COURSE CODE: *PHS 102*

COURSE TITLE: *General Physics II*

NUMBER OF UNITS: *3 Units*

COURSE DURATION: *Three hours per week*

COURSE DETAIL:

Course Coordinator: Dr. O. I Olusola B.Sc., M.Sc., Ph.D

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Other Lecturer: Dr. R. Bello B.Sc., M.Sc., Ph.D

COURSE CONTENT:

Electric charges, fields, potential, Coulomb's law, Direct current and measuring instruments; the potentiometer method. Chemical, thermal and magnetic effects of current. Electromagnetic waves; basic phenomenon of physical optics for illustration (interference, diffraction, polarization); Radiation and phonon, atomic theory, radioactivity.

COURSE REQUIREMENTS:

This is a compulsory course for students Engineering, Physical Sciences and Mathematical Sciences in the University. In view of this, students are expected to participate in all the course activities and have minimum of 75% attendance to be able to write the final examination.

READING LIST:

1. Sears, W., University Physics, Adddison-Willey Publishing company, Singapore, 1974

2. Nelkon, M and Parker, P., Advance level Physics, Heinemann Educational Books, London, 1982

3. Serway, R.A., Faughn, J.S., Vuille, C., College Physics Sollutions, Harcourt Brace College Publishers, 1997.

4. Halliday, D., Resnick, R. and J. Walker, Fundamentals of Physics, John Wiley and Sons, 1993.

5. O. Ajaja, First-Year University Physics (Mechanics, Heat and Sound), Lamiad Nigeria Ltd., 1993.

LECTURE NOTES:

1.0 ELECTRIC CHARGE, CONDUCTORS AND INSULATIONS

The fundamental quantity in electrostatics is electric charge. There are two kinds of charge, positive and negative. Charges of the same sign repel each other; charges of opposite sign attract. Charge is conserved; the total charge in an isolated system is constant.

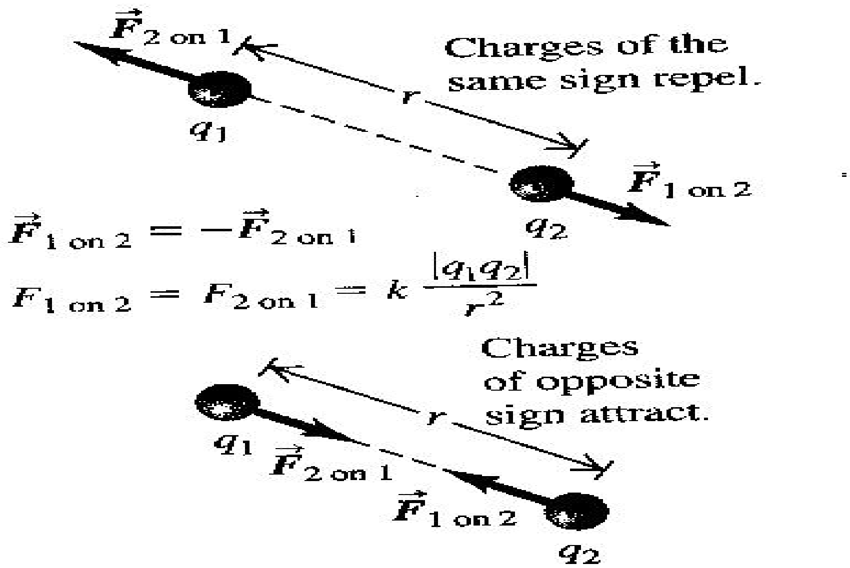
All ordinary matter is made of protons, neutrons and electrons. The positive protons and electrically neutral neutrons of an atom are bound together by the nuclear force; the negative electrons surround the nucleus at distances much greater than the nuclear size. Electric interactions are chiefly responsible for the structure of atoms, molecules and solids.

Conductors are materials that permit electric charge to move easily within them. Insulators permit charge to move much less readily. Most metals are good conductors; most nonmetals are insulators.

1.1 Coulomb's Law

Coulomb's Law is the basic law of interaction for point electric charges. For charges q_1 and q_2 separated by a distance r, the magnitude of the force on either charge is proportional to the product $q_1 q_2$ and inversely proportional to r^2

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \quad where \quad \frac{1}{4\pi\varepsilon_0} = 8.988\,x10^9\,N.m^2/C^2 \qquad 1$$



The force on each charge is along the line joining the two charges - repulsive if q_1 and q_2 have the same sign, attractive if they have opposite signs. The forces form an action- reaction pair and obey Newton's third law. In S.I Units, the unit of electric charge is the coulomb, abbreviated C.

Example 1.1:

An α particle is the nucleus of a helium atom. It has mass m = 6.64 x $10^{-27} kg$ and charge q = 2e = 3.2 x 10^{-19}C. Compare the force of the electric repulsion between two α particles with the force of gravitational attraction between them.

Solution:

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}, \quad F_g = G\frac{m^2}{r^2}$$

Therefore, the ratio of the electric force to the gravitational force is

$$\frac{F_e}{F_g} = \frac{1}{4\pi\varepsilon_0 G}\frac{q^2}{m^2} = \frac{9.0\,x10^9\,N.m^2/C^2}{6.67\,x\,10^{-11}N.m^2/kg^2}\,\frac{(3.2\,x10^{-19}C)^2}{(6.64\,x\,10^{-27}kg)^2}$$

$$= 3.2\,x\,10^{-35}$$

This astonishingly large number shows that the gravitational force in this situation is completely negligible in comparison to the electric force.

Example 1.2:

Two point charges, q_1 = +25nC and q_2 = -75nC, are separated by a distance of 3.0 cm. Find the magnitude of (a) the electric force that q_1 exerts on q_2; and (b) the electric force that q_2 exerts on q_1.

Solution:

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

$$= 9.0\,x\,10^9 N.m^2/C^2\,\frac{(+25\,x\,10^{-9}C)(-75\,x\,10^{-9}C)}{(0.03m)^2}$$

$$F = 0.019N$$

(b) Newton's third Law applies to the electric force. Even though the charges have different magnitude, the magnitude of the force that q_2 exerts on q_1 is the same as the magnitude of the force that q_2 exerts on q_1: $F_{2\,on\,1}$ = 0.019N.

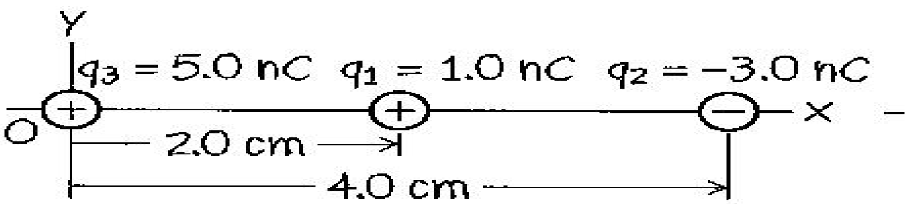
1.2 Superposition of Forces

The principle of superposition of forces states that when two or more charges each exert a force on a charge, the total force on that charge is the vector sum of the exerts by the individual charges.

Example 1. 3:

Two point charges are located on the positive x–axis of a coordinate system. Charges q_1 = 1.0nC is 2.0cm from the origin, and charge q_2= -3.0nC is 4.0 cm from the origin. What is the total force exerted by these two charges on a charge q_3=5.0nC located at the origin? Gravitational forces are negligible.

Solution:



We first find the magnitude $F_{1\text{ on }3}$ of the force of q_{1} or q_3:

$$F_{1\text{ on }3} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_3}{r^2} = 9.0x10^9 N.m^2/C^2 \frac{(1.0\times10^{-9}C)(5.0\times10^{-9}C)}{(0.02m)^2}$$

$$F_{1\text{ on }3} = 1.12\times10^{-4}\,N = 112\mu N$$

This force has a negative x-component because q_3 is repelled (that is, pushed in the negative x-direction) by q_1.

The magnitude $F_{2\text{ on }3}$ of the force of $q_{2\text{ on }}q_3$ is

$$F_{2\text{ on }3} = \frac{1}{4\pi\varepsilon_0}\frac{q_2 q_3}{r^2} = 9.0x10^9 N.m^2/C^2 \frac{(3.0\times10^{-9}C)(5.0\times10^{-9}C)}{(0.04m)^2}$$

$$F_{2\text{ on }3} = 8.4\times10^{-5}\,N = 84\mu N$$

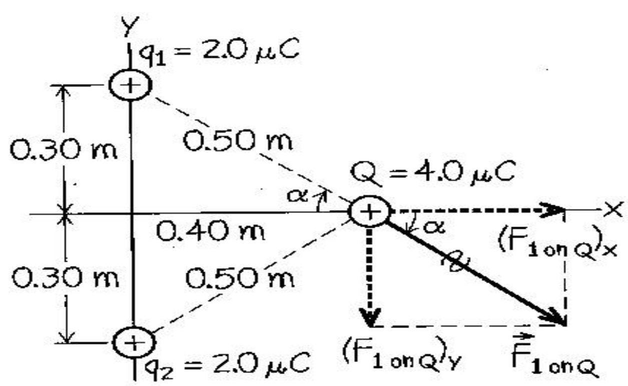
This force has a positive x-component because q_3 is attracted (that is, pulled in the positive x-direction) by q_2 .The sum of the x-components is

$F_x = -112\mu N + 84\mu N = -28\mu N$

There are no y- or z-components. Thus the total force on q_3 is directed to the left, with magnitude $28\mu N = 2.8 \times 10^{-5} N.$

Example 1.4:

Two equal positive point charges $q_1 = q_2 = 2.0\mu C$ are located at x = 0, y = 0.30m and x =0, $y = -0.30m$, respectively. What are the magnitude and direction of the total (net) electric force that these charges exerts on a third point charge $Q = 4.0\mu C \ at \ x = 0.40m, y = 0?$



The magnitude of force $q_1$on Q is

$$F_{1\ on\ Q} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 Q}{r^2}$$

$$= 9.0 \times 10^{9} N.m^2/C^2 \frac{(4.0 \times 10^{-6}C)(2.0 \times 10^{-6}C)}{(0.5m)^2}$$

$$= 0.29N$$

The angle α is below the x –axis, so the components of this force are given by :

$$(F_{1\ on\ Q})_x = (F_{1\ on\ Q})\cos\alpha = (0.29N)\frac{0.4m}{0.5m} = 0.23N$$

$$(F_{1\ on\ Q})_y = -(F_{1\ on\ Q})\sin\alpha = -(0.29N)\frac{0.3m}{0.5m} = -0.17N$$

The lower charges $q_2$exerts a force with the same magnitude but at an angle α above the x – axis. From symmetry we see that its x – component is the same as that due to the upper charge, but its y – component has the opposite sign. So the components of the total force $\vec{F}$ on Q are:

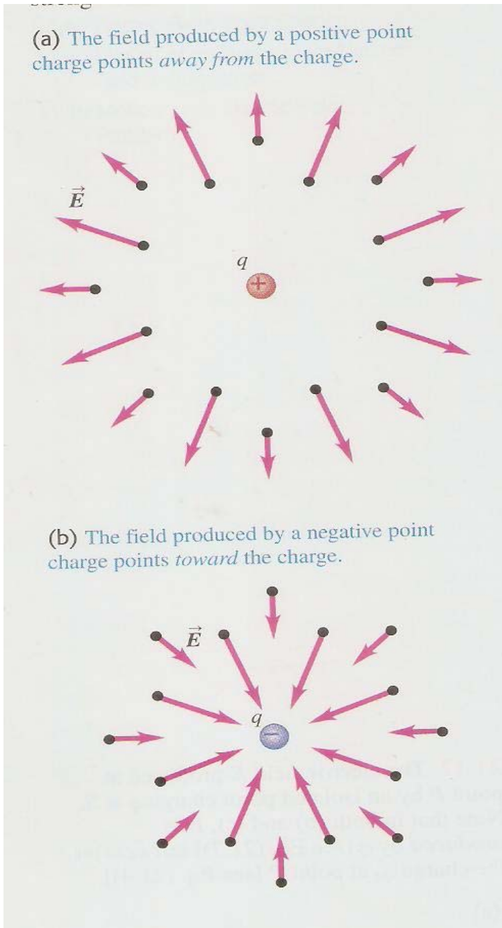
$$F_x = 0.23N + 0.23N = 0.46N$$

$$F_y = -0.17N + 0.17N = 0$$

The total force on Q is the + x – direction, with magnitude 0.46N.

1.3 Electric Field:

Electric Field Ē, a vector quantity, is the force per unit charge exerts on a test charge at any point, provided the test charge is small enough that it does not disturb the charges that cause the fields. The electric field produced by a point charge is directed radially away from or toward the charge.



(a) The field produced by a positive point charge points *away from* the charge.

(b) The field produced by a negative point charge points *toward* the charge.

$$\vec{E} = \frac{\vec{F}_0}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

Example 1.5:

What is the magnitude of the electric field at a field point 2.0m from a point charge q = 4.0nC?

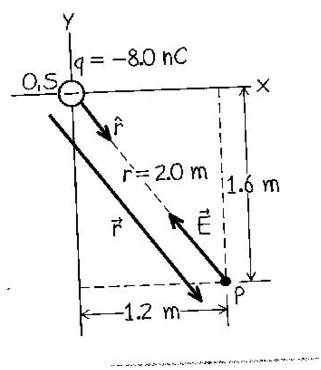
Solution:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2} = 9.0\ x10^9 N.m^2/C^2 \frac{4.0x10^{-9}C}{(2.0m)^2}$$

$$E = 9.0N/C$$

Example 1.6:

A point charge q = -8.0.nC is located at the origin. Find the electric – field vector at the field vector at the field point x = 1.2m, y= -1.6m.



The distance from the charge at the source point S (which in this example is at the origin 0) to the field point P is : $r = \sqrt{x^2 + y^2} = \sqrt{(1.2m)^2 + (-1.6m)^2} = 2.0m$

The unit vector r is directed from the source point to the field point. This is equal to the displacement vector r from the source point to field point, divided by its magnitude r;

$$\hat{r} = \frac{\vec{r}}{r}\frac{x_i + y_j}{r} = \frac{(1.2m)_i + (-1.6m)_j}{2.0m} = 0.60_i - 0.80_j$$

Hence the electric – field – field vector is

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

$$= \left(9.0 \times 10^{9} N.\frac{m^2}{C^2}\right)\frac{(-8.0 \times 10^{-9} C)}{(2.0m)^2}\,(0.60_i - 0.80_j)$$

$$= (-11N/(C)i) + (14N/C)j$$

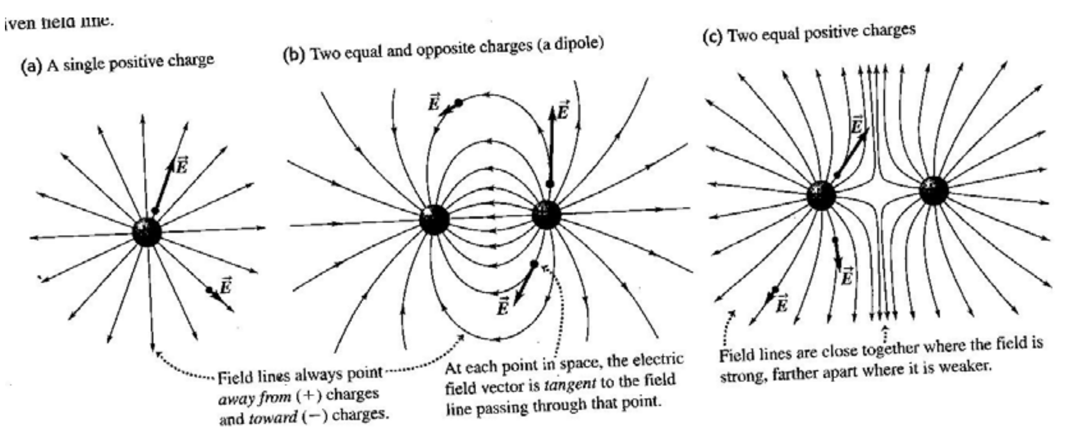
1.4 Superposition of Electric Fields

The principle of superposition of electric fields states that the electric field E of any combination of charges is the vector sum of the fields caused by the individual charges.

Charge distributions are described by linear charge density λ , surface charge density δ, and volume charge density ρ .

1.5 Electric field lines

Field lines provide a graphical representation of electric fields. At any point on a field line, the tangent to the line is in the direction of E at that point. The number of lines per unit area (perpendicular to their direction) is proportional to the magnitude of E at the point.



The actual field vectors have been drawn at several points in each pattern. Notice that in general, the magnitude of the electric field is different at different points on a given field line; a field line is not a curve of constant electric –field magnitude!

1.6 Electric Potential

Potential energy – short revision

The work – energy principle basically says:

$$W = \Delta E$$

$$W = \vec{F} . \Delta \vec{r}$$

In this most basic form, the energy is just kinetic energy (if you are not going near the speed of light). BUT …if you have a force that is conservative (meaning the work done does not depend on the path you take), then you can make it a potential energy and move it to the other side.

Warning: you cannot have a force and have that force do both work AND be a potential energy.

If you make the work done by a force a potential energy then that change in potential energy will be:

$$\Delta PE = -\vec{F} . \Delta \vec{r}$$

There is one small problem. What if the force is not constant? In that case, this really doesn't work, but you get the idea (you would need some calculus to fix this for this non – constant forces). But that is potential energy in a nutshell.

1.6.1 Electric Potential

As an example, let me start with the case of a constant electric field. This is not so crazy of an idea. It is a pretty good assumption to say the electric field inside of a parallel plate capacitor makes a constant electric field (where one side of the capacitor has a positive charge and one side has a negative charge of the same magnitude).

Now suppose that I take a positive charge from the negative side of the capacitor and move it to the positive side. During this time there is an electric force on the charge in the opposite direction it moves. The work done by the electric force would be:

$$W_E = F\,\Delta r = -qE\Delta r$$

If I now consider this work as a potential energy, it would have to be negative. So, moving from the negative side to the positive side the change in electric potential energy would be

$$\Delta U_E = qE\Delta r$$

I will leave it as a homework question, but it is not too difficult to show that this change in potential energy does not depend on the path the charge takes from one side to the other. What if I change the charge that I am moving? Well, then the change in electric potential energy would be different.

How about I just find the change in electric potential energy per unit charge? I could write that as
$\frac{\Delta U_E}{q} = \Delta V$

And this is the electric potential – though it is often called just “potential”. Really it is the change in electric potential and it has units of Joules per Coulombs or Volts. Some people even call this the voltage (but I like to call it potential difference – to emphasize that I am dealing with a charge).

2.0 Direct Current Circuits

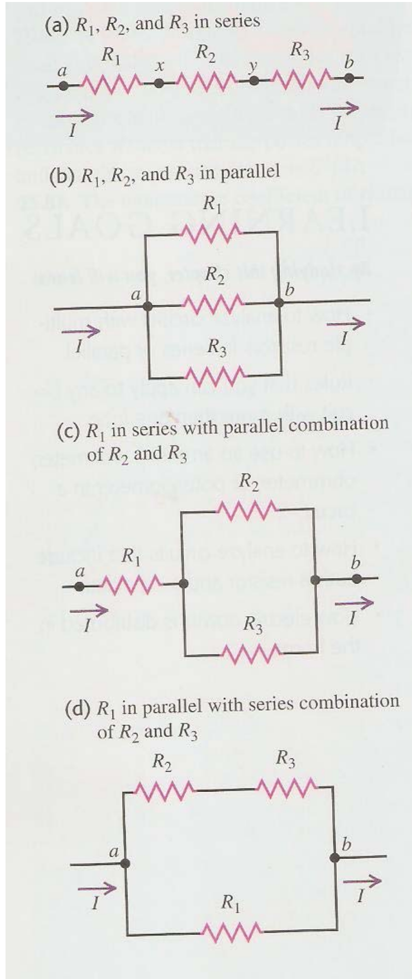
2.1 Resistors in Series and Parallel

When several resistors $R_1, R_2, R_3, \ldots,$ are connected in series, the equivalent resistance R_{eq} is the sum of the individual resistances. The same current flows through all the resistors in a series connection. When several resistors are connected in parallel, the reciprocal of the equivalent resistance R_{eq} is the sum of the reciprocals of the individual resistances. All resistors in a parallel connection have the same potential difference between their terminals.

(resistors in series), $R_{eq} = R_1 + R_2 + R_3 + \cdots$ $\quad (i)$

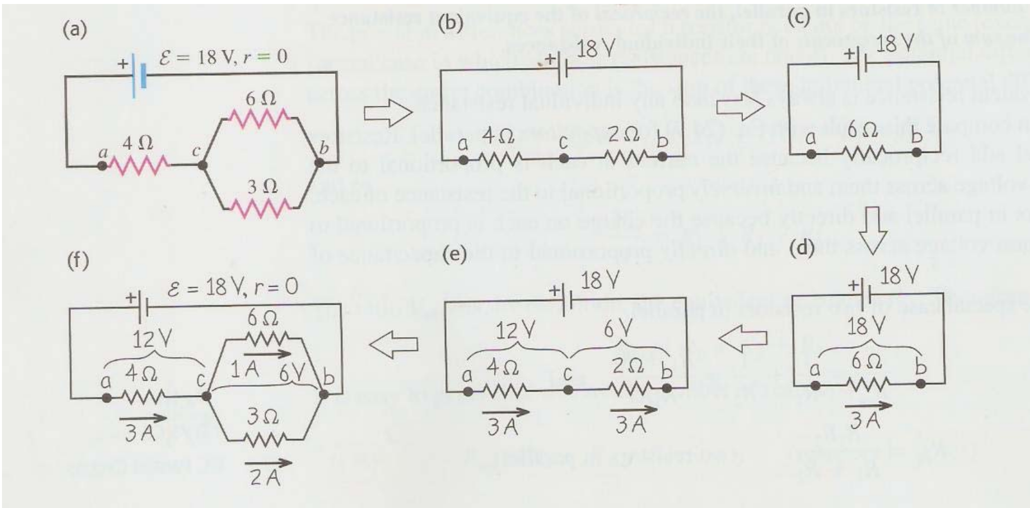
(resistors in parallel), $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$ $\quad (ii)$

Four different ways of arranging three resistors



Example 2.1

Compute the equivalent resistance of the network in the figure below, and find the current in each resistor. The source *emf* has negligible internal resistance.



Solution

Figures *b* and *c* show successive steps in reducing the network to a single equivalent resistance. From equation (ii) the 6Ω and 3Ωresistors in parallel in figure *a* are equivalent to the single 2Ω resistor in figure *b*.

$$\frac{1}{R_{eq}} = \frac{1}{6\Omega} + \frac{1}{3\Omega} = \frac{1}{2\Omega}, \quad R_{eq} = 2\Omega$$

From equation (i) the series combination of this 2 Ω resistor with the 4 Ω resistor is equivalent to the single 6 Ω resistor in figure *c*.

To find the current in each resistor of the original network, we reverse the steps by which we reduce the network. In the circuit shown in figure d, the current is

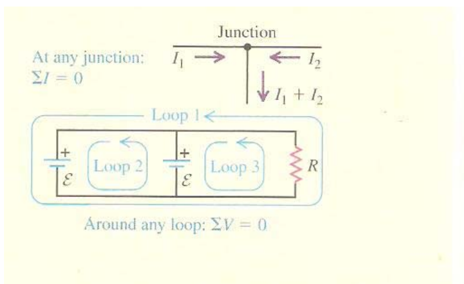
$$I = \frac{V_{ab}}{R} = \frac{18V}{6\Omega} = 3A.$$

So the current in the 4 Ω and 2 Ω resistors in figure e is also 3A. The potential difference V_{cb} across the 2 Ω resistor is therefore $V_{cb} = IR = (3A)(2\Omega) = 6V$. This potential difference must also be 6V in figure f. Using $I = \frac{V_{cb}}{R}$, the currents in the 6 Ω and 3 Ω

Resistors in figure f are $\left(\frac{6V}{6\Omega}\right) = 1A \ and \ \left(\frac{6V}{3\Omega}\right) = 2A \ respectively.$

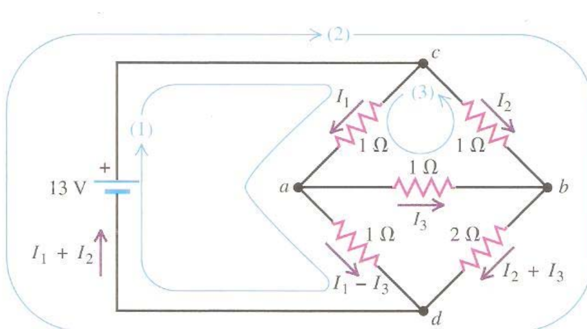
2.2 Kirchhoff's Rules

Kirchhoff's junction rule is based on conservation of charge. It states that the algebraic sum of the currents into any junction must be zero. Kirchhoff's loop is based on conservation of energy and conservative nature of electrostatic fields. It states that the algebraic sum of potential differences around any loop must be zero. Careful use of consistent sign rules is essential in applying Kirchhoff's rules.



Example 2.2:

The figure below shows a bridge circuit. Find the current in each resistor and the equivalent resistance of the network of five resistors.



Solution

We apply the loop rule to the three loops shown. Obtaining the following three equations.

$$13V - I_1(1\Omega) - (I_1 - I_3)(1\Omega) = 0 \qquad (1)$$

$$-I_2(1\Omega) - (I_2 + I_3)(2\Omega) + 13V = 0 \qquad (2)$$

$$-I_1(1\Omega) - I_3(1\Omega) + (I_2)(1\Omega) = 0 \qquad (3)$$

This is a set of three simultaneous equations for the three unknown currents. They may be solved by various methods; one straightforward procedure is to solve the third equation for I_2, obtaining $I_2 = I_1 + I_3$, and then substitute this expression into the second equation to eliminate I_2, when this is done, we are left with the two equations.

$$13V = I_1(2\Omega) - (I_3)(1\Omega) \qquad (1')$$

$$13V = I_1(3\Omega) + (I_3)(5\Omega) \qquad (2')$$

Now we can eliminate I_3 by multiplying equation $(1')$ by 5 and adding the two equations. We obtain $78V = I_1(13)\Omega, \quad I_1 = 6A.$

We substitute this back into equation $(1')$ to obtain $I_3 = -1A$, and finally from equation (3) we find $I_2 = 5A$. The negative value of I_3 tells us that its direction is opposite to our initial assumption.

The total current through the network is $I_1 + I_2 = 11A$, and the potential drop across it is equal to the battery *emf* – namely, 13V. The equivalent resistance of the network is

$$R_{eq} = \frac{13V}{11A} = 1.2\Omega.$$

Example 2.3

In the circuit of example 2 above, find the potential difference V_{ab}.

Solution:

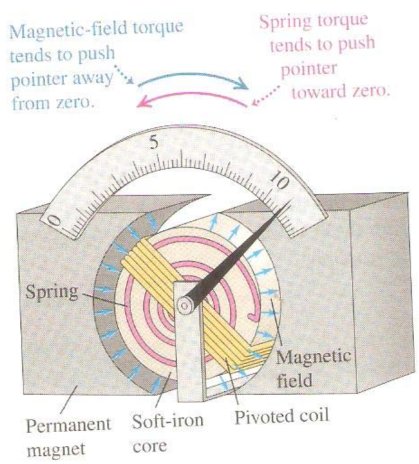
The simplest path to follow is through the centre 1Ω resistor. We have found $I_3 = -1A$, showing that the actual current direction in this branch is from left to right. Thus, as we go from *b* to *a*, there is a drop of potential with magnitude

$IR = (1A)(1\Omega) = 1V, and\ V_{ab} = -1V.$

That is, the potential at point *a* is 1V less than that at point *b*.

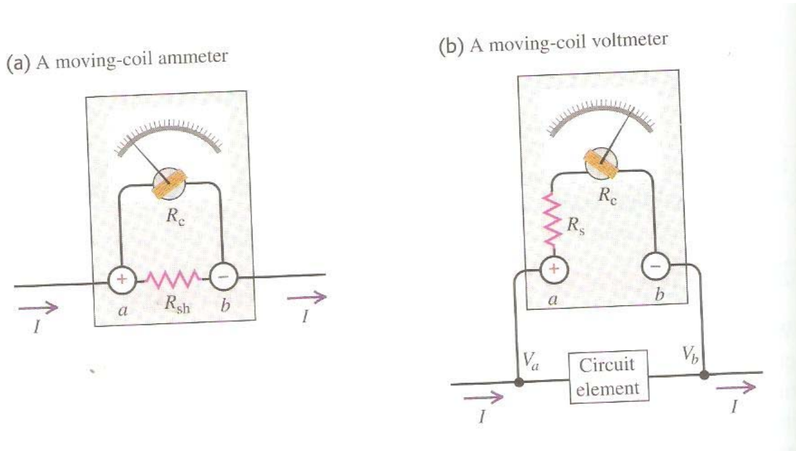
2.3 Electrical Measuring Instruments

A d'Arsonval galvanometer is used to measure potential difference (voltage), current, or resistance. A pivoted coil of fine wire is placed in the magnetic field of a permanent magnet. Attached to the coil is a spring, similar to the hairspring on the balance wheel of a watch. In the equilibrium position, with no current in the coil, the pointer is at zero. When there is a current in the coil, the magnetic field exerts a torque on the coil that is proportional to the current. As the coil turns, the spring exerts a restoring torque that is proportional to the angular displacement.



Thus, the angular deflection of the coil and pointer is directly proportional to the coil current, and the device can be calibrated to measure current.

For a larger current range, a shunt resistor is added, so some of the current bypasses the metre coil. Such an instrument is called an ammeter. If the coil and any additional series resistance included obey ohm's law, the meter can also be calibrated to read potential difference or voltage. The instrument is then called a voltmeter. A good ammeter has very low resistance; a good voltmeter has very high resistance.



Example 2.4

What shunt resistance is required to make the 1.00mA, 20.0Ω meter into an ammeter with a range of 0 to 50mA?

Solution

We want to make the ammeter to be able to handle a maximum current $I_a = 50mA = 50\ x10^{-3}A.$ The resistance of the coil is $R_c = 20\Omega,$ and the meter shows full-scale deflection when the current through the coil is
$I_{fs} = 1.00x10^{-3}A. Using\ eq. I_{fs}R_c = (I_a - I_{fs})R_{sh}$

$$R_{sh} = \frac{I_{fs}R_c}{I_a - I_{fs}} = \frac{(1.00\ x\ 10^{-3}A)(20\Omega)}{(50\ x\ 10^{-3}A) - (1.00\ x\ 10^{-3}A)} = 0.408\Omega$$

Example 2.5

How can we make a galvanometer with $R_c = 20\Omega\ and\ I_{fs} = 1.00mA$ into a voltmeter with a maximum range of 10.0V?

Solution

The maximum allowable voltage across the voltmeter is $V_v = 10.0V.$ We want this to occur when the current through the coil (of resistance $R_c = 20\Omega$) is $I_{fs} = 1.00mA$. We find the series resistance R_s using equation $V_v = I_{fs}(R_c + R_s).$

$$R_s = \frac{V_s}{I_{fs}} - R_c = \frac{10.0V}{0.001A} - 20\Omega = 9980\Omega$$

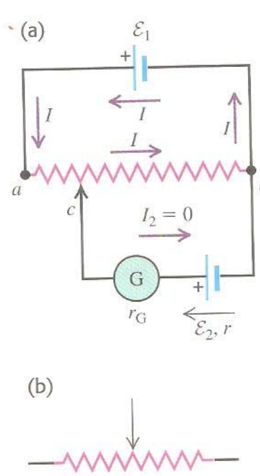
2.3 The Potentiometer

The potentiometer is an instrument that can be used to measure the *emf* of a source without drawing any current from the source. It balances an unknown potential difference against an adjustable, measurable potential difference.

The principle of the potentiometer is shown in the figure below. A resistance of wire *ab* of total resistance R_{ab} is permanently connected to the terminals of a source of known *emf*

ε_1 . A sliding contact C is connected through the galvanometer G to a second source whose *emf* ε_2 is to be measured. As contact *c* is moved along the resistance wire, the resistance R_{cb} is proportional to the length of wire between *c* and *b*. To determine the value of ε_2, contact C is moved until a position is found at which the galvanometer shows no deflection; this corresponds to zero current passing through ε_2. With $I_2 = 0$, Kirchhoff's loop rule gives $\varepsilon_2 = IR_{cb}$.

With $I_2 = 0$, the current I produced by the emf_1 has the same value no matter what the value of the emf ε_2. We calibrate the device by replacing ε_2 by a source of known emf; then any unknown emf ε_2 can be found by measuring the length of wire cb for which $I_2 = 0$. Note that for this to work, V_{ab} must be greater than ε_2.



3.0 Thermal, Chemical and Magnetic Effects of Electric Current

3.1 Thermal Effect of Electric Current: Joule's Law

The electric current in a conductor is due to the motion of electrons. During their motion, electrons collide with the oscillating positive ions in the conductor and impact part of their energy to them. Ions oscillate faster and their increased energy is manifested as heat.

The heat energy released in a conductor on passing an electric current is called the "Joule heat" and effect is called the "Joule effect".

The potential difference of V volt applied between two ends of a conductor means that V joule of electrical energy is utilized and converted into heat when one coulomb charge passes through the conductor.

If Q coulomb charge passes through the conductor in t seconds resulting in current I, the heat energy produced is

$$W = VQ \qquad joule$$

$$W = VIt \qquad joule$$

$$W = I^2 Rt \qquad joule \quad (V = IR \text{ according to ohm's law})$$

$$W = \left(\frac{V^2}{R}\right)t \qquad joule$$

The electric power, i.e., the electrical energy supplied per unit time or converted into heat energy per unit time in a resistance R, is

$$P = VI \qquad \frac{joule}{second}(= watt)$$

$$P = I^2R \qquad \frac{joule}{second}(= watt)$$

$$P = \left(\frac{V^2}{R}\right) \qquad \frac{joule}{second}(= watt)$$

Thus, mechanical unit of energy, joule = watt.second which is an electrical unit of energy. This being too small, kilowatt-hour (kwh) = $3.6 \times 10^6\ joule$ used as a practical unit of electrical energy.

R is the ohmic resistance of the conductor value of which does not depend upon V or I. Considering R as a constant,

$P \propto I^2 \text{ or } P \propto V^2$

In fact, all electrical appliances are rated to operate for a given potential difference and hence in household wiring, they are connected in parallel. Therefore, V is same for all whereas I varies. Hence, it is more convenient to use the formula $P = \left(\frac{V^2}{R}\right)$.

Joule's Law: "the heat produced per unit time, on passing electric current through a conductor at a given temperature, is directly proportional to the square of the electric current".

To express heat produced in calories, the following relation given by joule is used.

W = JH, where W is mechanical energy in joule,

H is heat energy in calorie and

J = 4.2 joule/calorie is joule's constant or mechanical equivalent of heat.

$$H(cal) = \frac{I^2Rt\ (joule)}{J}$$

3.1.1 Practical Applications of Joule Heating

Joule heat is used in domestic appliances such as electric iron, toaster, oven, kettle, room heater, etc. It is also used in electric bulbs to produce light. The temperature of the filament of the bulb rises considerably when current flows through it and it emits light. Hence it should be made of a high melting point such as tungsten, whose melting point is 3380^0C. Also it should be thermally isolated from the surrounding as far as possible. Only a small fraction of electric power supplied to the bulb is converted into light. Normally a bulb emits 1 candela of light per watt of electric power consumed.

Another common application of joule heat is fuse wires used in circuits. It consists of a piece of metal wire having low melting point (such as aluminum, alloy of tin/lead, copper etc.) and is connected in series with an appliance. If a current larger than a specified value flows, the fuse wire melts and breaks the circuit thus protecting the appliance.

3.2 Chemical Effect of Electric Current

3.2.1 Introduction

- Solid and molten metals are good conductors of electricity due to free electrons. When current flows through metals, only heating occurs and no chemical effect is observed.
- Most liquids have no free electrons and hence do not conduct electricity, e.g., water.
- When an acid, base or an inorganic salt is added to water it dissociates into positive and negative ions which conduct electricity. The solutions which conduct electric current are called electrolytes and the vessel containing it along with electrodes is called an electrolytic cell.
- Inorganic salts like NaCl and KCl conduct electric current even in solid form.
- Normally, the solutions of organic compounds are non-conductors.
- In NaCl crystal Na^+ and Cl^- ions are bound to each other due to electrostatic attraction. About 7.9eV (1eV = 1.6 x 10^{-19} joule) energy is required to separate them. Only 0.03eV thermal energy is available at room temperature which is insufficient to break NaCl crystal. When NaCl is added to water, polar water molecules get arranged in space between the ions which reduce attraction between them. Also, due to a specific distribution of charge inside them, some water molecules stick to each other forming a cluster around the ions. Each cluster is electrically polarized which reduces the strength of electric field between the ions. For this reason, dielectric constant, K, of water is very high which reduces the electric field

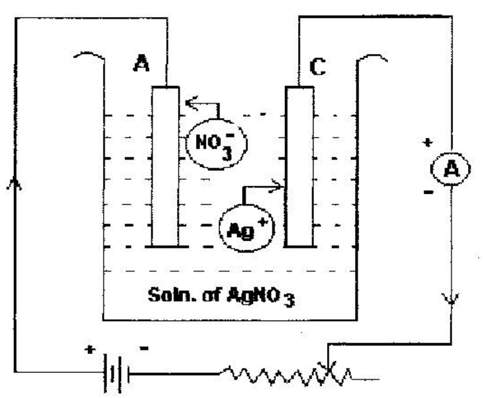
between Na^+ and Cl^- ions to 1/K times and they get dissociated. Due to its high dielectric constant, water acts as a good solvent. Ions dissociated this way participate in conduction of electric current.

- At room temperature, electric conductivity of electrolytes is 10^{-5} to 10^{-6} times that of metals because
  (i) The number density of ions is less compared to the number density of electrons in metals,
  (ii) Viscosity of solution increases electrical resistance and
  (iii) Drift velocity of ions is less compared to electrons due to their larger mass.

3.2.2 Electrolysis

The device in which electrolysis occurs is called an electrolytic cell or voltameter which is used to study the chemical effects of electric current.

Refer to the figure shown to understand the working of an electrolytic cell.



Here acqueous solution of $AgNO_3$ is used as an electrolyte and two plates A and C silver are partially immersed in it which are the electrodes. The electrodes are connected to a battery from which current enters the electrolyte through A and leaves through C.

$AgNO_3$ dissociates into Ag^+ and $NO3^-$ ions in the electrolyte. $NO3^-$ ions (anions) move towards the anode A and Ag^+ ions (cations) move towards the cathode C.

Each Ag^+ ion, on reaching the cathode, picks up an electron from it and reduces to become a neutral atom of silver and deposits on cathode. $(Ag^+ + e^- \rightarrow Ag)$. This process of plating of Ag on the cathode is called electroplating.

$NO3^-$ ion reaching the anode oxidizes Ag to Ag^+ ion and the electron so released goes to the positive terminal of the battery through the wire. $AgNO_3$ formed dissociates maintaining concentration of Ag^+ and $NO3^-$ ions ($Ag + NO_3^- \rightarrow Ag^+ + NO_3^- + e^-$). Thus, Ag^+ ion lost at the cathode is obtained back at the anode.

Summarizing,

1) Electric current is due to the motion of electrons in the external conducting wire and due to the motion of ions in the electrolyte.
2) Anode loses silver which gets deposited on the cathode.
3) Concentration of $AgNO_3$ is maintained.
4) Cathode is made of the metal which is to be plated, e.g., for silver-plating of copper, cathode is made of copper.
5) Anode is made of the metal of which is to be done and electrolyte must be a compound of that metal.

3.2.3 Faraday's Laws of Electrolysis

Law 1: "Mass m of the substance librated at the electrode from the electrolyte, on passing electric current through the electrolyte, is directly proportional to the amount of charge (Q) passing through it."

Thus, $m \propto Q$. $\therefore m = ZQ = ZIt$, where I is the current for time t.

"Z is called electrochemical equivalent of the substance librated and is defined as the mass of the substance librated from an electrolyte on passing one ampere current for one second, i.e., one coulomb of charge."

Its unit is g/C or kg/C.

Law 2: "When the same current is passed for the same time through different electrolytes, the masses of elements librated at electrodes are directly proportional to their respective chemical equivalents."

Chemical equivalent (e) of any element is the ration of its atomic mass to its valency. It is also called gram equivalent.

Let e_1 and e_2 be the chemical equivalents of two substances and m_1 and m_2 be their masses librated at the electrodes when the same current I passed through two electrolytic cells for the same time t. Then,

$$\frac{e_1}{e_2} = \frac{m_1}{m_1} = \frac{Z_1 It}{Z_2 It} \qquad \therefore \frac{e_1}{Z_1} = \frac{e_1}{Z_2} = F$$

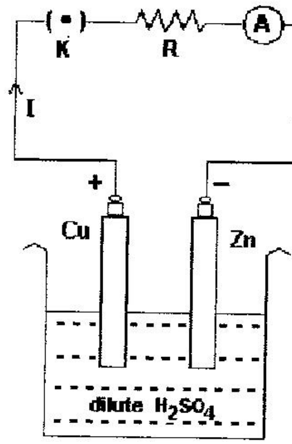
Where F is Faraday's constant having value 96500 coulomb/mole. This means that 96500C charge is required to liberate, through electrolysis, 1 mole of an element having valency 1. It also means that the amount of substance librated at the electrode when 96500 C charge is passed through an electrolyte is

$$m = \frac{atomic\,mass}{valency} = chemical\ equivalent$$

3.2.4 Electrochemical Cells

The device used to convert chemical energy into electrical energy is called an electrochemical cell.

When a metal plate (electrode) is immersed into an electrolyte, positive or negative ions from the electrolyte move towards it and a net *e.m.f.* is developed between it and the electrolyte. When two electrodes of different metals are immersed into the electrolyte, a net e.m.f. is generated between them. The electrode at higher electric potential is called the positive electrode and the one having lower potential is called the negative electrode. Steady electric current flows on completing the electric circuit by connecting the two electrodes with a conducting wire. Such a device is called an electrochemical cell.



Electrochemical cells are of two types:

1) Primary cells: the cells that get discharged only and cannot be recharged after use are called the primary cells.
2) Secondary cells: The cells which can be recharged after use and restored to original condition are called the secondary cells.

3.2.5 Voltaic Cell

Italian scientist Volta prepared such a cell for the first time. Hence it is known as voltaic cell in his memory.

Dilute H_2SO_4 is used as an electrolyte. Positive charge deposits on copper electrode and negative charge on zinc electrode. So copper electrode is at a higher potential that the zinc electrode.

3.3 Magnetic Effects of Electric Currents

3.3.1 Introduction

The branches of electricity and magnetism were unified by scientists like Oersted, Rowland, Faraday, Maxwell and Lorentz.

The branches of Physics covering a combined study of electricity and magnetism is known as electromagnetism or electrodynamics. It is useful in study of subjects like plasma physics, magneto-hydrodynamics and communication.

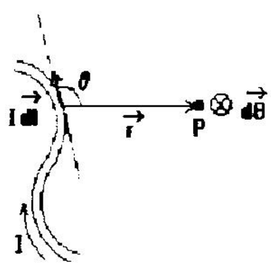
3.3.2 Oersted's Observation

In 1819 A.D., a school teacher from Denmark, observed that magnetic field is produced around a wire carrying electric current. If a conducting wire is kept parallel to the magnetic needle and electric current is passed through it, needle gets deflected and aligns itself perpendicularly to the length of the wire.

3.3.3 Biot-Servart's Law

The intensity of magnetic field due to a current element $I\vec{dl}$ at a point having position vector $\vec{r}$ with respect to the electric current element is given by the formula.

$$\vec{dB} = \frac{\mu_0 I\vec{dl} \times \hat{r}}{4\pi r^2} = \frac{\mu_0 I\vec{dl} \times \vec{r}}{4\pi r^3} \qquad and \ |\vec{dB}| = \frac{\mu_0 I dl \sin\theta}{4\pi r^2},$$



Where $\vec{dB}$ = magnetic intensity in tesla (T) or weber/m^2,

$I\vec{dl}$ = current element (product of electric current and length of small line element $\vec{dl}$ of the conductor)

$\mu_0 = magnetic\ permeability\ of\ vacuum$

$= 4\pi \times 10^{-7}\ tesla\ metre\ per\ ampere\ (T\ m\ A^{-1})$

$\hat{r}$ = unit vector along the direction of $\vec{r} = \frac{\vec{r}}{|\vec{r}|}$

and θ = angle between $\overrightarrow{dl}$ and $\vec{r}$

The direction of $\overrightarrow{dB}$ is perpendicular to the plane formed by $\overrightarrow{dl}$ and $\vec{r}$. As $\overrightarrow{dl}$ and $\vec{r}$ are taken in the plane of the figure, the direction of $\overrightarrow{dB}$ is perpendicular to the plane of the figure and going inside it, as shown by $\otimes$.

On integrating the above equation, we get the total intensity at the point P due to the entire length of the conducting wire as

$$\vec{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\vec{l}\, x\, \hat{r}}{r^2} \quad or\ \vec{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\vec{l}\, x\, \vec{r}}{r^3}$$

4.0 ELECTROMAGNETIC WAVES

Generally, different types of fields produced by electric and magnetic fields can be categorized into two. The first includes fields that do not vary with time, these are called **ELECTROSTATIC** fields. Examples of electrostatic field include (i) distribution of charges at rest and (ii) the magnetic field of a steady state current in a conductor. The electrostatic field can vary from point to point in space, but do not vary with time at any individual point.

The 2nd category includes situation in which the **FIELDS** do vary with time. In this case we cannot treat electric and magnetic field separately. Faraday's law tells us that a time varying magnetic field produces or acts as a source of electric field. This field is manifested in the induced emf's in inductances and transformers. Hence, when **EITHER** field is changing with time, a field of the other kind is induced in adjacent regions of space.

The properties of electromagnetic waves are:

(i) The solution's of Maxwell's third and fourth equations are wavelike, where both E and B satisfy the same wave equation.

ii) Electromagnetic waves travel through empty space (i.e. vacuum) with the speed of light i.e. $c = \sqrt{\frac{1}{\mu_0 \varepsilon_0}}$

where ε_0 = 8.854 X 10^{-12}F/m is the permittivity of free space, and μ_0 = 1.257 X 10^{-6}H/m is the permeability of the free space

iii) The electric and magnetic field components of plane electromagnetic waves are perpendicular to each other and also perpendicular to the direction of wave propagation. i.e. e – m waves are transverse waves.

iv) The relative magnitudes of E and B in empty space is given by $c = \frac{E}{B}$.

v) Electromagnetic waves obey the principle of superposition.

4.1. SPEED OF ELECTROMAGNETIC WAVES

According to Faradays law electric and magnetic fields are related according to the equation:

$$E = cB \text{ ------------------------- } (1)$$

The e – m wave is consistent with Faraday's law only if E, B and c are related according to the above equation.

Ampere's law is obeyed by the e – m wave, only if the magnetic field B, speed c and the electric field E are related by the equation.

$$B = \mu\varepsilon c\, E \text{ -------------------- } (2)$$

From Eq. (1):

$$B = \frac{E}{c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

By combining Eqs (2) and (3), we have

$$c = \sqrt{\frac{1}{\mu\varepsilon}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

4.2 ENERGY CARRIED BY E – M WAVES

Electromagnetic waves carry energy as they propagate through space. The total energy density in a region of space where E and B fields are present is given by

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0}B^2$$

Magnetic field strength $H = \frac{B}{\mu_0}$

In terms of E and H, the energy density is

$$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{\mu_0}{2} H^2$$

4.3 POYNTING VECTOR

The total energy densities (i.e. energy per unit vol.) for the electric and magnetic fields in free space are given respectively as

$$U_E = \frac{1}{2}\varepsilon_0 E^2 \text{ and } \quad U_B = \frac{1}{2\mu_0} B^2 \quad \text{---1}$$

Since $E = cB = \frac{B}{\sqrt{\mu_0 \varepsilon_0}}$ for an electromagnetic wave, the instantaneous values of these energy densities are equal. The **TOTAL ENERGY DENSITY** $U = U_E + U_B$ is therefore

$$U = \varepsilon_0 E^2 = \frac{B^2}{\mu_0} \sqrt{\frac{\varepsilon_0}{\mu_0}} EB \quad \text{---2}$$

Let us consider two planes, each of area A, a distance dx apart, and normal to the direction of propagation of the wave. The total energy in the volume between the planes is dv = UAdx). The rate at which this energy passes through a unit area normal this energy direction of propagation is

$$\vec{S} = \frac{1}{A}\frac{dV}{dt} \quad \text{---3}$$

Since the energy is carried by the fields, which moves at speed c, it is also transported at this speed. Thus,

$$\frac{dV}{dt} = \mu A c \quad \text{---4}$$

and so

$$\vec{S} = \mu c \quad \text{---5}$$

Using the fact that $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ and eqn (2) above, we have

$$\vec{S} = \sqrt{\frac{\varepsilon_0}{\mu_0}} EB \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

i.e.

$$\vec{S} = \frac{EB}{\mu_0} \quad \text{--6}$$

Since the energy flow in 1a to both E and B, we therefore pointing vector as

$$\vec{S} = \frac{E \times B}{\mu_0} \quad \text{---7}$$

NOTES

i. The magnitudes of $\vec{S}$ is the intensity, that is instantaneous power that crosses a unit area normal to the direction of propagation.

ii.The direction of $\vec{S}$ is the direction of energy flow. In e – m waves, the magnitude of the poynting vector, S, fluctuates rapidly in time. A more useful quantity is the average intensity of the wave, it is the average value of $\vec{S}$. Thus **AVERAGE INTENSITY** is

$$S_{ave} = U_{ave}c = \frac{E_0 B_0}{2\mu_0}$$

The quantity S_{ave} is measured in W/m^2 is the average power per unit area, normal to the direction of propagation.

iii. The average intensity of plane wave does not diminish as it propergates

4.4 THE E – M SPECTRUM

Electromagnetic waves span an immense range of frequencies, from very long wavelength radio waves, whose frequency is around 100Hz, to extremely high energy γ rays from space, with frequencies around 10^{23}Hz. The electromagnetic spectrum, shown below, covers appropriately 100 octaves. (The audible sound spectrum covers about nine octaves). There is no theoretical limit to the high end.

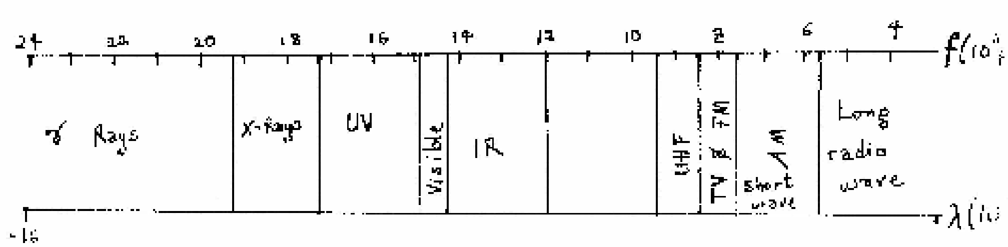


Fig.1.1: Electromagnetic spectrum

4.4.1 VISIBLE LIGHT

Visible light of e – m waves covers approximately one octave from 400 – 700nm. An approximate range for each colour is as follows:

Violet (400 – 450 nm), blue (450 – 520 nm), green (520 – 560 nm), yellow (560 – 600 nm), orange (600 – 625 nm) and red (625 – 700 nm). As electrons undergo transitions below energy levels in an atom, light is produced at well-defined wavelengths.

4.4.2 Ultraviolet Radiation

The UV region extends from 400 nm to 10 nm. It plays a role in the production of vitamin D in human skins and leads to tanning. In large or prolonged doses, UV radiation kills bacteria and can induce cancer in man. Glass absorbs UV radiation and hence can provide some protection again the sun's rays. If the ozone in the atmosphere did not absorb the UV below 300 nm, there would be a larger number of cell mutations, especially the cancerous ones, in human beings.

4.4.3 Infrared radiation

The IR region starts from 700 nm and extends to about 1 mm, just beyond the red end of visible spectrum. IR radiation is associated with the vibration and rotation of molecules and is perceived by man as heat. IR – sensitive film is used in satellites for geophysical surveying and in the detection of the hot exhaust gases of a rocket launch. IR is used in the detection of tumors – which are warmer than the surrounding tissue.

4.4.4 Microwaves

Microwaves cover wavelength from 1mm to 15cm. microwaves up to 30GHz (1cm) may be generated by the oscillations of elections in a device called **KLYSTRON**. In the microwaves ovens used in kitchens, the radiation has frequency of 2450MHz modern intensity communication, such as numerical data, phone conversations and TV programs are often carried via antennae.

4.4.5 Radio and TV signals

These signals span the range from 15cm to 2000m. dipoles are used for both transmission and reception. For AM radio, a coil is usually used for reception because the wavelength is so much larger than is practical for an electric dipole. For UHF TV, the cell is used because wavelengths are so small.

4.4.6 X-Rays

X-rays was discovered in 1895 by W. Roentgen. It extends from to 0.01 nm adjacent to the UV. X-ray machines produce these waves. This type of radiation passes a range of frequencies and is called **BREMSSTRAHLUNG** or "braking radiation". X-rays are used to study the atomic structure of crystals or molecules, such as DNA. Besides their diagnostic and therapeutic use in medicine, X-rays are used to detect tiny faults in machinery.

4.4.7 γ-Rays

γ -Rays were part of radiative emission. Whereas X-rays are produced by electrons, r-rays are usually produced within the nucleus of an atom and are extremely energetic. They cover the range from 0.01nm downward, or equivalently from 10^{20} Hz up.

5.0 HUYGENS' PRINCIPLE

In 1678, C. Huygens proposed a principle that is useful in predicting the propagation of wavefronts. He proposed that when a light pulse is emitted by a source, the nearby particles of "ether" are set into motion. The light propagates because this motion is communicated to the nearby particles. Thereby each particle acts as secondary **WAVELETS.** In order to explain the rectilinear propagation of rays, he asserted that only the wavelets in forward direction is strong. The wavelets that are spread to the sides were quietly ignored as being "too feeble" to be seen.

Huygens' principle states that "Each point on a wavefront acts as secondary wavelets". At a later time, the envelope of the leading edges of the wavelets form the new wavefronts.

The figure below shows plane wavefronts approaching a flat surface at angle θ to the surface and being reflected at angle θ' to the surface. Since the rays are far to the wavefronts, the angles θ and θ' are also the angles made by the rays to the **NORMAL** to the surface. When the edge A of wavefront AB meets the surface, it starts to produce its secondary wavelet. The same happens as each successive point of AB strikes the surface. The line DC forms the reflected wavefront. Since the speeds of the incident and reflected waves an identical AD = BC. Triangles ACD and ACB are both right angled and have a common hypotenuse. We conclude that $\theta = \theta'$ which is the law of reflection.

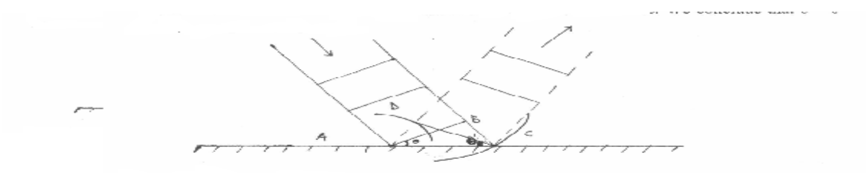


Fig. 1.2: Huygen.s Principle

From the geometry of the triangles ABC and ADC we conclude that $\theta = \theta'$

5.1 REFRACTION

A drinking straw appears to be bent when it is partially immersed in H_2O; a magnifying lens can focus the sun's rays or make the objects x cm larger. These and many other optical effects are caused by **REFRACTION.** An important phenomenon associated with refraction of light is termed **REFRACTIVE INDEX,** n; it is defined as the ratio of the speed of light in a vacuum, c, to the speed of light, v, in the medium.

i.e.

$$n = \frac{c}{v} \quad \text{---} 1$$

Let us consider the figure below wherein light travel from air (vacuum) into a medium of refractive index n_2. If the angle made by the incoming ray with the normal is θ_i while the angle of refraction is θ_r. Then we obtain a very important law of refraction called Snell's law of refraction as follows.

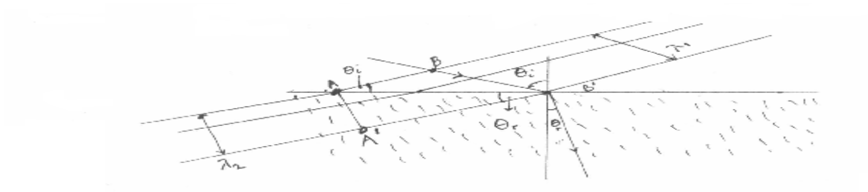


Fig 1.3: Using Huygen's principle to explains refraction.

In a short time interval Δt, the wavelet from point B of wavefront AB travels a distance.

$$S_1 = V_1 \Delta t \quad \text{--2}$$

to Point $B^{'}$, where

$$BB^{'} = V_1 \Delta t = AB^{'} \sin\theta. \quad \text{----------------------------3}$$

In this time, the wavelet from A travels a distance

$$S_2 = V_2 \Delta t \quad \text{--4}$$

to point A' in the 2^{nd} medium, where

$$AA^{'} = V_2 \Delta t = AB^{'} \sin\theta_r \quad \text{---5}$$

The new wavefront, A'B' is tangent to the wavelets from wavefront AB. The ratio BB^1/AA^1 yield,

$$\frac{V_1 \Delta t}{V_2 \Delta t} = \frac{AB^{'} \sin\theta_i}{AB^{'} \sin\theta_r}$$

i.e

$$\frac{v_1}{v_2} = \frac{\sin\theta_i}{\sin\theta_r} \quad \text{--6}$$

where V_1 and V_2 and the velocities of light from the 1^{st} and 2^{nd} medium respectively (with $v_1 > v_2$). Equation (6) is the Snell's law of refraction. In terms of refractive index, Eq. (6) can be written as:

$$\frac{n_1}{n_2} = \frac{\sin\theta_i}{\sin\theta_r} \quad \text{--6}$$

When $n_2 > n_1$, it follows that $\theta_r < \theta_i$ i.e, on entering a medium with a "higher refractive index the RAY BENDS TOWARDS the NORMAL, otherwise the ray moves away from the normal.

If the wavelength in the vacuum is λ_0 and that in the medium is λ_n, then

$$V = \lambda_n \quad \text{--7}$$

And

$$C = \lambda_0 \quad \text{--8}$$

Using (7) and (8) in (1)

$$n = \frac{\lambda_0}{\lambda_n} \quad \text{--9}$$

Worked example:

1) Light of wavelength 600 nm in air is incident at an angle of 35^0 to the normal of a plate of heavy fling glass of refractive index 1. 6. Assume that the refractive index of air is 1. Find (a) the angle of refraction, (b) the wavelength of the light in the glass, (c) the speed of light in the glass.

Solution

5.2 TOTAL INTERNAL REFLECTION

The figure below shows the boundary between two media with refractive . index n_1 and n_2, where $n_2 > n_1$. A ray approaching the boundary forms the medium of higher refractive index is refracted away from the normal. For a small angle of incident, there is both reflected and refracted ray. However, at some critical angle of incidence, θ_c the refracted ray emerges parallel to the surface. For any angle of incidence greater that θ_c the light is totally reflected back into the medium of higher refractive index. This is called TOTAL INTERNAL REFLECTION and way first reprinted by Kepler in 1604. The value of θ_c it can be found from Snells law by setting $\theta_r = \theta_c$ and $\theta_i = 90^0$.

$$n_2 \text{Sin}\theta_c = n_1 \quad \text{------------------------} \quad (1)$$

Fig.1.3: Total internal reflection

If the medium with the lower refractive index is air, we may take $n_1 = 1$. Then, for water where $n_2 = 1.33$, the θ_c will be $= 48.5^0$; on the other hand if n2 = 1.55 i.e. for glass, $\theta_c = 42^0$.

6.0 YOUNG'S TWO-SLIT EXPERIMENT

The English scientist named Thomas Young showed interference effects in 1800.

In his experiment a source, S, of monochromatic light is placed in front of a narrow slit C with two very narrow slits A, B, close to each other in front of S. Young then observed bright and dark bands on either side of O on a screen T, where O is on the perpendicular bissector of AB, see the fig. below.

Fig. 2.4: Young's double slit experiment

To explain Young's observation we consider the light from S illuminating the two slits A, B. Since the light diverging from A has exactly the same frequency as, and is always in phase, with light from B, A and B acts as two coherent sources. Interference thus takes place in the shaded region, where the light beams overlap. As AO = OB, a bright band is obtained at O. At a point close to O, such that $BP - AP = \lambda/2$, where λ is the wavelength of the light from S, a dark band is obtained.

Young demonstrated that the bands or FRINGES were due to interference by covering A or B, when the fringes disappeared.

Two conditions necessary to obtain an interference phenomenon in light are:

i) two coherent sources must be produced

ii) the coherent sources must be very close to each other as the wavelength of light is very small.

6.1 DIFFRACTION OF LIGHT WAVE

Diffraction is the name given to the spreading of waves after they pass through small openings (or round small obstacle). This phenomenon was observed by GRIMALDI in 1665. The diffraction is appreciable when the width of the opening is comparable with the wavelength of the waves and very small when the width is large compared to the wavelength. Light has a very short wavelength such as 6.0×10^{-7}m, hence it can only be diffracted appreciably through small openings. Sound on the other band has a long wavelength, hence it can be diffracted after passing through doorways.

If a source of white light is observed through the eyelashes a series of coloured images can be seen. These images are due to interference between sources on the same wavefront, and so the phenomenon is an example of diffraction.

6.2 DIFFRACTION AT SINGLE SLIT

Suppose a beam of parallel monochromatic light is incident on the opening AB in the fig. below. If these parallel wavefronts from a distant object are diffracted at a rectangular slit AB of width a. This is called FRAUNHOFER DIFFRACTION. If the light passing through the slit is received on screen T a long way from AB, we may consider that parallel wavefronts have travelled to T to form the image of the slit.

Fig. 3.1 Rectangular Slit Diffraction

Let us consider a plane wavefront which reaches the opening AB in fig. 1 above. All points on it between A and B are in phase, that is, they are coherent. The point acts as secondary centres, sending out waves beyond the slit. Their combines effect at any distance point can be found by summing the numeric waves arriving there, from the principle of superposition of waves.

It is important we note the difference between Fraunhofer and Freshnel diffraction. For example in Fraunhofer diffraction the screen is sufficiently distant from the slit (or the slit is sufficiently narrow) whereas in Fresnel diffraction, the screen is relatively close to the slit (or the slit is relatively wide). There is no difference in the nature of diffraction process in both cases. Fresnel diffraction gradually merges into Fraunhofer diffraction as the screen is moved away from the slit or as the slit width decreased.

Fraunhofer diffraction also occurs if a lens is placed just beyond the slit as shown in the figure below.

Fig. 3.2: Fraunhofer diffraction through lens

Let us consider two narrow strips, one just below the top edge of the slit and one at its centre. The difference in path length to point P in the fig. below is $^{a}/_{2}$ Sinθ , where a is the slit width. Assuming that this path difference happens to be equal to $\lambda/2$; then the light from these two strips at a point P with a half-cycle phase difference, and cancellation occurs.

Fig. 3.3:

Similarly, light from two strips just below these two will also arrived half cycle out of phase; and, in fact, light from every strip in the top half cycles cancels out that from the corresponding strip in the bottom half, resulting in complete cancellation, and giving a dark Fringe in the interference pattern. Hence a dark fringe occurs whenever

$$^{a}/_{2}\ \mathrm{Sin}\theta = \lambda/2$$

or

$$\mathrm{Sin}\theta = \lambda/a$$

Generally, the condition fro a dark fringe is

$Sin\theta = (n\lambda)/a$

and if θ is very small, then

$\theta = (n\lambda)/a$

6.3 THE DIFFRACTION GRATING

A diffraction grating is a large number of close parallel equidistant slits, ruled on glass or metal. It provides a very valuable way of studying spectra. This arrangement was first constructed by Fraunhofer.

The angles of deviation for which the maxima occur may readily be found from the fig. below. Let us consider the right angle Aba. Let d be the distance between successive grating, called "grating spacing". The necessary condition for a maximum is that ab = mλ, where m = 0, 1, 2, ..., It follows that

$Sin\theta = (m\lambda)/d$

is the necessary condition for a maximum. The angle θ is also the angle by which the rays corresponding to the maximum have been deviated from the direction of incident light.

SOLVED PROBLEMS

7.0 RADIOACTIVITY

In 1896, Becquerel found that a Uranium compound affected a photographic plate wrapped in light-proof paper. He found that fluorescent uranium sulphate did give out rays, which could affect photographic plate even when wrapped in thick black paper. He called the phenomenon **radioactivity**.

7.1 Properties of radioactive Rays

1. Radioactive rays ionize the surrounding air and affect photographic plates.
2. Radioactive rays act differently on different cells and tissues. Cells that are multiply rapidly are most readily destroyed by these rays.
3. Fluorescence is produced in substances like zinc sulphide, barium platinocynide etc. when minute quantities of radioactive is added to them.

4. Radioactive materials when subjected to electric or magnetic field can split into three different components i.e alpha particles (α), beta particles (β) and gamma rays (γ).

7.2 Alpha-particles

These are nuclei of helium atoms, which have a mass of about four times that of a hydrogen atom and carried a change of +2e, where e was the numerical value of the charge on an electron. These particles were identified by Rutherford and Royds in 1909.

In a transformation where parent element gives birth to a new element called daughter product by emitting radioactive rays is called a radioactive transformation.

A few examples of α-particles are:

(i) $^{222}_{86}Rn \rightarrow ^{4}_{2}He + ^{218}_{84}Po$

(ii) $^{218}_{84}Po \rightarrow ^{4}_{2}He + ^{214}_{82}Pb$

(iii) $^{238}_{92}U \rightarrow ^{4}_{2}He + ^{234}_{90}Th$

Alpha particles have the following properties

i) They can be stopped by a thin sheet of paper.
ii) α-particles from the same sources possess the definite velocity and the definite energy.
iii) Alpha particles cover definite distance in a given material, practically without any loss of intensity.

7.3 Beta Particles and Gamma-Rays

β-particles are identical with electrons. Therefore, a β-particles has a mass of (1/1836) of mass of a proton. Generally, β-particles have greater penetrating power of materials than α-particles and their ionization of gases is less than that of α-particles.

β-particles are strongly deflected by a magnetic field. The direction of their deflection corresponds to a stream of NEGATIVELY charged particles, that is, opposite to the deflection of α-particles in the same field. A few examples of β-decay are

(i) $^{234}_{90}Th \rightarrow ^{0}_{-1}e + ^{234}_{91}Pa$

(ii) $^{210}_{83}Bi \rightarrow ^{0}_{-1}e + ^{210}_{84}Po$

(iii) $^{238}_{92}U \rightarrow ^{0}_{-1}e + ^{14}_{7}N$

The γ-rays are part of e-magnetic spectrum. Experiments show that γ -rays are of shorter wavelengths than the wavelengths of x-rays and of order of 10^{-11}m or less. γ -rays can penetrate large thicknesses of metals, but have far less ionizing power in air/gasses than β-particles.

A beam of γ -rays does not show any deflection when passed through a strong magnetic field because they (i.e. γ -rays) are e – m waves that carry no charge.

7.4 The Law of Radioactive Decay

Radioactive, or the emission of α-, or β-particles and r-rays, is due to disintegrating nuclei of atoms. The disintegration obey the STATISTICAL LAW of chance.

The law of radioactive decay states that the number of disintegration per second, $^{dN}/_{dt}$, is directly proportional to the number of atoms, N, present at that instant.

Mathematically

$$\frac{dN}{dt} = -\lambda N \qquad \text{--------------------------------------1}$$

where λ is called radioactivity decay constant λ is the characteristics of the atom concerned. The negative indicates that N becomes SMALLER as time, t, increases. Therefore, if No is the number of atoms present at time t = 0 and N is the number left at time t, we have by integrating (1)

$$\int_{N_0}^{N} \frac{dN}{dt} = -\lambda \int_{0}^{t} N$$

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_{0}^{t} dt$$

i.e. $$N=N_0e^{-\lambda t} \qquad \text{---------------------------------------2}$$

So, the number N of undecayed atoms left decreases exponentially with time.

7.5. HALF LIFE

The half-life, $T_{\frac{1}{2}}$ of a radioactive alternate is defined as the time taken for the atoms to disintegrate to half their initial number (see the fig. below).

Fig. :Radioactive decay with time

So if N_0 is the initial number of atoms, from Eq. (2)

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{\frac{1}{2}}}$$

$$\frac{1}{2} = e^{-\lambda T_{\frac{1}{2}}}$$

Let's take the natural logarithm of both side of the above equation, we obtain:

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda} \qquad \text{-----------------------------3}$$

The S.I unit of the activity of an atom is Curie.

one Curie (1Ci) = 3.7 X 10^{10} disintegration/sec

From Eq. (1), activity = $\left|\frac{dN}{dt}\right| = |\lambda N|$ ----------------------------4

By using Eq. (3) in Eq. (4),

$$\text{activity} = \frac{0.693}{T_{\frac{1}{2}}} N$$

7.6 Solved Problem

1) Calculate the activity of (i) one gramm of radium 226_{88}Ra whose half is 1622 yrs and (ii)3 x 10^{-9} kg of active gold, ${}^{200}_{79}Au$ whose half life is 48 min.

8.0 PHOTOELECTRICITY

In thermonic emission of electrons from metals, the energy needed by an electron to escape from the metal surface is produced by the energy of thermal agitation. Electrons may also acquire enough energy to escape from a metal, even at low temperatures, if the metal is illuminated by light of sufficiently short wavelength. This phenomenon is called PHOTOELECTRIC EFFECT.

It is found that with a given material as emitter, no photoelectrons at all are emitted unless the wavelength of the light is "shorter" than some critical value. The corresponding "minimum" frequency is called "threshold frequency' of the particular surface. The threshold frequency, for most metals is in the "ultraviolet ($\lambda_{critical}$ = 200 to 200nm).

8.1 QUANTUM THEORY OF RADIATION

The fact that a beam of light consisted of small bundles of energy that are now called LIGHT QUANTA or PHOTONS was proposed by Einstein. The energy E of a photon is proportional to its frequency, f i.e.

$$E = hf \text{ --------------------- (1)}$$

where h is known as Planck's constant (h = 6.626 x 10^{-34} J.s).

It is only when the reversed potential, V is made large enough so that the P.E, eV is greater than maximum K.E, $\frac{1}{2}mv_{\max}^2$ with which the electrons leave the cathode, does the electron flow stop completely. This critical reversed potential is called "STOPPING POTENTIAL", denoted by V_0, and it provides a direct measurement of the maximum K.E with which electrons leave the cathode, through the relation.

$$\frac{1}{2}mv_{\max}^2 = eV_o \qquad \text{-------------------------2}$$

While leaving the surface of the metal, the electron loses an amount of energy β known as the work function of the surface. The maximum K.E of the photoelectrons ejected by light of frequency of f is

$$\frac{1}{2}mv_{\max}^2 = hf - \beta \qquad \text{------------------------3}$$

By using eqn (2) in Eqn (3), we have

$$eV_0 = hf - \beta \qquad \text{------------------------4}$$

where e is the electronic charge, V_0 is the stopping potential and β is the work function of the surface.

Based in relatively theory, every particle having energy must also have momentum, even if it has no rest mass. Photon of energy E has a momentum P given by

$$E = Pc \text{ ---------------- } (5)$$

Hence, the wavelength of a photon and its momentum are related by

$$P = \frac{h}{\lambda} \text{ ------------------ } (6)$$

8.2 LINE SPECTRA

The quantum hypothesis also plays an important role in the understanding of atomic spectra. If the light source incident on a prism is an incandescent solid or liquid, the spectrum is CONTINUOUS.

It has been shown that the wavelengths of the emitted line spectra can be obtained from the following equation:

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \text{ -------------------------------1}$$

where λ is the wavelength of the emitted light, R is the Rydberg constant, $R = 1.097 \times 10^7 \ m^{-1}$ and n = 3, 4, 5 etc.

Eq. (1) above can also be expressed in terms of the frequency of light i.e

$$c = f\lambda \text{ ------------------------------2}$$

Using (2) into (1) gives:

$$f = Rc\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \text{ --------------------------------3}$$

It is important to note that under proper conditions of excitation, atomic hydrogen may be made to emit the sequence of lines known as SERIES. For example, hydrogen atom have been shown to emit the following SERIES:

Lyman series

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \text{ where n = 2,3, ...}$$

Balmer series

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right), \text{ where n= 3,4, ...}$$

Paschen series

$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$$, where n= 4, 5 ....

Bracket series

$$\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$$, where n= 5,6 ....

Pfund series

$$\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$$, where n= 6,7 ....