Gleniffer High School

National 5

Electricity

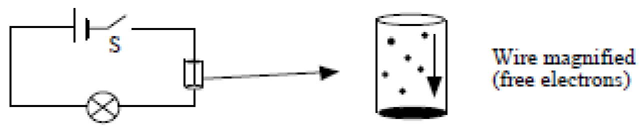
Summary Notes

Name: ______________________________

ELECTRICAL CHARGE CARRIERS

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.

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

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 3C of charge pass a point in a circuit in a time of one minute.

I = ?   Q = 3C   t = one minute = 60s

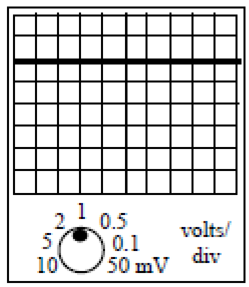
I = Q / t
I = 3 / 60
I = 0.05A

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

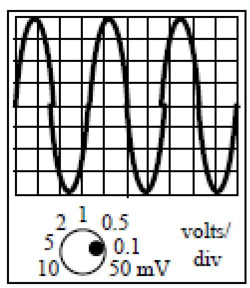
All power supplies can be grouped into tow categories depending on the way they supply energy to the charges in a circuit.
A d.c. supply produces a flow of charge in one direction only. The symbol for a d.c. supply is shown below:-

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.



The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.

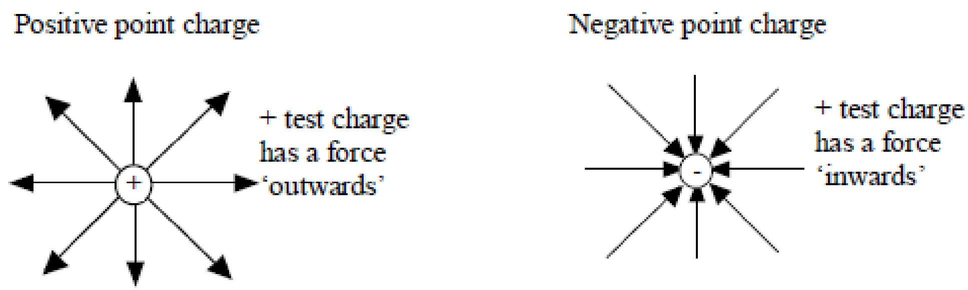
Year	Section One	Section Two
2015	No examples	2 b ii)
2016	No examples	1
2017	2	1 b)
2018	11	6 c)
2019	8	No examples

POTENTIAL DIFFERENCE (VOLTAGE)

Electric Fields

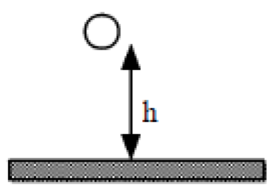
In an electric field, a charged particle will experience a force. We use lines of force to show the strength and direction of the force. The closer the field lines the stronger the force. Field lines are continuous - they start on positive and finish on negative charge. The direction is taken as the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

Electric Field Patterns



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.

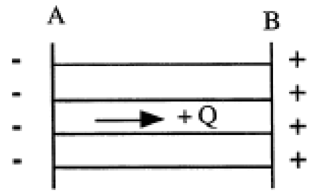
Gravitational Fields



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.

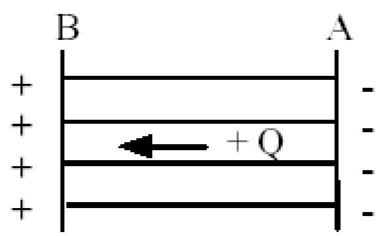
1 volt = 1 joule per coulomb

$$W = QV$$

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

Example

A positive charge of 3μC is moved, from A to B, between a potential difference of 10V.



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?

Solution

a)

$W = ?$ $Q = 3\mu C = 3 \times 10^{-6} C$ $V = 10V$

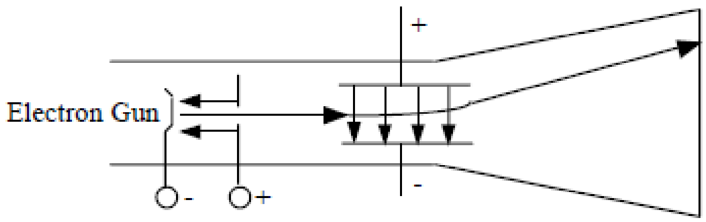
$$W = Q \times V$$
$$W = 3 \times 10^{-6} \times 10$$
$$W = 3 \times 10^{-5} J$$

b) Potential energy to kinetic energy

c) By conservation of energy, $E_k = 3 \times 10^{-5} J$

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.

The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.

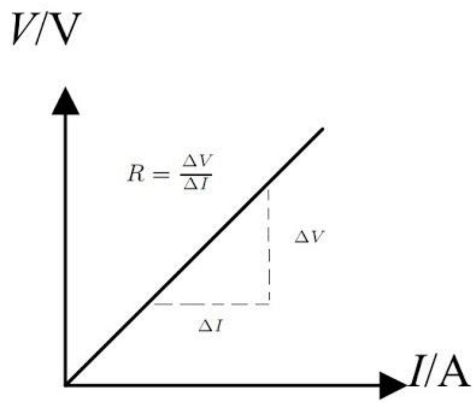
Year	Section One	Section Two
2015	2	No examples
2016	2	No examples
2017	No examples	No examples
2018	12	No examples
2019	No examples	No examples

OHM'S LAW

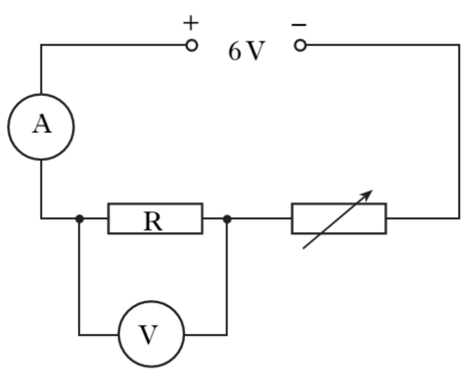
Resistance is a measure of the opposition of a circuit component to the flow of current through that component. The relationship between resistance, current and potential difference (voltage) is known as Ohm's Law. Ohm's Law is usually written as:

$$V = IR$$

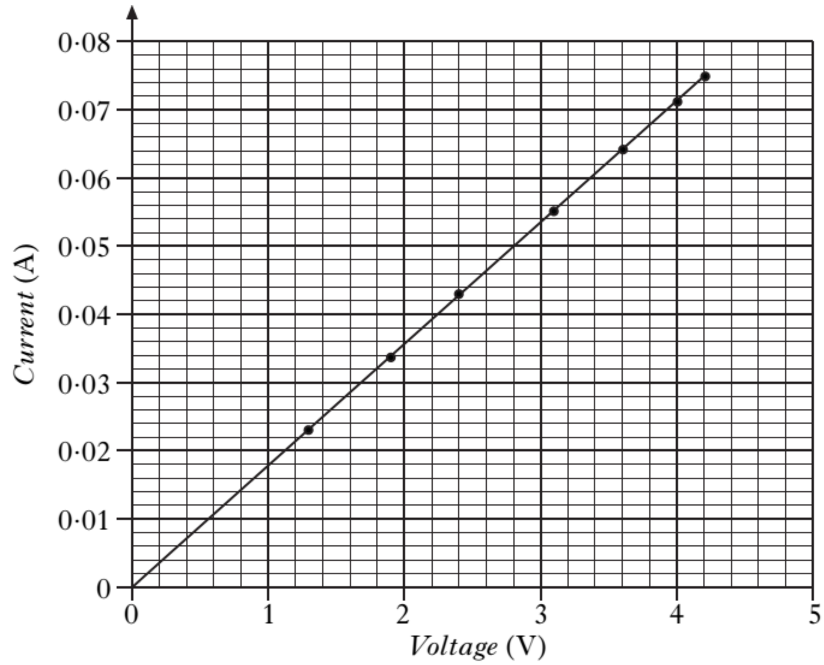
This law can be verified by a graphical or by an experimental approach.
Graphically by calculating the gradient of a V-I graph to find the resistance.



Experimentally by using the circuit below and adjusting the value of the variable resistor.



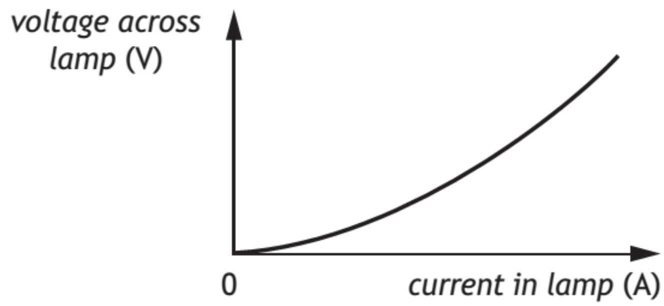
By noting the voltmeter and ammeter readings the following graph can be produced.



The graph is a staight line passing through the origin, which shows that the voltage and current are directly proportional to each other. This means that the resistance calculated at each voltage will have the same value. This in agreement with Ohm's Law.

V = 2.8V	V = 3.8V
I = 0.05A	I = 0.068A
R = ?	R = ?
R = V / I	R = V / I
R = 2.8 / 0.05A	R = 3.8 / 0.068
R = 56Ω	R = 56Ω

The relationship between the temperature and resistance of a conductor, e.g. a filament in a lamp, can also be displayed and interpreted from a graph.



In this case the resistance will increase as the temperature of the conductor (filament) increases.

The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.

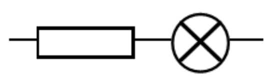
This area appears to have very few examples, but the knowledge for this area must be secure as it needed for the areas that follow.

Year	Section One	Section Two
2015	No examples	1
2016	No examples	2
2017	3	No examples
2018	No examples	No examples
2019	9	5 a)ii)

PRACTICAL ELECTRICAL and ELECTRONIC CIRCUITS

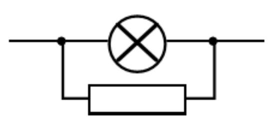
Series and Parallel Circuits

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

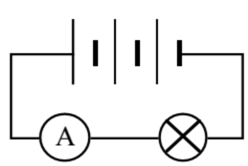


Parallel

Measuring Current

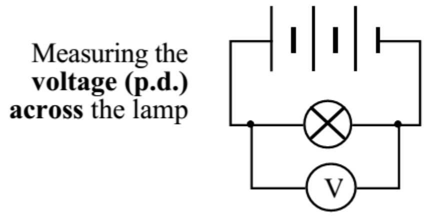
Current is measured using an **ammeter** which is connected in **series** with the component.

Measuring the **current through** the lamp



Measuring Potential Difference (Voltage)

Potential difference (voltage) is measured using a **voltmeter** which is connected in **parallel** with the component.



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. The value of R_T can be calculated using:

$$R_T = R_1 + R_2 + \dots$$

For components in series, R_T is always greater than the largest individual resistor value.

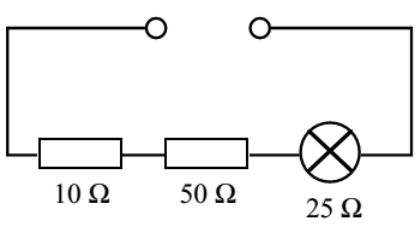
Resistors in Parallel

When more than one component is connected in parallel, the total resistance of all the components is equivalent to one single resistor, R_T. The value of R_T can be calculated using:

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

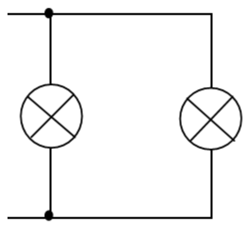
For components in parallel, R_T is always less than the smallest individual resistor value.

Example One
Calculate the total resitance of the circuit shown below.



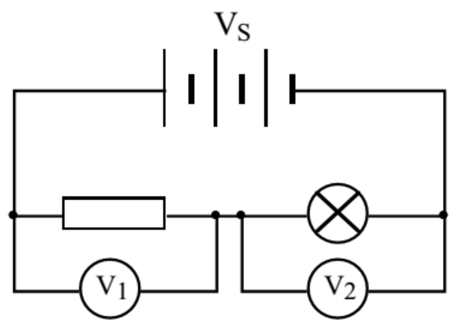
$R_T = R_1 + R_2 + R_3$
$R_T = 10 + 50 + 25$
$R_T = 85\Omega$

Example Two
Calculate the otoal resistance of the circuit shown below if the lamps have resistance values of 15Ω and 35Ω.



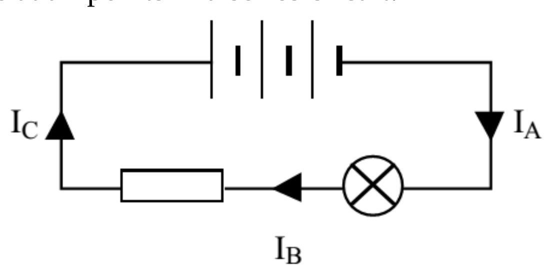
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$= \frac{1}{15 \cdot 0} + \frac{1}{35 \cdot 0}$$
$$R_T = 10 \cdot 5\ \Omega$$

Potential Difference (Voltage) 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.



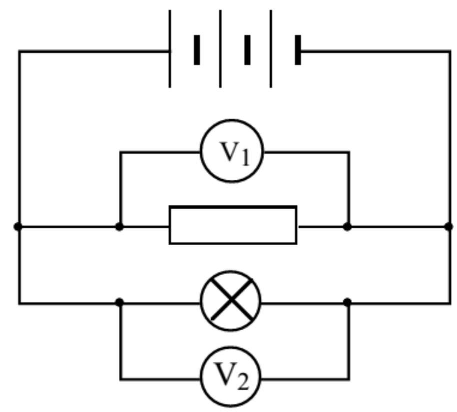
$$\mathbf{V_S = V_1 + V_2}$$

Current in a Series Circuit
The current is the same at all points in a series circuit.



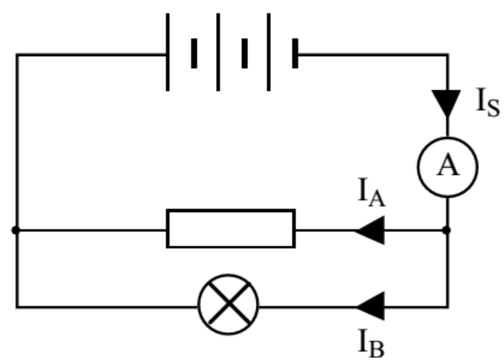
$$\mathbf{I_A = I_B = I_C}$$

Potential Difference (Voltage) in a Parallel Circuit
The potential difference (voltage) across components in a parallel circuit is the same for all components.



$$\mathbf{V_1 = V_2}$$

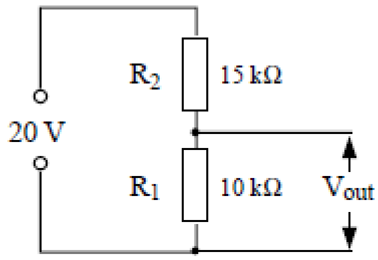
Current in a Parallel Circuit
The sum of the currents in parallel branches is equal to the current drawn from the supply.



$$\mathbf{I_S = I_A + I_B}$$

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.

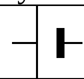
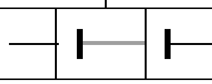
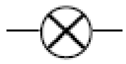
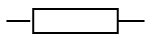
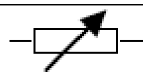
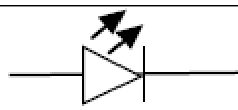
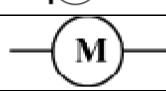
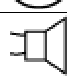
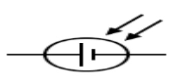
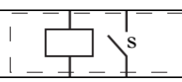
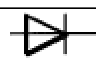
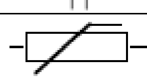
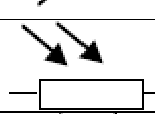
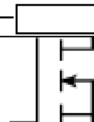
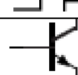
- $R_T = R_1 + R_2$
- Current is the same at all points in the circuit
- The sum of the component voltages is equal to the supply voltage.

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

b) $V_{supply} = 20V$ $R_T = 25\ k\Omega$ $I =?$
$V = I \times R$
$20 = I \times 25x10^3$
$I = 8x10^{-4}A$
$I = 0.8mA$

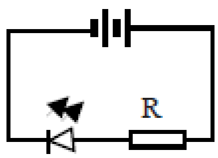
c) $V_{out} =?$ $I = 0.8mA$ $R = 10k\Omega$
$V = I \times R$
$V = 0.8\ x10^{-3}\ x\ 10x10^3$
$V = 8V$

d)
$V_s = V_1 + V_2$
$20 = V_1 + 8$
$V_1 = 12V$

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
microphone		Input device; changes sound energy into electrical 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
relay		A magnetically controlled switch
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

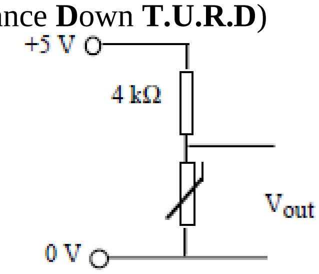
Electronic Circuits Theory

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.



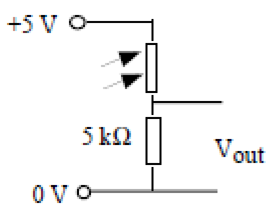
Note that the current in the above circuit will flow into the vertical line on the LED symbol. If the LED was reversed, current would not be able to flow and it would not light up.

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. (**T**emperature **U**p **R**esistance **D**own **T.U.R.D**)



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.

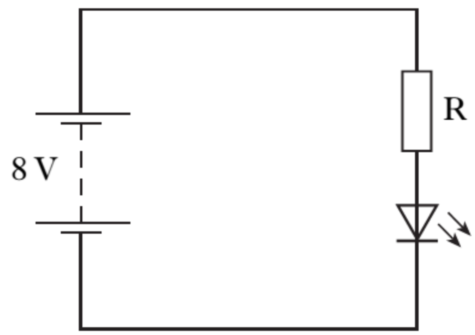
An LDR is an input device that is often used in light sensing circuits. The resistance of an LDR will increase when the light level around it decreases and vice versa. (**L**ight level **U**p **R**esistance **D**own **L.U.R.D**)



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.

Electronic Circuits Calculations

Example One
In the electronic circuit shown below the LED has an operating voltage of 2V and an operating current of 15mA. Calculate the value of the resistor R.



This is a typical assessment calculation question that would be worth 4 marks. This should tell you that the solution needs a calculation and an extra step.

In this example the extra step needs you to find the potential difference (voltage) across the resistor, R, before you attempt the calculation.

R = ?
I = 15mA = 15 x 10^{-3}A
$V_{across\ resistor} = V_{supply} - V_{LED}$
$V_{across\ resistor} = 8 - 2 = 6V$

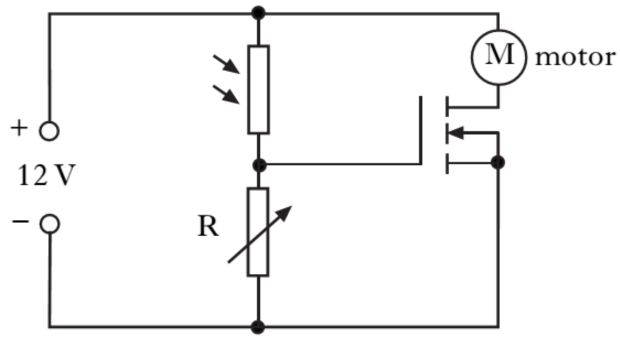
V = IR
6 = 15 x 10^{-3} x R
R = 400Ω

Electronic components are often used in **potential (voltage) divider circuits.** A potential (voltage) divider circuit uses two or more components to divide up the available potential difference (voltage) from the supply. The potential difference from the supply is divided across the component in proportion to their individual resistance values. The greater the resistance the greater the potential difference (voltage) and vice versa. There are two equations that are useful when carrying out **potential (voltage) divider** calculations.

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

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

Example Two
An office has an automatic blind that closes when the light level outside is too high. The circuit for the blind is shown below.



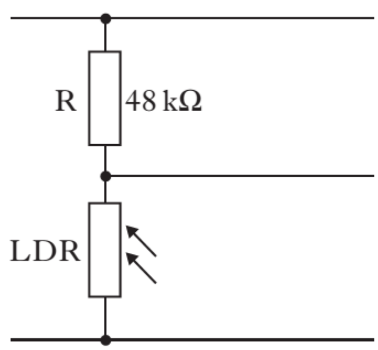
The resistance of the LDR on a cloudy day is 3000Ω and the variable resistor is set to a value of 600Ω.
Calculate the voltage across the variable resitor.

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

$$V_2 = \left(\frac{600}{600 + 3000}\right) \times 12$$

$$V_2 = 2 \cdot 0\ \text{V}$$

Example Three
A part of an electronic circuit is shown below.



When the LDR has a resistance of 2kΩ the potential differnce across it is 0.36V.
Under these conditions calculate the the potential difference across the resistor.

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

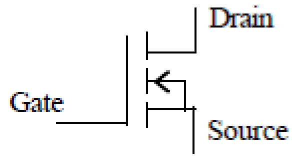
$$\frac{V_1}{0.36} = \frac{48000}{2000}$$

$V_1 = 8.64V$

Transistors

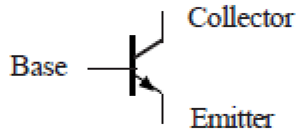
All transistors operate as **automatic electronic switches**. There are two different types of transistor that are included in this course.

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

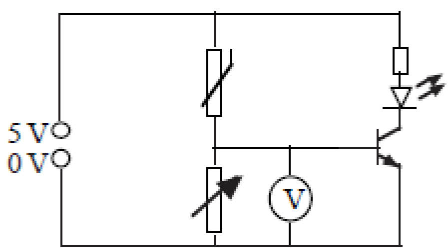


For a typical MOSFET when the voltage across the gate and source reaches 1.8V it will switch on.

NPN Transistor.
Symbol:

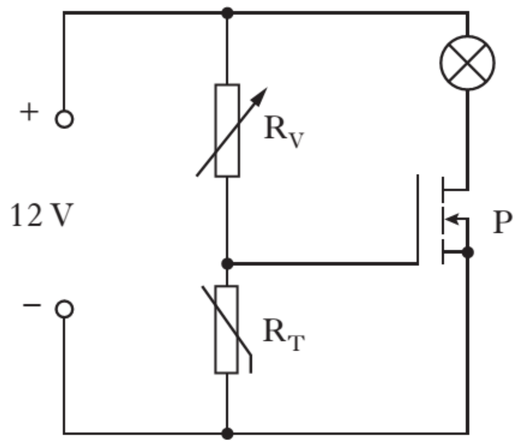


For a typical NPN transistor when the voltage across the base and emitter reaches 0.7V it will switch on.



In the above circuit, when the temperature increases the resistance of the thermistor will decrease. This means there will 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.

Example
The circuit shown switches a warning lamp on or off depending on the temperature.



a) Name component P.

b) As the temperature increases the resistance of the thermistor, R_T, decreases. State what happens to the voltage across R_T as the temperature increases.

When the voltage applied to component P is equal to or greater than 2.4V, component P switches on and the warning lamp lights.
R_V is adjusted until its resistance is 5600Ω and the warning lamp now lights.

c) For these conditions calculate:
i) the voltage across R_V
ii) the resistance of R_T

d) The temperature of R_T now decreases. Will the warning lamp stay on? Explain your answer.

Solution
a) MOSFET

b) The voltage across R_T will decrease.

c)
i) The 12V supply voltage has to be divided between the two components. If the voltage across R_T is 2.4V, the voltage across R_V must be 12 – 2.4 = 9.6V.
ii)

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

$$\frac{9.6}{2.4} = \frac{5600}{R_2}$$

$$R_2 = 1400\Omega$$

e) When the temperature falls the warning lamp will stay on. This happens because as the temperature decreases the resistance of thermistor R_T will increase. As the value of resistance R_T increases the voltage across R_T will also increase. This will keep the voltage that switches on the MOSFET above 2.4V and the warning lamp will stay on.

The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.

Year	Section One	Section Two
2015	1 and 3	2 a)
2016	1, 3 and 4	3c) and 12b)
2017	2 and 4	1a) i) ii) and 2a)i) b) i)
2018	13 and 14	6a) and b)
2019	10, 11 and 12	5 b) and 6 a) i) b) i)

ELECTRICAL POWER

When comparing electrical appliances or components it is often useful to know their power ratings.

Power is defined as the energy transferred per unit time. This definition leads to the following equation:

$$P = \frac{E}{t}$$

where,
P is the power measured in Watts
E is the energy measured in Joules
t is the time measured in seconds

It should be noted that power ratings can also be quoted in Joules per second (Js^{-1}).

Knowing the value of an appliance's power rating allows it to be fitted with the correct fuse. 3A fuses are most suited to appliances with a power rating under 720W and 13A fuses are most suited to appliances with a power rating over 720W.

Example
A kettle uses 0.9MJ of energy in 5 minutes. Calculate the power rating of the kettle.

E = 0.9MJ = 0.9×10^6J
T = 5 minutes = 5 x 60 = 300s
P =?

P = E / t
P = $0.9 \times 10^6 / 300$
P = 3000W

Power, Current and Voltage

Electrical power is also dependent on the potential difference (voltage) across the component, its resistance and the current flowing through it. This means that power can also be calculated using the following equations:

$$P = IV$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

Example One
The current flowing through a mains operated lamp is 0.26A. Calculate the power rating of the lamp.

I = 0.26A
V = 230V (mains voltage in the UK)
P = ?

P = IV
P = 0.26 x 230
P = 60W

Example Two
A data source states that the optimum operating conditions for a 1kΩ resistor happen when energy is transferred through it at a rate of 0.4 Joules per second.
a) Calculate its optimum operating current.
b) Calculate the potential difference (voltage) across it under optimum conditions.

a)
$R = 1k\Omega = 1 \times 10^3\Omega$
$P = 0.4Js^{-1}$ (or W)
I = ?

$P = I^2R$
$0.4 = I^2 \times 1 \times 10^3$
I = 0.02A

b)
$R = 1k\Omega = 1 \times 10^3\Omega$
$P = 0.4Js^{-1}$ (or W)
V = ?

$P = V^2 / R$
$0.4 = V^2 / 1 \times 10^3$
V = 20V

The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.

Year	Section One	Section Two
2015	4	2b)i)
2016	No examples	3b)i)
2017	No examples	1a)iii) and 2a)ii) b)ii)
2018	15	No examples
2019	No examples	6 a) ii) b) ii) and 7 a)

$E_p = mgh$

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

$Q = It$

$V = IR$

$R_T = R_1 + R_2 + \ldots$

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

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

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

$P = \frac{E}{t}$

$P = IV$

$P = I^2R$

$P = \frac{V^2}{R}$

$E_h = cm\Delta T$

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

$\frac{pV}{T} = \text{constant}$

$p_1V_1 = p_2V_2$

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

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

$d = vt$

$v = f\lambda$

$T = \frac{1}{f}$

$A = \frac{N}{t}$

$D = \frac{E}{m}$

$H = Dw_R$

$\dot{H} = \frac{H}{t}$

$s = vt$

$d = \bar{v}t$

$s = \bar{v}t$

$a = \frac{v-u}{t}$

$W = mg$

$F = ma$

$E_w = Fd$

$E_h = ml$

DATA SHEET

Speed of light in materials

Material	*Speed* in m s^{-1}
Air	$3{\cdot}0 \times 10^8$
Carbon dioxide	$3{\cdot}0 \times 10^8$
Diamond	$1{\cdot}2 \times 10^8$
Glass	$2{\cdot}0 \times 10^8$
Glycerol	$2{\cdot}1 \times 10^8$
Water	$2{\cdot}3 \times 10^8$

Gravitational field strengths

	Gravitational field strength on the surface in N kg^{-1}
Earth	9·8
Jupiter	23
Mars	3·7
Mercury	3·7
Moon	1·6
Neptune	11
Saturn	9·0
Sun	270
Uranus	8·7
Venus	8·9

Specific latent heat of fusion of materials

Material	*Specific latent heat of fusion* in J kg^{-1}
Alcohol	$0{\cdot}99 \times 10^5$
Aluminium	$3{\cdot}95 \times 10^5$
Carbon Dioxide	$1{\cdot}80 \times 10^5$
Copper	$2{\cdot}05 \times 10^5$
Iron	$2{\cdot}67 \times 10^5$
Lead	$0{\cdot}25 \times 10^5$
Water	$3{\cdot}34 \times 10^5$

Specific latent heat of vaporisation of materials

Material	*Specific latent heat of vaporisation* in J kg^{-1}
Alcohol	$11{\cdot}2 \times 10^5$
Carbon Dioxide	$3{\cdot}77 \times 10^5$
Glycerol	$8{\cdot}30 \times 10^5$
Turpentine	$2{\cdot}90 \times 10^5$
Water	$22{\cdot}6 \times 10^5$

Speed of sound in materials

Material	*Speed* in m s^{-1}
Aluminium	5200
Air	340
Bone	4100
Carbon dioxide	270
Glycerol	1900
Muscle	1600
Steel	5200
Tissue	1500
Water	1500

Specific heat capacity of materials

Material	*Specific heat capacity* in J kg^{-1} °C^{-1}
Alcohol	2350
Aluminium	902
Copper	386
Glass	500
Ice	2100
Iron	480
Lead	128
Oil	2130
Water	4180

Melting and boiling points of materials

Material	*Melting point* in °C	*Boiling point* in °C
Alcohol	−98	65
Aluminium	660	2470
Copper	1077	2567
Glycerol	18	290
Lead	328	1737
Iron	1537	2737

Radiation weighting factors

Type of radiation	*Radiation weighting factor*
alpha	20
beta	1
fast neutrons	10
gamma	1
slow neutrons	3