CHAPTER SIX

ELECTROMAGNETISM AND ELECTRONICS

Contents

1. Concept of electric charge, Coulomb's Law and Electric Field

Electric charge

- Electric charge is an inherent property of matter that makes it to have and experience electrical and magnetic characteristics.
- there are generally two basic types of electric charges in nature: **positive** and **negative** charges
- The SI unit of charge is coulomb (C), and its symbol is either Q or q.

$$1e = 1.6 \times 10^{-19}\ C$$

- basic law of electrostatics which states that: "Like charges repel each other & Unlike charges attract each other."

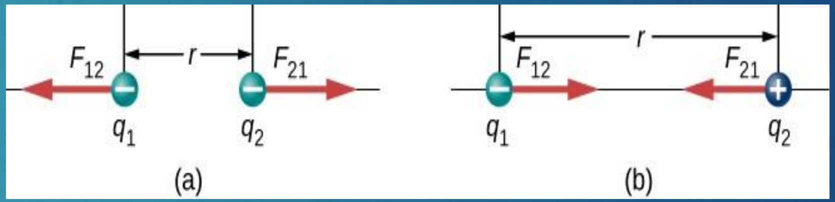
1. Concept of electric charge,Coulomb's Law and Electric Field

Coulomb's Law

- **States that:** "The magnitude of the force is linearly proportional to the net charge on each object and inversely proportional to the square of the distance between them."

$$\boldsymbol{F \propto \frac{q_1 q_2}{r^2}}$$

$$\boldsymbol{F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}}$$



$\boldsymbol{\varepsilon_0}$ =the permittivity of free space.

$=8.85 \times 10^{-12} C^2/Nm^2$

$$\boldsymbol{F = \frac{Kq_1 q_2}{r^2}}$$

Where K=electrostatic constant=$\frac{1}{4\pi\varepsilon_0}$=$9 \times 10^9 Nm^2/C^2$

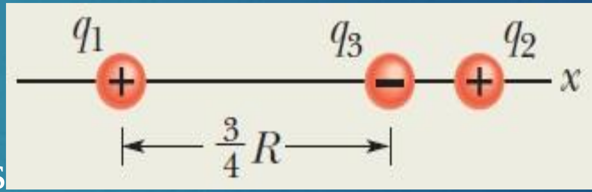
1. Concept of electric charge, Coulomb's Law and Electric Field

Examples

1. A charged particle *A* exerts a force of 2.62 N to the right on charged particle *B* when the particles are 13.7 mm apart. Particle *B* moves straight away from *A* to make the distance between them 17.7 mm. What vector force does particle *B* then exert on *A*? {Ans: 1.6N}

2. The force between two identical charges separated by 1 cm is equal to 90 N. What is the magnitude of the two charges? {Ans: $q = \pm 1.00\times 10^{-6}$ C or $q = \pm$ 1mC}

3. In figure 11.3 particle 3 lies on the x-axis between



particle 1 ($q1 = 1.6 \times 10^{-19} C$) and 2($q2 = 3.2 \times 10^{-19} C$).Particle 3 has

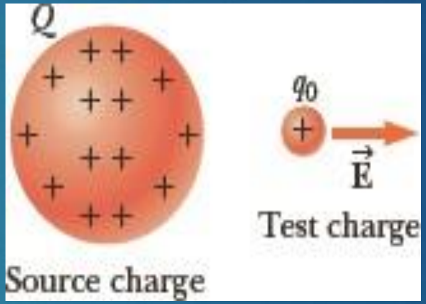
charge $q3 = -3.20´10^{-19}$ C and is at a distance $\frac{3}{4}$ R from particle 1 (R is particle 1 and 2 and it is 20 cm). What is the net electrostatic force $F1,net$ on particle 1 due to particles 2 and 3?{Ans:$\vec{F}13 = \vec{F}12 + \vec{F}13 = (-1.15 + 2.05) \times 10^{-24} N\hat{x} = 9 \times 10^{-25} N\hat{x}$}

4. A 7.50-nC point charge is located 1.80 m from a 4.20-nC point charge. (a) Find the magnitude of the electric force that one particle exerts on the other. (b) Is the force attractive or repulsive?

1. Concept of electric charge, Coulomb's Law and Electric Field

Electric Fields

- An electric field is a region around a charged object.



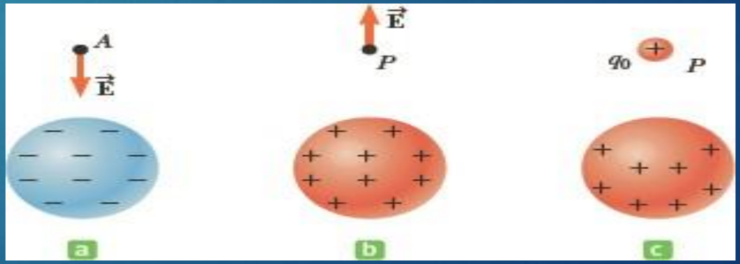
- Electric field exerts an electric force on any other

charged object within the field.

- The electric field $\vec{E}$ the electric force $\vec{F}$ produced by a

charge Q at the location of a small "test" charge q_0 is defined as exerted by Q on $q_0$divided by the test charge q_0.

$$\vec{E} = \frac{\vec{F}}{q_0}$$



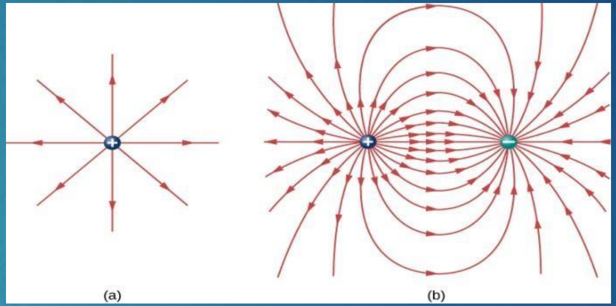
- The SI unit of electric field strength is N/C.
- The $\vec{E}$ of +ve radially outward and for –ve charge radially in ward.(see Fig.)

Concept of electric charge, Coulomb‘s Law and Electric Field

….(Continued $\vec{E}$)

Electric Field Lines

Electric field lines are models for representing electric field distribution over space around charged bodies.



<u>Examples</u>

1.A small object of mass 3.80 g and charge - 18.0 mC is suspended motionless above the ground when immersed in a uniform electric field perpendicular to the ground. What is the magnitude and direction of the electric field? {Ans:$\vec{E}$=2.1´10^{2}$N / C\ \hat{y}$}

3. The electric field of an atom in an ionized helium atom, the most probable distance between the nucleus and the electron is r = 26.5 x 10^{-12}m. What is the electric field due to the nucleus at the location of the electron? {Ans: 4.1× 10$^{?}$N/C

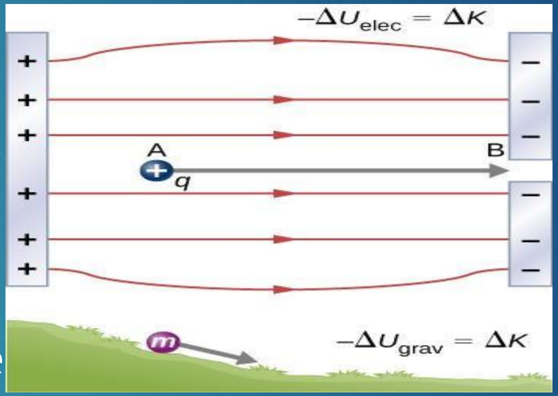
2. Electric Potential and Electric potential Energy of point charge

Electric Potential

- The electric potential created by a point charge *q* at any distance *r* from the charge is given by

$$V = \frac{-W_\infty}{q_0} = \frac{U_e}{q_0}$$

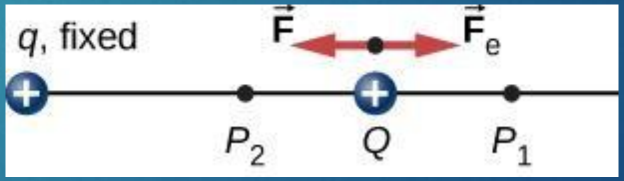
$$V = \frac{Kq}{r}$$



Electric potential energy(U_e or U)

- When a free positive charge q is accelerated by an electric field the

work done, W_{12} on the charge Q is:



$$W12 = Fr\cos\theta: ;\ \theta = 0^0$$

$$W12 = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r}$$

- This work done on the charge Q is exactly equivalent to the potential energy, $U = U_{12}$ of the configuration of the two (q and Q) systems of charges.

2. Electric Potential and Electric potential Energy of point charge

…(Continued U)

$$U = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{r}$$

- For systems of charges more than two, $q_1, q_2, \ldots, q_n,$ the electric potential energy is given by

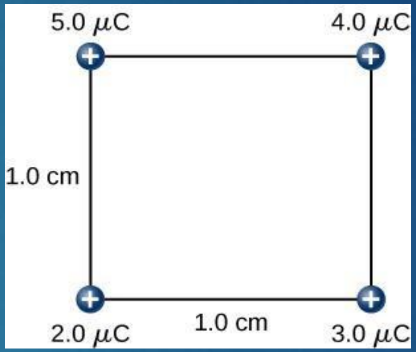
$$U = \sum_{i,j}^{n} \frac{1}{4\pi\varepsilon_0}\frac{q_i q_j}{r_{ij}}$$

Example

1. A particular 12 V car battery can send a total charge of 84.0*A.h* (ampere-hours) through a circuit, from one terminal to the other. (a) How many coulombs of charge does this represent (b) If this entire charge undergoes a change in electric potential of 12 V, how much energy is involved? {Ans: $Q = I\,t \approx 3.0 \times 10^5$ *C and* $PE = Q.V == 3.6 \times 10^6\ J$}

2. Electric Potential and Electric potential Energy of point charge

…(Continued U)



2. Find the electric potential energy in assembling four charges at the vertices of a square of side 1.0cm, starting each charge from infinity as shown in the figure. {Ans: U = 57.8J}

Electric Potential Difference(V_{AB})

- The electric potential difference between points A and B, $V_A - V_B$, is defined to be the change

$$V_{AB} = V_B - V_A = \frac{U}{q}$$

Example

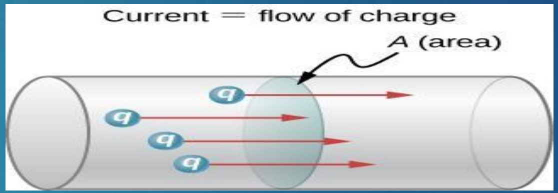
1. You have a 12.0-V motorcycle battery that can move 5000 C of charge, and a 12.0-V car battery that can move 60,000 C of charge. How much energy does each deliver?{U_{12}=0.7MJ}

3. Current, Resistance and Ohm’s Law

Current (I)

- equal to the amount of charge, ΔQ divided by the time interval, Δt.

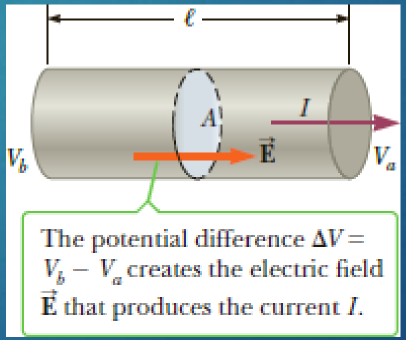
$$I = \frac{\Delta Q}{\Delta t}$$



- The SI unit of current is Ampere (A). $1A = 1C/1s=$
- $1A = 6.25 \times 10^{18}$ electrons flowing through the area A each second.

Resistance and Ohm’s Law

- When a voltage (potential difference) ΔV is applied across the ends of a metallic conductor the current in the conductor is found to be proportional to the applied voltage. This statement is known as **Ohm’s law**



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

Current, Resistance and Ohm's Law

<u>Example</u>

1.A typical lightning bolt may last for 0.200 s and transfer 1.0 $\times 10^{20}$ electrons. Calculate the average current in the lightning bolt and the resistance if a voltage of 30kV is produced by this lightning.

2. How long does it take electrons to get from a car battery to the starting motor? Assume the current is 300 A and the electrons travel through a copper wire with cross-sectional area0.21 cm^2 and length 0.85m .The number of charge carriers per unit volume is $\mathbf{8.49\times10^{28}}$ $\boldsymbol{m^{-3}}$ **.{Ans**t $=4.62\times10^3$ s}

Resistivity

- In some materials, including metals at a given temperature, the current density is approximately proportional to the electrical field

$$\vec{J} = \sigma\vec{E}$$

$$\sigma = \frac{\vec{J}}{\vec{E}}$$

- **SI unit of σ is** $^{A}/_{Vm} = \Omega m^{-1}$
- Resistivity is the reciprocal of electrical conductivity:

Current, Resistance and Ohm's Law

…(Continued Resistivity)

$$\rho = \frac{1}{\sigma} = \frac{\vec{E}}{\vec{J}}$$

- The unit of resistivity in SI units is the ohm-meter (Ω - m).
- The greater the resistivity, the larger the field needed to produce a given current density
- Good conductors have a high conductivity and low resistivity. Good insulators have a low conductivity and a high resistivity.

<u>Example</u>

1. A charged belt, 50 cm wide, travels at 30 m/s between a source of charge and a sphere. The belt carries charge into the sphere at a rate corresponding to100mA . Compute the surface charge density on the belt.

2. A voltmeter connected across the terminals of a tungsten filament light bulb measures 115V when an ammeter in line with the bulb registers a current of 0.522 A . Find the resistance of the light bulb.

4. Electric power, Equivalent resistance and Kirchhoff's law

Electrical Energy and Power

- The rate of electrical energy transfer , P is defined by:

$$P = VI$$

$$P = I^2 R \text{ or}$$

$$P = V^2 / R \qquad \text{(resistive dissipation)}$$

- **Electrical Energy ,W is given by:**

$$\boldsymbol{W = VIt = I^2Rt}$$

<u>**Examples**</u>

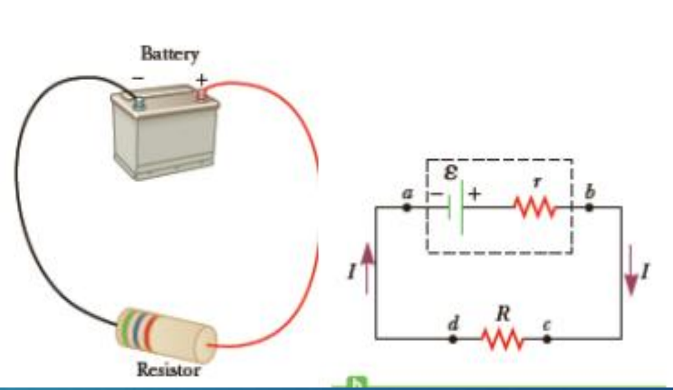
1. 1A 120.0Vpotential difference is applied to a space heater whose resistance is 14.0fi when hot.At what rate is electrical energy transferred to thermal energy? (b) What is the cost for 5.0 h at 1.5$cents/k$W. h?{Ans: (a)*P*= 1*kW* (b) *Energy cost==5.5cents*

4. Electric power, Equivalent resistance and Kirchhoff's law

Equivalent Resistance and Kirchhoff's law

- **Sources of electromotive forces (emf)**:- can be thought of as a "charge pump" that forces electrons to move in a direction opposite the electrostatic field inside the source.
- The emf ε of a source is the work done per unit charge; hence, the SI unit of emf is the volt.

$$\Delta V = \varepsilon - Ir$$
$$\varepsilon = \Delta V + Ir = I(R - r)$$
$$I = \frac{\varepsilon}{R + r}$$



<u>Examples</u>

1. A battery having an emf of 9.0 y V delivers 117mA when connected to a 72.0fi load. Determine the internal resistance of the battery.{Ans: r =4.92**Ω**}

4. Electric power, Equivalent resistance and Kirchhoff's law

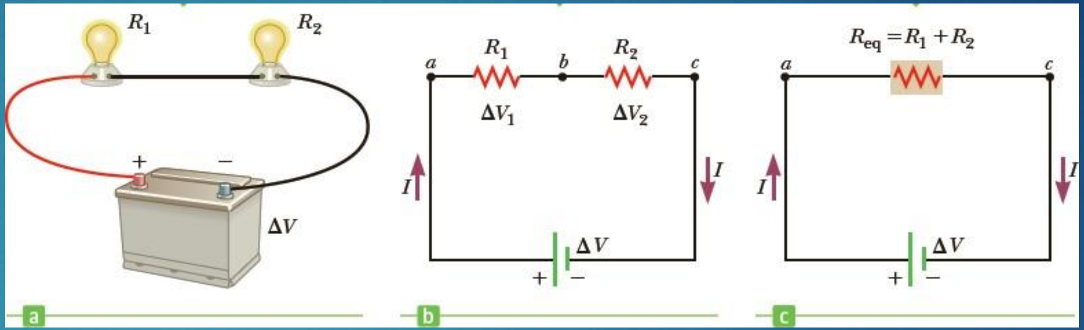
Combinations of Resistor

(a). Combinations of resistors in Series

$$I = I_1 = I_2$$

$$R = R1 + R2$$

- For N resistors connected in series



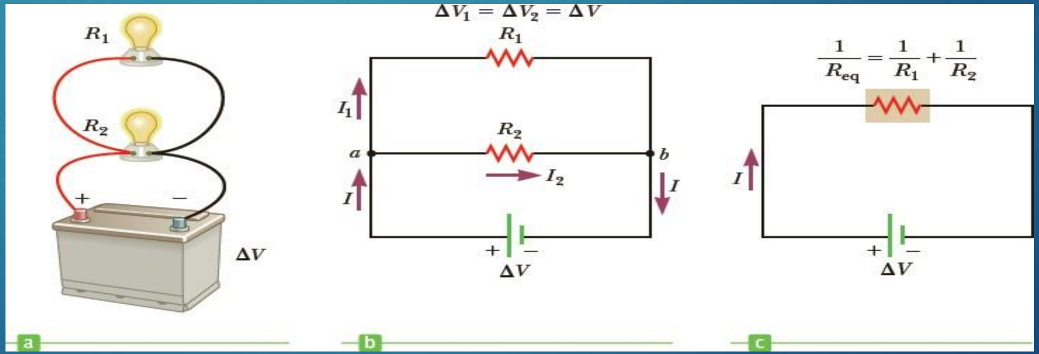
$$R_{eq} = \sum_{i}^{N} R_i$$

(b). Combinations of resistors in parallel

$$\mathbf{V} = \boldsymbol{V_1} = \boldsymbol{V_2}$$

$$\boldsymbol{I = I1 + I2}$$

$$\frac{\mathbf{1}}{\boldsymbol{R_{eq}}} = \frac{\mathbf{1}}{\boldsymbol{R_1}} + \frac{\mathbf{1}}{\boldsymbol{R_2}}$$



- For N resistors connected in parallel:

4. Electric power, Equivalent resistance and Kirchhoff's law

…(Continued Resistor in parallel)

$$\frac{1}{R_{eq}} = \sum_{i}^{N} \frac{1}{R_i}$$

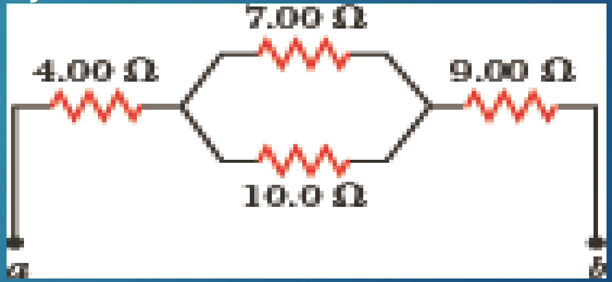
Examples

1. Three 9.0 W resistors are connected in series with a 12.0*V* battery. Find (a) the equivalent resistance of the circuit and (b) the current in each resistor. (c) Repeat for the case in which all three resistors are connected in parallel across the battery.{Ans:= 3**Ω**; 4.0 *A*}

2. (a). Find the equivalent resistance between points *a* and *b*

in Figure. (b) Calculate the current in each resistor

if a potential difference of 34.0 V is applied between points *a* and *b.*



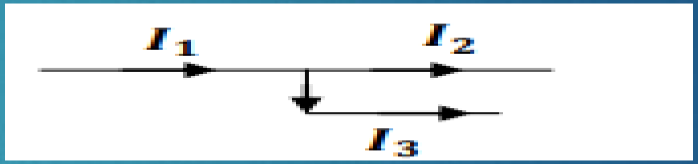
3. A 5.0 A current is set up in a circuit for 6.0 min by a rechargeable battery with a 6.0 V emf. By how much is the chemical energy of the battery reduced?

4. Electric power, Equivalent resistance and Kirchhoff‘s law

Kirchhoff’s Law

1. Kirchhoff’s First Rule (Junction Rule)

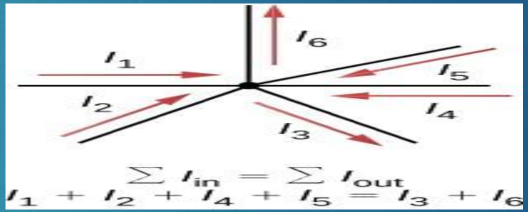
“The sum of the currents entering any junction must equal the sum of the currents leaving that junction.”



- This rule is often referred to

as the junction rule or *I*3 **Conservation of Charge**

$$I_1 = I_2 + I_3$$



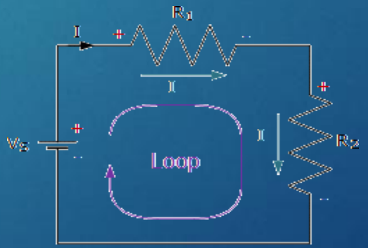
2. Kirchhoff‘s second rule (loop rule):

“The sum of the potential differences across all the elements

around any closed circuit loop must be zero.”

- This rule is usually the idea of **Conservation of Energy**.

$$\sum \Delta V = 0$$



4. Electric power, Equivalent resistance and Kirchhoff's law

Examples

1. For the loop shown by Fig. 11.30 determine the values of all currents.

For loop 1:

$$-I_2R_5 + I_3R_9 = 0 \text{ or } I_2R_5 = I_3R_9$$

Using the given values $5I_2 = 9I_3 \Rightarrow I_3 = \frac{5}{9}I_2$

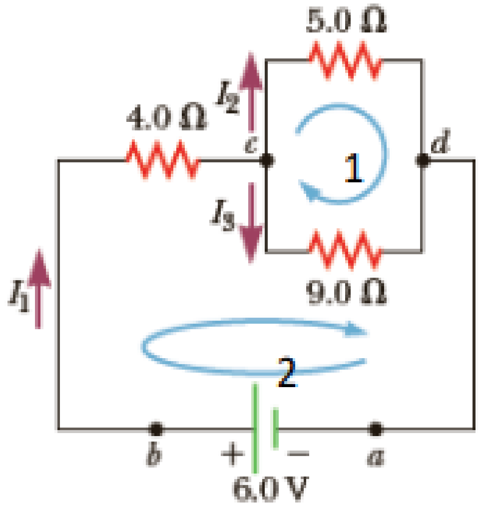
For loop 2:

$$6.0V - I_1R_4 - I_3R_9 = 0$$
$$6.0V = 4I_1R_4 + 9I_3$$

From junction rule: $I_1 = I_2 + I_3$

$$6.0V = 4(I_2 + I_3) + 9I_3 = 4I_2 + 4\frac{5}{9}I_2 + 5I_2 = \frac{101}{9}I_2$$

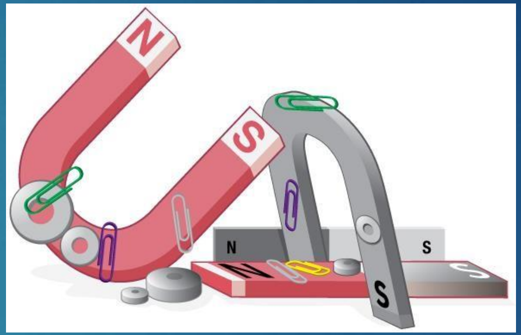
$$I_2 = \frac{6 \times 9}{101}A = 0.54A, \quad I_3 = \frac{5}{9}I_2 = \frac{0.54 \times 5}{9}A = 0.3A,$$



$$I_1 = I_2 + I_3 = 0.54 + 0{,}30 = 0.84A$$

Magnetic Field and Magnetic Flux

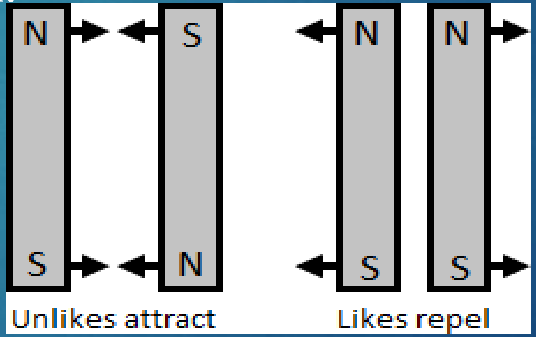
- When an electric charge moves, it generates other forces and fields. These additional forces and fields are what we commonly call ***magnetism.***



Magnetic Field

Magnets

- Magnets come in various shapes, sizes, and strengths .
- All magnets have two inseparable poles called north pole and a south pole.
- A single isolated pole (a monopole) has never been observed so far.
- The names come from the observation that a freely hanging bar magnet aligns itself in the north-south geographic direction; the north pole of the bar magnet is the one that points north.



- Observations also show that like poles repel each other and unlike poles attract each other

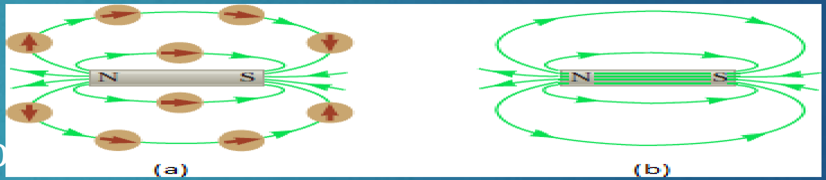
Magnetic Field and Magnetic Flux

Magnetic Fields and Magnetic Field Lines

- It is common experience to observe that magnets interact at a distance, that is, without touching each other. This is known as ***magnetic field.***
- To help us visualize magnetic fields we draw lines around magnets.

These lines, called ***magnetic field lines***, represent

both the strength and direction of the magnetic field.



- Studies of magnetic fields revealed the following pro
  - The direction of the magnetic field is tangent to the field line at any point in space. A small compass will point in the direction of the field line.
  - The strength of the field is proportional to the closeness of the lines. It is exactly proportional to the number of lines per unit area perpendicular to the lines.
  - Magnetic field lines never cross, that is, the field is unique at any point in space.
  - Magnetic field lines are continuous, forming closed loops without beginning or end.
- Moving charges produce currents, which in turn produce magnetic fields. These magnetic fields of moving charges interact with other magnetic fields through which the moving charges pass.

Magnetic Field and Magnetic Flux

Magnetic Force on a Moving Charge

- the magnetic field strength $\vec{B}$ based on the magnetic force $\vec{F}$ on a charge q moving at velocity $\vec{V}$ as the cross product of the velocity and magnetic field B , that is:

$$\vec{F} = q\vec{V} \times \vec{B}$$

- the magnitude of the force satisfies

$$F = qvB\sin\theta;$$

- The magnitude of the Magnetic Field, B is given by

$$B = \frac{F}{qV}$$

- The SI unit for magnetic field strength B is called the tesla (T) after the eccentric but brilliant inventor Nikola Tesla (1866–1943),

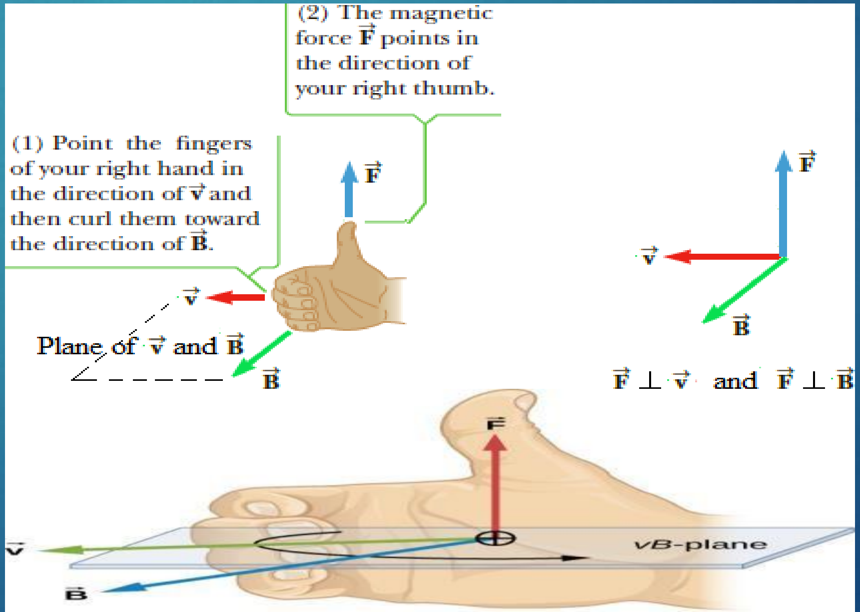
$$1T = \frac{1N}{Am}$$

Magnetic Field and Magnetic Flux

…Continued (Magnetic Field)

- Another unit is the gauss (G) which is defined as 1G = 10^{-4} T. The strongest permanent magnets have fields near 2T; superconducting electromagnets may attain 10 T or more. The Earth's magnetic field on its surface is only about 5×10^{-5} T, or 0.5 G.
- The direction of the magnetic force $\vec{F}$ is perpendicular to the plane formed by $\vec{V}$ and $\vec{B}$, as determined by the right-hand rule.
- The Lorentz force shows that if a charged particle moves in $\vec{B}$ & $\vec{E}$, the force $\vec{F}$ will be:

$$\vec{F} = q(\vec{V} \times \vec{B} + \vec{E})$$

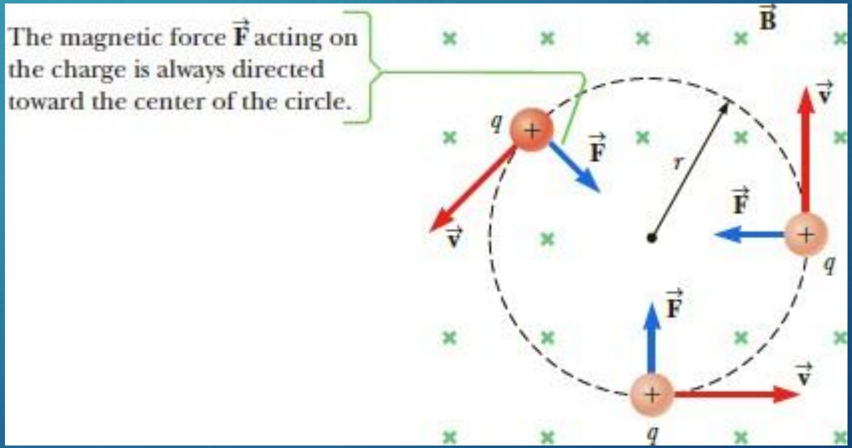


Magnetic Field and Magnetic Flux

Example

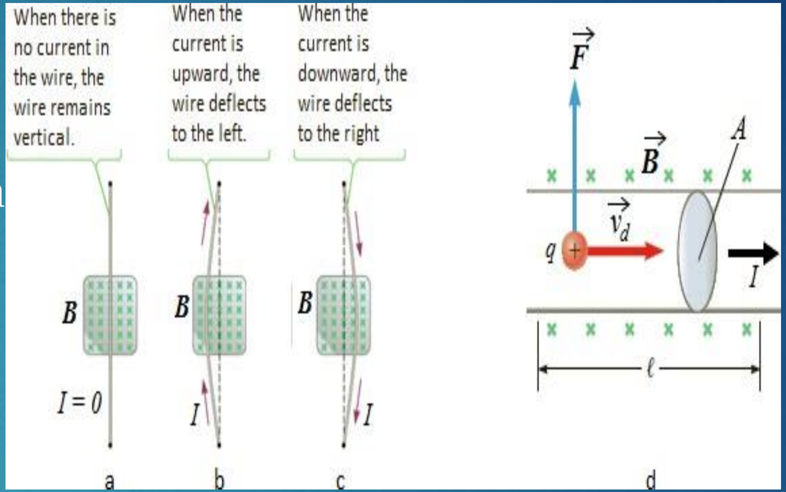
1. A proton moves with a speed of 1.00×10^{5} m/s through Earth's magnetic field, which has a value of 55.0×10^{-3} T at a particular location. When the proton moves eastward, the magnetic force on it is upward, and when it moves northward, no magnetic force acts on it. What is the direction of the magnetic field and the strength of the magnetic force when the proton moves eastward? {Ans: (i). The direction of $\vec{B}$: *When the particle travels east, the magnetic force is upward. Now employ the right-hand rule. Point your thumb in the direction of the force (upward) and your fingers in the direction of the velocity eastward. When you curl your fingers, they point north, which must therefore be the direction of the magnetic field*. ;(ii). $F = 8.80 \times 10^{19}\ N$)

2. . A charged particle shot perpendicular to a uniform B -field as shown in the figure traces out a circular path. Find the radius of the circular path. {Ans: r=mv/qB}



Magnetic Field and Magnetic Flux

Magnetic Force on a Current-Carrying Conductor



- We can derive an expression for the magnetic force on a current by taking a sum of the magnetic forces on individual charges.
- The magnetic force on a length l of wire carrying a current I in a uniform magnetic field B, as shown in Figure Is given by:

$$F = Ilbsin\theta$$

- The magnetic force per unit length of wire in a uniform field:

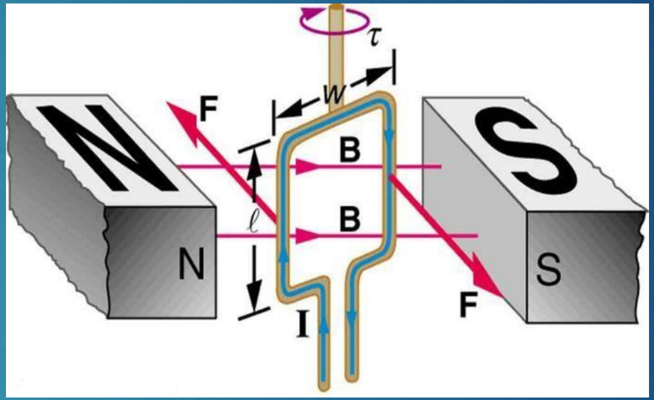
$$\frac{F}{L} = IBsin\theta$$

- The direction of this force is given by the right-hand rule – place your fingers in the direction of the current, curl them in the direction of the B-field, the thumb then points in the direction of the force

Magnetic Field and Magnetic Flux

Magnetic Torque

- Motors have loops of wire in a magnetic field. When current passes through the loops, the magnetic field exerts torque on the loops, which rotates a shaft.
- The total magnetic torque is



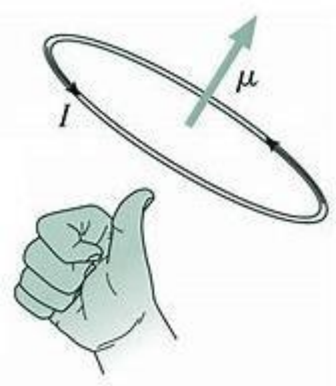
$$\tau = 2\tau_1$$

Where: $\tau_1 = \frac{w}{2} F sin\theta$

$$\tau = 2wFsin\Theta$$

$$\tau = I(wl)Bsin\Theta$$

- If we have a multiple loop of N turns, we get N times the torque of one loop



$$\tau = \mathrm{N}IABsin\Theta; \qquad \mathrm{A}=(wl)$$

$$\tau = \mu Bsin\Theta$$

Where: μ=NIA=magnitude of a vector μ called the magnetic moment of the coil

Magnetic Field and Magnetic Flux

Magnetic Flux(Φ)

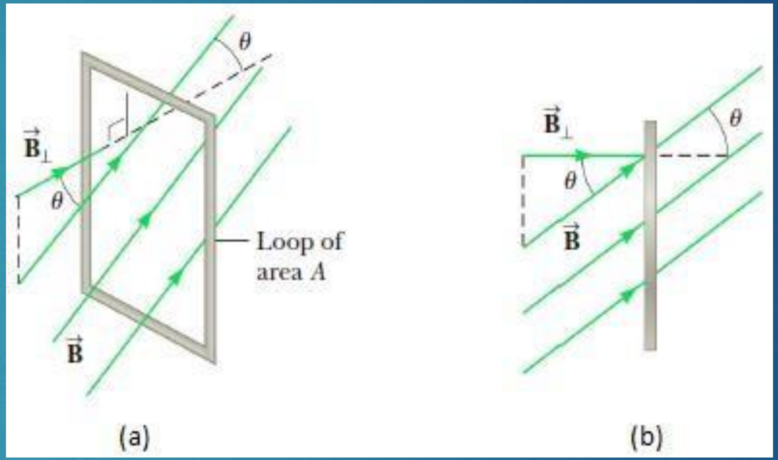
- To introduce the idea of magnetic flux consider an area, *A* in a uniform magnetic field B.

$$\Phi = \vec{B}.\vec{A} = B \perp A = BA\cos\theta$$

$$\Phi = BA\cos\theta$$

$$\Phi = BA; \quad \theta = 0^0$$

The unit of magnetic flux is the Weber (Wb)



$$1\text{Wb} = 1\text{T}m^2$$

- *B*= *Φ/A*, is then referred to as the density of the magnetic flux or, more properly, the *magnetic flux density*.

- *Φ is extremely useful* to calculate the size of the induced emf.

Electromagnetic Induction

THANKYOU

@HiLCOe
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K.