

Physics notes - Electricity

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Electric charge

One of the properties of an object is its electric charge, which is either positive or negative. The strength of its electrical interaction with other objects around it depends on its electric charge.

In nature there are two kinds of charged particles, electrons (negative) and protons (positive), the magnitude of their charges are equal. In a neutral object electron and proton numbers are equal. The object is negatively charged if there are more electrons than protons, positively charged if there are fewer electrons than protons.

Like charges repel and unlike charges attract each other. This is the driving force of electric current.

The coulomb

The SI unit of charge is the coulomb (C).

The magnitude of the charge on an electron or proton is approximately 1.60×10^{-19} C and it is called the **elementary charge**.

When an object has a charge of 1C, it has approximately 6.25×10^{18} electrons (or protons) in excess.

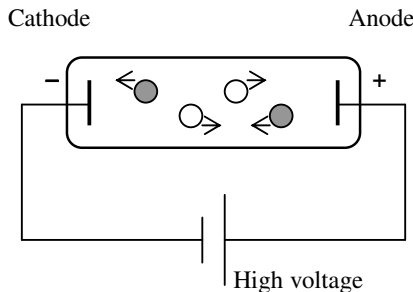
Conductors, insulators and electric current

Conductors are materials in which a significant number of charged particles are free to move.

The charged particles in insulators are not free to move.

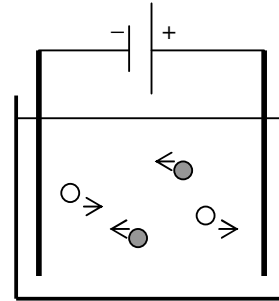
When charge particles move through a material, we say an electric current exists in the material.

Example 1 In a gas discharge tube, both kinds of charge are free to move in the electric field.



- Positively charged particle
- Negatively charged particle

Example 2 In an electrolyte, both kinds of charge (positive and negative ions) are free to move.

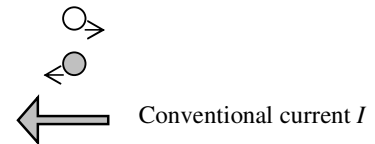


Example 3 In a metal, only electrons are free to move.

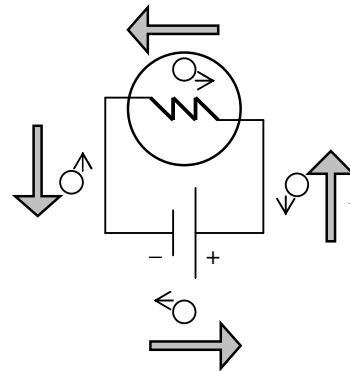


Direction of electric current

Since the oppositely charged particles move in opposite directions in an electric field, by convention we choose the direction of the positively charged particles (i.e. opposite direction to the negatively charged particles) as the direction of the electric current.



Example



In the light globe electrons flow in the clockwise direction and by convention the current flows anticlockwise.

Current flows from the positive terminal of a battery through the external circuit (the light globe) to the negative terminal.

Inside the battery current flows from the negative to the positive terminal.



Defining electric current

Electric current I is defined as the rate of flow of charge.

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

where Q is the amount of charge in coulombs (C) passing through a point during the time interval Δt in seconds (s).

The unit for I is C s^{-1} or A (ampere).

To find the amount of charge in coulombs (C) passing through during the time interval Δt , use $Q = I\Delta t$.

Electric potential

A large concentration of positive (or negative) charge has the *potential* to do work on another charge due to the electric force on the latter. Electric potential is measured in joules per coulomb (J C^{-1}) of the latter charge.

Joule per coulomb is equivalent to volt (V).

$$1 \text{ J C}^{-1} = 1 \text{ V}$$

By convention, a large concentration of positive charge has a high electric potential, a large concentration of negative charge has a low potential.

Work is done on a charge when electric potential energy is changed to kinetic energy of the charge. If the charge encounters resistance, its kinetic energy changes to other forms of energy, e.g. heat and light in a light globe; heat and mechanical energy in a motor.

When a charge moves from point A to point B and its energy changes to other forms, we say point A is at a higher potential than point B, and hence there is a **potential difference** between the two points. If there is no conversion of energy, the potential difference is zero, i.e. the two points are at the same potential.

Potential difference (V) is also measured in volts (V). The number of volts is called the **voltage** (V) of the potential difference.

The amount of conversion of electrical potential energy to other forms of energy is given by

$$E = QV$$

where Q is the amount of charge going through the potential difference V .

A battery is a reliable source of potential difference. Its two terminals are at different potentials. The maximum voltage that a battery can supply is given by its e.m.f., ξ , e.g. the e.m.f. of a standard car battery is $\xi = 12 \text{ V}$.

Example 1 A light globe is connected to a 6-V battery. How much electrical potential energy is converted to heat and light after 8.0 C of charge passes through the globe?

$$E = QV = 8.0 \times 6.0 = 48 \text{ J}$$

Example 2 A steady current of 2.5A flows in a wire connected to a battery. But after 4.0 min the current suddenly ceases because the wire is disconnected. How much charge passed through the circuit?

$$Q = I\Delta t = 2.5 \times 4.0 \times 60 = 600 \text{ C}$$

Example 3 Car batteries are often rated in ampere-hours (A-h). What does this rating mean?

Ampere-hour is a unit of charge supplied by a battery
 $= 1 \times (1 \times 60 \times 60) = 3600 \text{ C}$.

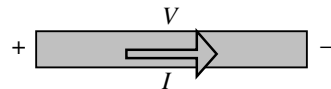
If a battery is rated 120 A-h and supplying a current of 1.0 A, it will last for 120 hours before it becomes flat. If the current is doubled to 2.0 A, it will last for half of the time, i.e. 60 hours.

Example 4 In a car one terminal of the battery is said to be connected to 'ground'. Since it is not really connected to the ground, what is meant by this expression?

It means the terminal is used as the reference point to measure the potential at any other point. Usually the negative terminal of the car battery is chosen as 'ground' and assigned a potential of 0 V. It is at the lowest potential in the car. The negative terminal is connected to the car body, so the car body is also at 0 V. Since the only power supply to the car circuitry is the 12-V battery, so the potential at any other point of the car must be $0 \leq V \leq 12 \text{ V}$.

Combining $I = \frac{Q}{\Delta t}$ and $E = QV$ gives the relationship

$E = VI\Delta t$. If the potential difference and the current through the component are known, the amount of energy conversion can be determined.



Example 5 The potential difference across an electric motor is 240V and the current through it is 8.0 A. Determine the amount of electrical energy converted to heat and mechanical energies in an hour.

$$E = VI\Delta t = 240 \times 8.0 \times (1 \times 60 \times 60) = 6.9 \times 10^6 \text{ J}, \text{ or } 6.9 \text{ MJ}$$

Electric power

Electric power is defined as the rate of conversion of electrical energy to other forms of energy.

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

The unit to measure electric power is watt (W, or J s^{-1}), e.g. a light bulb rated 60W 240V changes 60 J of electrical energy to heat and light in a second when it is connected to a potential difference of 240V.

Since $E = VI\Delta t$, $\therefore P = \frac{VI\Delta t}{\Delta t} = VI$ and $E = P\Delta t$.



Example 1 An electric heater draws 7.5 A on a 240 V line. How much power does it use? How much electrical energy does it use in 30 days if it operates for 3.0 hours per day?

$$P = VI = 240 \times 7.5 = 1800 \text{ W}$$

$$E = P\Delta t = 1800 \times (30 \times 3.0 \times 60 \times 60) = 5.8 \times 10^8 \text{ J, or } 580 \text{ MJ}$$

Example 2 What is the current through a 6.0-W light globe if it is connected to a 12-V battery?

$$P = VI, \therefore I = \frac{P}{V} = \frac{6.0}{12} = 0.5 \text{ W.}$$

Example 3 Which draws more current, a 100-W light globe or a 75-W globe when they are connected to the same potential difference?

$$I = \frac{P}{V}. \text{ Since } V \text{ is constant, } \therefore I \propto P.$$

\therefore a 100-W light globe draws more current than a 75-W globe.

Kilowatt-hour, a unit to measure household electrical energy consumption

When an electrical appliance rated 1kilowatt (kW) is switched on for an hour, the amount of electrical energy consumed is 1kWh.

$$E = P\Delta t = 1 \text{ kW} \times 1 \text{ h} = 1 \text{ kWh}$$

$$1 \text{ kWh} = 1000 \text{ W} \times (1 \times 60 \times 60) \text{ s} = 3.6 \times 10^6 \text{ J} = 3.6 \text{ MJ}$$

To convert kWh to J, multiply by 3.6×10^6 ; from kWh to MJ, multiply by 3.6.

To convert J to kWh, divide by 3.6×10^6 ; from MJ to kWh, divide by 3.6.

Example 1 Convert the electrical energy consumed by the heater (last example) during the 30 days to kilowatt-hour.

$$\frac{580}{3.6} \approx 160 \text{ kWh}$$

Example 2 Each day a particular household uses a 3.6-kW heater for 2.0 h, six 100-W light globes for 4.0 h, a 3.3-kW electric stove for 1.1 h, and others amounting to 1.8 kWh. If electricity costs \$0.19 per kWh, what will be the monthly (30 days) bill?

Heater: $E = 3.6 \times 2.0 = 7.2$ kWh per day.

Lighting: $E = (0.10 \times 4.0) \times 6 = 2.4$ kWh per day.

Stove: $E = 3.3 \times 1.1 = 3.63$ kWh per day.

Others: $E = 1.8$ kWh per day.

Total for a month = $(7.2 + 2.4 + 3.63 + 1.8) \times 30 = 450.9$ kWh.

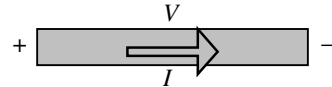
Monthly bill $\$0.19 \times 450.9 \approx \85.70 .

Resistance of a conductor

Any material, electrical component or electrical appliance is called a conductor in the following discussion.

The ability of a conductor to restrict the flow of electric current is called the resistance of the conductor, R .

Resistance R is defined as the ratio $\frac{V}{I}$, where V (V) is the potential difference across the conductor and I (A) is the current through it. The unit to measure resistance is ohm (Ω).



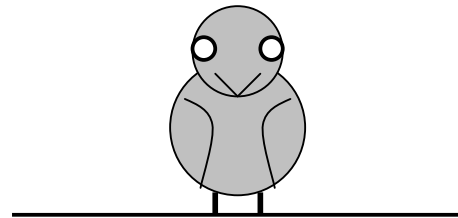
$$R = \frac{V}{I}, \therefore V = IR \text{ and } I = \frac{V}{R}.$$

Example 1 A 1.5-V battery is connected to a light globe of resistance 2.0Ω . How many electrons leave the battery in a minute?

$$I = \frac{V}{R} = \frac{1.5}{2.0} = 0.75 \text{ A, } Q = I\Delta t = 0.75 \times 60 = 45 \text{ C.}$$

$$\text{Number of electrons} = (6.25 \times 10^{18}) \times 45 \approx 2.8 \times 10^{20}.$$

Example 2 A bird stands on an electric transmission line carrying 1800 A. The line has $2.0 \times 10^{-5} \Omega$ resistance per metre and the bird's feet are 3.0 cm apart. What voltage does the bird experience?



Resistance of 3.0 cm of transmission line
 $= (2.0 \times 10^{-5}) \times 0.030 = 6.0 \times 10^{-7} \Omega.$

$$V = IR = 1800 \times (6.0 \times 10^{-7}) \approx 1.1 \times 10^{-3} \text{ V.}$$

Example 3 The following two sets of data consist of different values of potential difference across two conductors, X and Y, and the corresponding current values. Compare their resistances. Plot I-V graph for each conductor.

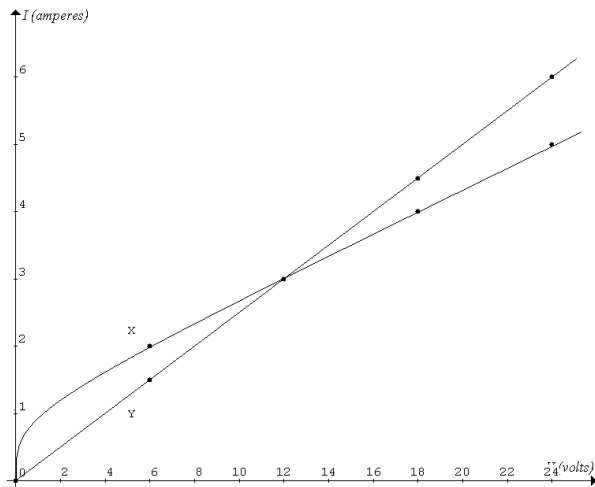
Conductor X:

V(V)	6.0	12	18	24
I(A)	2.0	3.0	4.0	5.0

Conductor Y:

V(V)	6.0	12	18	24
I(A)	1.5	3.0	4.5	6.0

The resistance of conductor X increases as current and voltage increase. The resistance of conductor Y remains constant.



Power dissipated in a conductor

Since $P = VI$ and $R = \frac{V}{I}$, power dissipated in a conductor

can also be expressed as $P = I^2R$ or $P = \frac{V^2}{R}$.

Example 1 What is the resistance of a light globe rated 75W240V when it is operating correctly?

$$P = \frac{V^2}{R}, \therefore R = \frac{V^2}{P} = \frac{240^2}{75} \approx 770\Omega.$$

Example 2 Is the filament resistance lower or higher in a 75-W light globe than in a 40-W globe? Both are designed to operate on 240V.

Since $R = \frac{V^2}{P}$, $\therefore R \propto \frac{1}{P}$ when V is constant, i.e. R is inversely proportional to P . Hence the 75-W light globe has lower resistance than the 40-W globe.

Example 3 An unknown resistor is connected between the terminals of a 3.00-V battery. The power dissipated in the resistor is 0.540 W. The same resistor is then connected between the terminals of a 1.50-V battery. What power is dissipated in this case?

Since the same resistor is used, assume that the resistance is the same.

$$\therefore R = \frac{V_A^2}{P_A} = \frac{V_B^2}{P_B}, \therefore \frac{1.50^2}{P} = \frac{3.00^2}{0.540}, P = 0.135 \text{ W}.$$

Example 4 A length of heating wire made of a nickel-chromium-iron alloy called Nichrome has a resistance of 72Ω . How much power is dissipated in each of the following situations?

- A potential difference of 120 V is applied across the full length of the wire.
- The wire is cut in half, and a potential difference of 120 V is applied across the length of each half.

$$(a) P = \frac{V^2}{R} = \frac{120^2}{72} = 200 \text{ W}$$

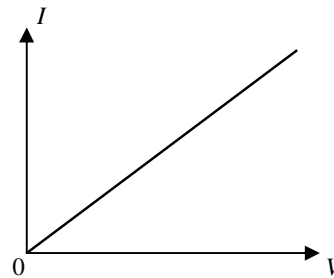
(b) Resistance of each half = 36Ω .

$$\text{Total power} = \frac{120^2}{36} + \frac{120^2}{36} = 800 \text{ W}$$

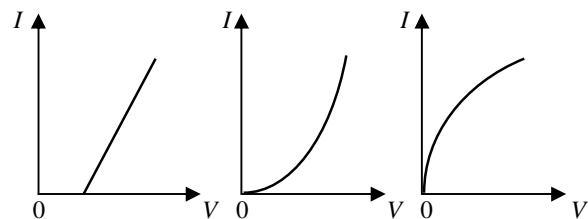
Ohm's Law

For some conductors V and I are directly proportional to each other, i.e. the ratio $\frac{V}{I}$ is a constant. Since the ratio is defined as the resistance, therefore the resistance remains constant for some conductors when V and I vary. This is known as **Ohm's law**.

Conductors that follow Ohm's law are called **ohmic conductors**. The characteristics of an ohmic conductor is shown by its I - V graph. It is a straight line through the origin.

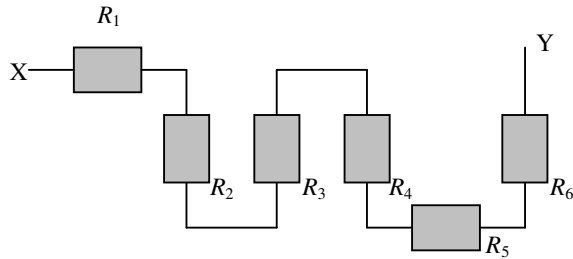


Conductors that do not follow Ohm's law are **non-ohmic conductors**. The following I - V graphs are examples of non-ohmic conductors.





Conductors connected in series



The conductors R_1, R_2, R_3, R_4, R_5 and R_6 are connected in series. If there is a potential difference, V_{XY} , between X and Y, and X is at a higher potential than Y, then a current I flows from X to Y through each conductor in the series connection.

Conductors in series:

- (1) The same current flows through each conductor, i.e. $I_1 = I_2 = \dots = I_6 = I$.
- (2) The sum of the potential difference across each conductor equals the potential difference between the two ends of the series connection, i.e. $V_1 + V_2 + \dots + V_6 = V_{XY}$.
- (3) The total resistance equals the sum of the resistances of the conductors, i.e. $R_T = R_1 + R_2 + \dots + R_6$.

Alternatively, it can be calculated using $R_T = \frac{V_{XY}}{I}$.

- (4) The total power dissipated equals the sum of the individual powers, i.e. $P_T = P_1 + P_2 + \dots + P_6$.

Alternatively, it can be calculated using $P_T = V_{XY} I$,

$$P_T = I^2 R_T \text{ or } P_T = \frac{V_{XY}^2}{R_T}.$$

Example 1 Three ohmic conductors (resistors), 1000Ω , 2000Ω and 3000Ω are connected in series with a 6.0-V battery.

- (a) What is the current through the 1000Ω resistor?
- (b) Which resistor has the highest potential difference across it?
- (c) Which resistor dissipates the most power?

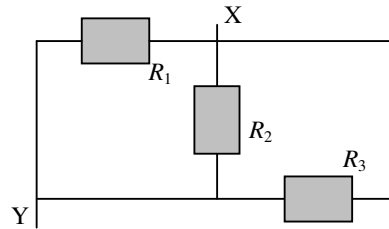
- (a) Total resistance $R_T = 1000 + 2000 + 3000 = 6000\Omega$,

$$I = \frac{V}{R} = \frac{6.0}{6000} = 1.0 \times 10^{-3} \text{ A or } 1.0 \text{ mA}.$$

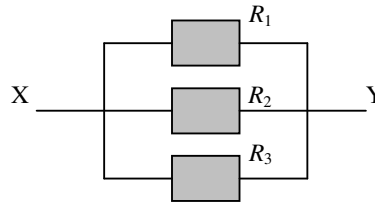
- (b) Since $V = IR$ and I is constant (same current through the series of resistors), $\therefore V \propto R$. Hence the 3000Ω has the highest potential difference.

- (c) Since $P = I^2 R$ and I is constant, $\therefore P \propto R$. Hence the 3000Ω resistor dissipates the most power.

Conductors connected in parallel



The three conductors R_1, R_2 and R_3 are connected in parallel between X and Y. This becomes apparent when the diagram is re-drawn as shown below.



When a potential difference, V_{XY} , is applied across the parallel circuit between X and Y, current I_T flowing from X to Y is split into three branches I_1, I_2 and I_3 .

Conductors in parallel:

- (1) The total current is equal to the sum of the currents through the conductors, i.e. $I_T = I_1 + I_2 + I_3$.
- (2) The potential difference across each conductor is equal to that between X and Y, i.e. $V_1 = V_2 = V_3 = V_{XY}$.
- (3) The total resistance of the parallel conductors can be calculated according to $R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$, or $R_T = \frac{V_{XY}}{I_T}$.
- (4) The total power dissipated equals the sum of the individual powers, i.e. $P_T = P_1 + P_2 + P_3$, alternatively, it can be calculated using $P_T = V_{XY} I_T$ or $P_T = I_T^2 R_T$ or $P_T = \frac{V_{XY}^2}{R_T}$.

Example 1 Two conductors, $R_1 = 100\Omega$ and $R_2 = 300\Omega$ are connected in parallel with a 6.0-V battery. (a) Calculate the current through the battery. (b) Calculate the power of the battery. (c) Use an alternative method to find (a) and (b).

$$(a) \quad I_1 = \frac{6.0}{100} = 0.060 \text{ A}, \quad I_2 = \frac{6.0}{300} = 0.020 \text{ A},$$

$$I_T = I_1 + I_2 = 0.080 \text{ A}.$$

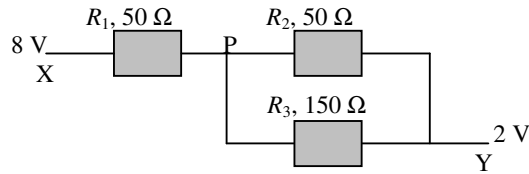
$$(b) \quad P_1 = \frac{6.0^2}{100} = 0.36 \text{ W}, \quad P_2 = \frac{6.0^2}{300} = 0.12 \text{ W},$$

$$P_T = P_1 + P_2 = 0.48 \text{ W}.$$

$$(c) \quad R_T = \frac{1}{\frac{1}{100} + \frac{1}{300}} = 75 \Omega,$$

$$I_T = \frac{6.0}{75} = 0.080 \text{ A}, \quad P_T = \frac{6.0^2}{75} = 0.48 \text{ W}.$$

Example 2 Analyse the following circuit.



$$V_{XY} = 8 - 2 = 6 \text{ V.}$$

R_1 is in series with the parallel connection of R_2 and R_3 .

$$R_T = 50 + \frac{1}{\frac{1}{50} + \frac{1}{150}} = 87.5 \Omega.$$

$$I_T = \frac{V_{XY}}{R_T} = 0.06857 \text{ A.}$$

$$I_1 = 0.06857 \text{ A, } V_1 = 3.4286 \text{ V.}$$

$$\text{Potential at point P} = 8 - 3.4286 = 4.5714 \text{ V.}$$

$$V_{PY} = 4.5714 - 2 = 2.5714 \text{ V.}$$

$$\text{Alternatively, } V_{PY} = V_{XY} - V_1 = 2.5714 \text{ V.}$$

$$\therefore V_2 = V_3 = 2.5714 \text{ V}$$

$$I_2 = \frac{V_2}{R_2} = 0.05143 \text{ A, } I_3 = \frac{V_3}{R_3} = 0.01714 \text{ A.}$$

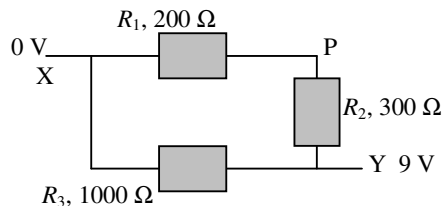
$$P_1 = V_1 I_1 = 0.235 \text{ W, } P_2 = V_2 I_2 = 0.132 \text{ W,}$$

$$P_3 = V_3 I_3 = 0.044 \text{ W.}$$

$$P_T = P_1 + P_2 + P_3 = 0.411 \text{ W.}$$

$$\text{Alternatively, } P_T = V_{XY} I_T = 0.411 \text{ W.}$$

Example 3 Analyse the following circuit.



$$V_{YX} = 9 - 0 = 9 \text{ V.}$$

R_3 is parallel to the series connection of R_1 and R_2 .

$$R_T = \frac{1}{\frac{1}{200+300} + \frac{1}{1000}} = 333.33 \Omega.$$

$$V_3 = V_{YX} = 9 \text{ V, } I_3 = \frac{V_3}{R_3} = 0.009 \text{ A.}$$

$$I_1 = I_2 = \frac{V_{YX}}{R_1 + R_2} = 0.018 \text{ A.}$$

$$V_1 = I_1 R_1 = 3.6 \text{ V, } V_2 = I_2 R_2 = 5.4 \text{ V.}$$

$$\text{Potential at point P} = 9 - 5.4 = 3.6 \text{ V.}$$

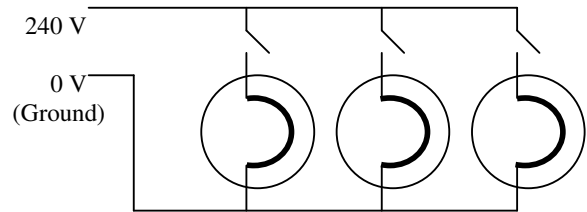
$$P_1 = V_1 I_1 = 0.0648 \text{ W, } P_2 = V_2 I_2 = 0.0972 \text{ W,}$$

$$P_3 = V_3 I_3 = 0.081 \text{ W.}$$

$$P_T = P_1 + P_2 + P_3 = 0.243 \text{ W}$$

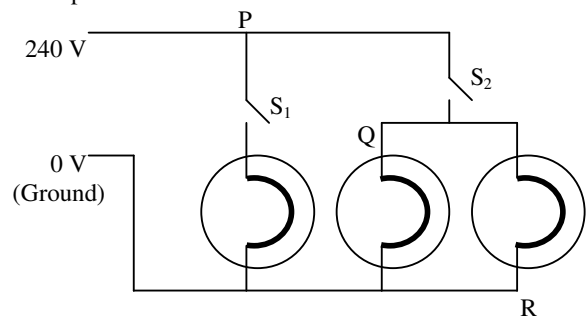
$$\text{Alternatively, } P_T = \frac{V_{YX}^2}{R_T} = 0.243 \text{ w.}$$

Example 4 Why are lights connected in parallel in household lighting circuits?



1. To ensure the lights are independent of each other.
2. To supply the correct voltage (240 V) to each light for proper operation when switch on.

Example 5



In the lighting circuit shown above both switches S_1 and S_2 are off. The potential at point P is 240 V, the potential at point Q is 0 V, and the potential at point R is 0 V, $\therefore V_{PQ} = 240 \text{ V, } V_{QR} = 0 \text{ V, } V_{PR} = 240 \text{ V.}$

These voltages remain the same when S_1 is on and S_2 is off.

When S_1 is off and S_2 is on, the potential at point P is 240 V, the potential at point Q is 240 V, and the potential at point R is 0 V, $\therefore V_{PQ} = 0 \text{ V, } V_{QR} = 240 \text{ V, } V_{PR} = 240 \text{ V.}$

Now both S_1 and S_2 are switched on. The potentials at points P and Q are the same, 240 V, the potential at point R is 0 V, $\therefore V_{PQ} = 0 \text{ V, } V_{QR} = 240 \text{ V, } V_{PR} = 240 \text{ V.}$

Example 6 Are household power points connected in series or in parallel? When additional appliances are plugged into a power board, are they connected to the circuit in series or in parallel?

They are connected in parallel so that they are independent and supplied with the same potential difference of 240 V.

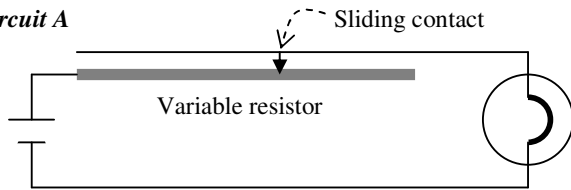
Example 7 Are headlights and other electrical components connected in series or in parallel to the battery in a car?

They are connected in parallel so that they are independent and supplied with the same potential difference of 12 V.

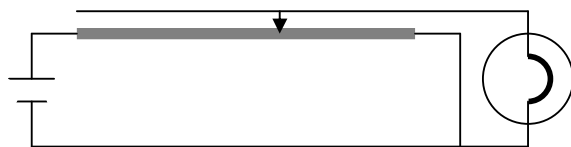
Circuits with variable resistors & non-ohmic devices

Example 1 Two possible connections of a variable resistor and a light globe are shown in circuits A and B.

Circuit A



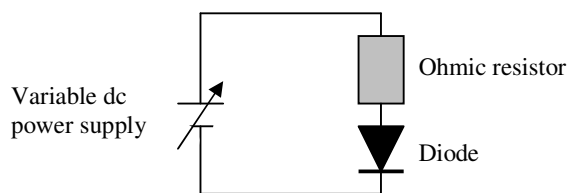
Circuit B



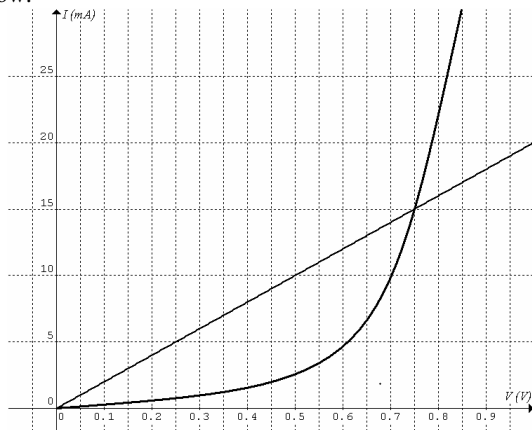
Circuit A: When the sliding contact moves to the far right, the total resistance of the circuit increases to a maximum, the current decreases to a minimum and the light globe is at its **lowest intensity**. When the sliding contact moves to the far left, the total resistance of the circuit decreases to a minimum, the current increases to a maximum and the light globe is at its brightest.

Circuit B: When the sliding contact moves to the far right, the voltage across the light globe decreases to zero and the light **goes off**. Why? When the sliding contact moves to the far left, the total resistance of the circuit decreases to a minimum, the current increases to a maximum and the light globe is at its brightest.

Example 2 An ohmic resistor and a diode are connected in series to a variable dc power supply.



The I-V characteristics of the resistor and diode are shown below.



(a) Find the resistance of the diode when the current through the diode is 10.0 mA.

From graph, $V_{diode} = 0.7 \text{ V}$,
 $\therefore R_{diode} = \frac{V_{diode}}{I_{diode}} = \frac{0.7}{10.0 \times 10^{-3}} = 70 \Omega$.

(b) Find the supply voltage when the current through the diode is 10.0 mA.

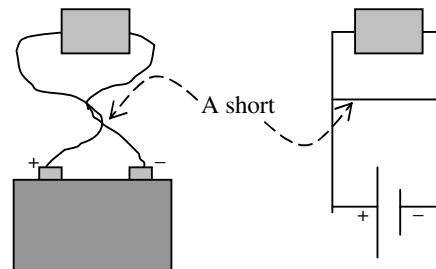
The same current flows through the ohmic resistor. From graph, $V_{resistor} = 0.5 \text{ V}$, $V_{diode} = 0.7 \text{ V}$,
 $\therefore V_{supply} = 0.5 + 0.7 = 1.2 \text{ V}$.

(c) Find the current through the ohmic resistor when the supply voltage is 0.86 V.

$V_{supply} = V_{resistor} + V_{diode} = 0.86 \text{ V}$.
 From graph, $I = 5.0 \text{ mA}$

Short circuit

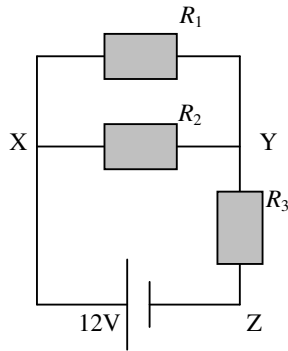
A short or short circuit means that two wires have crossed, perhaps because the insulation has worn down. If the crossed wires are at different potentials, the short provides a path of little resistance to the current.



The effects of a short are:

- (1) Practically zero current through the conductor.
- (2) Practically zero potential difference across the conductor, i.e. the two terminals of the conductor are at the same potential.
- (3) A great increase in the current through the battery and the connecting wires. This results in rapid heating in the wires and inside the battery.

Example 1



The conductors have the same resistance of 10Ω .

- (a) Analyse the circuit.
- (b) A short occurs between X and Y. Analyse the circuit.
- (c) The short between X and Y is rectified, now a new short occurs between Y and Z. Analyse the circuit.

(a) $R_T = \frac{1}{\frac{1}{10} + \frac{1}{10}} + 10 = 15 \Omega$, $I_T = \frac{V_{XZ}}{R_T} = \frac{12}{15} = 0.8 \text{ A}$.

$I_3 = 0.8 \text{ A}$, $V_3 = I_3 R_3 = 8 \text{ V}$, $\therefore V_{XY} = 12 - 8 = 4 \text{ V}$.

$V_1 = V_2 = 4 \text{ V}$, $I_1 = \frac{V_1}{R_1} = 0.4 \text{ A}$, $I_2 = \frac{V_2}{R_2} = 0.4 \text{ A}$.

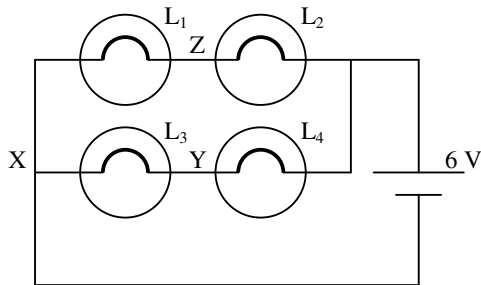
(b) $V_{XY} = V_1 = V_2 = 0$, $I_1 = I_2 = 0$, $\therefore V_3 = 12 \text{ V}$,

$I_3 = \frac{V_3}{R_3} = 1.2 \text{ A}$, $I_T = 1.2 \text{ A}$.

(c) $V_3 = 0$, $I_3 = 0$. $\therefore V_{XY} = V_1 = V_2 = 12 \text{ V}$,

$I_1 = \frac{V_1}{R_1} = 1.2 \text{ A}$, $I_2 = \frac{V_2}{R_2} = 1.2 \text{ A}$, $I_T = I_1 + I_2 = 2.4 \text{ A}$.

Example 2

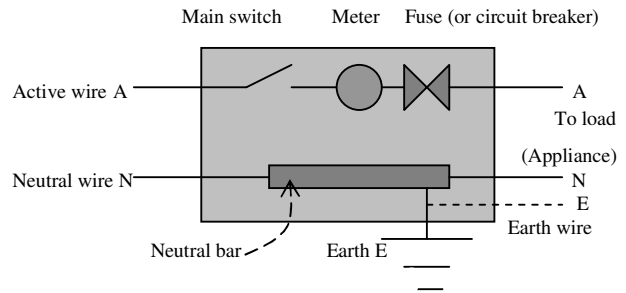


In the above circuit there are four identical light globes rated $1.5 \text{ W } 3.0 \text{ V}$. The series L_1 and L_2 is parallel to the series L_3 and L_4 .

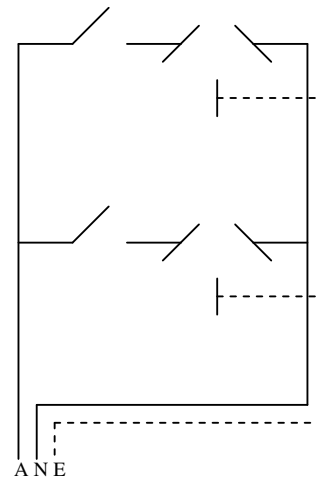
- (a) A short occurs between X and Y. Describe the effects of the short on the light globes.
- (b) Suppose the short occurs between Y and Z instead of between X and Y, describe the effects of the short on the light globes.
- (a) L_3 goes off and L_4 'blows'. No change to the brightness of L_1 and L_2 .
- (b) The short does not affect the circuit because Y and Z are at the same potential. No change to the brightness of the light globes.

Domestic power and lighting circuits

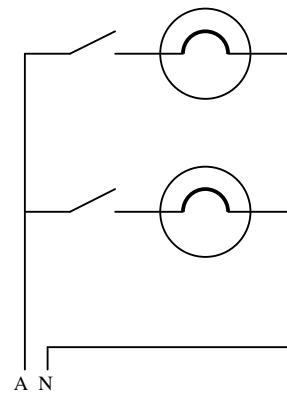
A household switchboard



A power circuit



A lighting circuit



Colour codes

Active (live) wire	brown
Neutral (passive) wire	blue
Earth (ground) wire	green and yellow

Fuse

A **fuse** is included at the switchboard along the active line. It is a piece of low-melting-point resistance wire that has been designed to melt at a preset current, **15 A for power circuit** and **8 A for lighting circuit**.

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When a fault develops in an appliance, there is an increase in current causing further damage to the appliance. Fires could also be started as a result of increased current exceeding that recommended for domestic wiring. A fuse can prevent these from happening, as well as overloading of the circuit.

An alternative to a fuse is the circuit breaker. Its operation is based on electromagnetism. It is a better method of ensuring that current flow is below the recommended level. This is because it responds to an increase in current almost instantaneously, whereas a fuse wire must first heat up and then melt before the supply is cut.

Example 1 How many 1.8kW electric kettles can be safely plugged into the mains supply?

Current drawn by kettle = $\frac{P}{V} = \frac{1.8 \times 10^3}{240} = 7.5$ A. The power

circuit allows no more than 15 A.

∴ a maximum of two 1.8 kW can be safely plugged into the same circuit.

Example 2 How many 100W light globes can be connected to the same lighting circuit without overloading the circuit?

Current drawn by each light = $\frac{P}{V} = \frac{100}{240} = 0.417$ A. The

lighting circuit allows no more than 8 A.

∴ a maximum of $\frac{8}{0.417} = 19.2$, i.e. 19 light globes can be connected to the same circuit without overloading it.

Example 3 Explain why fuses and switches are placed in the active line?

When a fuse is blown or a switch is turned off, an appliance becomes isolated from the active line and it will be at the earth potential (i.e. 0 V).

Function of the earth wire

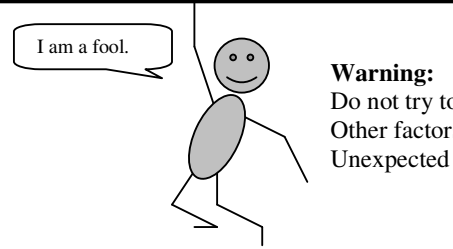
Some electrical appliances have metal casings. If loose strands from an active frayed cord inside an appliance come into contact with the protective casing, it becomes active as well. Without the earth wire, it will remain active. If a person touches the active casing, a potential difference exists between the point of contact and the ground, and current flows through the body.

If an earth wire is connected to the metal casing, the loose strands create a short circuit. Thus a large current flows through the circuit causing the fuse to blow and isolate the circuit from the active.

Another way of preventing this potential electrical hazard is by using **double insulation** in electrical appliances. Most parts of double insulated appliances are made of plastic, and the active and neutral wires are insulated by a double wrapping of plastic coating.

Electric shocks

High voltage



Warning:
Do not try to do this.
Other factors involved.
Unexpected may occur.

Ground

It is not the voltage of the source that you come in contact, which determine whether you feel an electric shock or not. The determining factors are:

- Size of the current through your body
- Duration of the current
- Which part of the body the current passes through

The size of the current in an electric shock depends on the resistance of the body part through which current passes, e.g. outer skin has a much greater resistance than tissue underneath the skin. The condition of the skin also affects the resistance, e.g. the resistance of dry skin is about 100 times that of wet skin. Resistance will be much lower if the skin has been broken.

The following information is from:
http://en.wikipedia.org/wiki/Electrical_shock

The minimum current a human can feel is thought to be about 1 mA. The current may cause tissue damage or **fibrillation** if it is sufficiently high. Death caused by an electric shock is referred to as **electrocution**.

Effects of electric shock

Psychological effects: The perception of electric shock can be different depending on the voltage, duration, current, path taken, frequency, etc. Current entering the hand has a threshold of perception of about 5 to 10 mA for DC and about 1 to 10 mA for AC at 60 Hz. Shock perception declines with increasing frequency, ultimately disappearing at frequencies above 15-20 kHz.

Burns: Heating due to resistance can cause extensive and deep burns. Voltage levels of (> 500 to 1000 V) shocks tend to cause internal burns due to the large energy (which is proportional to the duration multiplied by the square of the voltage) available from the source. Damage due to current is through tissue heating. In some cases 16 volts might be fatal to a human being when the electricity passes through organs such as the heart.



Ventricular fibrillation: A low-voltage (110 to 220 V), 50 or 60-Hz AC current through the chest for a fraction of a second may induce ventricular fibrillation at currents as low as 60 mA. With DC, 300 to 500 mA is required. If the current has a direct pathway to the heart (e.g., via a cardiac catheter or other kind of electrode), a much lower current of less than 1 mA, (AC or DC) can cause fibrillation. Fibrillations are usually lethal because all the heart muscle cells move independently. Above 200 mA, muscle contractions are so strong that the heart muscles cannot move at all.

Neurological effects: Current can cause interference with nervous control, especially over the heart and lungs. Repeated or severe electric shock which does not lead to death has been shown to cause neuropathy.

When the current path is through the head, it appears that, with sufficient current, loss of consciousness almost always occurs swiftly. (This is borne out by some limited self-experimentation by early designers of the electric chair and by research from the field of animal husbandry, where electric stunning has been extensively studied).

Avoiding danger of shock

Refer to http://en.wikipedia.org/wiki/Electrical_shock