "test" charge placed in the field.

Electric Field Patterns

Positive point charge

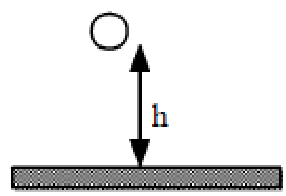


Negative point charge



These are called radial fields. The lines are like the radii of a circle. The strength of the field decreases as we move away from the charge.

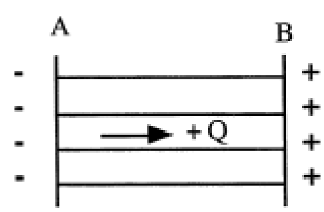
Gravitational Fields



If a mass is lifted or dropped through a height then work is done i.e. energy is changed.
If the mass is dropped then the energy will change to kinetic energy.
If the mass is lifted then the energy will change to gravitational potential energy.

Change in gravitational potential energy = work done.

Electric Fields



Consider a negative charge moved through a distance in an electric field. If the charge moves in the direction of the electric force, the energy will appear as kinetic energy. If a positive charge is moved against the direction of the force as shown in the diagram, the energy will be stored as electric potential energy.

Change in electric potential energy = work done

If the charge moved is one coulomb, then the work done is the potential difference or voltage.

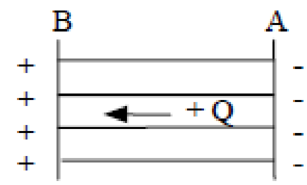
If one joule of work is done in moving one coulomb of charge between two points in an electric field, the potential difference, (p.d.) between the two points is one volt.

1 volt = 1 joule per coulomb

$$W = QV$$

In this section W will be used for the work done i.e. energy transferred.

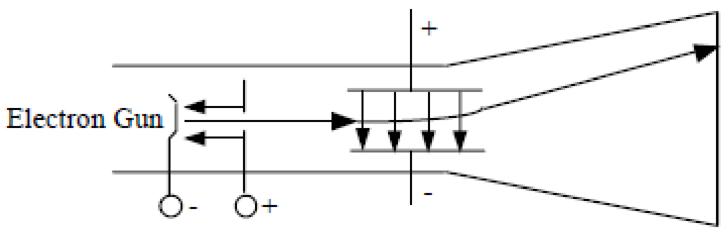
Example:
A positive charge of 3 μC is moved, from A to B, between a potential difference of 10 V.
(a) Calculate the electric potential energy gained.
(b) If the charge is now released, state the energy change.
(c) How much kinetic energy will be gained on reaching the negative plate?



(a) $W = QV = 3 \times 10^{-6} \times 10$
$= 3 \times 10^{-5}$ J
(b) *Electric potential energy to kinetic energy*
(c) *By conservation of energy the energy will be the same, i.e.* 3×10^{-5} *J.*

Applications of Electric Fields

A cathode ray oscilloscope (CRO) uses electric fields acting on electrons.

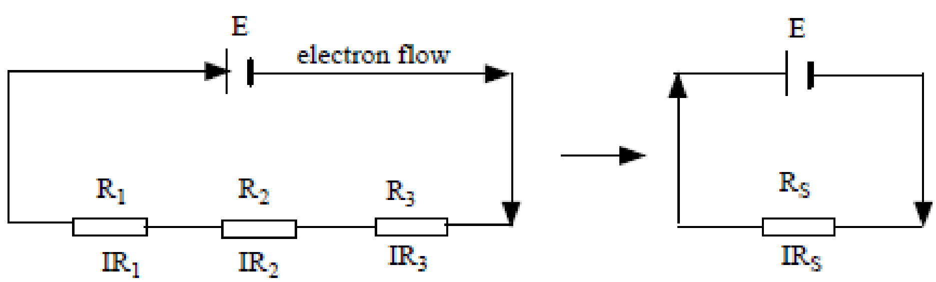


Electrostatic Spraying makes use of electric fields. Paint or powder particles are blown from a nozzle, where they acquire a charge. The object to be coated is earthed. The charged paint or powder particles follow the field lines and so reach the object, some reaching the back of the object as well as the front.

Other applications include photocopiers, ink jet and laser printers.

Conservation of Energy and Resistors in Series

The principle of conservation of energy can be applied to a circuit containing resistors in series.



where,
E is the energy supplied by the source
R_s is the equivalent series resistance

By applying the **conservation of energy** to one coulomb of charge. . .

Energy supplied by source = Energy converted by the circuit components

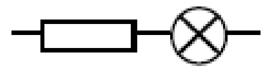
$$E = IR_1 + IR_2 + IR_3$$

$$IR_s = IR_1 + IR_2 + IR_3$$

$$\mathbf{R_s = R_1 + R_2 + R_3}$$

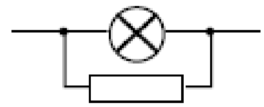
Series and Parallel Circuits

Components in a circuit can be connected in series or parallel.
A series arrangement of components is where they are **in-line** with each other, that is connected end-to-end.



Series

A **parallel** arrangement of components is where they are connected **across** each other where the current has more than one path through that part of the circuit.

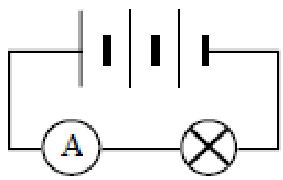


Parallel

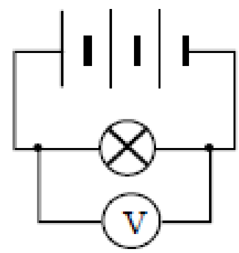
Measuring Current and Potential Difference or Voltage

Electric current is measured using an **ammeter** which is connected **in series** with the component.
Potential difference (p.d.), or voltage, is measured using a **voltmeter** which is connected **in parallel** with the component.

Measuring the **current through** the lamp

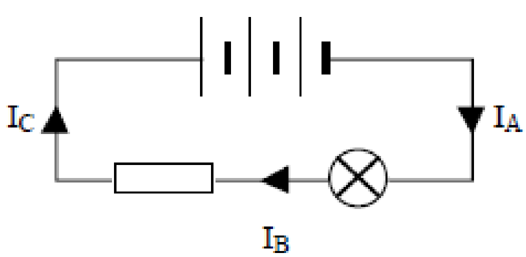


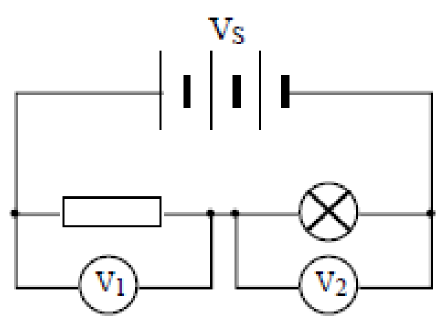
Measuring the **voltage (p.d.)** across the lamp



Current and Potential Difference or Voltage in Series Circuits

The current is the same at all points in a series circuit.
The sum of the potential differences across the components in a series circuit is equal to the voltage of the supply.



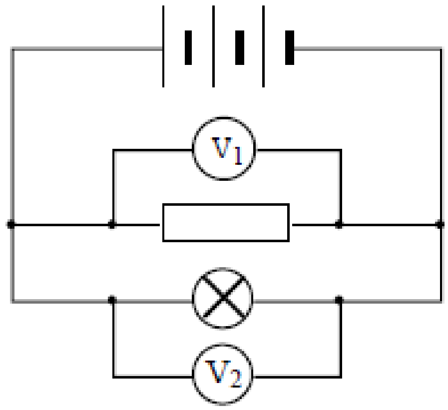


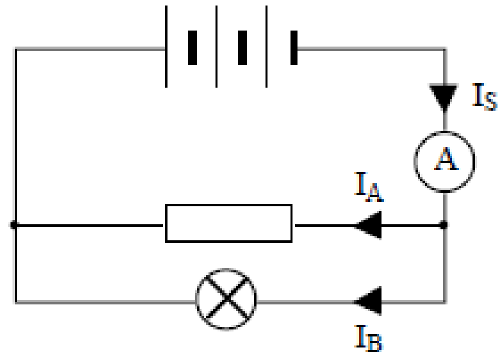
$$I_A = I_B = I_C$$

$$V_S = V_1 + V_2$$

Current and Potential Difference or Voltage in Parallel Circuits

The potential difference across components in parallel is the same for all components.
The sum of the currents in parallel branches is equal to the current drawn from the supply.





$$V_1 = V_2$$

$$I_S = I_A + I_B$$

Electrical Resistance

Resistance is a measure of the opposition of a circuit component to the flow of charge or current through that component. The greater the resistance of a component, the less will be the current through that component.
All normal circuit components have resistance and the resistance of a component is measured using the relationship

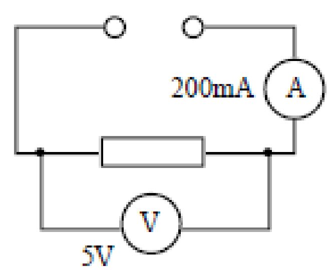
$$R = \frac{V}{I} \quad \text{or} \quad V = IR$$

R = resistance
V = potential difference (voltage)
I = current

Resistance is measured in ohms, Ω.
Potential difference (or voltage) is measured in volts, **V**.
Current is measured in amperes, **A**.
This relationship is known as **Ohm's Law**, named after a German physicist, Georg Ohm.
For components called **resistors**, the resistance remains approximately constant for different values of current therefore the ratio **V/I** (= R) remains constant for different values of current.

Example

Calculate the resistance of the resistor in the diagram opposite.
Ensure that all quantities are stated in the correct units.



$R = ?$
$V = 5\ V$
$I = 200\ mA = 0.2\ A$

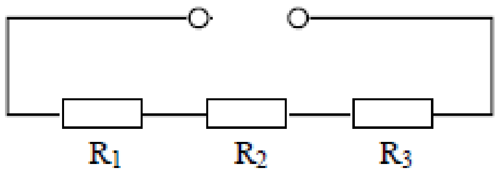
$$R = \frac{V}{I} = \frac{5}{0.2} = 25\ \Omega$$

Resistors in Series

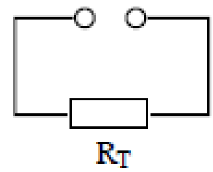
When more than one component is connected in series, the **total resistance** of all the components is equivalent to one single resistor, R_T, calculated using the relationship

$$R_T = R_1 + R_2 + R_3$$

For the following circuit with three components in series,



is equivalent to



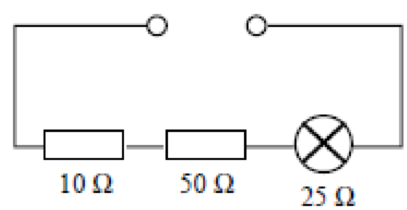
The above relationship is true for two or more components connected in series.

Resistors in Parallel

When more than one component is connected in parallel, the **total resistance** of all the components is equivalent to one single resistor, R_T, calculated using the relationship

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Example 1 Components in series
Calculate the total resistance of the circuit opposite.



$R_1 = 10\ \Omega$
$R_2 = 50\ \Omega$
$R_3 = 25\ \Omega$

$R_T = R_1 + R_2 + R_3$
$R_T = 10 + 50 + 25 = 85\ \Omega$

Example 2 Components in parallel
Calculate the total resistance of the components above when connected in parallel.

$R_1 = 10\ \Omega$
$R_2 = 50\ \Omega$
$R_3 = 25\ \Omega$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{10} + \frac{1}{50} + \frac{1}{25}$$

$$= \frac{5}{50} + \frac{1}{50} + \frac{2}{50} = \frac{8}{50}$$

$$\frac{1}{R_T} = \frac{8}{50} \quad \textit{therefore} \quad \frac{R_T}{1} = \frac{50}{8} \qquad R_T = 6.5\ \Omega$$

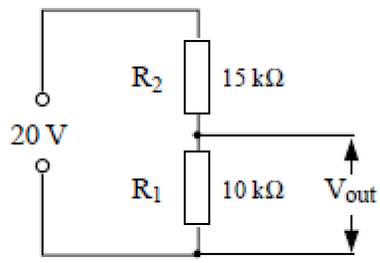
Note:

For components in series, R_T is **always** greater than the largest resistance.
For components in parallel, R_T is **always** less than the smallest resistance.

Example

For the circuit shown below calculate the following:-

a) The total resistance of the circuit.
b) The current flowing through the 15kΩ resistor.
c) V_{out}, the voltage (p.d.) across the 10 kΩ resistor.
d) The voltage (p.d.) across the 15kΩ resistor.



This is a series circuit, so Ohm's Law and the following rules can be applied.

- $R_T = R_1 + R_2$
- Current is the same at all points in the circuit
- The sum of the component voltages is equal to the supply voltage.

a) $R_T = R_1 + R_2$
$R_T = 15\text{k}\Omega + 10\text{k}\Omega$
$R_T = 25\ \text{k}\Omega$

b) $V_{supply} = 20\text{V}$ $R_T = 25\ \text{k}\Omega$ $I = ?$
$V = I \times R$
$20 = I \times 25\text{x}10^3$
$I = 8\text{x}10^{-4}\text{A}$
$I = 0.8\text{mA}$

c) $V_{out} = ?$ $I = 0.8\text{mA}$ $R = 10\text{k}\Omega$
$V = I \times R$
$V = 8\text{x}10^{-4} \times 10\text{x}10^3$
$V = 8\text{V}$

d) $V_s = V_1 + V_2$
$20 = V_1 + 8$
$V_1 = 12\text{V}$

ELECTRICAL ENERGY

In the earlier section on potential difference, it was stated that the potential difference of the supply is a measure of the energy given to the charges in the circuit.
The energy carried by these charges around the circuit is then converted to other forms of energy by the components in the circuit. Electrical components are devices that change or transform the electrical energy from the supply to the circuit into other forms of energy.
If energy is supplied to the charges in the circuit, then an electric current exists and there is an energy transformation in each of the components in the circuit.

Examples

An electric lamp is designed to emit light energy. This happens because the electric current passing through the filament causes it to get hot; hot enough to glow and emit light. A lamp therefore transforms electrical energy to heat and light energy.
An electric bar fire works in a similar way. The bar of the fire is made from a length of resistance wire similar to the filament of a lamp. The resistance wire is designed to get hot when a current passes through it. It also glows when it is hot, but not as much as the filament of the lamp.

Energy Units

Electrical energy, like all forms of energy, has the symbol **E** and is measured in **joules**, **J**.

Power and Energy

To compare different components, it is often useful to compare the **rate** at which energy is transformed, that is the energy transformed **each second**.
This electrical energy transformed each second is known as the **power**.

$$P = \frac{E}{t} \quad \text{or} \quad E = Pt$$

P = power
E = energy
t = time

Units

Power is measured in watts, **W**.
Energy is measured in joules, **J**.
Time is measured in seconds, s.
1 watt is equivalent to the transfer of 1 joule per second.

Example

If an electric fire uses 1.8 MJ of energy in a time of 10 minutes, calculate the power output of the fire.
Ensure that all quantities are stated with the correct units.

$P = ?$
$E = 1.8\ MJ = 1.8 \times 10^6\ J$
$t = 10\ min = 600\ s$

$$P = \frac{E}{t} = \frac{1.8 \times 10^6}{600} = 3000\ W$$

Power Current and Voltage

Electrical power is also dependent on the potential difference across the component and the current through it. If 1 volt across a component pushes a current of 1 ampére, then the power will be 1 watt.

$$\boxed{\mathbf{P = V\,I}}$$

P = power in watts
V = voltage or potential difference in volts
I = current in ampéres

Example

A 230 V toaster draws a current of 4 A from the mains supply. Calculate the power output of this toaster.

P = ?
V = 230 V
I = 4 A

$$P = V I = 230 \times 4 = 920\ W$$

More Power Equations

Using the equation **P = V I** and Ohm's Law equation **V = I R**, we are able to obtain -

$$P = V\,I$$

but $V = I\,R$ and $I = \frac{V}{R}$

therefore $P = (I\,R) \times I$ and $P = V \times \frac{V}{R}$

tidying up $\boxed{\mathbf{P = I^2R}}$ and $\boxed{\mathbf{P = \frac{V^2}{R}}}$

Example

A component data book states that a 1 kΩ resistor can safely handle a power output of 0.4 W.

a) What is the maximum current it can safely handle?

b) What potential difference would exist across the resistor at this current?

a) *I = ?*
P = 0.4 W
R = 1 kΩ = 1000 Ω

$$I^2 = \frac{P}{R} = \frac{0.4}{1000} = 4x10^{-4}$$

$$I = 0.02\ A$$

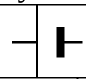
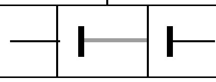
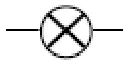
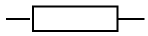
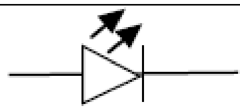
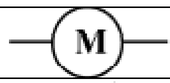
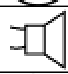
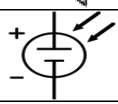
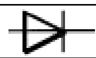
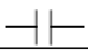
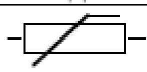
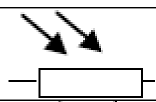
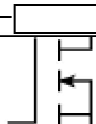
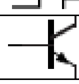
b) *V = ?*
P = 0.4 W
R = 1000 Ω
I = 0.02 A

$$V^2 = P\,R = 0.4 \times 1000 = 400$$

or

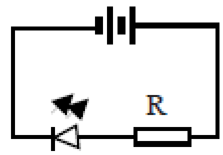
$$V = I\,R = 0.02 \times 1000$$
$$V = 20\ V$$

$$V = 20\ V$$

Component	Symbol	Description
cell		Supplies electrical energy
battery		Supplies electrical energy
lamp		Converts electrical energy to light energy
switch		Open – breaks a circuit Closed – completes a circuit
resistor		Opposes current; converts electrical energy into heat energy
variable resistor		A resistor whose resistance can be changed
voltmeter		Used to measure voltage; always connected in parallel
ammeter		Used to measure current; always connected in series
LED		Output device; converts electrical energy into light energy
motor		Output device; converts electrical energy into kinetic energy
loudspeaker		Output device; converts electrical energy into sound energy
photovoltaic cell		Light activated cell; used in solar panels
fuse		A protection device; melts when current gets too high
diode		Allows current to flow in one direction only
capacitor		Used to store electrical charge
thermistor		Input device; resistance lowers when its temperature is increased
LDR		Input device; resistance lowers when it is in brighter conditions
MOSFET		Process device; behaves like an automatic switch
NPN transistor		Process device; behaves like an automatic switch

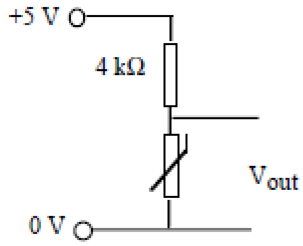
Electronic Circuits

An LED is a small, usually plastic, output device that is often used as a warning indicator on an appliance. In a circuit diagram the LED is always shown with a series resistor. The series resistor prevents large currents flowing through the LED. This ensures that the LED will not melt.



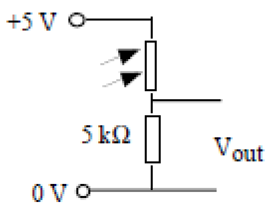
Note that the current in the above circuit will flow into the vertical line on the LED symbol. If the LED was reversed, current would not be able to flow and it would not light up.

A thermistor is an input device that is often used in temperature sensing circuits. When the temperature around a thermistor is increased its resistance will decrease and vice versa.



In the above circuit the reading at V_{out} will increase as the temperature around the thermistor decreases. This increase in V_{out} could allow another component or circuit to be activated. This is the principle behind frost detection circuits.

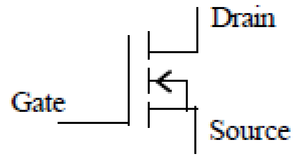
An LDR is an input device that is often used in light sensing circuits. The resistance of an LDR will increase when the light level around it decreases and vice versa.



In the above circuit as the light level increases, the resistance of the LDR will decrease. This means that there will be less voltage needed across the LDR. As the available voltage has to be shared out between the LDR and the resistor, the voltage V_{out} will increase. This increase in V_{out} could allow another component or circuit to be activated. This is the principle behind automatic blinds.

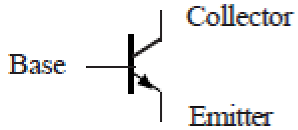
Transistors

N-channel enhancement MOSFET (Metal Oxide Semiconductor Field Effect Transistor).
Symbol:

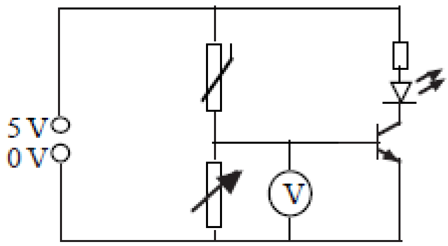


For a typical MOSFET when the voltage across the gate and source reaches 1.8V it will switch on.

NPN Transistor.
Symbol:



For a typical NPN transistor when the voltage across the base and emitter reaches 0.7V it will switch on.

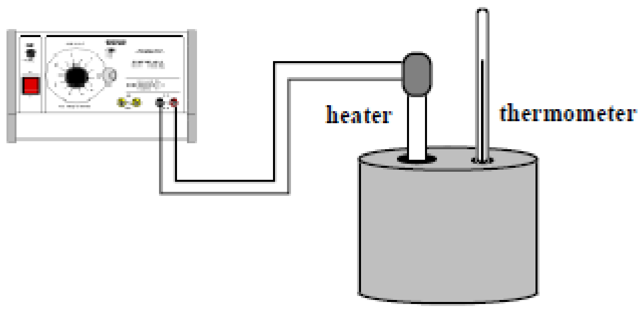


In the above circuit, when the temperature increases the resistance of the thermistor will decrease. This means there will be less voltage needed across the thermistor. As the available voltage has to be shared out between the thermistor and the variable resistor, the voltmeter reading will increase.
When the reading reaches 0.7V the NPN transistor will be able to switch on. This will allow the LED to light up. So this circuit could be used to give a warning when the temperature gets too high e.g. an incubator.

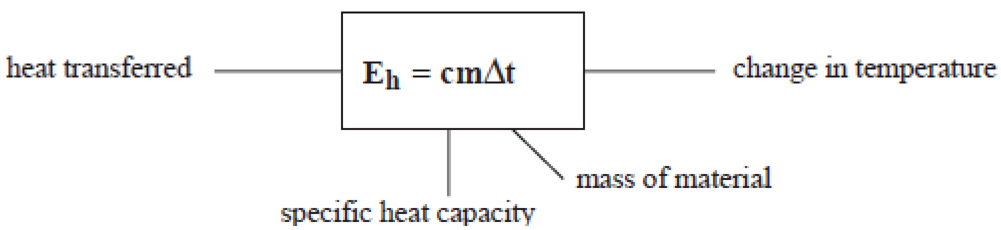
Heat and Temperature

Temperature is a measure of how hot or cold something is. Temperature is measured in units called degrees celsius (^{0}C).
Heat is a type of energy. Heat is measured in units called joules (J) or kilojoules (kJ).

The following experiment could be carried out to show the heat energy required by one kilogram of a material to increase its temperature by $1^{0}C$. This value is known as the material's **specific heat capacity (c).**



Specific heat capacity is calculated using the following equation:-



where,
E_h is heat energy measured in joules (J)
c is specific heat capacity measured in Joules per kilogram degrees celsius ($Jkg^{-10}C^{-1}$)
m is the mass measured in kilograms (kg)
ΔT is the change in temperature measured in degrees celsius (^{0}C)

Example
When a kettle containing 2.5kg of water ($c_{water} = 4180Jkg^{-10}C^{-1}$) is heated from $20^{0}C$ to $80^{0}C$, calculate the heat taken in by the water.

$E_h = ?$ $c_{water} = 4180Jkg^{-10}C^{-1}$ $m = 2.5kg$ $\Delta T = (80 - 20)$

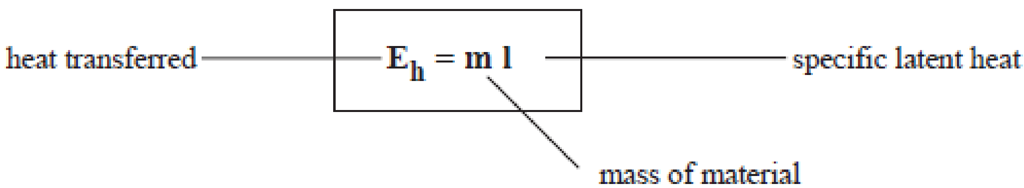
$$E_h = c \times m \times \Delta T$$
$$E_h = 4180 \times 2.5 \times (80 - 20)$$
$$E_h = 4180 \times 2.5 \times 60$$
$$E_h = 627{,}000J$$
$$E_h = 627kJ$$

Changes of State

When ice at its melting point of 0 °C gains heat energy, it changes into water, also at 0 °C. When the process is reversed, water at its freezing point of 0 °C changes into ice at 0 °C. In this case energy is released with no change in temperature.

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:



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})

Example
Ammonia of mass 5kg is vaporised using 13kJ of heat energy. Calculate the specific latent heat of vaporisation of ammonia.

E_h = 13kJ or 13,000J m = 5kg l = ?

$$E_h = m \times l$$
$$13{,}000 = 5 \times l$$
$$l = 2{,}600 Jkg^{-1}$$

Pressure

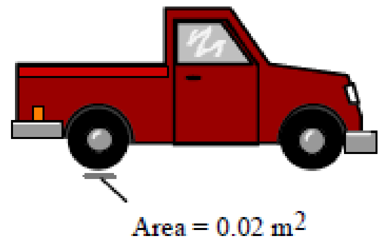
Pressure on a surface is defined as the force acting normal (perpendicular) to the surface.

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

p = pressure in pascals, Pa
F = normal force in newtons, N
A = area in square metres, m^2

1 pascal is equivalent to 1 newton per square metre; ie 1 Pa = 1 N m^{-2}.

Example
Calculate the pressure exerted on the ground by a truck of mass 1600 kg if each wheel has an area of 0.02 m^2 in contact with the ground.



Total area A = 4 × 0.02 = 0.08 m^2
Normal force F = weight of truck = mg = 1600 × 9.8 = 15680 N

p = ?
F = 15680 N
A = 0.08 m2

$$p = \frac{F}{A} \quad \frac{15680}{0.08}$$

= 196,000 Pa or 196 kPa

GAS LAWS

Kinetic Theory of Gases

The kinetic theory tries 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 which are far apart and which move randomly at high speeds, colliding elastically with everything they meet.

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 gas depends on the kinetic energy of the gas particles. The faster the particles move, the greater their kinetic energy and the higher the temperature.

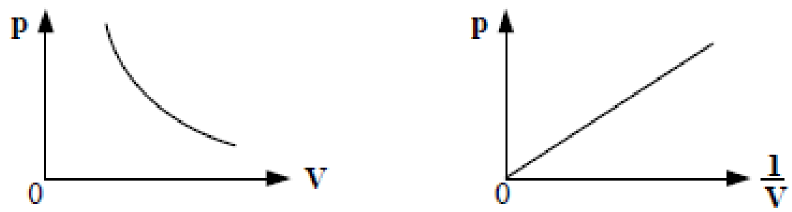
Pressure The pressure of a gas is caused by the particles colliding with the walls of the container. The more frequent these collisions or the more violent these collisions, the greater will be the pressure.

Relationship Between Pressure and Volume of a Gas

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



***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.

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	$V_2 = 10$ litres
$V_2 = ?$	

Kelvin Temperature Scale

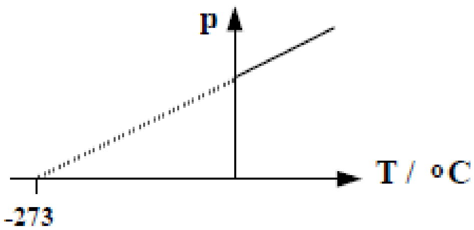
-273°C is called **absolute zero** and is the zero on the kelvin temperature scale. At a temperature of absolute zero, 0 K, all particle motion stops and this is therefore the lowest possible temperature.
One division on the kelvin temperature scale is the same size as one division on the celsius temperature 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

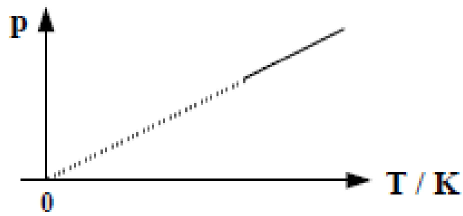
Converting °C to K	add 273
Converting K to °C	subtract 273

Relationship Between Pressure and Temperature of a Gas

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 °C. This is true for all gases.



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.



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).

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

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.

Example

Hydrogen in a sealed container at 27^0C has a pressure of 1.8×10^5Pa. If it is heated to a temperature of 77^0C, what is its new pressure?

$p_1 = 1.8 \times 10^5$Pa $\quad T_1 = 27^0C = 300K \quad p_2 = ? \quad T_2 = 77^0C = 350K$

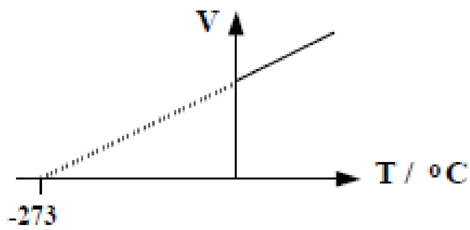
$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

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

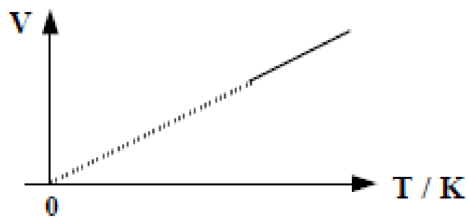
$$p_2 = 2.1 \times 10^5 \text{Pa}$$

Relationship Between Volume and Temperature of a Gas

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.



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).

$V \propto T$ $\qquad$ $\frac{V}{T} = \text{constant}$ $\qquad$ $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

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.

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?

$V_1 = 400\ cm^3$

$T_1 = 20\ °C = 293\ K$

$V_2 = 500\ cm^3$

$T_2 = ?$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad \frac{400}{293} = \frac{500}{T_2}$$

$T_2 = 366\ K = 93\ °C$ (convert back to temperature scale 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.

$$\frac{p \times V}{1} = \text{constant} \qquad \frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

Example
A balloon contains 1.5 m³ 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.

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

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

$$V_2 = 0.8 \text{ m}^3$$

Equations required for this topic

$Q = It$

$V = IR$

$R_{total} = R_1 + R_2 + R_3$ etc

$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ etc

$\frac{V_1}{V_2} = \frac{R_1}{R_2}$

$V_2 = \left(\frac{R_2}{R_1 + R_2}\right)V_1$

$P = E/t$

$P = IV$

$P = I^2R$

$P = V^2/R$

$\% \text{ efficiency} = \frac{\text{useful } E_o}{E_i} \times 100\%$

$\% \text{ efficiency} = \frac{\text{useful } P_o}{P_i} \times 100\%$

$E_h = Cm\Delta T$

$E_h = ml$

$P = F/A$

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$E_p = mgh$

$E_k = ½ mv^2$