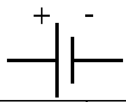
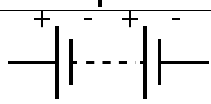
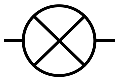
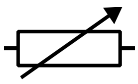
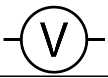
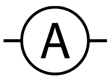
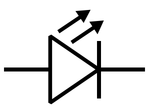
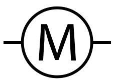
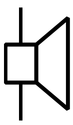
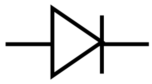
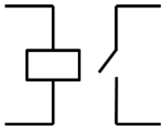
Electricity Summary Notes

Electronic Component	Symbol	Function	Practical Application
Cell		Converts chemical energy into electrical energy	Supplies energy to a car battery
Battery		Converts chemical energy into electrical energy	Supplies energy to a torch
Lamp		Converts electrical energy into light	Bulb
Switch		To complete a circuit	Allows a circuit to be switched on or off
Resistor		To limit the current in a circuit	Changes electrical energy into heat in a toaster
Variable resistor		To vary to current in a circuit.	To vary the amount of current to a dimmer lamp
Voltmeter		To measure the voltage between two points. (p.d)	Measures the voltage through a component
Ammeter		To measure the current flow (charge per second) in a circuit / component	Measures the charge per second through a component
LED		To convert electrical energy into light	To act as a warning light. Lighting for car / home.
Motor		To convert electrical energy into kinetic energy	To allow the rotation of a washing machine drum
Loudspeaker		To convert electrical energy into kinetic energy - produces sound energy	To listen to music Telephone handset

Diode		Allows current to flow in one direction only	Converting ac to dc
Relay		Activates a switch by use of a small current in primary circuit	Controlling a secondary circuit, usually high powered.

Electric Current

When we define an electric current we consider it to be the movement of a *electrons* around a circuit.

The smallest unit of electric charge is the charge on one electron, but this is too small a number to use practically, therefore we use the term Charge to describe a group of electrons at any one point.

A quantity of Charge has the symbol Q and is measured in units of Coulombs, C.

The size of an electric current will depend on the number of coulombs of charge passing a point in the circuit in one second.

amperes or **A** coulombs or **C**

$$\textbf{current} = \frac{\textbf{charge}}{\textbf{time}} \qquad \mathbf{I} = \frac{\mathbf{Q}}{\mathbf{t}}$$

seconds or **s**

This means that **electric current is defined** as the **electric charge transferred per unit time**, usually in seconds.

Example

A current of 5 amperes flows through a lamp for 7 seconds. How much *charge* has passed through the lamp in that time?

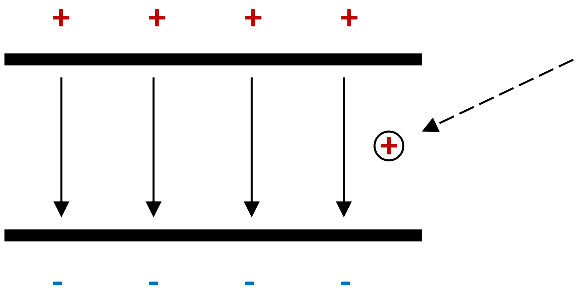
$$\left.\begin{array}{l} I = 5\text{ A} \\ t = 7\text{ s} \\ Q = ? \end{array}\right\} \qquad \begin{aligned} \mathbf{Q} &= \mathbf{I \times t} \\ &= 5 \times 7 \\ &= \mathbf{35C} \end{aligned}$$

Therefore 35 coulombs of charge have passed through the lamp in 7 seconds.

Electric field

An electric field is a region of space in which a charge placed in that region will experience a force.

Below is a diagram of the electric field between two parallel charged plates. The normally invisible electric field lines have been drawn to show the direction of the electric field.



The direction of the electric field is the direction of the force experienced by a positive charge placed in the field.

The diagram shows the positive charge being accelerated towards the negative plate, due to both repulsion of the positive plate and the attraction to the negative plate.

If a *negative charge* was placed in the electric field it would be *accelerated towards the positive plate*, due to both repulsion of the negative plate and the attraction to the positive plate.

The parallel plates will have a voltage across them this called *the potential difference*, symbol V, measured in volts, V.

The potential difference is a measure of the energy given to the charges when they move between the plates.

Potential difference is equal to the work done in moving one coulomb of charge between the plates. Therefore a potential difference of one volt indicates that one joule of energy is being used to move one coulomb of charge between the plates.

Practical Electricity

Electric Current

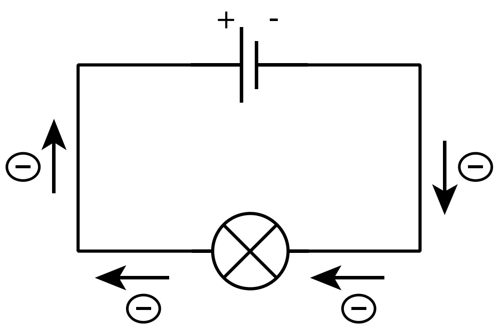
Materials can be divided into two main groups as conductors and insulators

Electrical conductors contain electrons which are free to move throughout the structure.

In electrical insulators, the electrons are tightly bound and cannot move.

All circuits need a source of energy and some electrical components which are connected by wires. The source of energy may be a battery or the mains.

If a battery is connected across a conductor such as a bulb, then the electrons will move in one direction around the circuit:



An **electric current** is the flow of electrons around a circuit. The greater the flow of electrons in a circuit, the greater is the current.

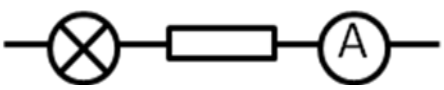
The **voltage** is the electrical energy supplied by the battery (or mains) to make the electrons move around the circuit.

Series Circuits

When components are connected in line, we say that they are connected in series.

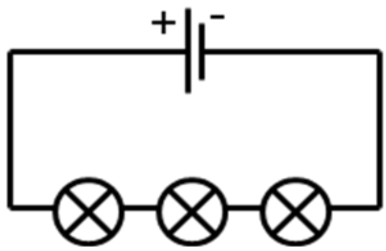
The three bulbs are connected in series

N4



If the components form a circuit, the circuit is called a

series circuit.



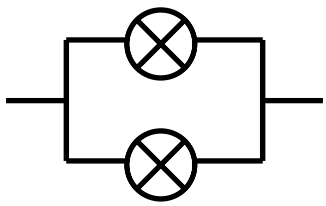
The bulb, resistor and ammeter are connected in series.

In the circuit, the current from the battery passes through each of the bulbs in turn before returning to the battery.

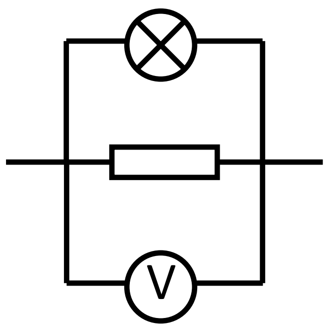
The cell and the three bulbs are connected in series. In a series circuit, there is only one path for the current to take from the negative terminal of the battery to the positive terminal.

Parallel Circuits

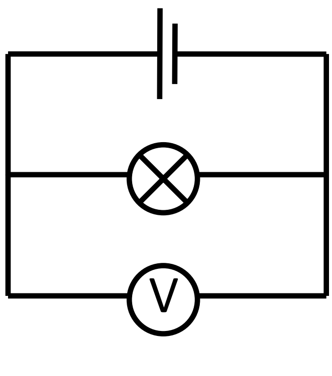
When components are connected so that there is more than one path for the current, we say that they are connected in parallel.



The two bulbs are connected in parallel

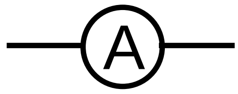


The bulb, resistor and voltmeter are connected in parallel



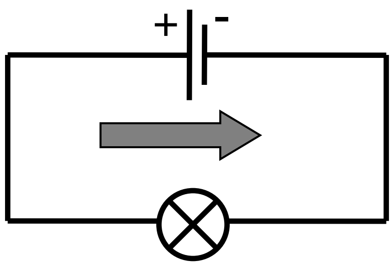
In the circuit, the current from the battery splits up and goes through each of the components (or branches) separately before recombining and returning to the battery

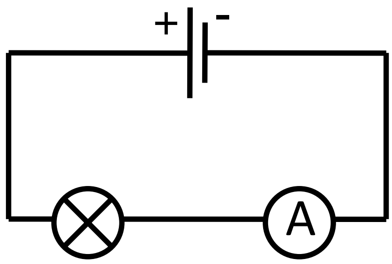
Measuring Current

Current is measured using an ammeter which has the symbol: 

Electric current is given the symbol I and is measured in amperes (A)

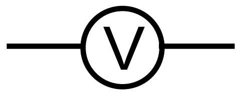
To measure the current through a component, make a gap in the circuit and connect the ammeter in series with the component.





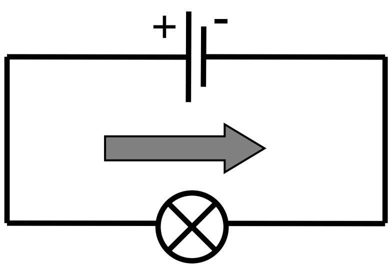
In the circuit, the ammeter is in series with the bulb. The reading on the ammeter is the current through the bulb.

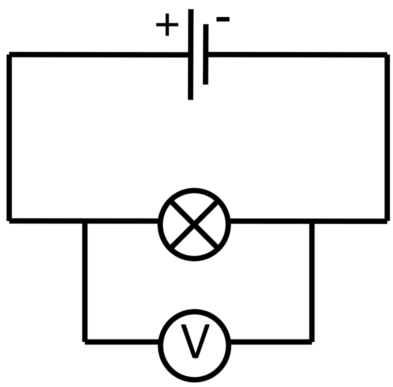
Measuring Voltage

Voltage is measured using a voltmeter which has the symbol: 

Electrical voltage is given the symbol V and is measured in volts (V).

To measure the voltage across a component, use two extra wires to connect the voltmeter in parallel with the component.

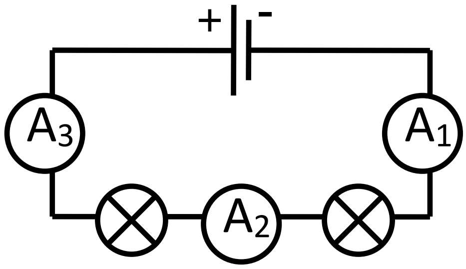




In the circuit, the voltmeter is added in parallel with the bulb. The reading on the voltmeter is the voltage across the bulb.

Current and voltage in series circuits

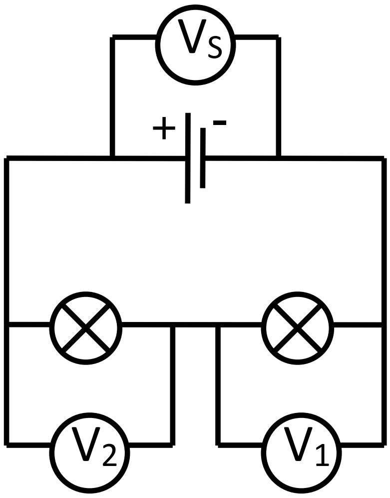
The current through every component in a series circuit is identical and is the same as the current from the battery.



Each ammeter will have the same reading.

$A_1 = A_2 = A_3$

The sum of the voltages across each component in a series circuit adds up to the supply voltage.

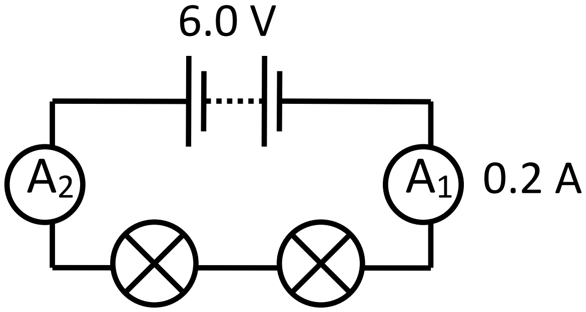


The voltmeter readings across the lamps in this circuit add up to the voltage across the battery.

$V_S = V_1 + V_2$

Examples

1. In the circuit shown below, the current readings on A_1 is 0.2 A. What is the current reading on the other ammeter and through each lamp?

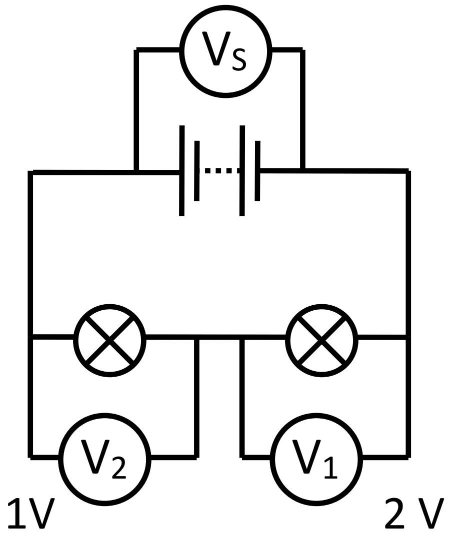


In a series circuit, the current is the same at all points.

Reading on A_2 = 0.2 A

Current through each lamp = 0.2 A

2. Find the voltage of the battery in the circuit shown below.

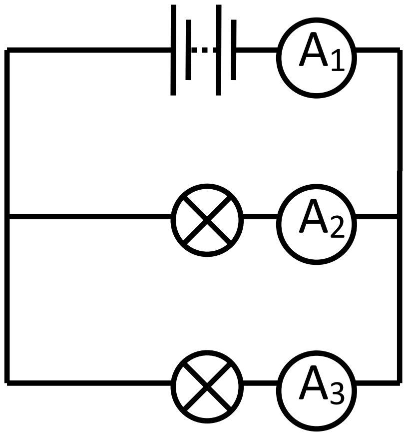


In a series circuit, the voltage across each component adds up to the supply voltage.

So the battery voltage = 2 + 1 = 3 V

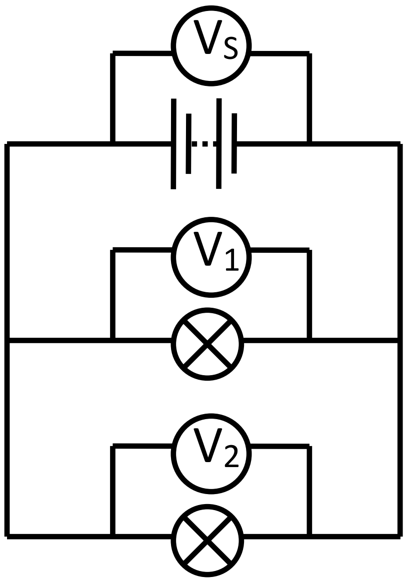
Current and voltage in parallel circuits

The sum of the currents through each component (branch) in a parallel circuit, adds up to the current which flows from the supply.



The currents through each component (branch) add up to the current from the battery.

$$A_1 = A_2 + A_3$$



The voltage across every component (branch) in a parallel circuit is the same as the supply voltage.

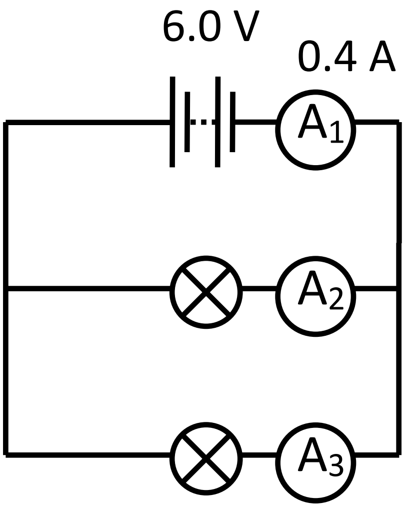
Each voltmeter has the same reading.

$$V_S = V_1 = V_2$$

The supply voltage is the same as the voltage across each of the components in parallel.

Examples

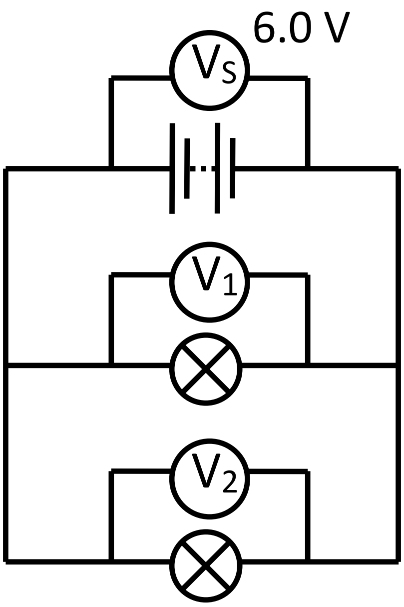
1. In the circuit shown below, the current from the battery flows through two identical bulbs. What are the current readings on A_2 and A_3?



In a parallel circuit, the current from the battery is divided equally between the branches as the bulbs are identical.

So the current through each bulb = 0.4/2 = 0.2 A

2. The voltage across the battery is 6.0 V. What is the voltage across the two bulbs?



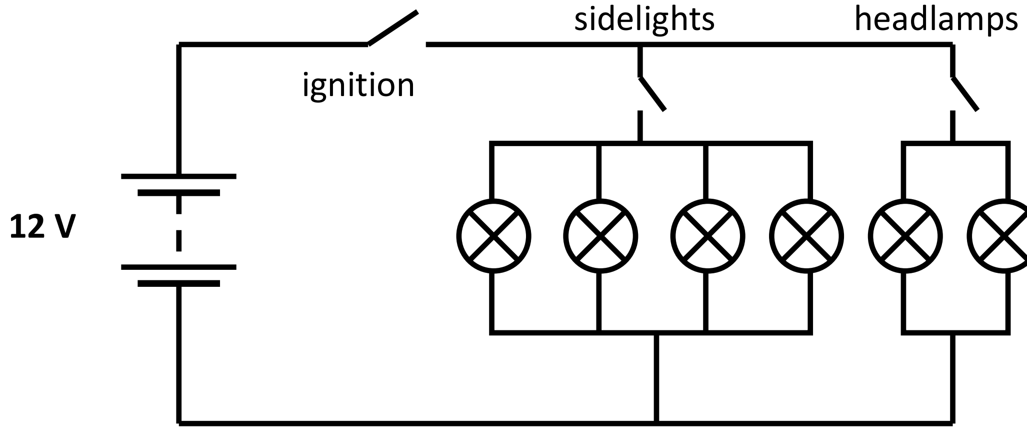
In a parallel circuit, the voltage across each of the components in parallel is the same as the supply voltage.

So the voltage across $V_S = V_1 = V_2$

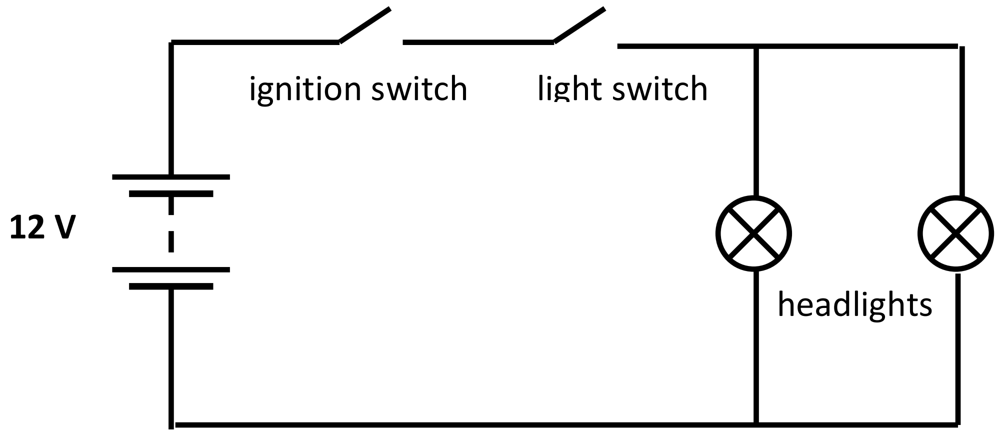
Therefore the voltage across each bulb is 6.0 V

Practical uses of series and parallel circuits

<u>Car lights</u>:



All the bulbs are placed in parallel with the battery so that each has 12 V across it.



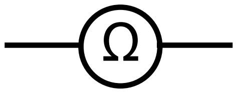
The two headlights are connected across the battery. They operate together only when the ignition switch and the light switch are on. The headlights are connected in parallel while the switches are connected in series.

Resistance

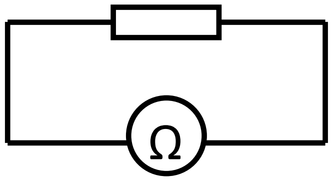
When an electric current flows through a wire some of the electrical energy is changed to heat in the wire. All materials oppose the current passing through them. This opposition to current flow is called resistance. The resistance is a measure of the opposition to the flow of current in a circuit. Insulators have a high resistance, while conductors have a low resistance.

The symbol or resistance is R and resistance is measured in units of ohms (Ω).

Electrical resistance is measured using an ohmmeter which has the symbol:



To measure the resistance of a component, an ohmmeter is connected directly across the component which must be disconnected from the circuit:



The larger the resistance in a circuit, the smaller the current that flows in it.

The smaller the resistance in a circuit, the larger the current that flows in it.

The resistance of a material depends on a number of factors:

Type of material – the better the conductor, the lower the resistance

Length of material – the longer the material, the higher the resistance

Thickness of material – the thicker the material, the lower the resistance

Temperature of material – for most conductors, the higher the temperature, the higher the resistance. As the electrons gain energy they collide more with one another, reducing their ability to move in current flow direction as easily.

Ohm's Law

In a conductor at constant temperature, the current increases as the voltage is increased.

Therefore, the ratio of V/I remains constant and is known as the resistance.

Therefore,

$$\textbf{Resistance} = \frac{\textbf{voltage}}{\text{Current}}$$

Ohms or **Ω**

Volts or **V**

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

Amperes or **A**

Example

The current flowing through a resistor is 0.5 A and the voltage across it is 6.0 V.

Calculate the resistance.

Solution

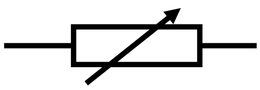
V= 6 V	**V = IR**
I = 0.5 A	6 = 0.5 x R
R = ?	R = 6 / 0.5 = 12 Ω

Variable Resistors

Resistors are components that have the property of electrical resistance. Resistors transform electrical energy into heat in domestic appliances such as heaters, toasters etc. Resistors are used also to limit the current in electronic circuits.

A variable resistor can alter the current in a circuit by changing the resistance in the circuit.

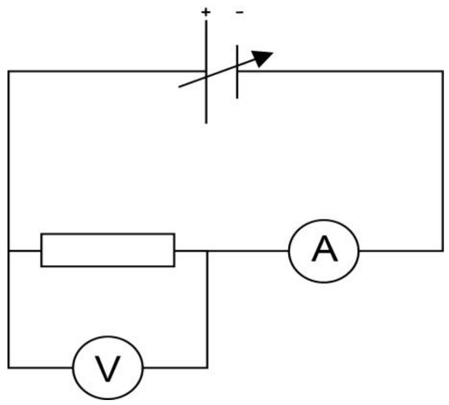
The symbol for a variable resistor is:



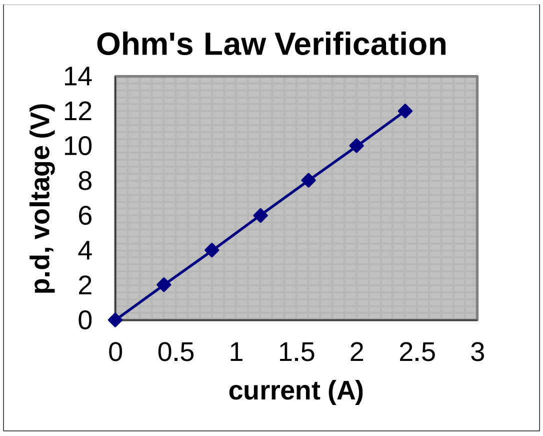
Practical uses for variable resistors include:

- Light dimmer controls
- Volume and brightness controls
- Speed controls on electric motors.

Determining the relationship between V (p.d), current and resistance



- Using a fixed value of resistor, vary the voltage supply to the circuit.
- Measure and note the values of voltage and current.
- Draw a graph of p.d against I, as shown below



This graph shows that

$V \propto I$

V = I x constant

$$\frac{V}{I} = \text{constant}$$

This constant = gradient of the line

Pick values of potential difference and current from the graph to show that: V/ I = constant.

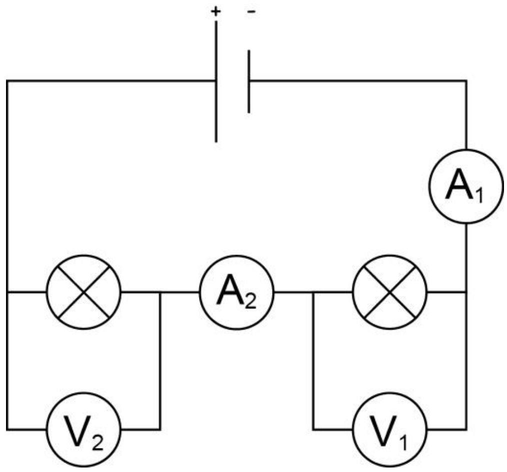
Potential difference (V)	Current(A)	V/ I = constant
2	0.4	5
4	0.8	5
6	1.2	5
8	1.6	5
10	2.0	5
12	2.4	5

Which quantity from the experiment is equal to a constant value of 5?

- **The size of the resistor.**

Further Circuits with Current and Voltage

Series Circuit



All bulbs are identical

(a) V_1 reads 3 V, what does V_2 read?

V_2 reads 3V since the bulbs are identical each bulb gets the same share of the voltage.

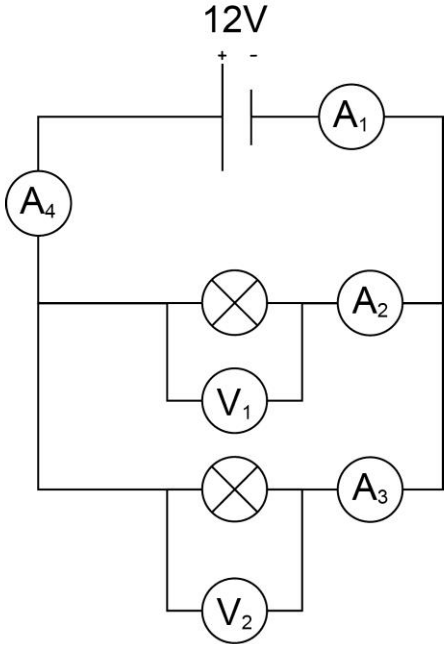
(b) Hence, calculate the voltage supply.

$V_s = V_1 + V_2$ therefore $V_s = 3 + 3 = 6V$

(c) The reading on ammeter A_2 is 1 A, what will the reading be on A_1?

The current is the same at all points in a series circuit therefore A_1 will read 1 A.

Parallel Circuit



All bulbs are identical

(a) What are the readings on voltmeters V_1 and V_2?

Both read 12 V, since in parallel each branch of the circuit receives the same voltage as the voltage supply.

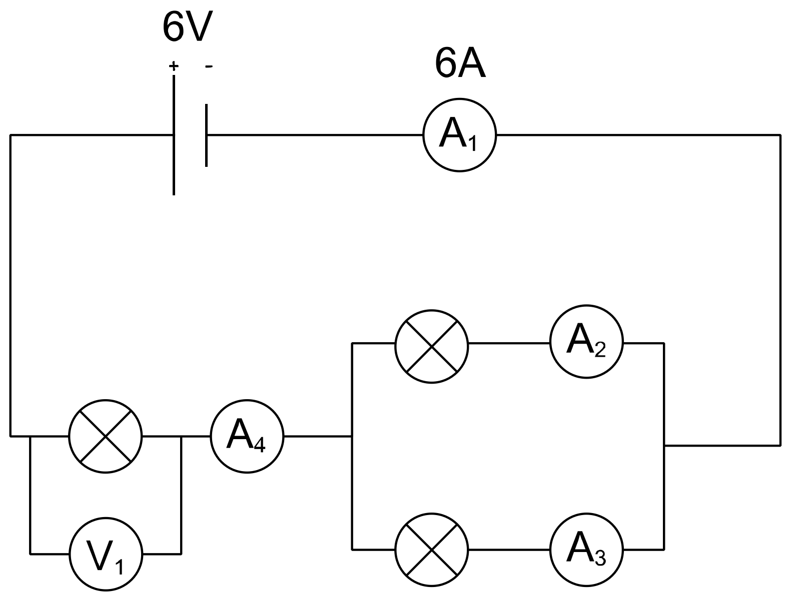
(b) If A_1 reads 3A, calculate the readings on A_2, A_3 and A_4.

The current will split equally between both branches since the bulbs are identical.

Therefore, A_2 and A_3 will both read 1.5A.

A_4 will read 3A since this is the point in the circuit where the current recombines.

Combined series and parallel circuits



All bulbs are identical

(a) A_1 reads 6A, what are the readings on A_2, A_3 and A_4?

A_2 and A_3 = 3A, since the supply current is split between both branches equally.

A_4 = 6A, at this point the current recombines.

(b) What is the reading on V_1?

The parallel arrangement of bulbs will have half the resistance of the single bulb.

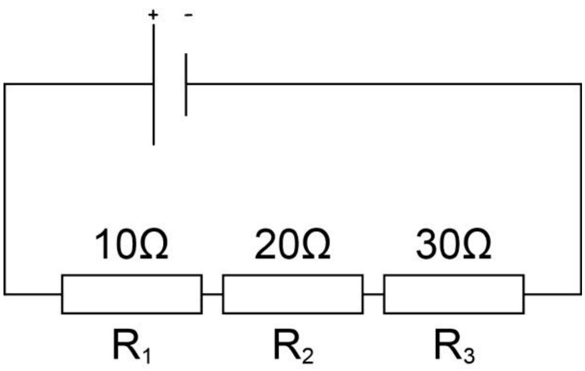
Therefore the parallel bulbs will receive only half the voltage the single bulb will get.

V_1 will read 4V and each bulb will receive only 2V.

[This is explained under the heading resistance in parallel]

Calculations involving resistors in series and parallel

Resistors in Series



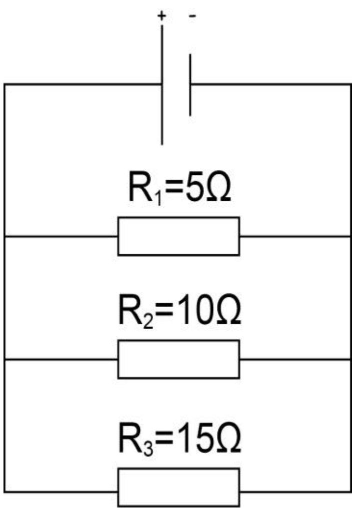
The **total resistance** of all three resistors in series is calculated using the following equation:

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

$$R_T = 10 + 20 + 30$$

$$\mathbf{R_T = 60\ \Omega}$$

Resistors in Parallel



The **total resistance** of all three resistors in parallel is calculated using the following equation:

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

Therefore

$$\frac{1}{R_T} = \frac{1}{5} + \frac{1}{10} + \frac{1}{15}$$

- Multiply both the top and bottom of each fraction to make all the denominators the same.

$$\frac{1}{R_T} = \frac{6}{30} + \frac{3}{30} + \frac{2}{30}$$

- Add fractions

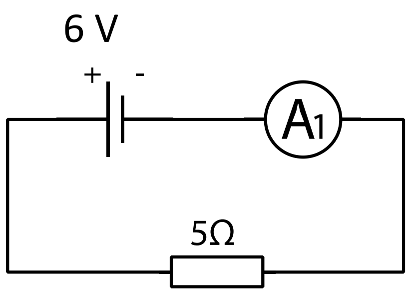
$$\frac{1}{R_T} = \frac{11}{30}$$

- Invert to calculate R_T

$$\frac{R_T}{1} = \frac{30}{11} = \mathbf{2.72\Omega}$$

More on resistors in parallel

Shown below is a simple series circuit complete with a 5Ω resistor.



Calculate the value of current through the resistor.

V = 6 V

R = 5 Ω

I = ?

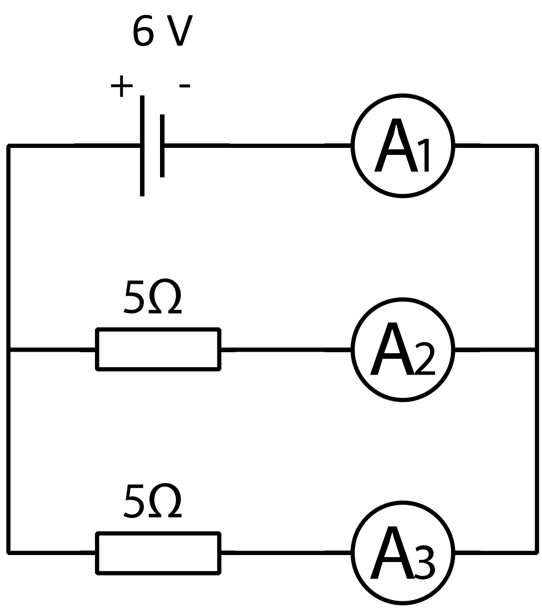
V = I x R

6 = I x 5

6/ 5 = I

1.2 A = I

Now add another 5 Ω resistor in parallel to the original, the circuit now looks like:



Calculate the value of the current through ammeter A_1.

- To do this the total resistance of the circuit must be calculated first.

Step 1

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

$\frac{1}{R_T} = \frac{1}{5} + \frac{1}{5}$

$\frac{1}{R_T} = \frac{2}{5}$

$\boldsymbol{R_T}$ **= 2.5 Ω**

Step 2

V = I x R

6 = I x 2.5

6/ 2.5 = I

2.4 A = I

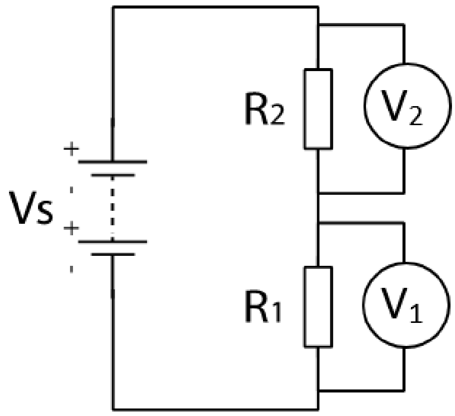
This result shows that when another resistor is added in parallel the total resistance of a circuit is decreased and the current in the circuit is increased.

i.e. by adding an identical resistor in parallel the resistance has halved and the current drawn doubled.

Potential Dividers

A potential divider circuit is made up with resistors or other components connected across a supply.

For example:



Drawn as above, the potential divider circuit is simply a series circuit following all the same rules; the current is the same at all points and the supply voltage splits up across each component to give them a share of the voltage (or potential difference).

Through experimentation the following relationships can be derived:

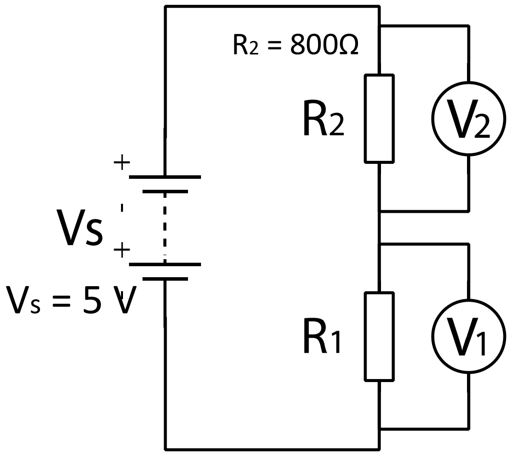
$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

$$V_1 = \frac{R1}{R1 + R2} \times V_s$$

$$V_2 = \frac{R2}{R1 + R2} \times V_s$$

Example 1

Calculate the potential difference V_1.



$$V_1 = \frac{R1}{R1 + R2} \times V_s$$

$$V_1 = \frac{200}{200 + 800} \times 5$$

$$\underline{V_1 = 1\ V}$$

Electrical Power

All electrical appliances convert electrical energy into other forms of energy. Energy has the symbol E and is measured in units of joules, J.

All appliances have a known power rating which can be found on the appliance's rating plate. Power has the symbol P and is measured in units of watts, W. The power rating of an appliance is measured as the number of joules of energy it transforms per second.

The table below shows some household appliances along with their main energy transformation and their typical power rating.

Appliance	Main energy transformation	Power (watts, W)
Lamp	Electrical into light	60
Toaster	Electrical into heat	1100
Food mixer	Electrical into kinetic	120
Radio	Electrical into sound	630

The number of joules of energy an appliance uses depends on two factors:

1. how long the appliance is on
2. the power rating of the appliance

Therefore the longer an appliance is on and the greater its power rating the more electrical energy it will use.

Energy Consumption

In a world concerned with saving energy, it is necessary to be able to calculate the energy consumption of different appliances in order that we make an informed decision on which appliances we may want to purchase.

This can be calculated using the following equation:

seconds, **s**

Power = Energy / Time **P = E / t**

Watts (W)

Energy (J)

Calculations involving power, energy and time

Example 1

A typical washing machine is rated 1200W. It is switched on for a washing cycle of 60 minutes, how much energy does it consume during this cycle?

P = 1200W

t = 60 minutes (60 x 60 = 3600s)

E = ?

P = E / t

E = 1200 x 3600

E = 432 0000 J

Example 2

A toaster switched on for 5 minutes uses 330,000 J of energy, calculate its power.

P =?

t = 5minutes (5 x 60 =300s)

E = 330,000 J

P = E / t

P = 330,000 / 300

P = 1100 W

Example 3

The power rating of a lamp is 60 W, during the time it has been on it has used up 10,000 J of electrical energy. For how long was the lamp on?

P = 60 W

t =?

E = 10,000 J

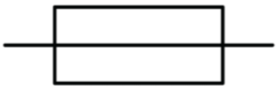
P = E / t

60 = 10000 / t

$\frac{10,000}{60} = t$

167 s = t

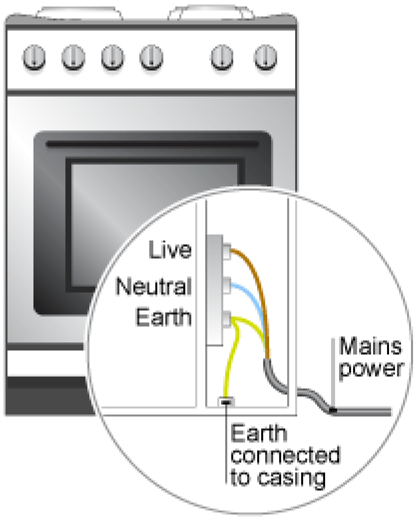
Fuses



A fuse is a sacrificial safety device which melts if the current in the circuit is too high thus 'breaking' the circuit and cutting of the power supply. They are used to **protect flexes and household wiring** from overheating.

A fuse is usually constructed using a thin metal strip or filament encased in a protective transparent glass or plastic enclosure. Fuses are available in pre-defined ratings, such as 3A and 13A etc. Plugs on electrical devices have a fuse in the live wire. The value of this fuse is determined by the power rating of the appliance. High power ratings (>720W require a 13A fuse) whereas low power ratings (≤720W) require a 3A fuse. Modern household wiring is protected by circuit breakers – a type of fuse that can be reset once it has 'tripped'

The fuse works with the Earth wire to protect the user if the metal casing becomes 'live'.



This can happen if the flex wiring becomes loose and touches the metal casing. Without the protection of the fuse and Earth wire the user would be electrocuted if they touched this live casing. The Earth wire is attached to the metal casing. If the metal casing becomes 'live' the high current drawn from the supply flows through the Earth wire (in preference the user touching the appliance) and at the same time the high current melts the fuse cutting of the power to the appliance.

The **electrical energy transformed each second** is **P = I x V**

To determine which fuse should be used, calculate current from P = I V, then choose fuse value just above normal operating current.

Carry out calculations involving P, I, V and R

Example 1

A torch bulb has a voltage of 6 V and a current of 0.3 A passing through it. What is its power?

$$\left.\begin{array}{l} V = 6\ V \\ I = 0.3\ A \\ P = ? \end{array}\right\}$$

P = I x V

P = 0.3 x 6

P = 1.8 W

Example 2

A car headlamp has a power of 24 W and a resistance of 6 Ω. Calculate its voltage supply.

$$\left.\begin{array}{l} P = 24\ W \\ R = 6\ \Omega \\ V = ? \end{array}\right\}$$

P = V^2/R

24 = V^2 / 6

24 x 6 = V^2

144 = V^2

$\sqrt{144}$ = V

12 V = V

Example 3

An electric heater has a voltage supply of 240 V and a power of 960 W. Calculate the current passing through it then the resistance of its elements.

$$\left.\begin{array}{l} V = 240\ V \\ P = 960\ W \\ I = ? \\ R = ? \end{array}\right\}$$

Step 1

P = I x V

960 = I x 240

960 / 240 = I

4 A = I

Then

Step 2

P = I^2 x R

960 = (4 x 4) x R

960/16 = R

60 Ω = R

Practical Electronic Systems

All electronic systems can be broken down into three main parts or sub-systems called the **input**, the **process** and the **output**

INPUT ⇨ PROCESS ⇨ OUTPUT

For example, a baby alarm consists of three main parts:

Input		**Process**		**Output**
microphone	⇨	amplifier	⇨	loudspeaker

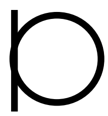
Input devices

An input device changes some form of energy into electrical energy.

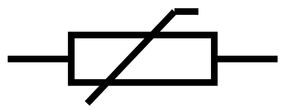
Examples of input devices:

<u>Circuit Symbol</u>

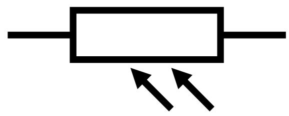
A microphone changes sound energy into electrical energy.



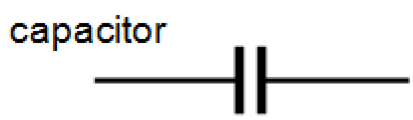
A thermistor is a resistor, the resistance of which varies with temperature. As the temperature increases, the resistance decreases.



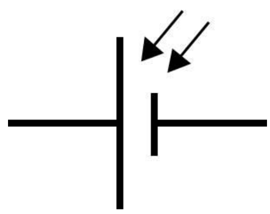
An LDR is a light dependant resistor, the resistance of which varies with light level. As the light intensity increases, the resistance decreases.



Capacitor:- these store electric charge and are often used in time delay circuits. When uncharged the voltage across a capacitor will be 0 V rising to the same voltage as the supply when fully charged.



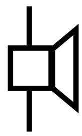
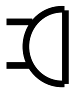
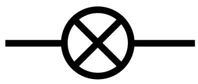
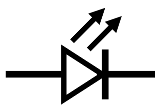
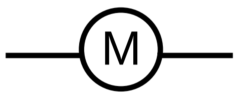
Photovoltaic cell, or solar cell, produces a small current when light is absorbed.



Output devices

An output device changes electrical energy into another form of energy.

Examples of output devices:

Device	Circuit Symbol	Energy Change
Loudspeaker		Electrical energy → Sound Energy
Buzzer		Electrical energy → Sound energy
Lamp		Electrical energy → Light energy
LED		Electrical energy → Light energy
Motor		Electrical energy → Kinetic energy

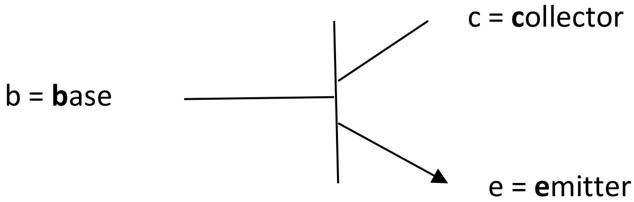
Examples of output applications:

Application	Device	Reason
Output of a radio	Loudspeaker	The output from the loudspeaker is sound waves
Output of a smoke alarm	Buzzer	A voltage across the buzzer makes it sound
Output of a security lamp	Lamp	A voltage across the lamp makes it light

Transistor

A transistor is a **process** device. It acts as an **automatic switch**.

Symbol

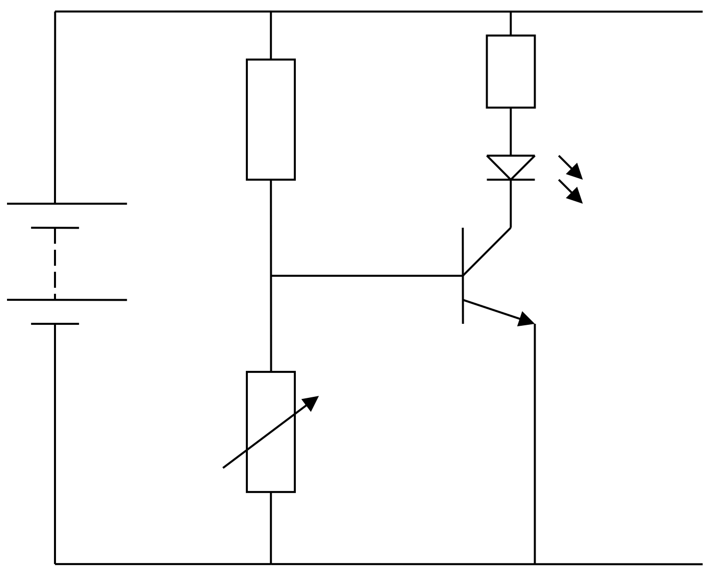


Electrons flow from the emitter through the base to the collector. This only happens if the **voltage across the base /emitter** is high enough.

The conducting voltage is 0.7V - ON

Anything less and the transistor will not allow current to flow through it. Below 0.7 V the transistor is non-conducting - OFF.

Example

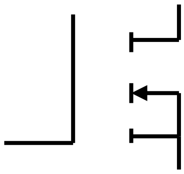


As the **resistance of the variable resistor is gradually increased**, the voltage across it increases and the voltage applied to the emitter- base increases. When the voltage applied to the emitter-base of the transistor is 0.7 V or more, the transistor will **switch on** and conduct allowing current to flow through it to the LED and the LED will switch 'on'.

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor)

A MOSFET is another type of transistor. It is also a **process** device and can act as an **automatic switch.**

The symbol is:

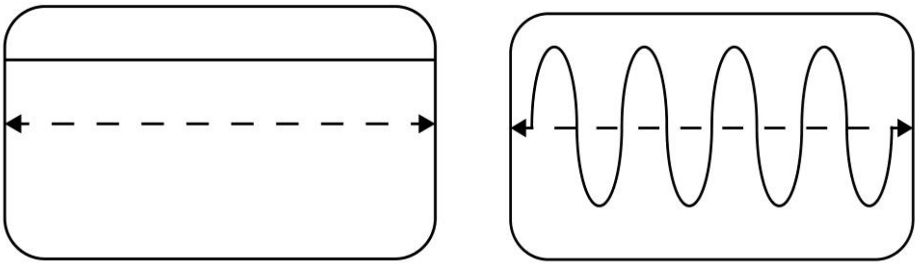


The three terminals are called the gate, source and drain.

The MOSFET will switch on when the potential applied to the gate (V_{GS}) is above the threshold voltage. The threshold voltage is about 2V

Alternating and Direct Current

Figure 1 and Figure 2 show the electron directions for each type of current flow as viewed on an oscilloscope.



- Figure 1, direct current shows that electrons always flow in one direction around the circuit.
- Figure 2, alternating current shows that electrons flow around in one direction then the direction changes and the electrons flow in the opposite direction.

Alternating and direct currents are produced from different sources of electrical energy. Alternating current is produced from the mains supply and direct current from a battery.