N5 Electricity & Energy

Conservation of Energy

Summary

When energy is changed from one form to another the total amount of energy remains constant; in other words energy can neither be created nor destroyed. This is known as the *principle of conservation of energy*.

Very often during energy transformations some energy appears to be “lost”, but this is because it is changed into heat due to friction or air resistance.

Examples of energy transformations include:

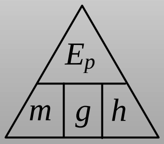
car accelerating - chemical to kinetic (and heat) energy

ball falling - gravitational potential to kinetic (and heat) energy

bicycle braking - kinetic to heat energy

Gravitational Potential Energy

$$\underset{\text{J}}{\textit{gravitational potential energy}} = \overset{\text{kg}}{\textit{mass}} \times \overset{\text{N kg}^{-1}}{\textit{gravitational field strength}} \times \underset{\text{m}}{\textit{height}}$$



(on Earth g = 9·8 N kg^{-1})

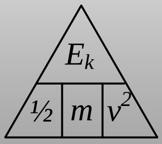
$$E_p = mgh$$

$$m = \frac{E_p}{gh}$$

$$h = \frac{E_p}{mg}$$

Kinetic Energy

$$\overset{\text{J}}{\textit{kinetic energy}} = ½ \times \underset{\text{kg}}{\textit{mass}} \times \overset{\text{m s}^{-1}}{\textit{speed}^2}$$



$$E_k = ½mv^2$$

$$m = \frac{E_k}{½v^2}$$

$$v = \sqrt{\frac{E_k}{½m}}$$

N5 Electricity & Energy

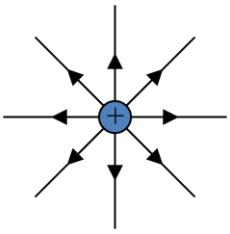
Electric Circuits

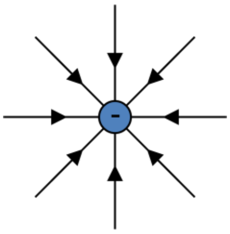
Summary

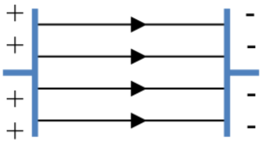
Electrical **charge** is a property of particles. Electrons have negative charge and protons have positive charge.

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

$$\underset{A}{current} = \frac{\overset{C}{charge}}{\underset{s}{time}}$$

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

$$Q = It$$

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

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.

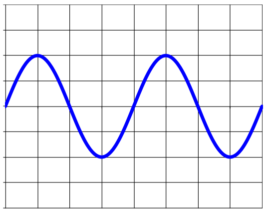
Current is measured in **amperes** (A).

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

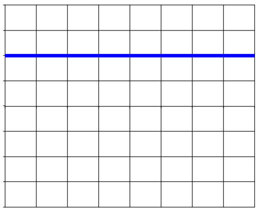
Direct current (**d.c.**) is when the current is always in the same direction. Batteries supply d.c.

Alternating current (**a.c.**) is when the current changes direction every fraction of a section. 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.



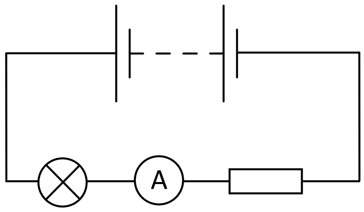
d.c.

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).

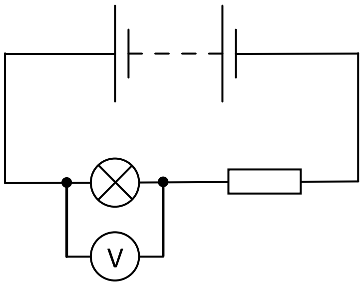
Electrical components can be connected in either **series** or **parallel**.

Measuring current



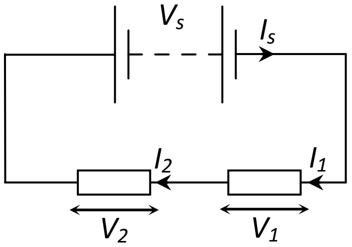
In order to measure the current in a component an **ammeter** should be placed in **series** with the component.

Measuring voltage



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

Series circuits



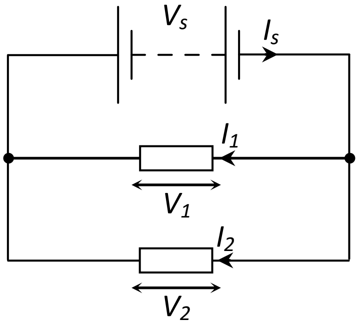
There is only one path for current in a series circuit, so the current is the same at all points.

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

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.

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

N5 Electricity & Energy

Resistance

Summary

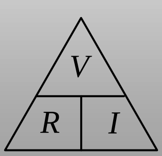
Resistance is the opposition to the movement of charge through a material.

Increasing the resistance in an electrical circuit decreases the current.

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

Resistance, Voltage & Current (Ohm's Law)

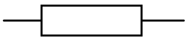
$$\underset{\Omega}{resistance} = \frac{\overset{V}{voltage}}{\underset{A}{current}}$$



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

$$V = IR$$

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



resistor

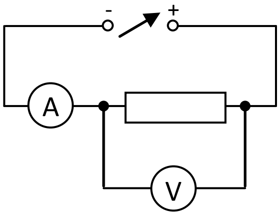
For a given resistor the ratio V/I remains approximately constant, provided there is no change in temperature.

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

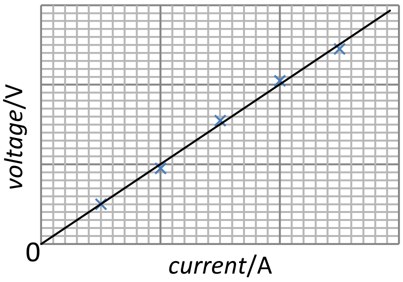
The relationship between resistance, current and voltage is known as **Ohm's Law**.

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

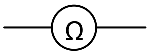
An accurate value for the resistance of a resistor can be established by connecting the resistor to a variable voltage power supply and taking a range of measurements of voltage across and current in the resistor



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.

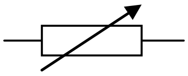


Resistance can also be measured directly with an **ohmmeter**.



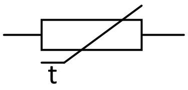
Variable Resistors

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.

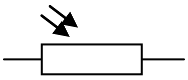


variable resistor

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



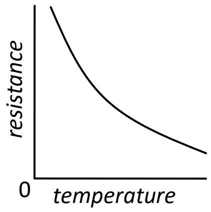
thermistor



light dependent resistor
(LDR)

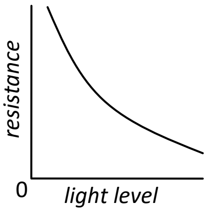
For most thermistors, as temperature increases resistance decreases.

Temperature
Up
Resistance
Down



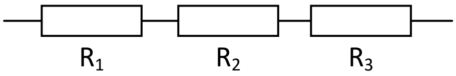
For LDRs, as light level increases resistance decreases.

Light
Up
Resistance
Down



Resistance in Series

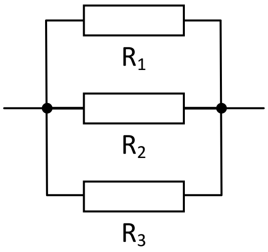
The total resistance of resistors connected in series is equal to the sum of the individual resistances.



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

Resistance in Parallel

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

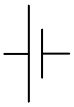


$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots$$

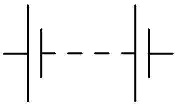
N5 Electricity & Energy

Electrical & Electronic Components

Summary



cell

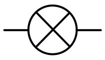


battery

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.

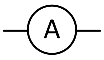


lamp

Lamps (or bulbs) convert electrical energy into light.

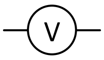
switch

Switches can make or break electrical circuits.



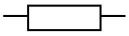
ammeter

Ammeters are used to measure current.



voltmeter

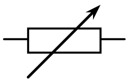
Voltmeters are used to measure potential difference (voltage).



resistor

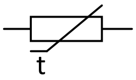
Resistors oppose the movement of charge (current).

Resistors have resistance, measured in ohms (Ω).



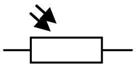
variable resistor

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



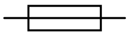
thermistor

The resistance of thermistors varies with temperature.



light dependent resistor (LDR)

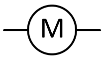
The resistance of light dependent resistors (LDRs) varies with light level.



fuse

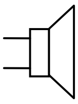
Fuses are thin pieces of wire which melt and break if too large a current passes through them.

Fuses protect wiring from overheating.



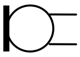
motor

Motors convert electrical energy into kinetic energy.



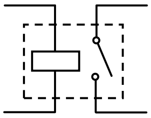
loudspeaker

Loudspeakers convert electrical energy into sound.



microphone

Microphones convert sound into electrical energy

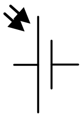


relay

Relays are electrically operated switches.

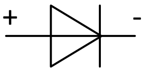
Applying a low voltage to the coil of the relay closes (or opens) the switch.

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



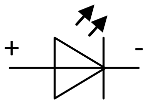
photovoltaic cell

Photovoltaic (solar) cells convert light into electrical energy.



diode

Diodes only allow current to pass in one direction.

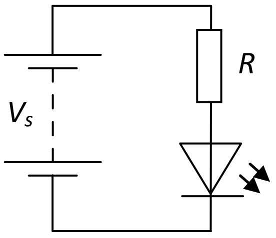


light emitting diode (LED)

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.



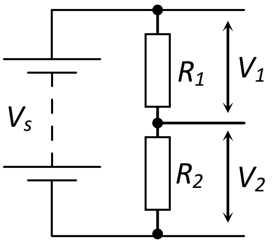
LEDs require a certain voltage V_{LED} and current I_{LED} to operate

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

$$I_R = I_{LED}$$

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

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



voltage divider circuit

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

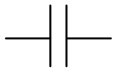
In a voltage divider circuit the supply voltage is shared (or divided) between the resistors.

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:

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



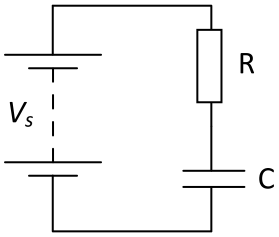
capacitor

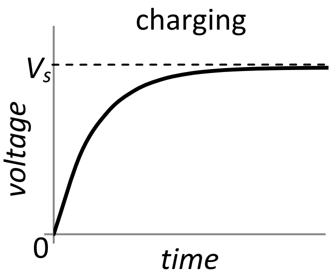
Capacitors store electrical charge.

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.

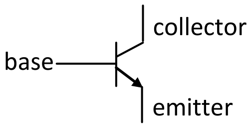




Increasing the capacitance of the capacitor increases the time taken to charge/discharge.

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

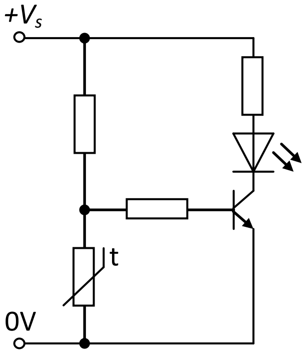
Transistors can be used as electronic switches.



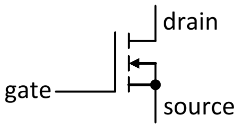
bipolar junction transistor

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



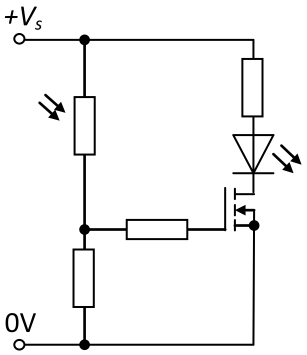
- temperature decreases
- resistance of thermistor increases
- voltage across thermistor increases
- voltage at transistor base reaches a certain value
- transistor switches on
- LED lights



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

N5 Electricity & Energy

Electrical Power

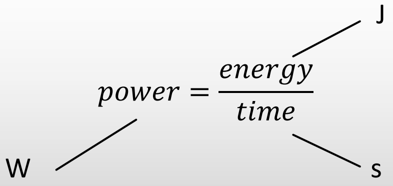
Summary

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



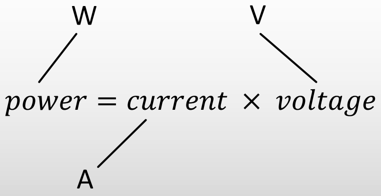
$$power = \frac{energy}{time}$$

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

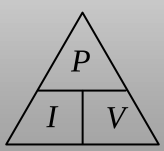
$$E = Pt$$

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

Power, Current & Voltage



$$power = current \times voltage$$



$$P = IV$$

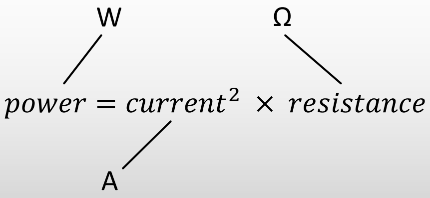
$$I = \frac{P}{V}$$

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

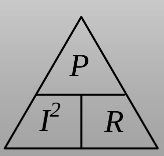
When there is a current in a component with resistance electrical energy is converted into heat (or other forms of energy such as light).

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



$$power = current^2 \times resistance$$

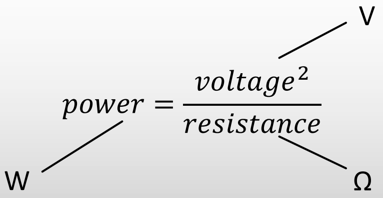


$$P = I^2R$$

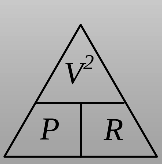
$$I^2 = \frac{P}{R}$$

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

Power, Voltage & Resistance



$$power = \frac{voltage^2}{resistance}$$



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

$$V^2 = PR$$

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

N5 Electricity & Energy

Specific Heat Capacity

Summary

Heat is a form of energy that is measured in **joules** (J).

The **temperature** of an object is a measure of the average kinetic energy of the particles in the object and is measured in **degrees Celsius** (°C).

Heat moves from regions of high temperature to regions of low temperature by three processes:

Conduction - In conduction the vibration (kinetic energy) of hot particles is passed from one particle to the next.
Conduction takes place in solids.

Convection - Cold fluids are more dense than hot fluids and so they fall, whilst the hot fluids rise, setting up *convection current*.
Convection takes place in liquids and gases.

Radiation - Heat radiation is energy in the form of electromagnetic rays (infrared rays).
Radiation is the only method of heat transfer in a vacuum.

The rate of heat loss depends on the temperature difference between the two objects.

Heat loss from the home can be reduced in the following ways:

Loft insulation reduces heat loss by convection through the roof space.

In **double (or triple) glazing** a space between the panes of glass reduces heat loss by conduction.

Draught excluders reduce heat loss by convection.

Foil-backed plasterboard reduces heat loss by radiation from the walls.

Foil behind radiators reflects heat back into room and so reduces heat loss by radiation.

In **cavity wall insulation** a filling between the inner and outer walls prevents heat loss due to convection in the gap.

Carpets reduce heat loss by conduction through floor.

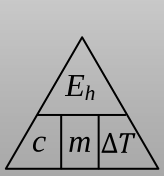
The same mass of different materials requires different quantities of energy to raise the temperature of the material by one degree Celsius.

The quantity of heat energy required to raise the temperature of 1 kg of a material by 1 °C is called the **specific heat capacity**, c, of a material.

Specific heat capacity has the unit joules per kilogram per degree Celsius (J kg^{-1} °C^{-1}). For example water has a specific heat capacity of 4 180 J kg^{-1} °C^{-1}.

Energy, Mass, Temperature Change and Specific Heat Capacity

$$\overset{\text{J}}{energy} = \underset{\text{J kg}^{-1}\,{}^{\circ}\text{C}^{-1}}{\begin{matrix} specific \\ heat \\ capacity \end{matrix}} \times \underset{\text{kg}}{mass} \times \underset{{}^{\circ}\text{C}}{\begin{matrix} temperature \\ change \end{matrix}}$$



$$E_h = cm\Delta T$$

$$c = \frac{E_h}{m\Delta T}$$

$$m = \frac{E_h}{c\Delta T}$$

$$\Delta T = \frac{E_h}{c\text{m}}$$

N5 Electricity & Energy

Gas Laws & The Kinetic Model

Summary

The pressure, temperature and volume of gases are related to each other by the **gas laws**.

Pressure is a measure of the force per unit area exerted on a surface.

Pressure is measured in pascals (Pa) or newtons per square metre (N m^{-2}).

1 Pa = 1 N m^{-2}.

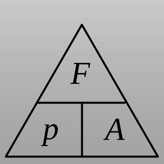
Pressure can be reduced by spreading the force out over a large area (e.g. snowshoes and tractor tyres).

Pressure can be increased by exerting a force on a small area (e.g. the blade of a knife or the point of a nail).

The pressure of a gas is due to the force exerted by the particles of the gas when they collide with the walls of the container.

Pressure, Force & Area

$$\underset{\text{Pa}}{pressure} = \frac{\overset{\text{N}}{force}}{\underset{\text{m}^2}{area}}$$



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

$$F = pA$$

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

The **temperature** of a gas is a measure of the average kinetic energy of the particles in a gas.

The lowest possible temperature, the temperature at which all particle motion stops, is known as **absolute zero**.

On the **Celsius** temperature scale absolute zero is -273 °C.

On the **kelvin** temperature scale absolute zero is 0 K.

NOTE: To convert temperatures from Celsius to kelvin, add 273.

To convert temperatures from kelvin to Celsius, subtract 273.

A change in temperature of 1 °C is the same as a change of 1 K.

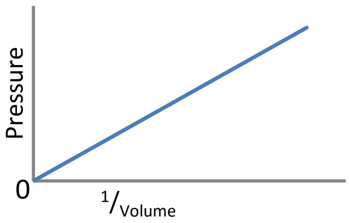
Gases expand to fill the container they are in, so the **volume** of a gas is the same as the volume of the container the gas is in.

Pressure and Volume (Boyle’s Law)

The pressure of a fixed mass of gas is inversely proportional to the volume of the gas, provided the temperature of the gas remains constant.

$$p \propto \frac{1}{V}$$

$$\boxed{p_1V_1 = p_2V_2}$$

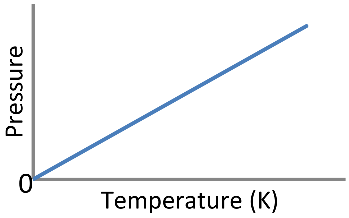


Pressure and Temperature (Gay-Lussac’s Law)

The pressure of a fixed mass of gas is directly proportional its kelvin temperature, provided the volume of the gas remains constant.

$$p \propto T$$

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

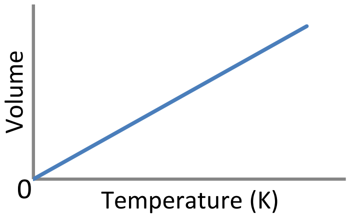


Volume and Temperature (Charles’ Law)

The volume of a fixed mass of gas is directly proportional its kelvin temperature, provided the pressure of the gas remains constant.

$$V \propto T$$

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



The three gas laws can be combined into a **general gas equation**:

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

The relationships between pressure, temperature and volume can be explained by **kinetic theory**. In kinetic theory it is assumed that all the particles in a gas are in constant random motion and do not lose energy when they collide with each other or the walls of the container.

Pressure and Volume

(Boyle's Law)

- decrease the volume of the gas
- particles collide with walls of container more often, but with the same individual force
- total force on container walls increases
- area of walls decreases
- pressure increases

Pressure and Temperature

(Gay-Lussac's Law)

- increase the temperature of the gas
- kinetic energy, and speed, of gas particles increases
- particles collide with walls of container more often and with a greater individual force
- total force on container walls increases
- area of walls is the same
- pressure increases

Volume and Temperature

(Charles' Law)

- increase the temperature of the gas
- kinetic energy, and speed, of gas particles increases
- particles collide with walls of container more often and with a greater individual force
- total force on container walls increases
- for pressure to remain constant the area of the walls must increase
- volume increases