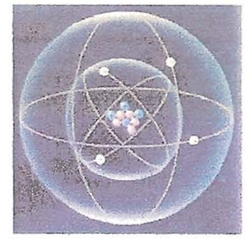
Module 2- Electricity and Magnetism

1. ELECTRIC CHARGE



Material bodies are made up of atoms. Each atom has a central nucleus (protons & neutrons) which is surrounded by a cloud of electrons.

There are two kinds of electric charges: **positive and negative.**

The charge on the electron is *-e*.
The charge on the proton is *+e*.
The charge on the neutron is *0e*.

The elementary unit of charge is $e = 1.602 \times 10^{-19}$ C.
A body is electrically neutral if the sum of all its charges is zero.

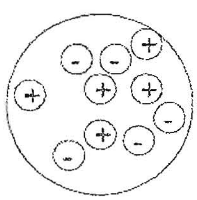
An electrically charged body is called an ion. A **positive ion** has a net positive and a **negative ion** has a net negative charge.

Experiments show that like **charges repel each other** and **opposite charges attract each other.**

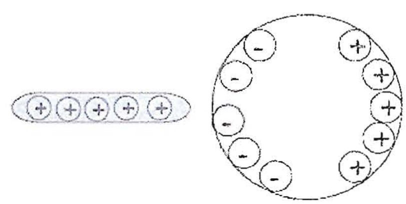
Remember: Charge is a conserved quantity.

Polarization

By holding a charged object (for example a rod) near an object, we can polarize this object. This is explained with the help of two diagrams given below.



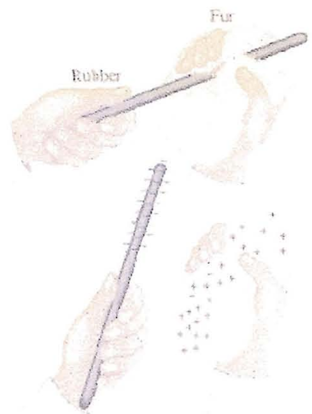
A neutral object (containing equal number of positive and negative charges) in which charges are not separated.

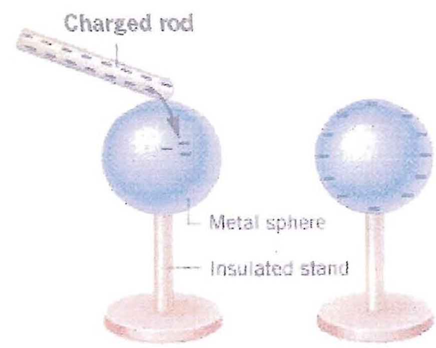


The positive and negative charges are separated when a positively charged rod is brought very close to the object. Though the object is still neutral but its left side becomes negatively charged and the right side becomes positively charged.

Remember: The separation of positive and negative charges by holding a charged object near another object is called **polarization**.

How the objects are charged? The objects can be charged by various methods.





(a) Charging by rub

If we rub a rubber rod with a piece of fur, the rubber removes some electrons from the fur atoms. The rubber rod becomes negatively charged and the fur becomes positively charged.

(b) Charging by contact

When a negatively charged rod is in direct contact with a metallic sphere as shown above, some electrons leave the rod and spread over the sphere.

(c) Charging by induction

If the rod is brought very close to the sphere without making a direct contact with the sphere, it pushes electrons away from the portion of the sphere which is closer to the rod. These electrons travel down the wire to ground leaving a positive charge on the sphere as shown. The ground wire is disconnected to prevent the return of the electrons from the ground, and then the rod is removed. The metallic sphere becomes positively charged.

What will happen when a positively charged rod is brought closer to the metallic sphere?

Neutral objects are attracted to charged objects

Charged comb attracts neutral pieces of paper.

Charged comb attracts neutral water molecules.

What is the difference between a conductor and an insulator?

A **conductor** is made of material that allows electric charge to move through it very easily.

An **insulator** is made of material that does not allow electric charge to move through it

2. COULOMB'S LAW

Charles Augustin de Coulomb (1736-1806)

The Coulomb's law states that the magnitude of the force between two point charges is given by

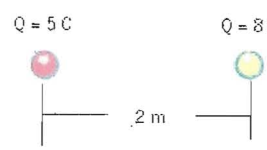
$$F = k\frac{q_1 q_2}{d^2}$$

where q_1 and q_2 are the magnitude of charges and d is the separation between the two charges.

$$k = 9\times10^9\ N\,m^2/C^2 \qquad \text{(SI units)}$$

The SI unit of charge is "Coulombs" (*C*). One Coulomb is a huge quantity which is equal to the charge on 6.25×10^{18} electrons.

Example: Simple force calculation
What is the force between the charges shown in the figure? Is it a force of repulsion, or attraction?



$$F = k\frac{q_1 q_2}{d^2}$$

$$F = (9 \times 10^9)\,(5)(8)/2^2 = 9 \times 10^{10}\,N$$

This is an enormous force, because 5 and 8 Coulomb is a huge charge.

Question:
Two charges are separated by a distance *d*. If the charges are then moved so that they are *d/2* apart, how much stronger/weaker is the force between these two charges now when compared with the distance before they were moved?

Try to solve this question.

3. ELECTRIC POTENTIAL

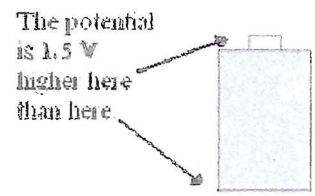
We already know that to raise an object (near the Earth's surface), we must do some work against the force of gravity. This work changes the object's potential energy. Similarly to separate one charge from another charge, we must do work against the electric force. The amount of work done will change the charge's potential energy which is generally called **electric potential** or **electric voltage.** The electric potential (V) is defined as

$$\textit{Electric potential (voltage)} = \frac{\textit{Electric potential energy}}{\textit{Amount of charge}}$$

The SI unit of electric potential is the volt (V). We can write the electric potential in unit form as

$$1\ V = 1\ J/C$$

Consider a common battery of *1.5 V*. The battery will provide *1.5 joules* of energy to each coulomb of charge that passes through it.



4. ELECTRIC CURRENT

The difference in electrical potential (voltage) causes the charged particles to flow. The flow of charged particle is called electric current.

The amount of charge per second that passes a given point is defined as current.

$$\textit{Electric current} = \frac{\textit{Charge}}{\textit{Time}}$$

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

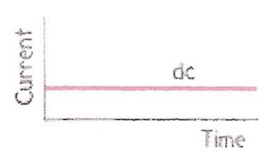
The current is measured in amperes (A). In unit form we can write ampere as 1 A = 1 C / 1 s.

Conventional Current Direction

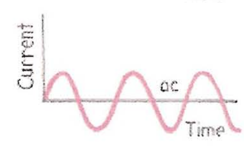
In a wire, electrons are the only charged particles that move in an electrical current. The direction of the **conventional current** is the direction opposite to the direction in which the electrons are flowing.

Direct current (DC) and alternating current (AC)

The direct current (DC) is the current that stays constant with time as shown.



The alternating current (AC) is the current that varies with time as shown.



5. ELECTRICAL RESISTANCE

The current in a circuit depends on two things: the voltage difference and the amount of resistance. The Electrical resistance is the property of a material to resist the flow of electrons.

The resistance of a material depends on its length and cross-sectional area. (It will also depend on temperature.) The resistance (R) is measured in ohms (Ω).

Filament provides resistance to the flow of electrons.

6. OHM'S LAW

The Ohm's law provides a relationship between voltage (V), current (C) and resistance (R). The Ohm's law is defined as

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

The unit of Voltage V is volt (V). The unit of current I is amperes (A). The unit of resistance R is ohms (Ω). Therefore, Ohm's law can be written in the unit form as

$$1\,A = \frac{1\,V}{1\,\Omega}$$


Georg Simon Ohm (1787-1854)

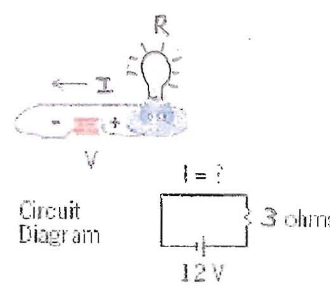
Solved Examples

Calculating I from Ohm's Law

Ohm's Law: $I = \frac{V}{R}$

$I = (12\ V) / (3\ \Omega)$
$= 4$ *amperes (A)*

Battery is assumed to be ideal (i.e., it has zero internal resistance).

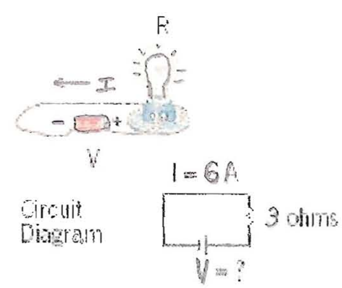


Calculating V from Ohm's Law

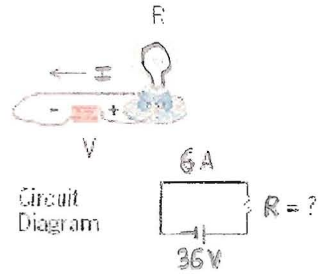
Ohm's Law: $V = IR$

$V = (6A)\ (3\ \Omega)$
$= 18$ *volts (V)*

Again the battery is assumed to be ideal (i.e., it has zero internal resistance).



Calculating R from Ohm's Law



Ohm's Law: $R = \dfrac{V}{I}$

$$R = (36\ V) / (6\ A)$$
$$= 6\ \Omega$$

Again the battery is assumed to be ideal.

7. ELECTRIC POWER

Power is the rate at which energy is delivered. Electric power is defined as

$$Power = \quad Current \times Voltage \quad = Current^2 \times Resistance$$

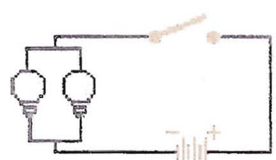
The power is measured in watts (W). In unit form we can write watt as

$$1\ W = 1A \times 1V.$$

8. ELECTRIC CIRCUITS

To have continuous charge flow (current) in a circuit there must be at least one complete loop with no gaps. The electric circuits contain various components (such as devices, batteries, etc.). The electrical components can be connected in one of the two ways shown below.

Series circuit



Parallel circuit

A combination of series and parallel circuit is also possible but here we only consider simple cases.

Series Circuits

The total resistance in a series circuit is the sum of resistances of each component

$$R_T = R_1 + R_2 + \ ...$$

The total voltage is the sum of the voltage on each component.

$$V_T = V_1 + V_2 + ...$$

In a series circuit, the components have the same current. The total current is equal in every component.

$$I_T = I_1 = I_2 \ = ... = I_n$$

The current flowing though each component can also be written as

$$I_T = V_T / R_T$$

(In this case)

$$R_T = R_1 + R_2$$

$$V_T = V_1 + V_2$$

$$I_T = I_1 = I_2$$

Parallel Circuits

The total voltage is equal in every component.

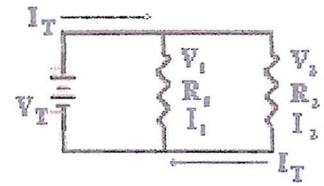
$$V_T = V_1 = V_2 = \ldots = V_n$$

The total resistance of a parallel circuit is written as

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

The total current is equal to the sum of current in each component.

$$I_T = I_1 + I_2 + \ldots$$



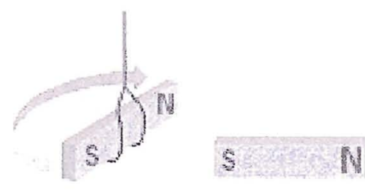
(In this case)

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

$$V_T = V_1 = V_2$$
$$I_T = I_1 + I_2$$

9. MAGNETISM

All magnets have at least one North Pole and one South Pole.

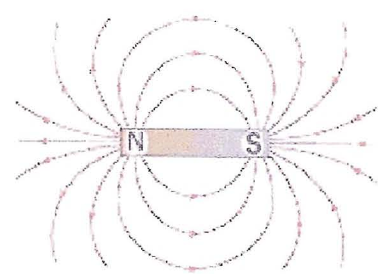


Magnets exert forces on one another. **Opposite magnetic poles attract and like magnetic poles repel.**

North is attracted to south, and is repelled by north.

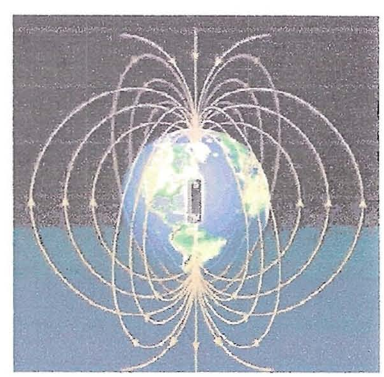
Magnetic field

The space around the magnet contains a magnetic field (B). The magnetic field can be represented with the help of lines.



Magnetic field lines are closed loops. They leave north pole and enter at south pole.

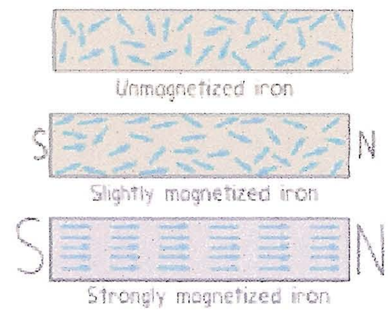
The direction of the field lines outside a magnet is from the north pole to the south pole as shown in the figure.



Magnetic field of a bar magnet is similar to the Earth's magnetic field.

Magnetic Domains

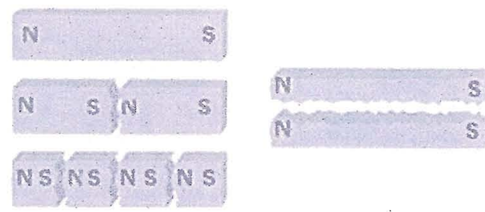
Large clusters of iron atoms line up with one another. These clusters of aligned atoms are called **magnetic domains.** Figure on the right shows a piece of iron in successive stages of becoming magnetized.



The arrows represent domains; each arrowhead represents a north pole and each tail represents a south pole.

Can we isolate North and South poles?

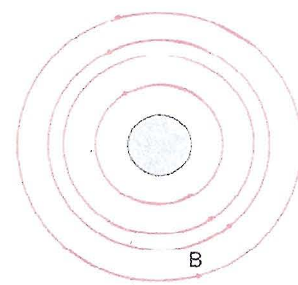
Cutting a magnet in half will not isolate a single north or south pole. One magnet becomes two, then four, and so on. This process will never end. Thus a magnet cannot be cut to reveal a single north or single south pole.



Magnetic field around a current carrying wire

Consider a current carrying wire with current (I) flowing out of page. The moving charges in the wire produce a magnetic field that wraps counter clock-wise (CCW) around the wire as shown in the figure. A compass needle would align itself tangent to these circular lines of magnetic field.

If the direction of the current is reversed (i.e., the current I is into the page) then the magnetic field lines will also reverse (i.e., the magnetic field wraps clockwise (CW) around the wire).



10. MAGNETIC FORCE ON CHARGES AND CURRENT CARRYING WIRE

When a charged particle enters a region of magnetic field, if its velocity is perpendicular to the field lines, it will be deflected.

When a charged particle enters a region of magnetic field, if its velocity is parallel to the field lines, no deflection occurs.

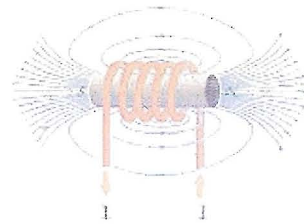
A positive charge and a negative charge will be deflected in opposite direction.

Using the simple logic one can easily find that if a charged particle moving through a magnetic field experiences a force, then a current carrying wire (in which charged particles are moving) placed in the magnetic field will also experience a deflecting force.

By reversing the direction of the current the direction of the deflecting force will also be reversed.

11. THE ELECTROMAGNET

If a piece of iron is placed in a current-carrying coil of wire, the magnetic field of current creates strong alignment of magnetic domains in the iron. This strong alignment of domain produces a strong magnet. This type of magnet is called electromagnet.

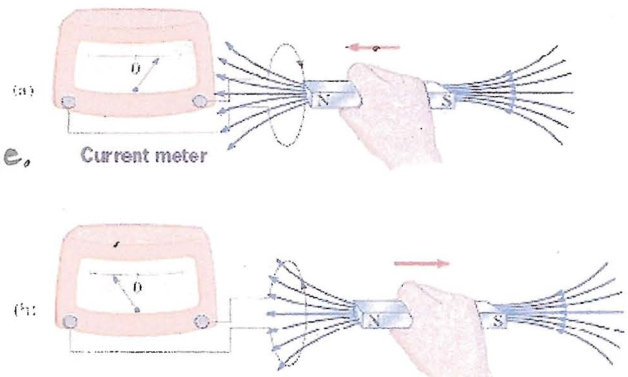


The electromagnets can be made powerful enough to lift automobiles.

12. ELECTROMAGNETIC INDUCTION

Induced current and induced voltage

When a magnet is plunged into a coil, charges in the coil start moving and a current is produced. This is called **induced** current. The induced current ~~then produces an~~ **induced** voltage.

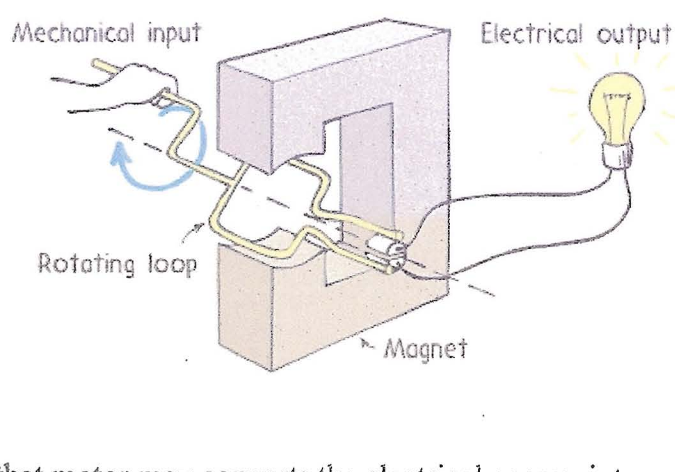


The induced current and induced voltage can **only** be produced as long as there is a **relative motion** between the coil and the magnet. No relative motion – no induced current and no induced voltage.

Note the direction of the current in the coil changes when the direction of the relative motion between coil and magnet is changed.

13. GENERATORS AND MOTORS

A generator works by rotating a loop of wire in the magnetic field. The rotation induces a voltage that is used to run electrical devices (such as bulb).



The loop must be rotated by some external agent (e.g. falling water, steam etc.). You cannot produce electrical energy for free.

A generator just converts one kind of energy (in this case it is mechanical) into electrical energy.

A motor is a generator in reverse. This means that motor may converts the electrical energy into other forms of energy such as mechanical energy.