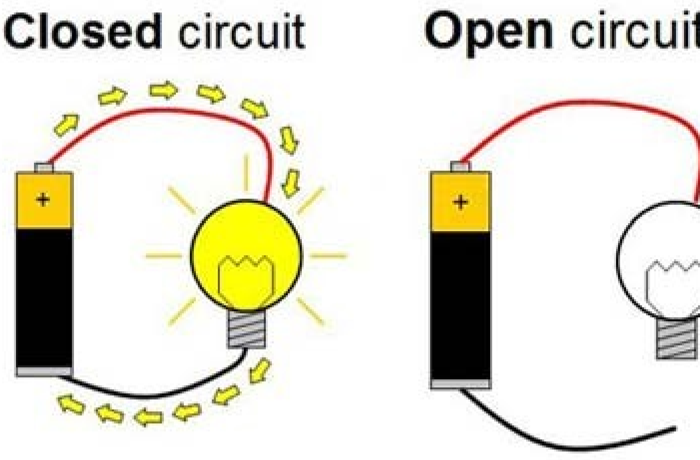
Electric current

Vladan Bernard

Circuit

- Closed Circuit

Allows a complete path for electrons to travel

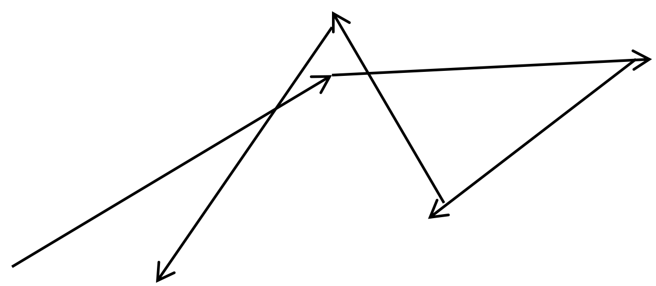


- Open Circuit

Does not allow a complete path for the electrons to travel

While the switch is open:

- Free electrons (conducting electrons) are always moving in random motion.

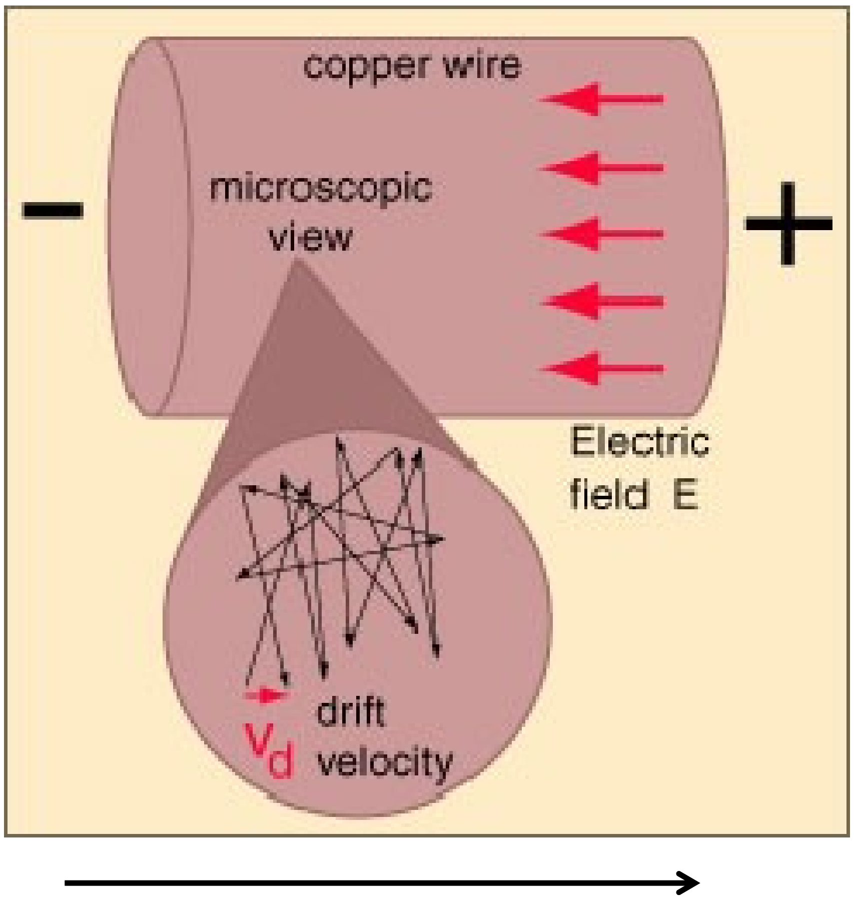


- The random speeds are at an order of

  10^6 m/s.

- There is no **net** movement of charge across a cross section of a wire.

What occurs in a wire when the circuit switch is closed?



Force of electric field

Movement of charge because of electric force

Free electrons, while still randomly moving, immediately begin drifting due to the electric field, resulting in a net flow of charge.

Potential Difference

- Potential Difference: When the ends of an electric conductor are at different electric potentials (voltages)

- Potential difference = voltage (in case of work per unit charge)
- $U=\Delta\varphi$ ---- exist force which affected charged particle

- Charge continues to flow until the ends of the conductor has the same voltage

Electric Current

- Electric Current: the flow of electric charge
  – The loosely bound outer electrons of conductors carry the charge through circuits
  – Protons tightly bound to the nuclei of atoms

The electric current through a wire is a measure of the amount of charge with passes through it per second.

Definition – electric curent

- Electric current = charge / time -I   scalar

$$I = Q/t$$

- Units: Amps (A)
- An amper is the flow of 1 C of charge per second
- NOTE: 1 C = the charge of 6,240,000,000,000,000,000 electrons ($6.2*10^{18}$)

???

- 10^{20} electrons passed through the electric conductor during 4 second. Find the electric current through this conductor.

- The electric current of 0.5 A is flowing through the electric conductor. What electric charge is passing throughcduring each second? What electric charge will pass through the conductor during 1 minute?

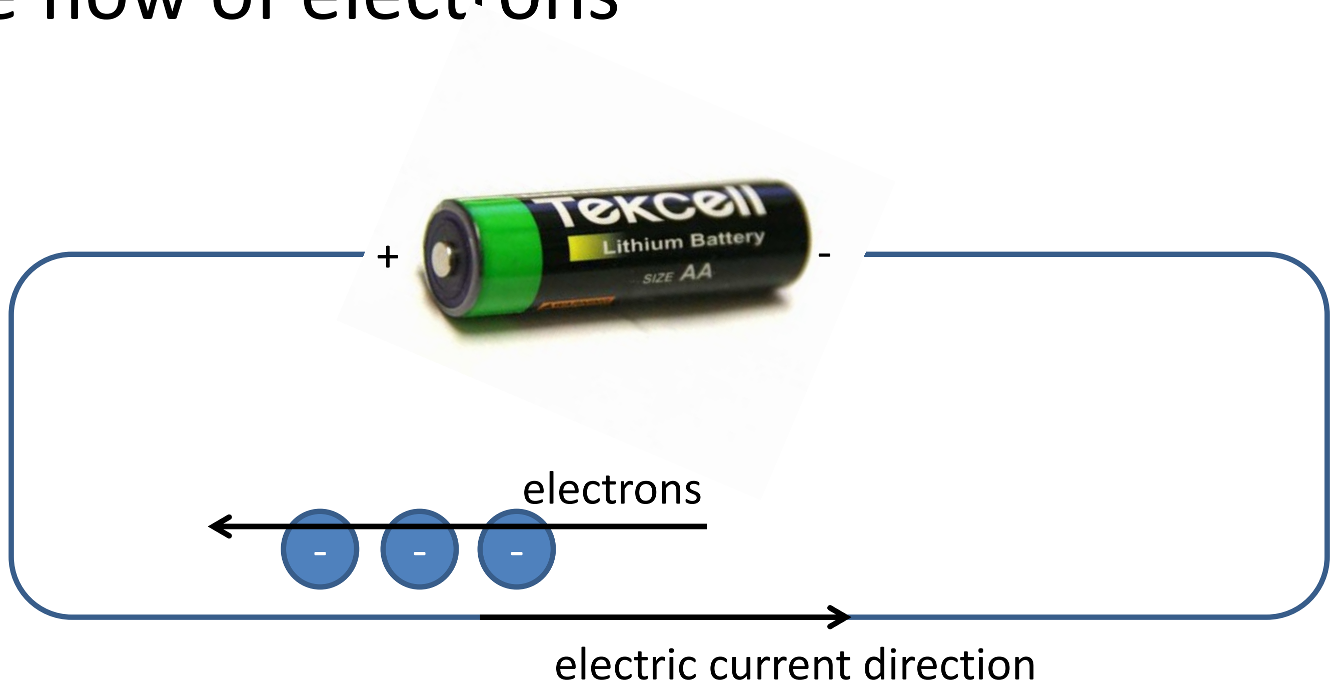
result

- $I=Q/t=(1.6x10^{-19} * 10^{20})/4=$ 4 A

- $Q=It=(0.5 * 1)=$0.5 C
- $Q=It=(0.5 * 60)=$ 30 C

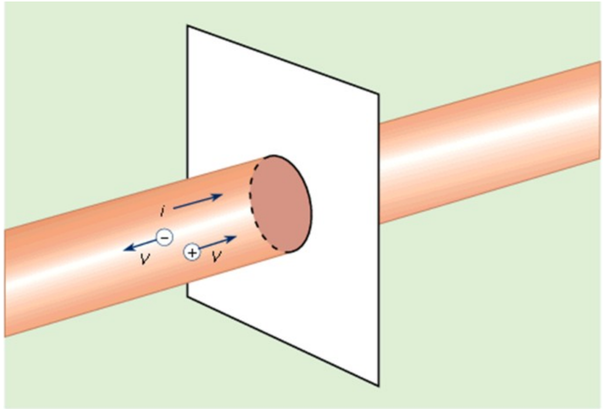
Current’s Direction

- Electrons travel from – to +
- Current is actually the opposite direction of the flow of electrons

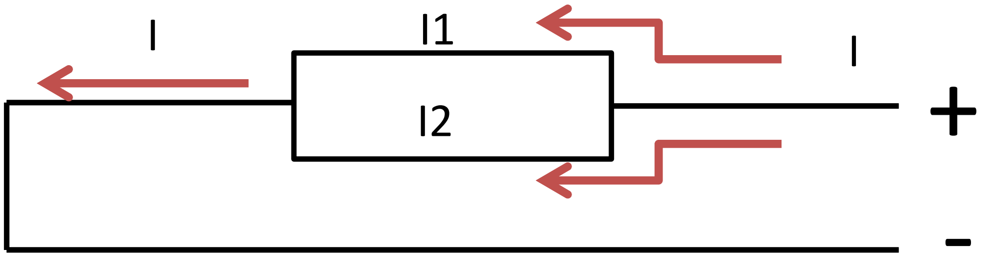


Current's Direction

Conventional current has the direction that the (+) charges would have in the circuit.



Branches in electric circuit – the electric current is divided into two (more) streams in electric node



$I=I_1+I_2$

Question ???

What is required in order to have an electric current flow in a circuit?

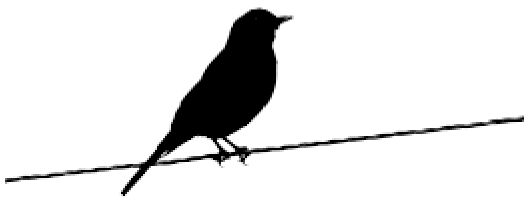
Answer:

- A voltage source.
- The circuit must be closed.

Calculate electric current of total charge 30 C flow through wire per 1 minute.

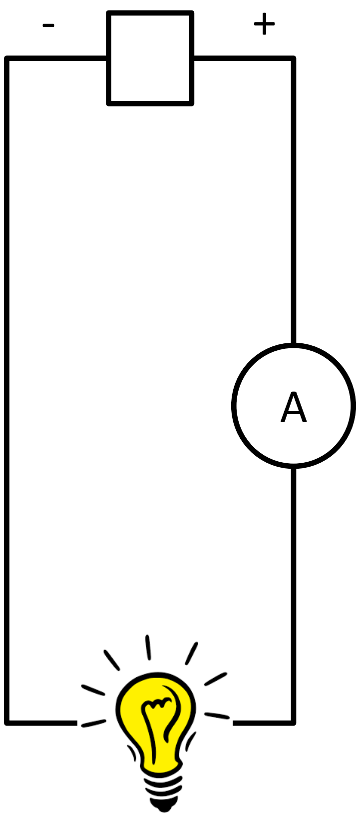
- I=Q/t, t =1 min. 60 sec
- I=30/60=0.5 A

Why is the bird on the wire safe?



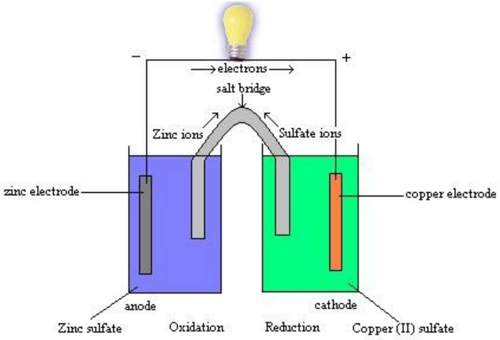
How to measure electric current?

- Ammeter – device which measures electric current.
- Multimeter (digital)
- Ammeter must be placed in series.



Voltage Sources

- Voltage Source: A device which provides a potential difference in order to keep current flowing
  - **Dry/Wet Cells**: Convert chemical energy to electrical energy
  - **Generators**: Convert mechanical energy to electrical energy
- The voltage available to electrons moving between terminals is called electromotive force, or emf.



Current vs. Voltage

Current – Flow rate, quantum of electric charge per time

- Measured in Amperes
- Ammeter- in series

Voltage – difference of potential, work per unit charge

- Measured in Volts
- Voltmeter- in parallel

Electric resistance

- Electric Resistance: „ Like an ability of a material to resist the flow of charge“

Electric resistance - **R**

Units: Ohms (Ω)

The amount of charge that flows through a circuit depends on two things:

- Voltage provided by source
- Electric resistance of the conductor
- Usually used graphic symbol 

Electric resistance - factors

- Thick wires have less resistance than thin wires
- Short wires have less resistance than long wires
- Higher temperatures usually cause more resistance
- The resistance in some materials becomes almost zero at very low temperatures

Electric resistance – factors

- The resistance depends on the geometry of the conductor. Therefore, a geometry independent quantity resistivity – specific resistance was introduced:

$$R = \rho \frac{l}{A}$$

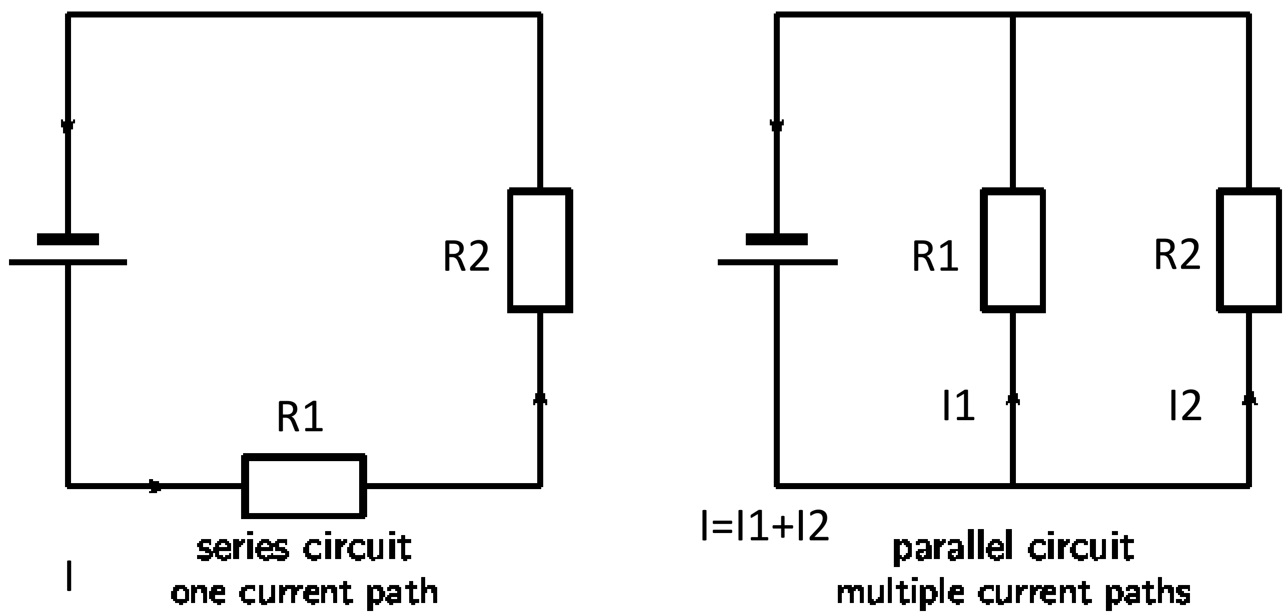
l is lenght of a conductor, *A* is the cross-section area of conductor and *ρ* is the resistivity

Resistance is depend on temperature: $$R = R_0(1 + \alpha t)$$

Where R_0 is the resistance of the conductor at the temperature t=0°C, t is temperature (°C) of conductor and α is the temperature coefficient of resistance (tabelated value).

Resistor combination

- The combination rules for any number of resistors in series or parallel can be derived with the use of Ohm's Law, the voltage law, and the current law.



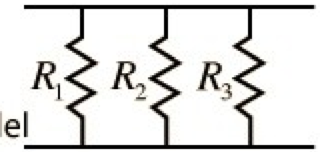
Resistor Combinations

Series

$$R_{equivalent} = R_1 + R_2 + R_3 + \ldots$$

$$R_{equivalent} = \frac{V}{I} = \frac{V_1 + V_2 + V_3 + \ldots}{I} = \frac{V_1}{I_1} + \frac{V_2}{I_2} + \frac{V_3}{I_3} + \ldots = R_1 + R_2 + R_3 + \ldots$$

Series key idea: The current is the same in each resistor by the current law.



Parallel

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

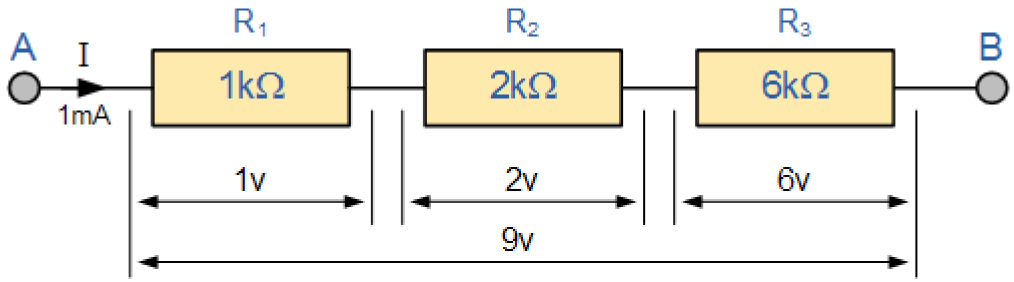
Parallel:

$$\frac{V}{R_{equivalent}} = I = I_1 + I_2 + I_2 + \ldots = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \ldots$$

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

Parallel key idea: The voltage is the same across each resistor by the voltage law.

Example



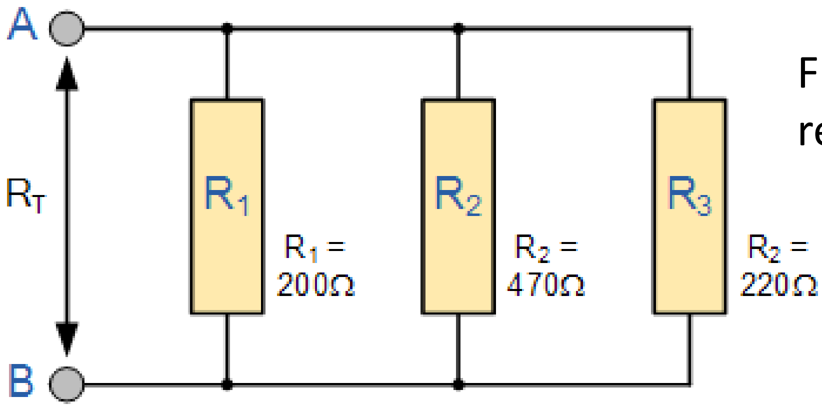
R total ???

As the resistors are connected together in series the same current passes through each resistor in the chain and the total resistance, R_T of the circuit must be **equal** to the sum of all the individual resistors added together. That is: Rt=R1+R2+R3
and by taking the individual values of the resistors in our simple example above, the total equivalent resistance, R_{EQ} is therefore given as:

$$R_{EQ} = R_1 + R_2 + R_3 = 1k\Omega + 2k\Omega + 6k\Omega = 9k\Omega$$

So we see that we can replace all three individual resistors above with just one single “equivalent” resistor which will have a value of 9kΩ.

Example



Find the total resistance, R_T of the following resistors connected in a parallel network.

The total resistance R_T across the two terminals A and B is calculated as:

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

$$= \frac{1}{200} + \frac{1}{470} + \frac{1}{220} = 0.0117$$

$$\text{therefore: } R_T = \frac{1}{0.0117} = 85.67\Omega$$

Ohm's Law

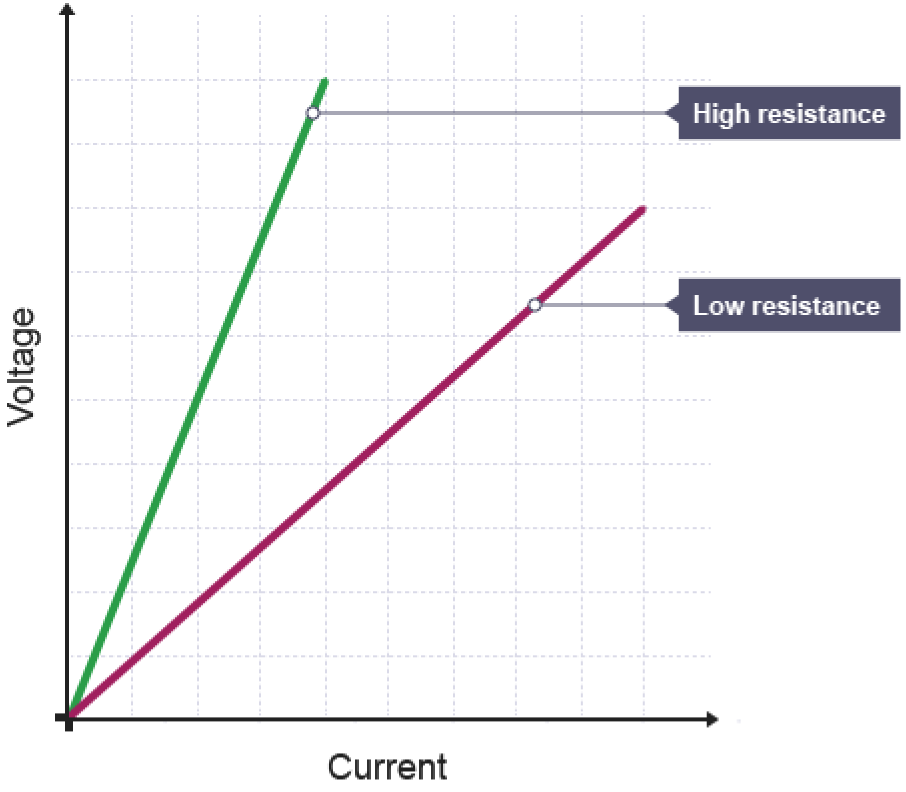
The current in a circuit is:

- Directly proportional to the voltage across the circuit
- Inversely proportional to the resistance of the circuit

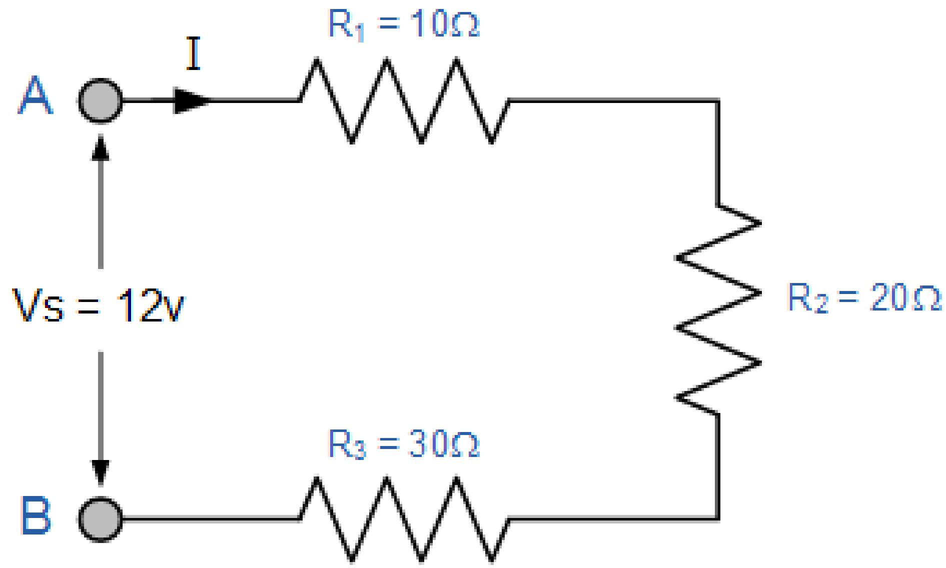
Therefore:

$$U = RI \text{ or } R = \frac{U}{I} \text{ or } I = \frac{U}{R}$$

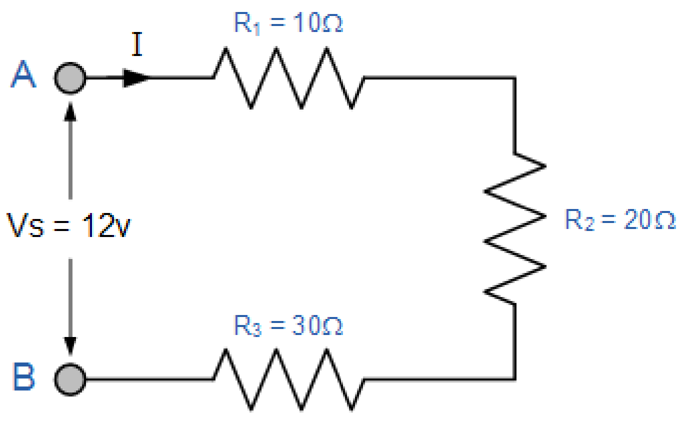
Ohm's Law



- Using Ohms Law, calculate the equivalent series resistance, the series current, voltage drop and power for each resistor in the following resistors in series circuit.



All the data can be found by using Ohm's Law, and we can present this data in tabular form (next slide).



Resistance	Current	Voltage	Power
$R_1 = 10\Omega$	$I_1 = 200mA$	$V_1 = 2V$	$P_1 = 0.4W$
$R_2 = 20\Omega$	$I_2 = 200mA$	$V_2 = 4V$	$P_2 = 0.8W$
$R_3 = 30\Omega$	$I_3 = 200mA$	$V_3 = 6V$	$P_3 = 1.2W$
$R_T = 60\Omega$	$I_T = 200mA$	$V_S = 12V$	$P_T = 2.4W$

Electric Power

The rate at which electrical energy is converted to other forms

- Electric Power = Current x Voltage

$$P = IU$$

- Units: Watts (W)

$$Power = volts\ x\ amperes = \left[\frac{joule}{coulomb}\right]\left[\frac{coulomb}{\text{second}}\right] = \frac{joule}{\text{second}} = watt$$

1 kilowatt (kW) = 1000 W

Example ???

- **What is the power when a voltage of 230 V drives a 1 A current through a device?**

P=UI=230*1=230 W

- **How much current does a 50 W lamp draw when connected to 230 V?**

P=UI   I=P/U=50/230= 0.21 A

DC Electric Power

The electric power in watts associated with a complete electric circuit or a circuit component represents the rate at which energy is converted from the electrical energy of the moving charges to some other form, e.g., heat, mechanical energy, or energy stored in electric fields or magnetic fields. For a resistor in a D C Circuit the power is given by the product of applied voltage and the electric current: W=UI.

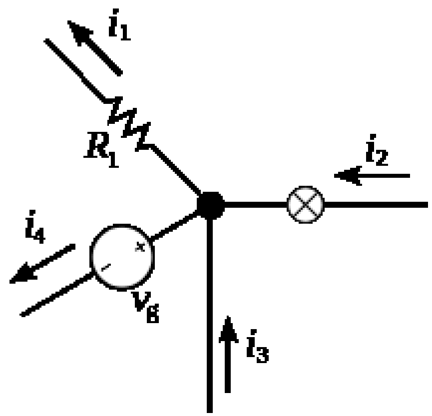
Convenient expressions for the power dissipated in a resistor can be obtained by the use of Ohm's Law.

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

The fact that the power dissipated in a given resistance depends upon the square of the current dictates that for high power applications you should minimize the current. This is the rationale for transforming up to very high voltages for cross-country electric power distribution.

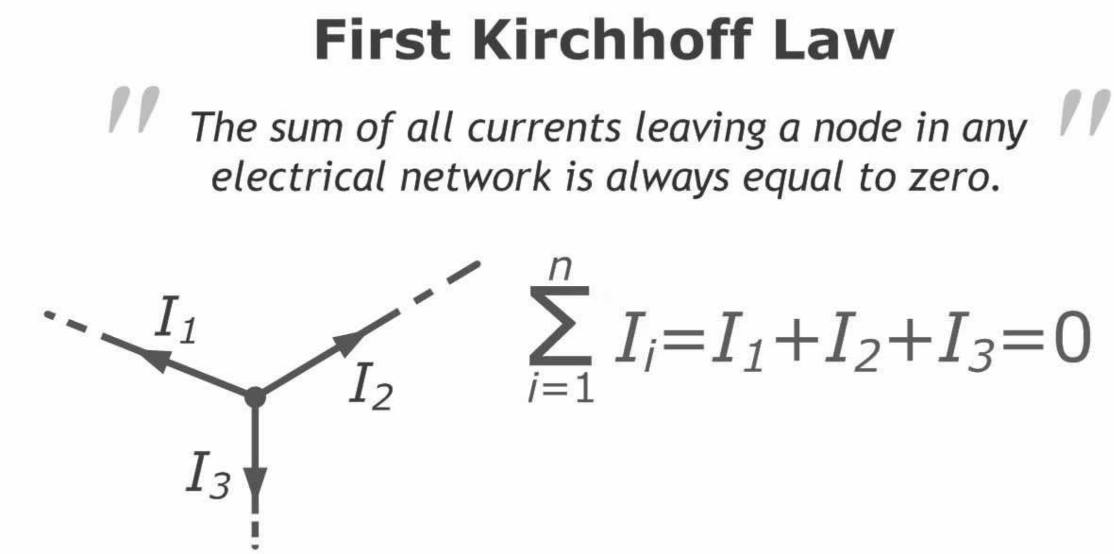
Kirchhoffś laws

Kirchhoff's circuit laws are two equalities that deal with the current and potential difference (commonly known as voltage) in the lumped element model of electrical circuits. They were first described in 1845 by German physicist Gustav Kirchhoff.



- It is fact, that : The current entering any junction is equal to the current leaving that junction. i2 + i3 = i1 + i4
- It is fact, that : Every electrical appliance in electric circuit has characteristic voltage U, obtained by

Kirchhoff's current law



The principle of conservation of electric charge implies that:

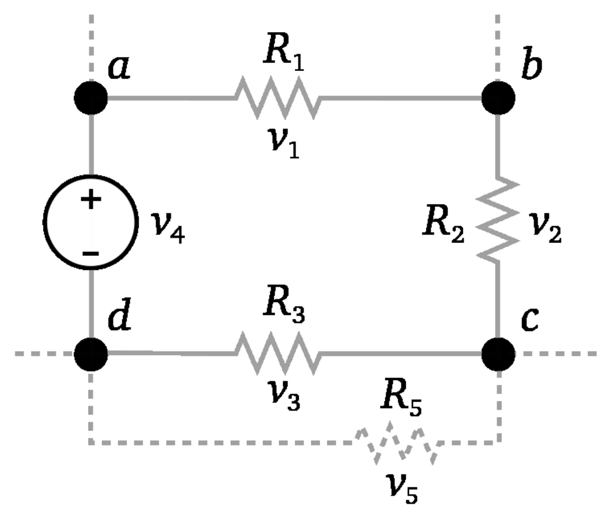
- At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node or equivalently.
- The algebraic sum of currents in a network of conductors meeting at a point is zero.

Recalling that current is a signed (positive or negative) quantity reflecting direction towards or away from a node.

Kirchhoff's voltage law

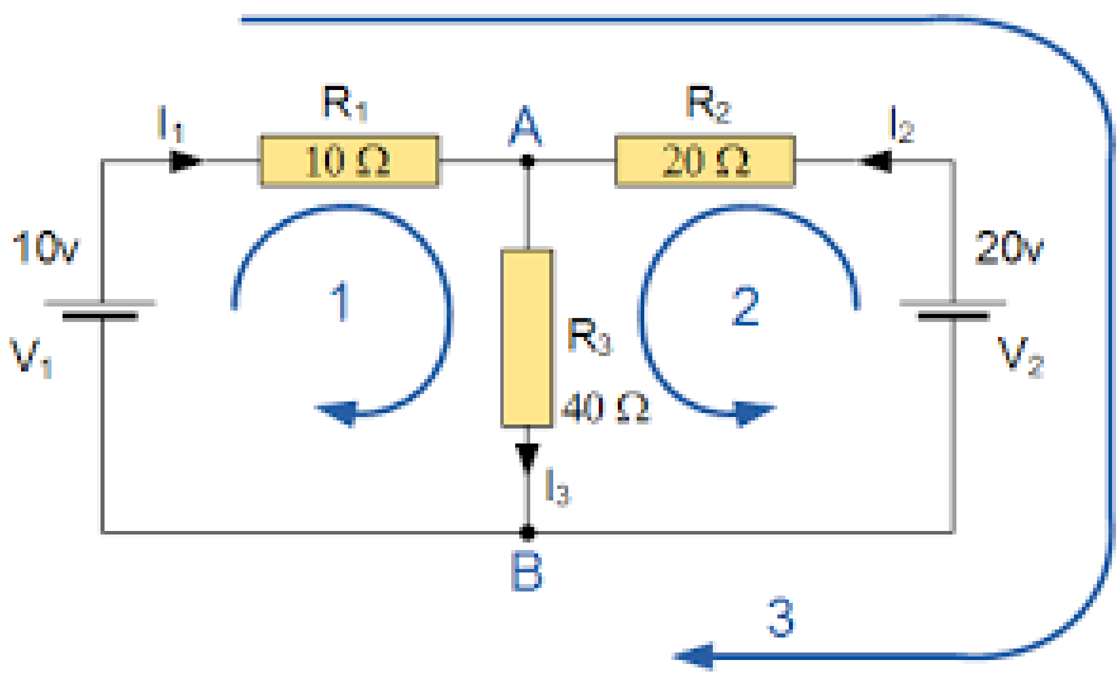
- This law is also called Kirchhoff's second law, Kirchhoff's loop (or mesh) rule, and Kirchhoff's second rule.
- The principle of conservation of energy implies that
- **The directed sum of the electrical potential differences (voltage) around any closed network is zero**, or:
- **More simply, the sum of the electromotive forces in any closed loop is equivalent to the sum of the potential drops in that loop**, or:
- **The algebraic sum of the products of the resistances of the conductors and the currents in them in a closed loop is equal to the total electromotive forces available in that loop.**

$$\sum \quad = \sum$$



The sum of all the voltages around a loop is equal to zero. U1 + U2 + U3 – U source4 = 0

Example



Capacity, electrical capacity

- **electrical capacity** - an electrical phenomenon whereby an electric charge is stored

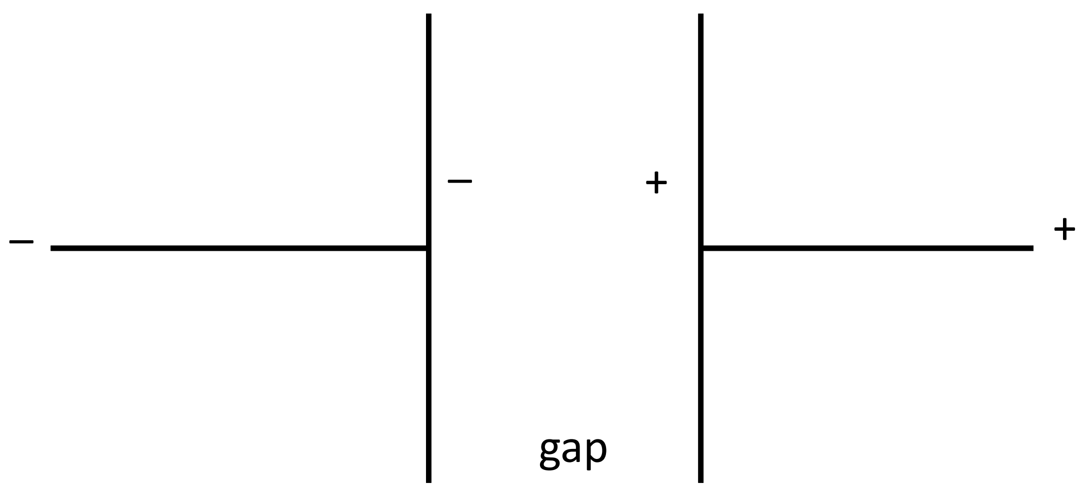
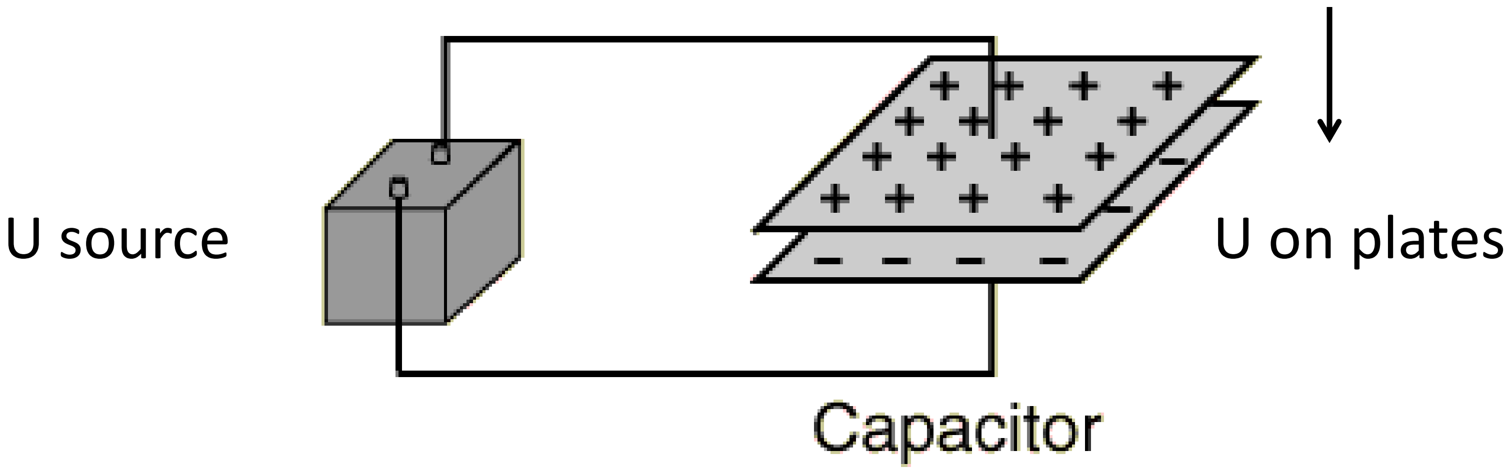


Plate capacitor

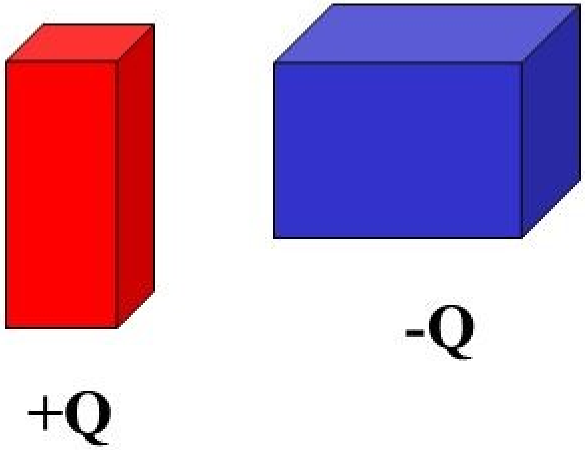
Capacitance of capacitor is typified by a parallel plate arrangement and is defined in terms of charge storage: C=Q/U, where Q = magnitude of charge stored on each plate and V = voltage applied to the plates.



A battery will transport charge from one plate to the other until the voltage produced by the charge buildup is equal to the battery voltage.

Plate capacitor

Capacitor: any two conductors, one with charge +Q, other with charge -Q



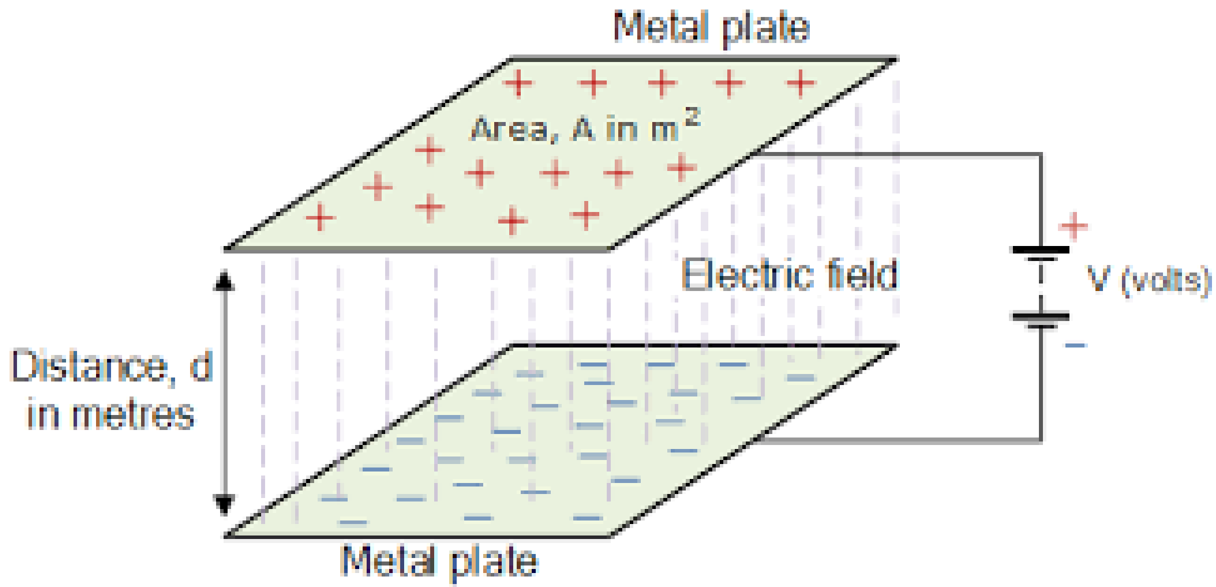
Potential DIFFERENCE between conductors = V

Q = **C**V -- C = capacitance

Units of capacitance:
Farad (F) = Coulomb/Volt

Uses: storing and releasing electric charge/energy.
Most electronic capacitors: micro-Farads (μF), pico-Farads (pF) -- 10^{-12} F
New technology: compact 1 F capacitors

Plate capacitor



$$C = \frac{\varepsilon A}{d}$$

Where,

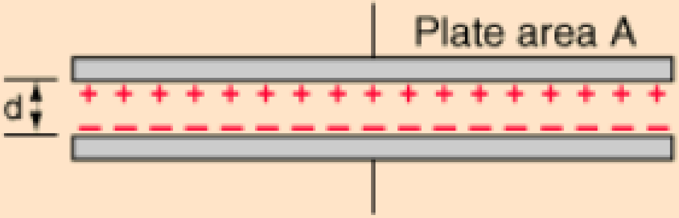
$C =$ Capacitance in Farads

$\varepsilon =$ Permittivity of dielectric (absolute, not relative)

$A =$ Area of plate overlap in square meters

$d =$ Distance between plates in meters

Parallel Plate Capacitor



$$C = \frac{\varepsilon A}{d} = \frac{k\varepsilon_0 A}{d}$$

The capacitance of flat, parallel metallic plates of area **A** and separation **d** is given by the expression above where:

$\varepsilon_0 = 8.854 \ x \ 10^{-12} \ F/m$ = permittivity of space and

k = relative permittivity of the dielectric material between the plates.

k=1 for free space, k>1 for all media, approximately =1 for air.

Example

- A parallel plate capacitor consists of two metal plates, each of area , separated by a vacuum gap cm thick. What is the capacitance of this device? What potential difference must be applied between the plates if the capacitor is to hold a charge of magnitude on each plate?

solution

- Making use of formula, the capacitance is given by

$$C = \frac{(8.85 \times 10^{-12})(150 \times 10^{-4})}{(0.6 \times 10^{-2})} = 2.21 \times 10^{-11} = 22.1\,\mathrm{pF}.$$

- The voltage difference U between the plates and the magnitude of the charge Q stored on each plate are related via C=Q/U, U=Q/C. Hence, if Q=1x10^{-3} microcoulomb then :

$$V = \frac{(1.00 \times 10^{-9})}{(2.21 \times 10^{-11})} = 45.2\,\mathrm{V}.$$