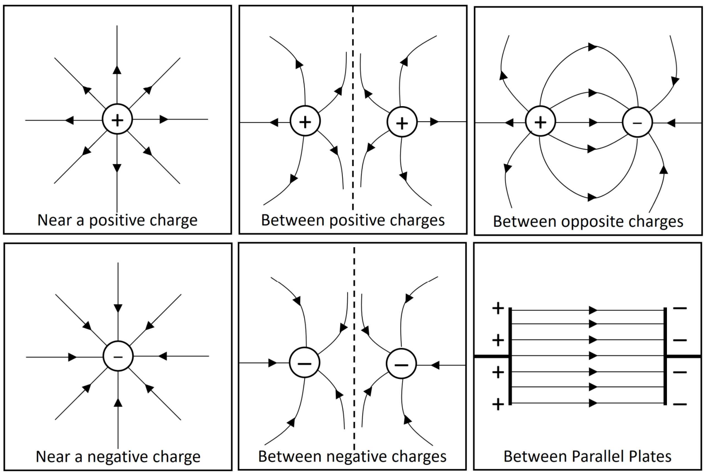
Electrical Charge Carriers and Electric Fields

Electrical Charges

There are 2 types of charges, positive and negative. Electric fields exist around charges. These fields cause other charges to experience a force, either attraction or repulsion. Opposite charges attract. Like charges repel.

In electricity we follow the flow of the negative charges. These are known as electrons.

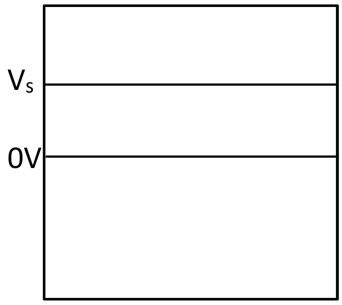
Motion of charged particles near charged objects



Since charges experience forces in electric fields, if they are placed in certain situations, they will move. In these diagrams the arrowed lines are electric field lines. They show the direction of the force experienced by a positive charge at any location in the diagram. A negative charge would experience a force in the opposite direction. These diagrams can therefore be used to determine the direction of motion too

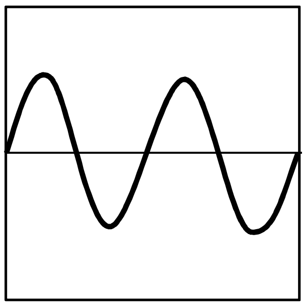
Direct and Alternating Current

A **direct current** is one which flows in one direction. A good example of this is current from a **battery or cell**. The flow is always from the negative terminal to the positive terminal.



Oscilloscope trace is always positive and at the constant value Of the supply voltage.

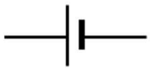
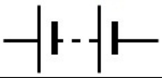
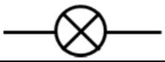
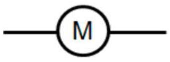
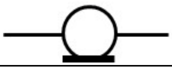
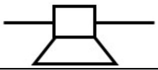
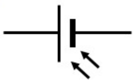
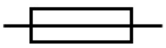
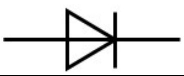
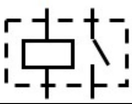
An **alternating current** is when the negative and positive terminals reverse polarity at regular intervals. This causes the current to flow in one direction and then the opposite direction. The mains electrical supply provides an alternating current. It has a frequency of 50 Hz and a voltage of 230V.



Oscilloscope trace continuously changes smoothly from positive to negative. The negative "trough" will have the same (negative) voltage as the positive "peak" voltage. It looks like a sin wave.

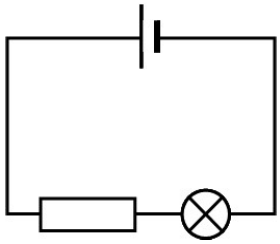
Components

Circuits may consist of many components. In a component, an energy change normally takes place. For example, in a lamp electrical energy is converted into light (and heat).

Component	Function and use
cell 	Most common energy source in an electric circuit. Cells have chemically stored energy. Energy is given to the electrons which pass through the cell. This energy is then passed on to components
battery 	A combination of two or more cells connected in series. The voltage supplied by a battery is the sum of the voltages of each of the cells.
lamp 	A lamp converts electrical energy into light energy (and some heat too). It is an example of an output device.
switch 	A switch is used to “break” the circuit. This creates an open circuit and stops electrons from flowing.
motor 	A motor converts electrical energy into rotational kinetic energy. It does this using magnets and coils of current carrying wire. A motor is used as an output device.
microphone 	A microphone converts sound energy into electrical energy. It is an example of an input device.
loudspeaker 	A loudspeaker converts electrical energy into sound energy. It is an example of an output device.
photovoltaic cell 	A photovoltaic cell converts light energy into electrical energy. It may be used as an input device. It is the basis for the solar cells used in solar panels.
fuse 	A fuse is a safety device. It contains a piece of wire which melts when the current reaches a certain level. This isolates an appliance from the mains and protects the appliance and the user. Appliances usually have a 3A (under 720W) or 13A (over 720W) fuse.
diode 	A diode is an electrical one-way-street. It only allows the current to flow in one direction. In the case of the one shown, electrons would only be able to flow from right to left.
capacitor 	A capacitor is able to “store” charge. It is initially neutral, however when connected to a DC power supply, like a cell, one plate becomes positively charged while the other becomes negatively charged. If it is then connected across a lamp, the capacitor will discharge and the lamp will come on for a short period. It is often used in electronics for timing circuits, since its charge/discharge time can be controlled by its capacitance and the resistance of a resistor.
relay switch 	A relay is an electrical switch. It allows a low voltage (6V) primary control circuit (see electronics section) to control a high voltage (230V) secondary circuit.

Circuits

A current will only flow in a circuit which is complete. There must be at least one continuous connection between the two terminals of the power supply. Energy is supplied by the power supply and is converted into other forms of energy by the components in the circuit.



In this circuit the electrons flow in a clockwise direction.

Current

An electrical current is the quantity of charge that flows past a fixed point every second.

$$\text{current} = \frac{\text{charge}}{\text{time}}$$

$$\boxed{I = \frac{Q}{t}}$$

Current is measured in amperes (A), charge is measured in coulombs (C) and time is measured in seconds (s).

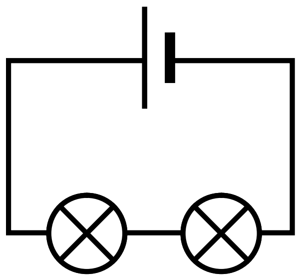
Potential Difference (Voltage)

When a charge is moved by an electric field, the charge is given energy. This energy is then used elsewhere in the circuit. The **energy per unit charge** is known as the **voltage**.

Voltage is measured in volts (V).

Series Circuits

A series circuit is one in which the component are connected in a single loop.

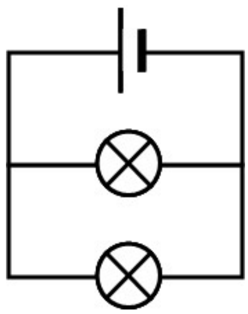


In a series circuit:

- the current is the same at all points
- the voltages across the separate components add up to the supply voltage.

Parallel Circuits

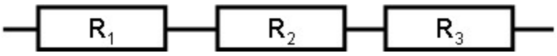
In a parallel circuit, current can take more than one path.



In a parallel circuit:
- the currents in the branches add up to the current from the supply
- the voltage is the same across each branch and is equal to the supply voltage

Resistors is Series

In a series circuit, the total resistance is the sum of all the individual resistances.



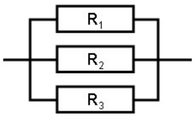
The following equation is used:

$$\boxed{R_T = R_1 + R_2 + R_3 + \ldots}$$

Adding resistors in this way increases circuit resistance.

Resistors is parallel

The total resistance in parallel circuits is more complicated.



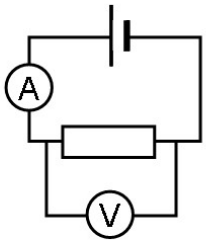
The following equation can be used to calculate the total resistance.

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

Adding resistors in this way decreases circuit resistance.

Ammeters and Voltmeters

Each meter is responsible for measuring a different quantity and each meter is connected in a different way. Ammeters are connected in series (in line with) with components, while voltmeters are connected in parallel (across) components.



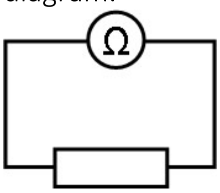
Resistance

All conductors have some level of resistance. In metals this resistance increases with temperature. This can be demonstrated by trying to establish Ohm's Law with a lamp (voltage and current will not be proportional).

Resistors deliberately reduce the current (flow of charge) in a circuit.

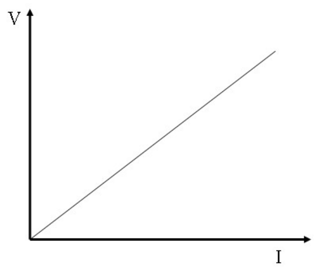
Resistance is measured in ohms (Ω).

An ohm meter is used to measure the resistance of a component directly. The ohm meter does not require a separate power supply and so is connected as shown in the diagram.



Ohm's Law

Ohm's Law describes the relationship between voltage, current and resistance. For a fixed value resistor there is a directly proportion relationship between the current through the resistor and the voltage across it.



The gradient of this graph will give the resistance of the resistor used. This relationship is known as Ohm's Law.

$$\boxed{V = IR}$$

Electrical Power

Power

Power is the quantity of energy transformed from one form into another form (or other forms) every second.

$$\text{Power} = \frac{\text{Energy}}{\text{time}}$$

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

Power is measured in watts (W), energy measured in joules (J) and time measured in seconds (s).

1 watt = 1 joule per second

Electrical Power

In electric circuits, the power transferred by a component can be calculated from the voltage across the component and the current passing through it.

$$\text{Power} = \text{Current} \times \text{Voltage}$$

$$\boxed{P = IV}$$

If resistance is known, then the following two equations can also be used to determine power. They are produced by combining Ohm's Law with $P=IV$.

$$\boxed{P = I^2R} \qquad \boxed{P = \frac{V^2}{R}}$$

Electronics

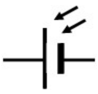
Electronic Systems

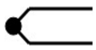
All electronic systems consist of 3 main parts.

Input Devices

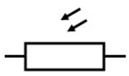
Input devices convert one form of energy into electrical energy. This allows an external signal to be converted into an electrical one, for use in the circuit.

Examples include:

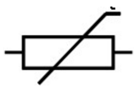
solar cell  light energy → electrical energy

thermocouple  heat energy → electrical energy

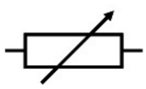
Dependant resistors as Input Devices

Light Dependant Resistors 

Light Dependant Resistors, often abbreviated to LDR. These resistors have a varying resistance which depends on light level. For an LDR as light level increases, resistance decreases. This is often abbreviated to L.U.R.D. to help you remember.


Thermistors

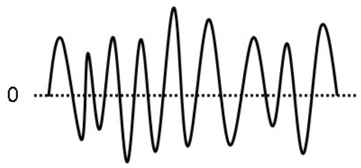
These resistors have a varying resistance which depends on temperature. For a thermistor as temperature level increases, resistance decreases. This is often abbreviated to T.U.R.D. to help you remember.


Variable resistors

Variable resistors which can be controlled by the user.

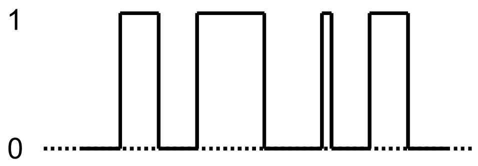
Analogue Systems

An analogue system is often described as continuously variable. The signal can exist at any state between its maximum and minimum value. It is often described as a wave:



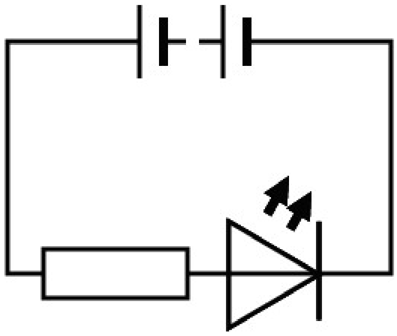
Digital Systems

A digital system is one in which the signal can only exist at one of two states, off and on, also often described as 1 and 0:



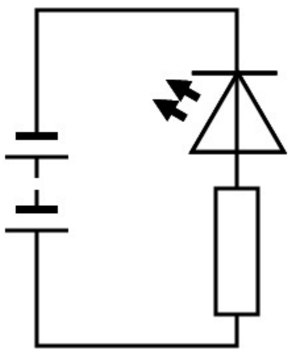
The Light Emitting Diode

The LED is an example of an output device. It converts electrical energy into light energy. Unlike a lamp it produces very little heat energy. The **LED only allows a current to flow through it in one direction** and so it must be connected the right way round.



The LED should always be connected in series with a resistor. The purpose of the resistor is to reduce the current passing through the LED since too large a current will damage the LED.

LED Protective Resistor Calculation



Consider an LED rated at 2V and 10mA connected to a 6V supply.

This circuit is like a voltage divider. If there needs to be 2V across the LED then there must be 4V across the resistor.

In a series circuit the current is the same through each of the component. We can now do a calculation using Ohm's Law.

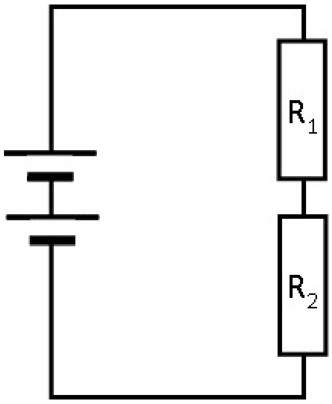
$$V = IR$$

$$4 = 0.01 \times R$$

$$R = \frac{4}{0.01}$$

$$R = 400\Omega$$

Voltage Dividers



In a circuit with more than one resistor the voltage of the supply is split across the resistors in that circuit. There are 2 equations that can be helpful in finding missing values in these types of circuits.

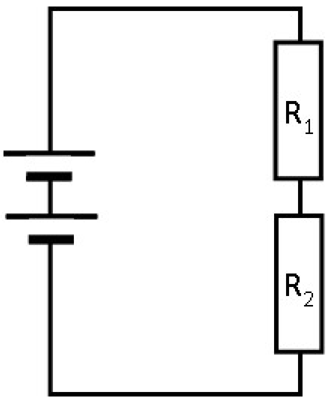
The ratio of the resistances is the same as the ratio of the voltages across them:

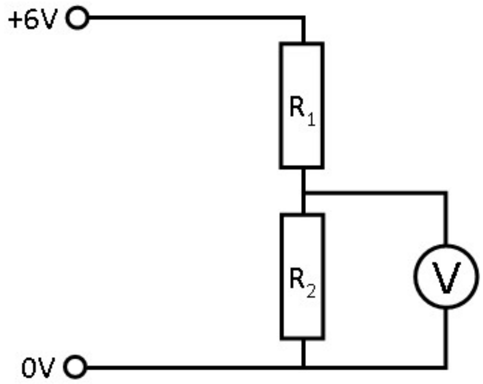
$$\boxed{\frac{V_1}{V_2} = \frac{R_1}{R_2}}$$

The voltage across the second resistor can be calculated using:

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

Alternative Diagrams

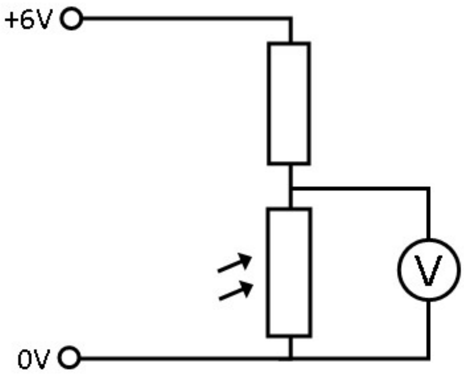




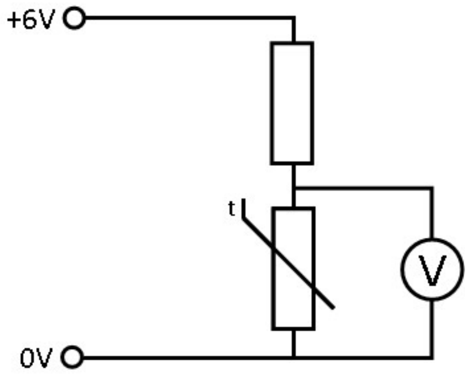
In these circuits the reading on the voltmeter is determined by the ratio of the resistors. The ratio can be controlled by the use of variable resistors including thermistors and LDRs. This makes them excellent as input devices.

Voltage Dividers as Input Devices

Light Sensing

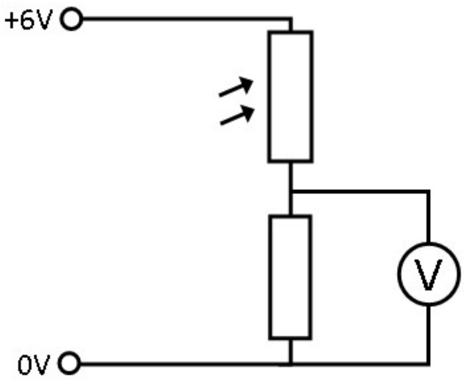


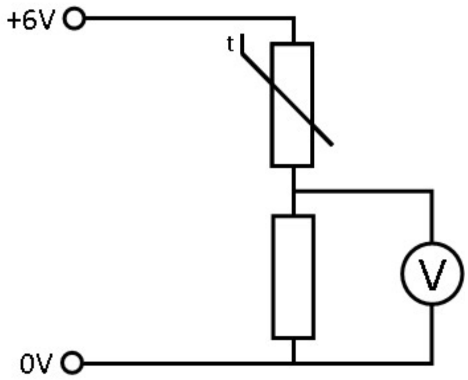
Temperature Sensing



As light/temperature increases the resistance of the LDR/thermistor decreases. As a result the voltage across the LDR/thermistor decreases. The reading on the voltmeter decreases.

Connected in reverse they carry out the opposite function:



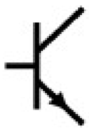


As light/temperature increases the resistance of the LDR/thermistor decreases. As a result the voltage across the LDR/thermistor decreases. The share of the voltage across the fixed resistor increases and the reading on the voltmeter increases.

The npn transistors and the MOSFET

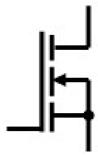
Transistors are electronic switches. When connected in a circuit with a voltage divider they are controlled by the voltage across the lower resistor. There are two main types:

npn transistor



switches "on" at around 0.7V

MOSFET

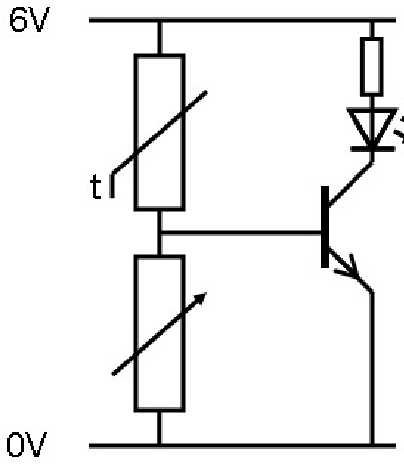


switches "on" at around 2V

The switch on voltage for the MOSFET is usual 2.4 V in SQA questions. Use the number given.

Control Circuits

Control circuits use all of the pieces we have looked at so far. They include a sensing section, dependant on light or temperature, an electronic switch and an LED (or other output device).

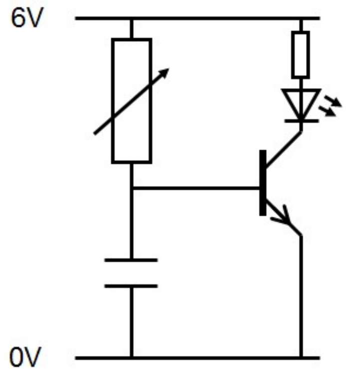


This is a temperature dependant circuit.

As temperature increases the resistance of the thermistor decreases.
As the resistance of the thermistor decreases the voltage across it also decreases.
As the voltage across the thermistor decreases the voltage across resistor 2 increases.
When the voltage across resistor 2 rises above 0.7V the transistor starts conducting and the LED goes on.

The control circuit can be reversed by switching the locations of the resistors. The circuit can be calibrated by varying the resistance of the variable resistor.

Capacitors as time delays



In this type of circuit, the capacitor will take a set time to "charge". As it charges, the circuit current decreases, the voltage across the resistor decreases and the voltage across the capacitor increases (eventually reaching the 6V of the power supply). When the voltage across the capacitor reaches 0.7V the transistor will conduct, allowing the LED to light. Swapping the locations of the resistor and capacitor will cause the LED to go off after a delay.

The Relay Switch

The relay switch consists of an electromagnet an a switch. The relay allows a low voltage d.c. circuit to control a high voltage a.c. circuit. Here a drop in temperature increases the resistance of the thermistor, this increases the voltage across the thermistor, once it reaches 0.7 V the transistor conducts, causing the relay switch to close. This switches on the secondary circuit, switching on the heating automatically when it is cold.