Electricity

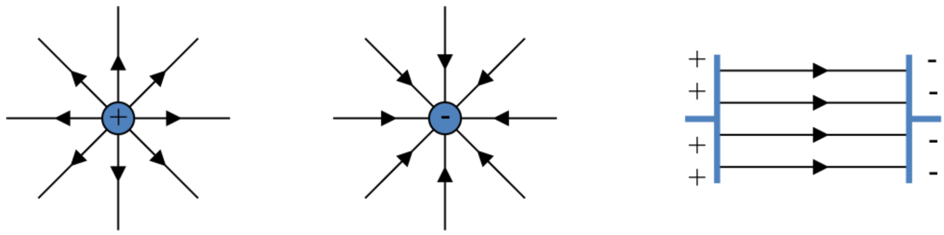
Electric Circuits

Summary

Electrical **charge** is a property of particles. Electrons have negative charge and protons have positive charge.

Objects with similar charges **repel** each other. Objects with opposite charges **attract** each other.

Electric fields exist round electrical charges. (The arrows show the direction in which positive charges experience a force)



Charge, Current & Time

C

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

A

s

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

$$Q = It$$

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

Charge is measured in **coulombs** (C).

Electric charges experience a force in an electric field.

When electric charges move there is said to be an electric **current.**

Current is the rate of flow of electric charge.

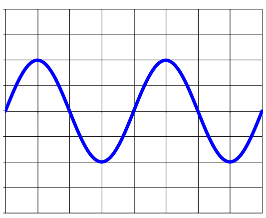
Current is measured in **amperes** (A).

Current can pass through a conductor because there are charges (e.g. electrons) that are free to move. Metals are good conductors of electricity.

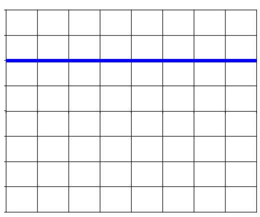
Direct current (**d.c.**) is when the current is always in the same direction. Batteries supply d.c.

Alternating current (**a.c.**) is when the current changes direction every fraction of a second. The mains supply in the UK is 230 V a.c. with a frequency of 50 Hz.

The difference between a.c. and d.c. can be observed by connecting the supplies to an oscilloscope.



a.c.



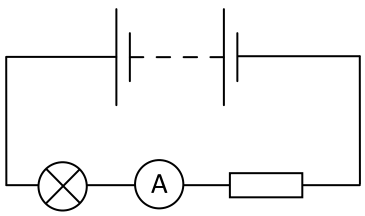
d.c.

The **potential difference** (voltage) across a component is a measure of the energy transferred by each unit of charge.

Potential difference (voltage) is measured in **volts** (V).

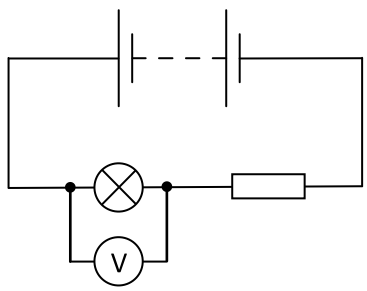
Electrical components can be connected in either **series** or **parallel**.

Measuring current



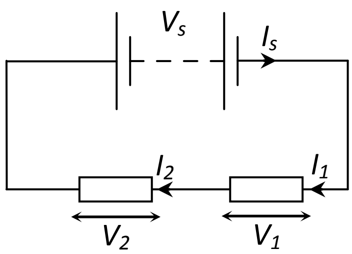
In order to measure the current in a component an **ammeter** should be placed in **series** with the component.

Measuring voltage



In order to measure the voltage across a component a **voltmeter** should be connected in **parallel** with the component.

Series circuits



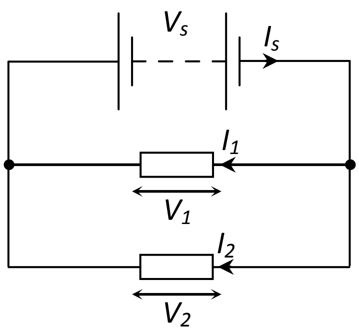
There is only one path for current in a series circuit, so the current is the same at all points.

$$I_S = I_1 = I_2 = \cdots$$

The sum of the voltages across components in series is equal to the supply voltage.

$$V_S = V_1 + V_2 + \cdots$$

Parallel circuits



In a parallel circuit the sum of the currents in each branch of the circuit is equal to the current in the supply.

$$I_S = I_1 + I_2 + \cdots$$

The voltages across parallel branches in the circuit are the same.

$$V_S = V_1 = V_2 = \cdots$$

Electricity

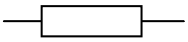
Resistance

Summary

Resistance is the opposition to the movement of charge through a material.

Increasing the resistance in an electrical circuit decreases the current.

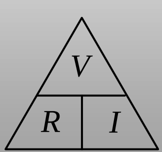
Resistance is measured in **ohms** (Ω).



resistor

Resistance, Voltage & Current (Ohm's Law)

$$\underbrace{resistance}_{\Omega} = \frac{\overbrace{voltage}^{V}}{\underbrace{current}_{A}}$$



$$R = \frac{V}{I}$$

$$V = IR$$

$$I = \frac{V}{R}$$

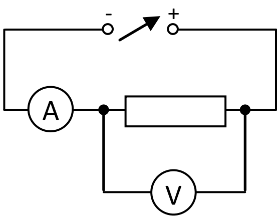
For a given resistor the ratio V/I remains approximately constant, provided there is no change in temperature.

This ratio is defined as the **resistance** of the resistor.

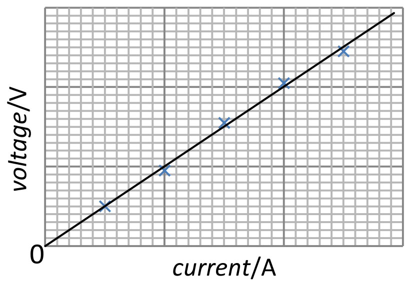
The relationship between resistance, current and voltage is known as **Ohm's Law**.

(NOTE: For some components, such as lamps, the ratio of voltage to current is not fixed, as their resistance varies with temperature.)

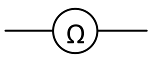
An accurate value for the resistance of a resistor can be established by connecting the resistor to a variable voltage power supply and taking a range of measurements of voltage across and current in the resistor



The graph of voltage against current for this resistor is a "best-fit", straight line and its gradient is equal to the resistance of the resistor.

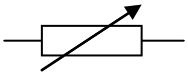


Resistance can also be measured directly with an **ohmmeter**.



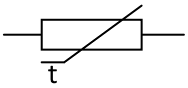
Variable Resistors

Variable resistors can be use to alter the current in a circuit. For example, variable resistors are used in the volume controls of radios and in dimmer switches.

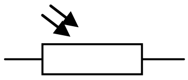


variable resistor

Certain types of variable resistor respond to changes in temperature (**thermistors**) and light level (**light dependent resistors (LDRs)**).



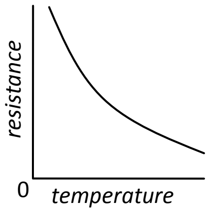
thermistor



light dependent resistor (LDR)

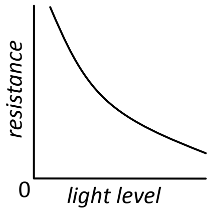
For most thermistors, as temperature increases resistance decreases.

Temperature
Up
Resistance
Down



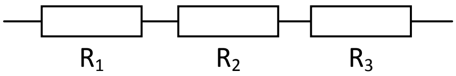
For LDRs, as light level increases resistance decreases.

Light
Up
Resistance
Down



Resistance in Series

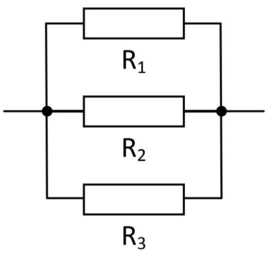
The total resistance of resistors connected in series is equal to the sum of the individual resistances.



$$R_T = R_1 + R_2 + R_3 \ldots$$

Resistance in Parallel

The total resistance of resistors connected in parallel is less than the smallest value of the individual resistors.



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

Electricity

Electrical Power

Summary

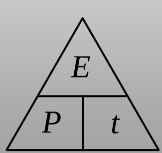
Electrical power is the rate at which electrical energy is converted into other forms.

Electrical power is measured in watts (W).

Electrical power is also equal to the current (charge per second) multiplied by the voltage (energy per charge).

Power, Energy & Time

$$\underset{\text{W}}{power} = \frac{\overset{\text{J}}{energy}}{\underset{\text{s}}{time}}$$



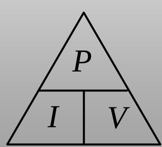
$$P = \frac{E}{t}$$

$$E = Pt$$

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

Power, Current & Voltage

$$\overset{\text{W}}{power} = \underset{\text{A}}{current} \times \overset{\text{V}}{voltage}$$



$$P = IV$$

$$I = \frac{P}{V}$$

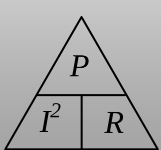
$$V = \frac{P}{I}$$

When there is a current in a component with resistance electrical energy is converted into heat (or other forms of energy such as light).

It can be useful to combine the power equation with Ohm's Law to establish relationships between power, current and resistance or between power, voltage and resistance,

Power, Current & Resistance

$$\overset{\text{W}}{power} = \underset{\text{A}}{current^2} \times \overset{\Omega}{resistance}$$



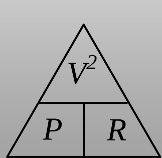
$$P = I^2R$$

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

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

Power, Voltage & Resistance

$$\underset{\text{W}}{power} = \frac{\overset{\text{V}}{voltage^2}}{\underset{\Omega}{resistance}}$$



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

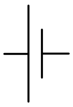
$$V^2 = PR$$

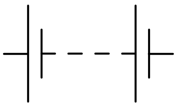
$$R = \frac{V^2}{P}$$

Electricity

Electrical & Electronic Components

Summary

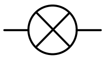

cell


battery

Cells and batteries convert stored chemical energy into electrical energy.

Cells produce low voltage d.c.

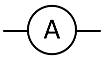
Batteries consist of two or more cells connected together.


lamp

Lamps (or bulbs) convert electrical energy into light.

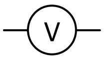

switch

Switches can make or break electrical circuits.



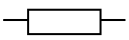
ammeter

Ammeters are used to measure current.



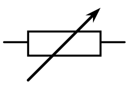
voltmeter

Voltmeters are used to measure potential difference (voltage).

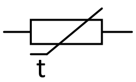

resistor

Resistors oppose the movement of charge (current).

Resistors have resistance, measured in ohms (Ω).

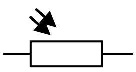

variable resistor

Variable resistors are used to change the resistance in a circuit.

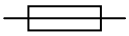


thermistor

The resistance of thermistors varies with temperature.


light dependent resistor (LDR)

The resistance of light dependent resistors (LDRs) varies with light level.

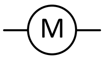


fuse

Fuses are thin pieces of wire which melt and break if too large a current passes through them.

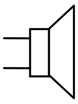
Fuses protect wiring from overheating.

3A fuse for most appliances with a power rating up to 720 W, 13A fuse for appliances rated over 720W.



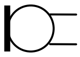
motor

Motors convert electrical energy into kinetic energy.



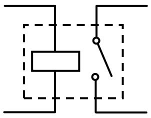
loudspeaker

Loudspeakers convert electrical energy into sound.



microphone

Microphones convert sound into electrical energy

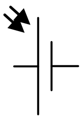


relay

Relays are electrically operated switches.

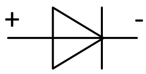
Applying a low voltage to the coil of the relay closes (or opens) the switch.

Relays are used to allow low voltage electronic circuits to switch on and off higher power devices.



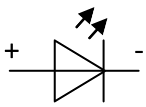
photovoltaic cell

Photovoltaic (solar) cells convert light into electrical energy.



diode

Diodes only allow current to pass in one direction.

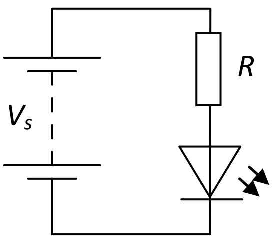


light emitting diode (LED)

Light emitting diodes (LEDs) convert electrical energy into light

LEDs only work when connected the right way round.

Resistors are connected in series with LEDs to prevent them being damaged by too large a current.



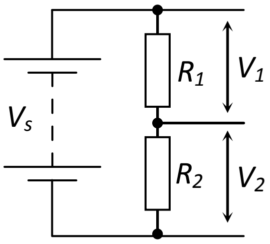
LEDs require a certain voltage V_{LED} and current I_{LED} to operate

$$V_R = V_s - V_{LED}$$

$$I_R = I_{LED}$$

$$R = \frac{V_R}{I_R}$$

LEDs only require a small current to light and are more efficient than



voltage divider circuit

A voltage divider circuit is made up of two (or more) resistors connected in series.

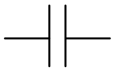
In a voltage divider circuit the supply voltage is shared (or divided) between the resistors.

The ratio of the voltages across the resistors in a voltage divider is the same as the ratio of their resistances:

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

The voltage across a resistor in a voltage divider can be calculated using:

$$V_2 = \frac{R_2}{R_1 + R_2} \times V_s$$



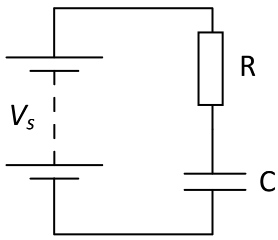
capacitor

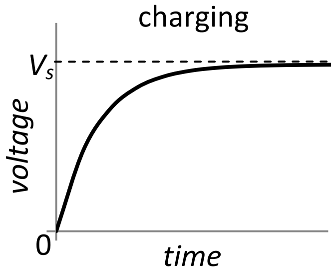
Capacitors store electrical charge.

The amount of charge a capacitor can store per volt across it is known as the capacitance the capacitor.

Capacitance is measured in farads (F).

When connected in series with a resistor a capacitor takes time to charge and discharge.

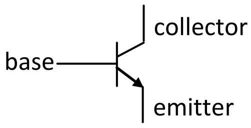




Increasing the capacitance of the capacitor increases the time taken to charge/discharge.

Increasing the resistance of the resistor increases the time taken to charge/discharge.

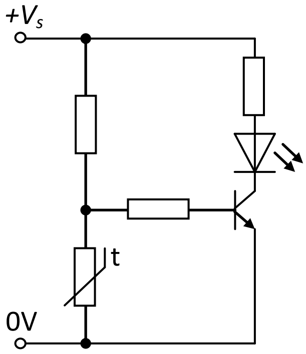
Transistors can be used as electronic switches.



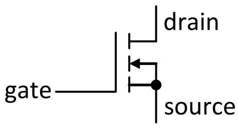
bipolar junction (npn) transistor

A bipolar junction transistor will conduct between its emitter and collector when the base-emitter voltage is above a certain value.

e.g. Low temperature sensor



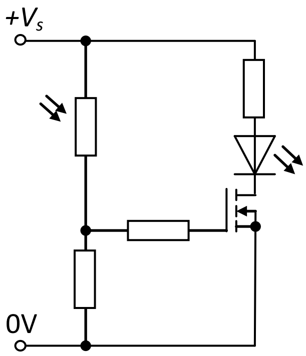
- temperature decreases
- resistance of thermistor increases
- voltage across thermistor increases
- voltage at transistor base reaches a certain value
- transistor switches on
- LED lights



MOSFET transistor

A MOSFET transistor will conduct between its source and drain when the gate-source voltage is above a certain value

e.g. High light level sensor



- light level increases
- resistance of LDR decreases
- voltage across LDR decreases
- voltage at transistor gate increases
- voltage at transistor gate reaches a certain value
- transistor switches on
- LED lights