Experimental
Edition

RESOURCE MATERIAL IN PHYSICS
(FOR SOME SELECTED TOPICS AT THE SECONDARY SCHOOL LEVEL)

REGIONAL COLLEGE OF EDUCATION, MYSORE 570 006
(National Council of Educational Research & Training, New Delhi 110 016)

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PREFACE

Department of Physics ofRCE, Mysore has been frequently getting letters from secondary school physics teachers that they find it difficult to teach certain topics, such as constellations, galaxy, satellites, magnetic field of a soloroid, emf, electromagnetic waves, Raman effect, lasers, peizo-electric effects, earthquakes, television, transistors, etc. which are either just mentioned in passing or are very briefly described in their text books. Since it is not possible for us to arrange meetings with all of them, we thought of developing suitable resource materials to meet their requirements. Accordingly, we arranged a workshop in which 19 teachers and 7 teacher educators from the states of Andhra Pradesh, Karnataka, Kerala and Tamil Nadu participated.

We divided the participants into groups and asked them to go through the physics text books of classes VIII, IX and X from the four states. They listed many topics and sub-topics which they thought the classroom teachers are not at ease. Luckily for us, many of the topics listed were found in the Physics Resource Material Vol.I and Vol.II already developed by this department. We, therefore, set about developing resource materials for rest of the topics.

We broadly divided these remaining topics into five groups - solar system, waves, electricity and magnetism, modern physics and electronics. These chapters contain only certain selected topics in physics at the level of classes VIII, IX and X and that too which are not covered inPRM I & II.

In developing these topics we thought of a novel way. We thought of getting the materials developed by the participating teachers under our supervision. We believed that (i) teachers can better explain the difficulties to their colleagues; (ii) teachers will have some training in learning new topics and developing resource materials and (iii) we, in this department can save some time. (But only now we have realized that we were wrong!) The participants worked very hard for 12 days and prepared hundreds of pages of resource materials. Later our project staff improved these write-ups and tried to give some uniformity for the five units.

Next, we arranged one more workshop in which six physics teachers from the University who are familiar with the development of textual material at the school level were involved. Along with our project staff, they worked in groups for ten days and refined the draft.

Finally, our editorial committee went through this refined draft and brought it to the present form. But the fact remains that though many of us have toiled hard in refining and editing the materials, it is developed basically by the practising teachers in the schools.

The chapters in this book are further divided into following five sections.

1. **Introduction:** We have recalled some familiar situations related to this unit and have highlighted the significance of the topics covered in this unit.
2. **Concepts:** Relevant concepts of the topics in the unit are listed. It gives a good idea as to what is it that they are going to learn in this unit. In so doing, we have not made a sharp distinction between concepts and definitions.
3. **Development:** Concepts which we thought are too simple have not been discussed. We have also avoided descriptions that are easily available elsewhere. The description for the remaining concepts are such that the teachers of classes VIII, IX and X find it instructive and useful in their class-room teaching. We have emphasised activity based learning. The activities are linked with the concepts and are such that they are within the reach of an average school and can be readily demonstrated.
4. **Evaluation:** Emphasis is given to objective evaluation. Considering the fact that multiple choice questions are often used these days in evaluation, an attempt has been made to list many of them. Besides we have short answer questions and numericals. We have avoided questions of the type fill in the blanks, derive, write short notes on, etc.
5. **Reference:** Many teachers will be curious to have more details about some of the topics described in this book. For them, we have listed additional books for reference. Care has been taken to list only those books which are within their reach.

Because of the above described procedure followed in developing this book, the topics presented in the units are neither continuous nor complete. Even otherwise, we believe that there is ample scope for improvement. Any constructive suggestion regarding class-room activities, numericals, diagrams and other enrichment materials are most welcome and will be gratefully acknowledged. Your suggestions will go a long way in improving this draft edition. But we hope that you will still agree with us that even in the present form, this book will be found useful by many secondary school physics teachers.

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1. SOLAR SYSTEM

1.1 INTRODUCTION

The SolarSystem consists of the Sun and a large number of smaller objects gravitationally associated with it. It is populated by a single star called the Sun, nine planets and their satellites, a large number of asteroids, comets and dust particles. About 99.9% of the total mass of the Solar System is in the Sun.

1.2 TEACHING POINTS

1. The Sun and all the bodies revolving around it constitute the Solar System.
2. Planets revolve around the Sun in elliptical orbits, with the Sun at one of the foci.
3. There are nine known planets in the Solar System.
4. The nearest planet from the Sun is Mercury and the farthest known planet is Pluto.
5. The Earth is one of the nine planets of the Solar System.
6. Jupiter is the largest planet of the Solar System.
7. The Bodies which revolve round the planets are known as satellites.
8. The Earth has only one natural satellite, the Moon.
9. Jupiter, Saturn and Uranus possess ring systems.
10. Meteors are small fragments of matter. When entering the earth's atmosphere, they burn up and become shooting stars.
11. Meteorites are fragments of meteors which reach the Earth.
12. The asteroids, which are also called minor planets, form countless minor members of the Solar System.

1.3 DEVELOPMENT

THE SUN

The Sun is a star. Most of the elements found on Earth are also found in the atmosphere of the Sun. Because of its higher temperature the constituent elements in the Sun are in the gaseous state. The thermo-nuclear conversion of hydrogen into helium is the source of the energy which is continuously radiated by the Sun.

Physical Properties of the Sun:

Mass = 1.99×10^{33} kg

Radius = 6.09×10^{5} km

Surface Temperature = 6000 K

Interior Temperature = 12×10^{6} K

Energy output = 4×10^{26} joule/sec.

THE PLANETS

The word planet comes from a Greek word which means wanderers, and refers to the way the planets seem to drift in the background of fixed stars. They give off no light of their own but shine because of the reflected sunlight.

Of the nine planets, the five which can be seen by naked eye namely, Mercury, Venus, Mars, Jupiter, and Saturn were known to the ancients too. Uranus, Neptune, Pluto were discovered since the invention of the telescope.

As far as their internal structure is concerned, the planets fall naturally into two groups. Mercury, Venus, Earth, Mars and Pluto are known as the terrestrial planets. These are relatively small and dense and are believed to be composed mostly of rocky and metallic material. The term terrestrial is used for these planets because they resemble the Earth in size and density.

Jupiter, Saturn, Uranus and Neptune form a group distinct from the terrestrial planets and are called the Jovian planets or gas giants. The Jovian planets are relatively large, gaseous and of low mean density. The planets of this group mainly contain hydrogen and helium.

All the planets revolve around the sun in the same direction and excepting Pluto all of them move nearly in the same plane.

The Indian names for some of the planets are

Mercury	Budha
Venus	Shukra
Earth	Prithvi
Mars	Mangal
Jupiter	Brihaspati
Saturn	Shani

The distances in the SolarSystem are measured in Astronomical units. An Astronomical unit is the semi-major axis of the Earth's orbit around the Sun and is equal to 149,600,000 km. The mean distance of the planets from the Sun ranges from 0.39 AU for Mercury to 39.96 AU for Pluto. The periods of orbital revolution of the planets range from 88 daysfor the nearest planet to the Sun to 248 years for the farthest known planet.

All the planets except Mercury and Venus have natural satellites called moons. Details are given in Table 1.1 at the end.

When we observe a planet, it is generally seen to move from west to east. However, at times, the direction of motion is reversed, i.e. from east to west. This is known as 'Retrograde Motion' of the planet. For example, studying the movement of Mars for a few months, one can notice that its motion changes in direction, i.e., it moves eastward relative to stars for most of the time but at times its motion reverses briefly westward. It must be remembered that our earth completes one revolution in 365 days whereas the Mars completes in 687 days. Because of this, the line joining to earth and Mars makes different inclinations with reference to fixed stars. This causes the retrograde motion of Mars.

A brief description of the planets is given below:

1. Mercury

It is the nearest planet to the Sun and probably also the smallest of all known planets. It completes one revolution around the sun in 88 days. Although it is a bright object in the sky, it is rather elusive. This is because of its position in its orbit relative to the Earth and the Sun. It can be seen either after sunset in the western horizon as an evening star, or before sunrise in the eastern horizon as a morning star. Its period of rotation is about 59 days. The sunlit side of Mercury has a temperature of about 450 K. Mercury shows phases like the Moon.

2. Venus

Venus is very much like the Earth in mass and size. Like Mercury, Venus is inside Earth's orbit: consequently it appears to swing back and forth in the sky. It is visible either as a morning star or as an evening star. It is the brightest object in the sky after the Sun and the Moon and can even cast a shadow. Venus too goes through phases like the Moon. It completes one revolution around the Sun in 225 days. The surface of Venus is not visible because it is shrouded by dense clouds. The temperature of its surface is about 700 K. The atmosphere of Venus contains about 90 to 95 per cent carbon dioxide.

3. Earth

Earth is the third planet from the Sun. It is the only planet in the solar system where life exists. It rotates about its axis once in 24 hours and completes its revolution around the Sun in about 365 days.

The earth's axis of rotation makes 23½° with the normal to the plane of the sun's apparent path. This apparent path of the sun round the earth is called the Ecliptic. Because of this angle of 23½° between the plane of earth's equator and the plane of the ecliptic, the sun's rays strike the earth's surface more obliquely during part of its motion causing winter. Similarly, the sun's rays strike more normally during another part of the motion and we get summer. Looking from the northern hemisphere on December 21, the sun reaches its southern most point and one gets the shortest day of winter. Similarly on June 21, the sun swings to its maximum to the north and we get the longest day of summer. When the sun is near the equator in March and September, we get spring and autumn. Thus the seasons are caused due to the inclination of the axis of earth's rotation to the ecliptic plane.

The atmosphere of Earth contains mainly oxygen and nitrogen. The surface temperature of the earth varies from its poles to the equator. At the equator, the temperature can be as high as 333 K. At the poles it can be as low as 188 K. It has one natural satellite called the Moon. Earth's average density is about 5.5 times that of water.

4. Mars

Mars is the first of the planets with its orbit lying outside that of the earth. Hence it is called a Superior Planet. Planets whose orbit lies inside the orbit of the Earth are called Inferior Planets. Mars is the most favourably situated planet for observation from the Earth. Its precise observations by Tyco Brahe and the empirical analysis by Kepler provided Newton the basis to formulate his theory of gravitation.

Its mean distance from the Sun is about 228 x 10^6 km. It goes round the sun once in 687 days. Its diameter is 6830 km. It is only about 1/10th as massive as the earth, which gives it a mean density of approximately four times that of water and a surface gravity of 38 per cent that of the earth.

It appears yellowish orange in colour. Often white areas can be seen at its poles and these are called polar caps.

The equator of Mars is inclined to its orbital plane by about 25°. Thus each of Mars' poles is alternately tipped toward and away from the Sun, and the planet goes through seasons, much like those on earth. The white polar caps consist mainly of frozen carbon dioxide.

The maximum equatorial temperatures are slightly over 300 K. and the night temperature drops to nearly 200 K.

Carbon dioxide makes up about 90 per cent of the gaseous content of the martian atmosphere. Oxygen is absent exc ept in traces. There is evidence of a very low concentration of water vapour on Mars.

Much of Mars is covered with craters, some of which are as large as hundreds of kilometers across. Most of the martian craters have been made by meteoritic impacts. However, there is evidenc e of volcanic craters supported by lava-like slopes.

Of all other planets, Mars is the one planet that has always been the best candidate for supporting some form of life. Observations of the surface of the planet by the Mars-probes have found no evidence of life of the type known on Earth.

5. Jupiter

Jupiter is the largest and the most massive planet in the solar system. Its equatorial diameter is 142,400 km, which is more than eleven times that of the earth. However, its mass is only 318 times that of the earth. The mean density of the planet is only 1.33 times the density of water.

Jupiter has sixteen known satellites. Its four largest moons were first discovered by Galileo and are called the Galilean satellites. Two of these moons are about 4,800 km across. The other two are of the same size as of the earth's moon. These satellites can be easily seen with binoculars.

The colour of the planet ranges from white to dark yellow. One of the most striking surface features of Jupiter is the Great Red Spot. It is as large as 50,000km across. Distinct details in the cloud patterns on Jupiter allow us to determine its rotational rate. It rotates in 9 h 50 m and is the most rapidly spinning planet in the solar system. Jupiter's rapid rotation has caused it to become noticeably oblate. Jupiter's equator is inclined at only 3° to its orbital plane, so the planet has no appreciable seasons.

The ratio of hydrogen to carbon in Jupiter's atmosphere is of the order of 10^3.

6. Saturn

Saturn is the second largest planet of the solar system. Its rings make it one of the most impressive objects that can be seen with a telescope. In addition to its ring system, Saturn has 17 known satellites. The largest one,Titan is the only satellite in the solar system that is known to possess an atmosphere.

Saturn is a gaseous planet like Jupiter. There are three concentric rings in its equatorial plane of which three are quite prominent. The brightest and the broadest is the central ring. The outer ring has an outside diameter of 260,000 km. The faintest is the inner ring whose inside diameter is about 140,000 kms. The rings are not solid sheets. Background stars can be seen shining through them. The equatorial plane is inclined about 28° to its orbital plane. Therefore, we can see not only the globe of the planet at varying degrees of the tilt but also the ring system as well. The thickness of the rings is too small to be measured. The rings are composed of innumerable number of minute solid particles. The reflection of sunlight from these tiny specs gives the illusion of solid rings.

The only gases detected spectroscopically in Saturn are hydrogen and methane. Saturn's atmosphere is estimated to be atleast 90% hydrogen. Its temperature is of the order of 75 K. The structure of Saturn's atmosphere is similar to that of Jupiter.

7. Uranus

Uranus is a gaseous planet beyond Saturn. Although it can be seen by the unaided eye on a dark clear night, it had remained unnoticed till its discovery using a telescope because of its faint appearance. Recent Voyager II mission has revealed that it has rings like that of Saturn and has additional satellites other than the five known satellites which had been discovered telescopically from the earth.

Due to its large orbital distance, its period of revolution around the sun is 84 years. The interior diameter of its ring system is probably about 75,000 km.

Uranus has a greenish appearance when seen through the telescope. The green colour is probably due to its atmospheric methane.

A unique feature about Uranus is that its axis of rotation lies almost in the plane of its orbit. During some part of its orbit, it is so oriented that one or the other of its poles is in the line of sight.

The atmosphere of the planet is composed mainly of hydrogen, helium and methane. Its temperature is expected to be about 90 K. Uranus is the first planet in which hydrogen was identified spectroscopically.

8. Neptune

Neptune has an important place in the history of science because its existence was theoretically predicted by comparing the calculated orbit of Uranus with the observations of its motion. The discrepancy between the observed and calculated positions of Uranus could be accounted for by assuming the existence of an eighth planet. The discovery of this planet is a triumph of the Newtonian theory of gravitation.

It is also a gaseous planet like Jupiter, Saturn and Uranus. Its equatorial plane is inclined about 29° to that of its orbital plane.

Neptune appears through a telescope as a small greenish disc.Both methane and hydrogen have been detected in Neptune spectroscopically.

Neptune has six satellites. One of the satellites has a most eccentric orbit of any satellite in the solar system. The space craft Voyager II which had passed Uranus in January 1986 came closest to Neptune in 1989 and discovered the sixth satellite.

9. Pluto

Pluto's discovery was also based on alleged residuals in the positions of Uranus after accounting for perturbation on its orbit by Neptune and the other known planets. Pluto is several thousand times too faint to be seen with the unaided eye. Spectroscopically Pluto is unlike the Jovian planets and is more like the terrestrial planets. There is still a possibility of the existence of undiscovered planets. The issue whether there are planets beyond Pluto can be convincingly answered by space mission such as Voyager II.

The solar system contains smaller objects other than planets, called asteroids or minor planets, comets and meteors.

The Asteroids or Minor Planets:

The asteroids, also called the minor planets, are planet-like objects which have been observed through the telescope between the orbital space bounded by Mars and Jupiter. These objects whose size is of the order of a few kilometers or less are too small to be seen by unaided eye. There may be between 50000 and 100,000 asteroids in the asteroid belt. Among them more than 2,000 asteroids have been listed. The Ceres, the biggest asteroid has a diameter of 768 km. The mass of Ceres is probably about 1/8000 that of the earth. The velocity of escape from Ceres is expected to be about 0.5 km/s. Therefore, it is not expected to have any atmosphere. Of all the known asteroids Icarus has the smallest orbit with a semi-major axis equal to 1.0777 AU. It is the only known object in the solar system other than comets and metorites that passes within the orbit of Mercury. It is probable that the minor planets were formed from the principal planets. The combined mass of all minor planets is not known but is expected to be of 1/20 that of the Moon.

The Comets:

The comets derive their name froma Latin word which means long-haired. The comets appear as small hazy patches of light, often accompanied by long tails. Most of the comets are visible only through a telescope, but occasionally some spectacular comets that can reach the naked-eye-visibility even in day light, are also seen.

Unlike the planets most of the comets appear at unpredictable times. The orbits of the comets are highly eccentric ellipse. If the eccentricity of the orbit is greater than 0.99 the orbit may be indistinguishable from a parabola. Therefore, the comets have closed orbits and are members of the solar system. The comets have long periods. The period of Halley's comet is 76 years. Halley's comet has been observed and recorded on its every passage near the Sun since 240 B.C. In the twentieth century, it has appeared in 1910 and 1986.

The comets are visible only at their perihelion i.e., at the closest distance to the Sun. Comets are seldom observed when they are farther away from the Sun than the planets Jupiter or Saturn. When a comet is within 3 AU of the Sun, volatile materials inside the comet begin to vapourize. The vapours give their characteristic light which is superimposed on the reflected light from the dust particles surrounding the nucleus. The nucleus of the comets are about a few kilometers across.

Many comets develop tail as they approach the sun. The tails point away from the sun. The tails are caused by the combined effect of the radiation pressure pushing the dust particles and the repulsive force due to the solar wind. The solar wind consists of charged atomic nuclei ejected from the Sun into space. The solar wind pushes the ions in the comet and forms tails sometimes as long as 100 million kilometres.

The nucleus of the comets is generally composed of balls of rocky and metallic material coated with frozen ice, ammonia, methane and carbon dioxide. These chemicals are vapourized by the heat of the Sun, as comets approach the Sun. As comets move out towards their return journey to the fringe of the solar system, the gases condense and freeze once again around their nucleus. The tail disappears and comets shrink till they are back in the proximity of the sun after one orbital period.

Meteroid, Meteorite and Meteor:

Meteors are small solid particles in the solar system which are seen only when they enter the earth's atmosphere from inter-planetary space. Since these particles move with a speed of a few kilometers per second they get vapourized due to the intense heat generated by the frictional deceleration due to the air. They appear from earth as shooting stars.

These particles before they enter into the earth's atmosphere are called meteoroids. when they become luminous due to burning they are called meteors, and when they survive and reach the ground they are called meteorites.

The mass of a typical meteoroid producing the phenomenon of shooting star is about 0.25 g. Most meteoroids are believed to be the debris of disintegrated comets or minor planets.

Occasionally, spectacular meteorite falls have taken place. The Meteor Crator in Arizona, U.S.A. belong to this category. Meteorites resemble terrestrial rocks and sometimes have been found to contain 85 to 95 per cent iron. The largest meteorite ever found on the earth is Hoba West and its mass is more than 50 tonnes.

Table 1.1

SOLAR SYSTEM - IMPORTANT DATA

Sl. No.	Name	Distance from the Sun (1.6×10^6 km)	Revolution Period (Earth Year)	Rotation Period (Hours or days)	Mass (Earth's Mass=1)	Diameter (kms)	Density (water=1)	Effective Temperature (K)	Number of satellites(*)
1.	Mercury	36	0.24	59 d	0.05	4,800	5.4	450	0
2.	Venus	67	0.62	243 d	0.82	12,160	5.1	283	0
3.	Earth	93	1.00	23h 56m 4.13	1.00	12,690	5.52	240	1
4.	Mars	142	1.88	24h 27m 22.65	0.12	6,830	3.97	220	2
5.	Jupiter	483	11.86	9h 50m	317.80	142,400	1.33	100	16
6.	Saturn	886	29.46	10h 14m	95.2	120,000	0.68	75	17
7.	Uranus	1780	84.01	10h 49m	14.5	52,800	1.68	50	15
8.	Neptune	2790	164.97	15h	17.2	49,600	1.51	40	6
9.	Pluto	3670	248.4	6.39 d	0.1	6,400	4	40	1
	Sun			25-30 days	333,000	1,384,00	1.4		9 planets
	Moon			27 1/3 days	0.01	3,460	3.4		

m = Minutes; h = Hours; d = Days

(*) As on 1989.

Some activities are suggested below for making the teaching of the unit on solar system interesting.

Activity 1.1: To find the distance of the Sun from the Earth.

Materials Needed: A card-board and a screen.

Procedure: Take a card board and make a pin hole. Keep it in line with sun's rays. Place a screen on the other side of the cardboard. Prevent any stray light. Catch the image of the Sun on it. Measure the diameter of the image. Measure the distances of the screen from the pin hole. Study the diagram, fig.1.1 shown below.

AB = diameter of the sun
MNOP = Cardboard
C = Pin hole in the cardboard
DE = diameter of the image of the sun
QRST = screen
Triangle ABC, DCE are similar,
Therefore, AB/DE = BC/CD

$$BC = \frac{AB}{DE} \times CD.$$

Measure the diameter of the image DE.
Measure the distance from the cardboard to the screen (it is approximately equal to CD).
Diameter of the sun = AB.
Distance from the sun = BC.
Assume the diameter of the sun as $2 \times 6.95 \times 10^8$ m and calculate

$$BC = \frac{AB}{DE} \times CD,$$

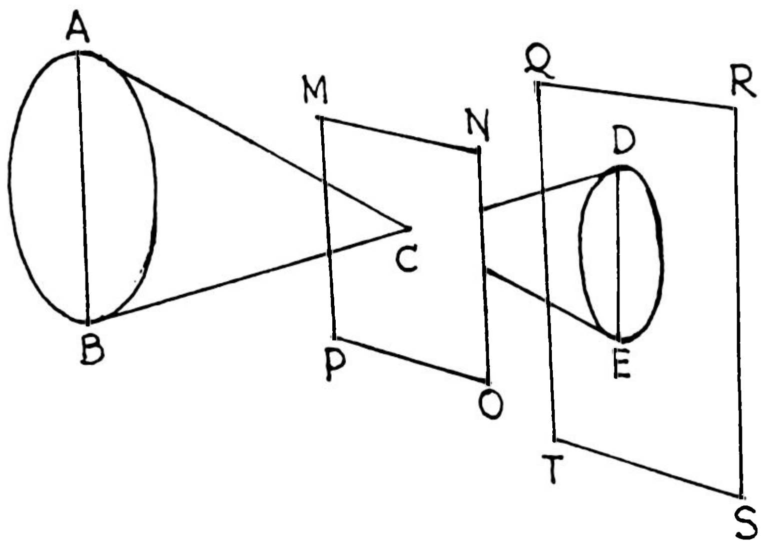

Fig 1.1 To find the distance of theSun from the Earth

Compare the result so obtained with the standard value of the distance of the Sun from the earth = 1.49×10^{11} m.

Activity 1.2: To find the diameter of the Moon.

Materials Needed: A meter stick, drawing pins, coins, craft paper.

Procedure: Make a pin hole in the craft paper. Paste the paper at one end of the meter stick with a drawing pin. When the moon is near the full moon phase view it with the meter stick device. Placea circular coin in between the cardboard and the moon and move it backwards and forward. Look at the moon along the stick through the pin hole until the circular coin covers completely the view of the Moon. Read the distance from the pin hole to the coin fig 1.2. Make several measurements and take the average.

The diameter of the coin and the distance of the coin to the pin hole can be easily measured. Assuming the distance of the moon from earth to be 3.844×10^8m, even the diameter of the moon can be estimated by the triangulation relations.
BC= distance of the moon; bc = distance of the coin from pin hole;
AB = diameter of the moon: ab = diameter of the coin. BC: bc = AB : ab
The same experiment can be repeated with the coins of different diameters.

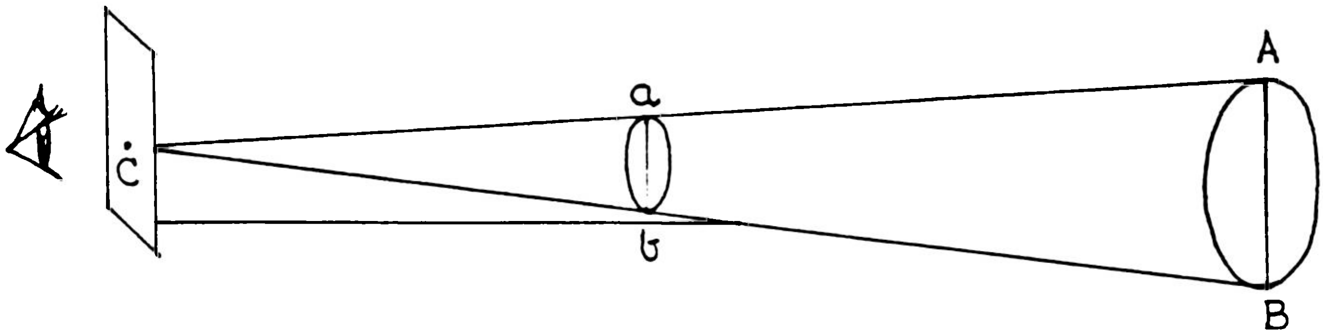

Fig 1.2 To find the diameter of the Moon

Activity 1.3: To identify the elements found in the Sun with the help of an improvised spectroscope.

A cylindrical cardboard tube of about 3 to 4 cm in diameter and about 30 cm in length.

Materials Needed: A replica of diffraction grating, razor blades.

Procedure: Tape the grating over the round hole, at one end of the tube. Protect the grating by covering it with a clear plastic or a piece of glass. At the other end of the tube, tape the razor blades as closely as possible to form a narrow slit such that the slit is exactly parallel to the fine lines of the grating. Now this functions as a grating spectroscope.

Looking at the Sun through the spectroscope one observes a continuous spectrum ranging from blue to red and superposed with dark lines. These dark lines are called Fraurhofers lines and they correspond to the different elements present in the Sun. Now it is known that Sodium absorbs yellow light and calcium absorbs red light. In the above spectrum, if a dark line is seen instead of an yellow line, one canconclude that sodium is present in the Sun.

1.4 EVALUATION

1. Which of the following is the nearest planet to the Sun?

   a) The Pluto b The Venus c) The Mercury d) The Earth

2. Which of the following is the biggest planet?

   a) The Uranus b) The Jupiter c) The Saturn d) The Neptune

3. Which of the following is the brightest planet?

   a) The Mars b) The Venus c) The Mercury d) The Jupiter

4. Which of the planets has more satellites?

   a) The Saturn b) The Jupiter c) The Mercury d) The Neptune

5. Which of the celestial bodies is usually called as "Shooting Star"?

   a) Asteroids b) Meteors c) The Comets d) Satellites

6. The constituent elements in the Sun ~~cannot~~ do not exist in solid or liquid Stat . Why?

7. The Sun is said to be a perenniel source of energy. Explain.

8. How can an observer on earth differentiate a planet from a star?

9. What do you mean by "retrograde motion" of the planets?

10. Can planet Venus be called MorningStar and also Evening Star during the same period? Substantiate your answer.

11. Why Jupiter is noticeably oblate?

12. What is the unique feature of the planet Saturn?

13. What are the special common features of the planets Jupiter, Saturn and the Uranus?

14. The discovery of Neptune was a triumph of the Newtonian theory of gravitation. How?

15. How was Pluto discovered?

16. Ceres is quite a big asteroid. But even then it cannot possess any atmosphere. Why?

17. How do comets develop tails?

18. When does the tail of a comet disappear?

19. What are the shooting stars? Why are they called so?

20. What is the differerence between a meteoroid, a meteor and a meteorite?

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II. WAVES

A. Mechanical Waves:

2.2A TEACHING POINTS.

1. The rate of change of displacement of a particle during its oscillatory motion is particle velocity.

2. There is an apparent change in the pitch due to relative motion between the source and the observer.

3. Ultrasonic waves are sound waves of frequencies greater than the audible range.

4. Infrasonics are the sound waves of frequencies less than the audible range.

5. Supersonic refers to speed of an object moving with speed greater than that of sound in air.

6. Acoustics of buildings refer to the design of buildings to maintain sufficient loudness and clarity of sound.

7. In tape recording, sound waves are recorded as variation of magnetisation.

8. Earthquake is caused by disturbances in the earth's crust.

2.3 A DEVELOPMENT

Whenever a mechanical wave passes through a medium, the particles in the medium do not move forward along with the wave but oscillate about their mean positions. The motion of these particles is simple harmonic, either transverse or longitudinal. The oscillating disturbances which constitute a wave transmit energy. In a wave motion, there is a definite relationship between the phases of the successive particles of the medium. In this, we generally come across two velocities.

a) The particle velocity which is the velocity of the simple harmonic oscillator about its equilibrium position,

b) The wave or phase velocity that is the velocity with which the planes of equal phase, progress through the medium.

Activity 2.1:

Take a slinky with a coloured thread tied at the mid point. Stretch it on a table (or combination of tables) such that it can be stretched to about 5 meters. Keeping one end fixed move the other end sideways rapidly so that a transverse wave is produced. Note how the coloured thread moves. Compare its speed with the movement of the hand which produces the wave pattern. These two speeds will be the same and such velocities of the particles of the medium when a wave progresses is called the particle velocity. Note the speed of the wave as it moves towards the fixed end, though the coloured thread does not have to move forward. This velocity is the wave velocity and is also called phase velocity. It depends on the properties of the medium.

Produce longitudinal wave pattern on the same slinky by suddenly stretching the hand outwards and inwards. Note how the coloured ribbon moves.

Doppler Effect:

It is a matter of common experience that the pitch of the whistle blown from an approaching train heard by a stationary listener appears higher than the pitch when the train is at rest. Also the pitch appears lower when the train is receeding away from the listener. The pitch suddenly drops when the train rushes past the observer. Whenever there is a comparable relative motion between the listener and the source one can detect such a change in the pitch of the sound.

Activity 2.2:

Doppler in 1842, explained this apparent change in pitch and hence it is known as Doppler Effect. The Doppler Effect can be observed with an approaching or receding locomotive with its whistle blowing or a scooter with its horn on. The change in the pitch can be easily calculated as described below:

Case 1 : Source in motion and listener at rest:

Consider a source of sound 'S' which is in motion, fig 2.1 'L' is the stationary listener. When 'S' approaches 'L' with high speed the pitch of the note appears to rise. It can be explained as follows: Let the frequency of the sound emitted be n and the wavelength be λ . Then the velocity of sound $V = n\lambda$ T is the period or the time required to travel a distance $T = 1/n$.

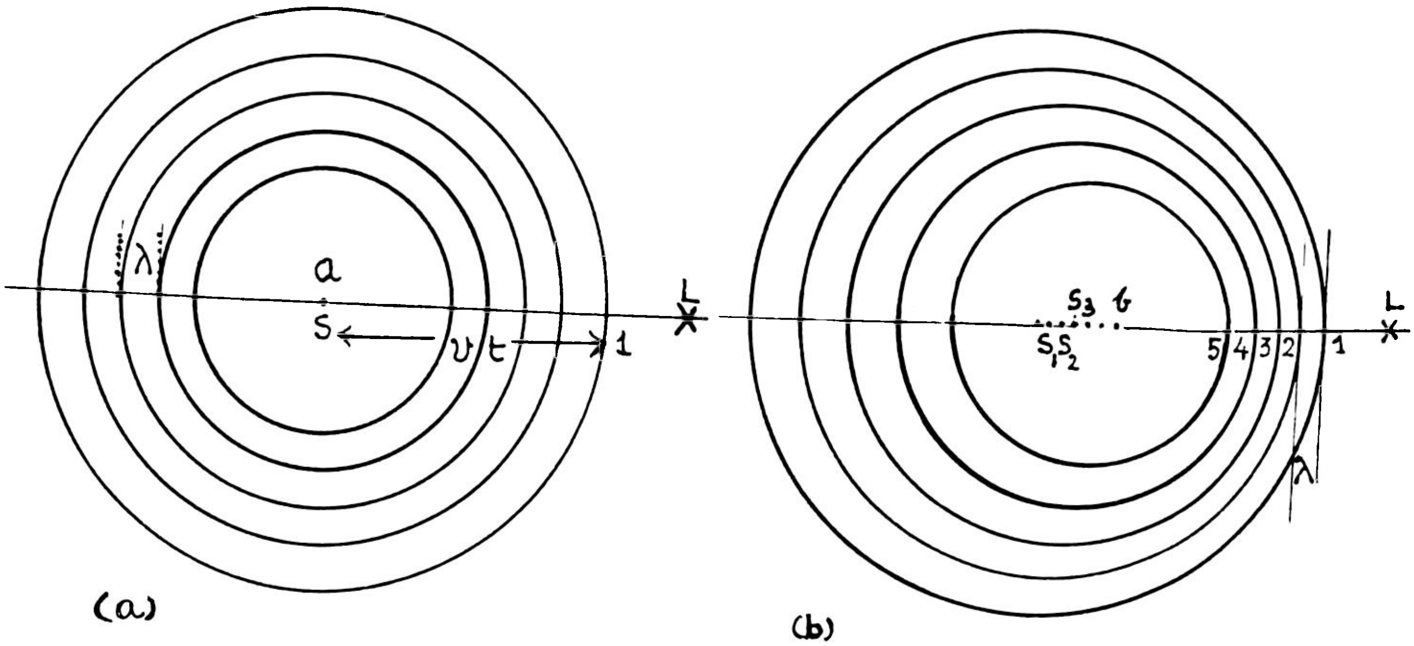

Fig 2.1 Doppler Shift-Source moving towards the stationary listener

If the source is stationary the wavefronts would have travelled in all directions with a uniform velocity of v units. It is shown in the fig 2.1(a).

Since the source is in motion with a velocity v_s, it will cover a distance 'ab' equal to v_s t. In the fig 2.1(b) the various positions of the source S and the positions of the wavefronts are shown. The disturbance from the source S_1 i.e., from position 'a' will reach the position 1 during the time interval. t..
In the same time, interval the source will occupy a position 'b' and new wave fronts will commence from this point. Fig 2.1(b) also shows the position of the wavefront 2 for the source position S_2 and similarly, position of the wavefront 3 for S_3 etc. Because of this motion of the source one can observe from the fig 2.1(b) that wavefronts are crowded towards the listener. The effective distance traversed by the wavefronts during t will be $(vt - v_s t)$ and the number of wavefronts seen during this time interval will be nt. This gives rise to a new wavelength.

$$\lambda' = \frac{v - v_s}{n} \qquad \text{showing that} \qquad \lambda' < \lambda$$

The new frequency as observed due to the motion of the source will be

$$n' = \frac{vn}{(v - v_s)}$$

Obviously $n' > n$.

Refer to fig 2.1(b) and try to find out the change in the wavelength if the source is moving away from the listener i.e. the position of L is towards the left of the source.

Will the frequency decrease or increase in this case? Find an expression for the new frequency n".

Ultrasonics:

A normal human ear can hear sounds produced by objects vibrating at frequencies from 20 to 20,000 Hz. This range of frequencies is called the audible range. Bodies vibrating with frequencies greater than 20,000 Hz will also produce waves in air but human ear is not sensitive to such frequencies. Sound waves having frequencies beyond the upper limit of audible range constitute the ultrasonic sound and these frequencies are called ultrasonic frequencies or simply ultrasonics.

Dogs can hear ultrasonics upto 50.000 Hz. Bats produce ultrasonic pulses of frequencies ranging from 30,000 Hz to 50,000 Hz. These pulses are echoed by obstacles in their path. The bats can detect the echoes and locate the object. This is the principle of SONAR (Sound Navigation and Ranging) which will be discussed later.

Piezo-electric quartz oscillator method:

Piezo-electric effect : It was discovered in 1880 that when a particular pair of opposite faces of crystals, like quartz, tourmaline are subjected to compression, a potential difference is developed between the pair of opposite faces. Fig 2.2 shows a properly cut crystal. When the crystal is compressed mechanically by pressure or tension, opposite electric charges appear at the end of the axis or on the surface at right angles to it. (fig 2.2b). A quartz plate is cut with the directions of the axes X,Y & Z showing the following effects:

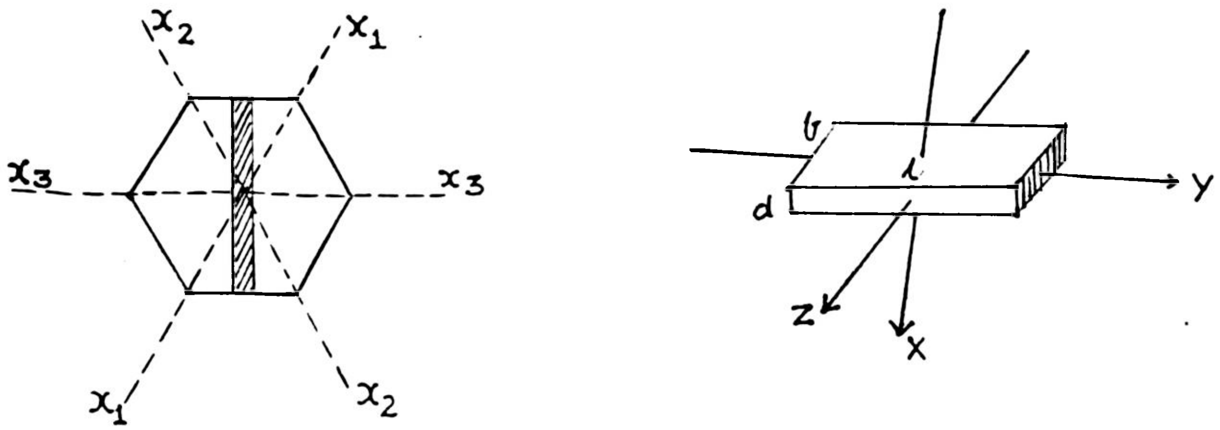

Fig 2.2 Pressure in the direction of X-axis charges the two surfaces bl normal to the X-axis.

i) Pressure in the direction of theX axis charges the two surfaces bl, normal to the X axis, positively or negatively giving longitudinal direct piezo-electric effect.

ii) Tension in the direction of the Y axis charges the surfaces bl in the same way positively or negatively giving transverse direct piezo-electric effect.

Conversely, if potential difference across opposite faces is applied, compression or extension occurs on opposite faces.

Thus, if an alternating p.d. is applied between a pair of opposite faces of a quartz crystal, the alternate increases or decreases in length between another pair of opposite faces causes in air mechanical vibrations of the same frequency as the alternating electric field. If the frequency of the applied alternating p.d. is equal to or nearly equal to the natural frequency of the crystal, resonance occurs and ultrasonic vibrations of large amplitude are set up in the crystal. The frequency of the ultrasonics produced by a quartz crystal depends entirely on its thickness.

Activity 2.3:

Stand in front of a distant wall. Produce loud sound. If the distance is more than about sixty feet an echo can be heard. If the time taken by the sound waves to go to the reflector and come back to the source is known, the distance between the source and the wall can be calculated, knowing the velocity of sound in air.

Uses of Ultrasonic Waves:

SONAR (SOUND NAVIGATION AND RANGING)

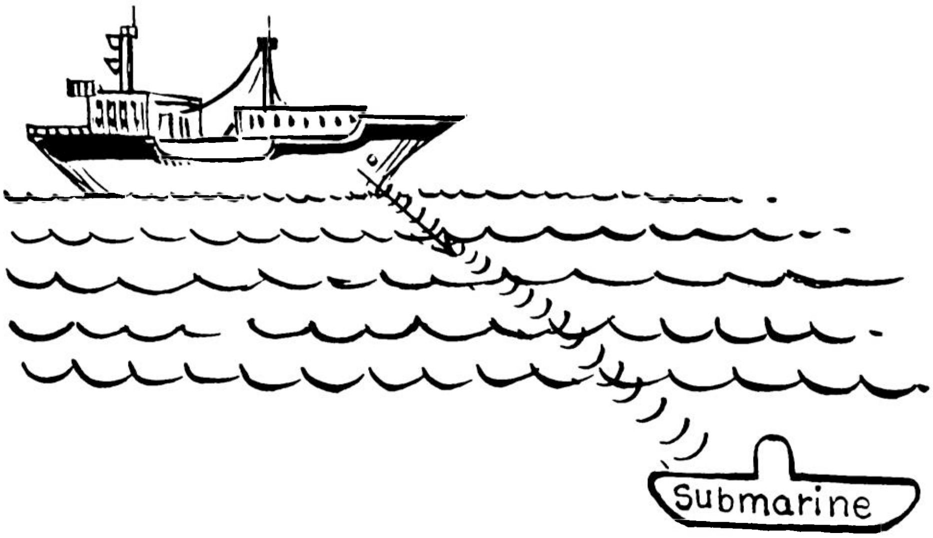

Fig 2.3 Ultrasonic Ranging

1. When an ultrasonic pulse impinges on an object, the pulse is reflected back and the reflected pulse can be detected. By determining the time elapsed between the emission and reception of the ultrasonic pulse, the distance and hence the location of the object can be found. This is the principle of SONAR, (Fig 2.3). By this technique, the depth of the sea can be determined, the presence of submarines, shoals of fish, sunken obstacles like iceberg can be detected.

2. A glass rod oscillating with ultrasonic frequency can bore a hole through steel, or even through diamond. It produces a hole by its to and fro motion through a distance of the order of 10^{-5} cm with each stroke.

3. Ultrasonics are used for removing grease and metallic dust in the manufacture of delicate instruments. Clothes having dust particles which cannot be generally cleaned by detergent can be cleansed by ultrasonic waves by shaking off the dust particles. It is used to clean watches, hypodermic needles, etc. It is also used to detect internal flaws or cracks in materials.

4. Ultrasonic waves are able to produce emulsion of two imissible liquids, so it is used to manufacture paints. Ultrasonic waves break up the molecular chain of high polymers and accelerate the reactions.

5. Ultrasonic waves are preferred in under-water communication because electromagnetic waves are heavily damped in water. The speech wave is superimposed over ultrasonic wave which acts asa carrier wave. The modulated wave is transmitted through an electrostriction oscillator. The transmitter itself can be used as a receiver.

6. Ultrasonic waves are used to cure rheumatic pain as it produces a smoothing massage action in the affected area. When a fine beam of ultrasonic wave is directed towards the diseased tissue inside the body, the tissue is destroyed without loss of blood. Strong beams of ultrasonic waves kill bacteria, destroy corpuscles and protozoa. It is used in sterilization and in the preparation of vaccines.

7. Ultrasonic waves are used along with electric current in soldering of metals like aluminium. It removes the oxide-film coating present and helps soldering.

Infrosonics:

Infrasonics are the sound waves of frequency less than 20 Hz. When we shake our hands swiftly, why do we not hear sound? It is not producing compressions and rarefication in the air?

It does produce vibrations but the human ear is not able to hear them, as the frequency of such vibrations is very low to affect our nerves. Most human beings cannot hear sound frequencies below 20 Hz which is the lower limit of audibility.

The waves of frequency lower than our audible limit are called infrasonics. It is said that elephants communicate by infrasonic waves.

Supersonics:

Bullets move faster than sound. Some of the jet planes move faster than sound. They are said to have supersonic speeds. On the supersonic scale, the speed of an object is expressed in Mach number.A speed of 2 mach numbers = 2 x velocity of sound in air (about 2,500 km/hr).

Shock Waves:

When the source producing the sound waves moves faster than the speed of the sound i.e. $v_s > v$, the wavefront takes the shape of a cone with the moving body as its apex. This causes 'shock waves'. Supersonic jet planes fly faster than the speed of sound causing shock waves in its vicinity. Depending on the Mach number and the distance from buildings these supersonic jets cause damages to the buildings.

Acoustics of Buildings:

In big auditoria such as theatres, concert halls, etc. it is necessary that sound produced by the source should be heard with sufficient loudness and clarity. The intensity of sound varies inversely as the square of the distance and in a room, it is also influenced by the reflections and absorption by the surrounding walls and the materials in the room. If there is no proper absorption of sound, the echoes from the walls will interfere with the successive syllables rendering the speech, etc. not clear to the listener. Therefore, while constructing an auditorium one has to pay greater attention to the acoustic conditions of the hall.

The sound emitted by the source will reach a point not only directly but also after successive reflections (echoes) from the walls. Since the velocity of sound is low, sufficient time will elapse between the arrival of the first echo and the last one. This will decrease the clarity. We generally say that reverberation should be reduced to increase clarity. This means that the intensity of the echo should be reduced considerably.

The following conditions are necessary for obtaining good acoustic effects:

1. Each separate syllable should have sufficient energy throughout the hall, i.e. sound should be sufficiently loud everywhere.
2. Sound of each syllable should soon die out to enable the succeeding syllable to be heard distinctly. In other words, the auditorium must be free from reverberation.
3. There should be no undesirable focussing of sound anywhere in the hall.
4. Unpleasant reinforcement of some overtones of a complex sound should not be there.

As reverberation is due to repeated reflections of sound waves, the remedy lies in increased absorption of sound which may be brought about by having

1. open windows
2. maps or pictures hanging from walls
3. heavy curtains
4. adequate audience
5. no curved walls or corners bounded by two walls, so as to avoid concentration of sound at one place.
6. Walls and ceiling covered with absorbent materials such as perforated cardboards, felt, coarse cloth, etc. or walls engraved and roughened with decorative materials.
7. Upholstered seats

Activity 2.4

In a lecture hall, if large reflectinq surfaces like tin sheets are placed and someone gives a lecture lot of echoesare heard. If mud pots with mouths downwards or if heavy curtains are hung on the points where the reflection takes place, a decrease in echo is noticed. This shows the importance of placing absorbing materials in the auditorium.

Tape-Recordcer:

The representation of the wave-form by variation of magnetisation in a magnetic tape is the fundamental principle of tape-recording. Earlier thin steel tape was used for recording. But now it is being replaced by plastic tape of 0.05 cm thick, impregnated with a magnetic oxide of iron.

The tape is drawn from one reel to another at a constant speed of about 3 metres per minute. Three heads of electro-magnets having chisel shaped poles are present in a tape-recorder. The first one is known as the "washing or erasing head". Here the tape is subjected to a strong high frequency magnetic field which wipes out any residual field in the tape and thereafter becomes suitable for fresh recording.

The second electromagnet is known as the "recording head". The amplified current from the microphone is superimposed upon a high frequency current, which is allowed to pass through the coil of the electromagnet. The tape, while passing over the chisel-ended poles of this magnet with uniform speed is magnetised by the microphone current.

For reproduction of the sound, the magnetised tape is passed through between two chisel-shaped poles of the third electromagnet. The flux variation in the tape includes corresponding current variation in the coil of the electromagnet. This current is amplified and it is fed to a loudspeaker which reproduces the original sound.

Earthquake:

The surface of the earth is covered by a thin layer of soil. Below this layer is a region of hard substance called the crust. Rock layers of crust can move and thereby shift a part of the crust to a new position. The shift is normally slow and takes hundreds of years. But sometimes, the crust shifts suddenly and when this happens, there is an earthquake.

Whenever there is an earthquake. seismic waves are produced. These waves travel through the earth in all directions. If the intensity of this wave is large, destruction is caused.

Detection of earthquakes:

Seismograph is the instrument used to record the seismic waves produced during an earthquake, this instrument is very sensitive and can even record minute disturbances. When the waves caused by an earthquake reach a seismograph, a record is make in the form of a large disturbance, on a moving roll of paper. This record is then interpreted. Its working can be illustrated from the following activity.

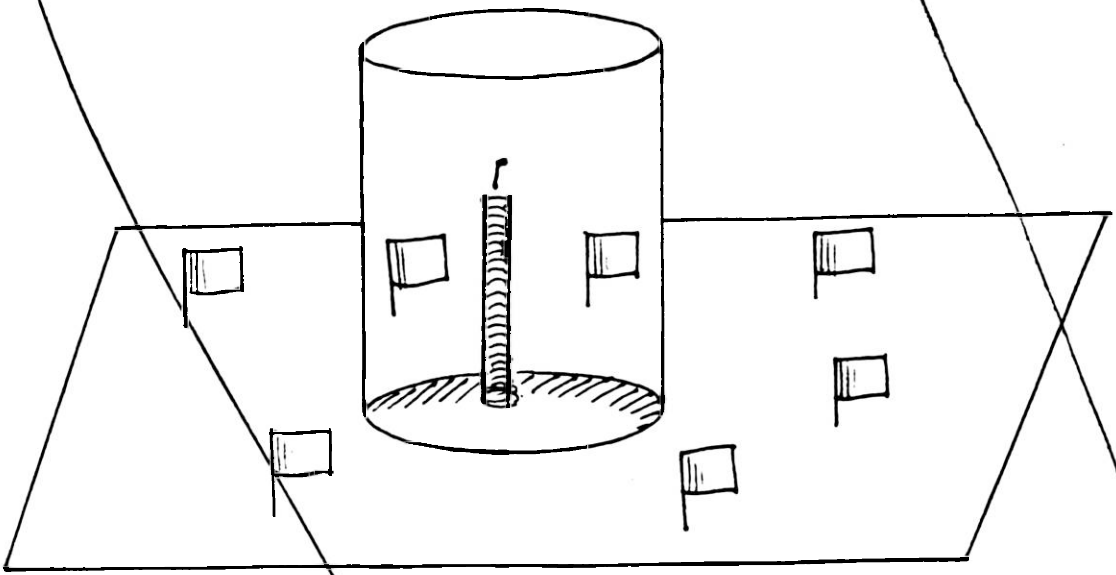

Fig 2.4 Flags flutter when a cracker is exploded inside a tin

The vibrations created due to the explosion of crackers progress all around and as a result the flags kept nearby begin to flutter.The fluttering of flags indicates some explosion nearby.

B. ELECTROMAGNETIC WAVES

One of the notable achievements of science in the nineteenth century was the discovery that light is an electromagnetic wave. Electromagnetic waves were hypothesized by James Clerk Maxwell in 1864 on the basis of his theory of electric and magnetic fields. Maxwell calculated and found that the speed of these waves is same as the speed of light. So he concluded that, light is an electromagnetic wave.

ELECTRO MAGNETIC WAVES

2.2 B TEACHING POINTS

1. Any fluctuation in a charge or current distribution produces an effect in space which propagates as an electromagnetic wave.

2. An electromagnetic wave consists of fluctuating electric and magnetic fields perpendicular to each other and also to the direction of the propagation.

3. Electromagnetic waves do not require a medium to travel.

4. Electromagnetic waves can be detected and measured by converting them to other forms of energy.

5. Electromagnetic waves can be reflected and refracted like any other wave.

6. The electromagnetic spectrum extends from gamma rays (frequency 10^{22} Hz) to radio waves (frequency 10^{4} Hz).

7. Velocity of the electromagnetic waves in any material medium is less than that in vacuum.

8. Electromagnetic waves of suitable wavelength can be used to detect and locate objects at a distance.

2.3 B DEVELOPMENT

Electric field and magnetic field have their separate existence only so long as each one of them is kept unchanged. Any change in one of them automatically creates the other by induction i.e. the change in the electric field produced by the motion of a charge is always accompanied by a magnetic field, and a changing magnetic field is accompanied by an electric field. This generation and regeneration effects propagate through space as electromagnetic wave, with a speed equalto the velocity of light.

Hertz showed that the electromagnetic waves obey the laws of reflection and refraction similar to light waves. He also found that the velocity of electromagnetic waves is the same as the velocity of light. Therefore, it was concluded that light is an electromagnetic wave.

Activity 2.5:

Take a rectangular tin-box with a glass window on one of the sides and with a provision to connect a vacuum pump. Place a torch bulb and an electric bell inside the box such that the ends of the lead wires are outside the box. Connect the leads to dry cells. The light from the bulb can be seen and also the sound of the bell can be heard. A vacuum pump is now connected to the box and the box is evacuated. Through the glass window the light is still visible. No sound is heard even though the bell is working. This shows that unlike sound, light does not require material medium to traverse, (fig 2.4). The activity can be modified if a pump is not available.

Take a conical flask which can be closed with one-holed cork. Suspend a bell inside with the leads connected to a dry cell outside. Insert a plastic tube in a hole and connect a rubber tube. Heat the flask to evacuate and clamp the rubber tube. Sound becomes faint. But the light intensity does not change.

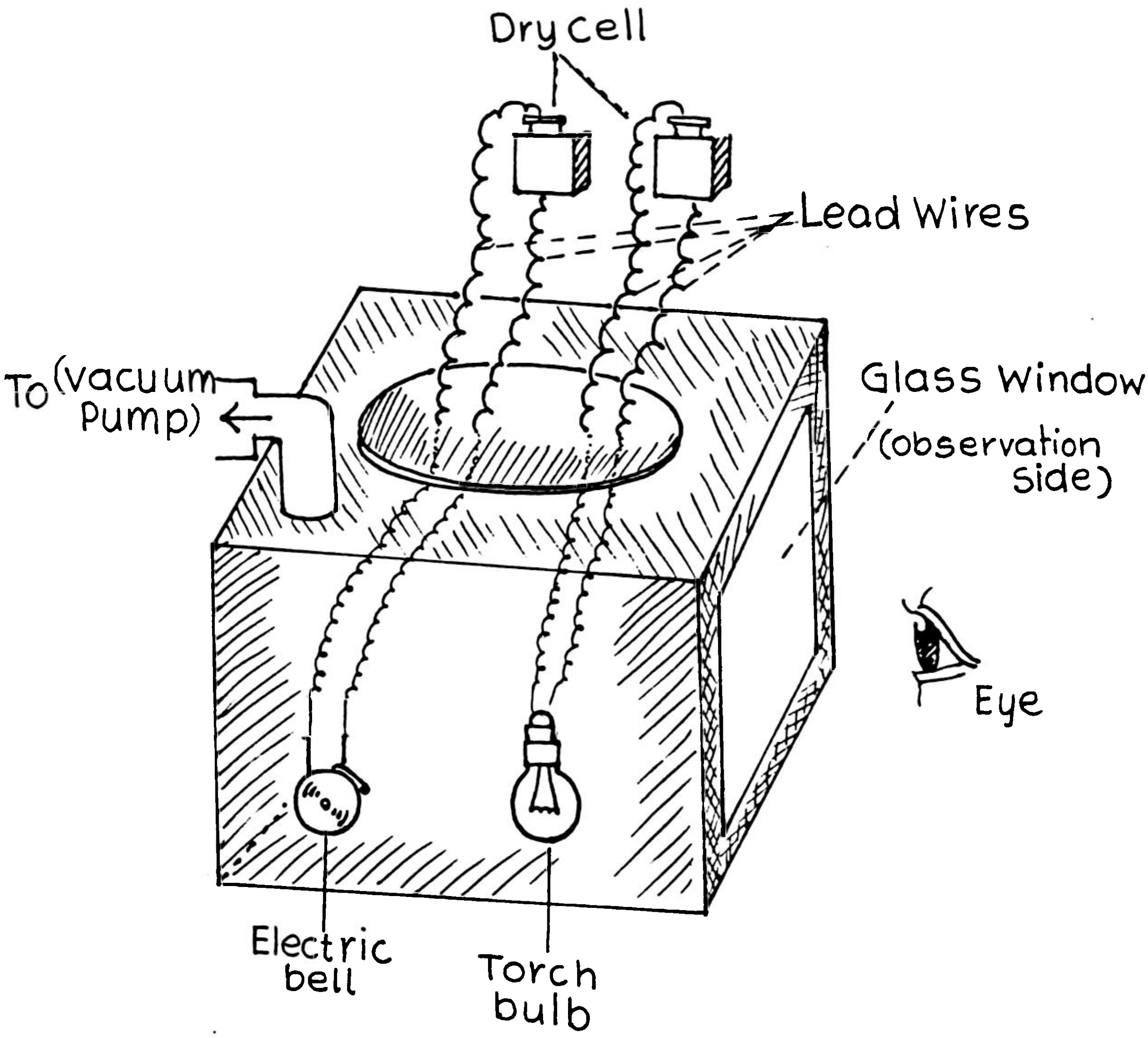

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Fig 2.5 To show that light, unlike sound does not require a material medium for propagation

Activity 2.~~7~~6:

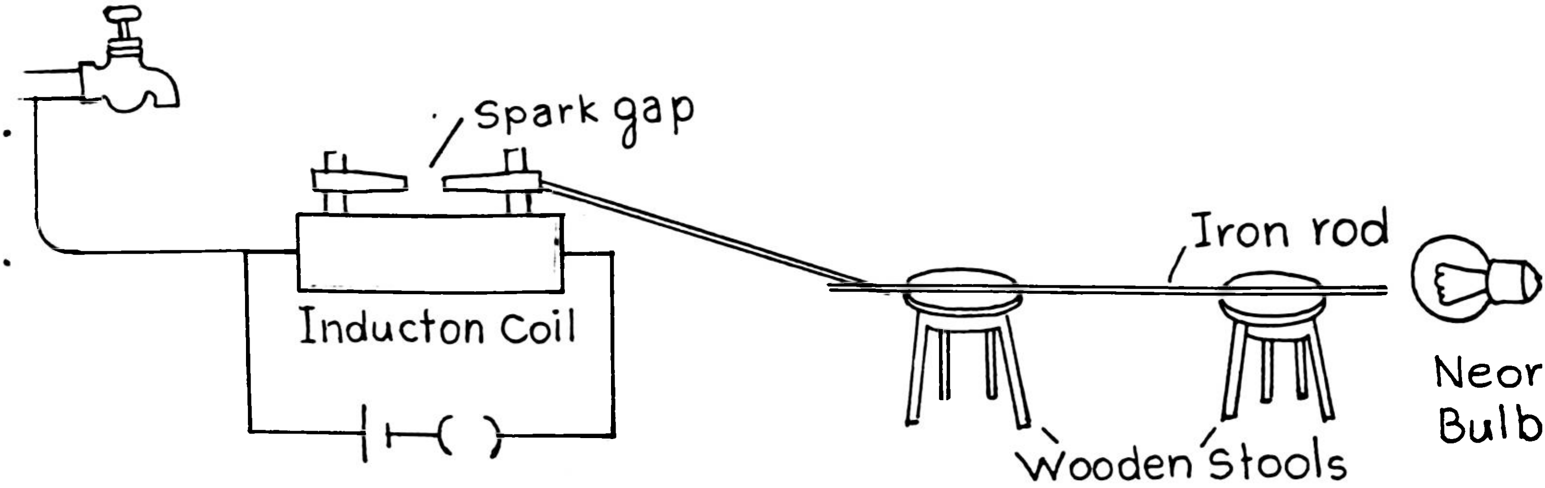

Fig 2.~~6~~5 To show that neon bulb glows when exposed to electromagnetic waves.

Set the induction coil, working (fig 2.~~6~~5). Adjust the spark gap to obtain sparks across the gap. Switch of the primary of the induction coil. Connect one knob of the induction coil to a water pipe, (ground connection) and the other knob to a thick metal rod of about one metre length and resting on two wooden stools. Close to the rod-end place a neon bulb. Switch on the induction coil. The bulb glows.

Notice that the neon bulb glows even when there is no direct connection to the bulb. The glowing of bulb is due to the excitation of neon by electromagnetic waves.

Keep a metallic reflector between the bulb and the rod, you will notice that bulb does not glow. This shows that metallic plate is opaque to electromagnetic waves. But when the bulb is kept in front of the metallic-reflector in certain positions, it glows. From this, we canconclude that electromagnetic waves can be reflected by a metallic reflector.

Activity 2.~~8~~7:

Take a converging lens. Focus the sun's rays on a paper. After some time you notice that the paper burns. The burning of the paper is due to conversion of light (electromagnetic) wave energy to thermal energy.

In the experiment with induction coil and the rod,we got electromagnetic waves. Hertz with the help of a grating made of parallel copper wires discovered that the electromagnetic waves passed through the grating when all the c copper wires of the grating are kept parallel in the particular plane but the wave did not pass through the grating when copper wires are arranged perpendicular to this plane.

This shows that electromagnetic waves are transverse.

The wave length of the electromagnetic waves vary over a wide range of 10^{-1} m to 10^{4} m. The physical nature of radiation like velocity is the same throughout the whole range. Radio waves and micro waves are obtained from electrical oscillations, infrared waves from hot objects, visible light from glowing objects, ultra violet rays from arcs and gas discharges, X-rays from electrons striking a metal target and γ rays from nuclei of radio active atoms. (fig 2.7).

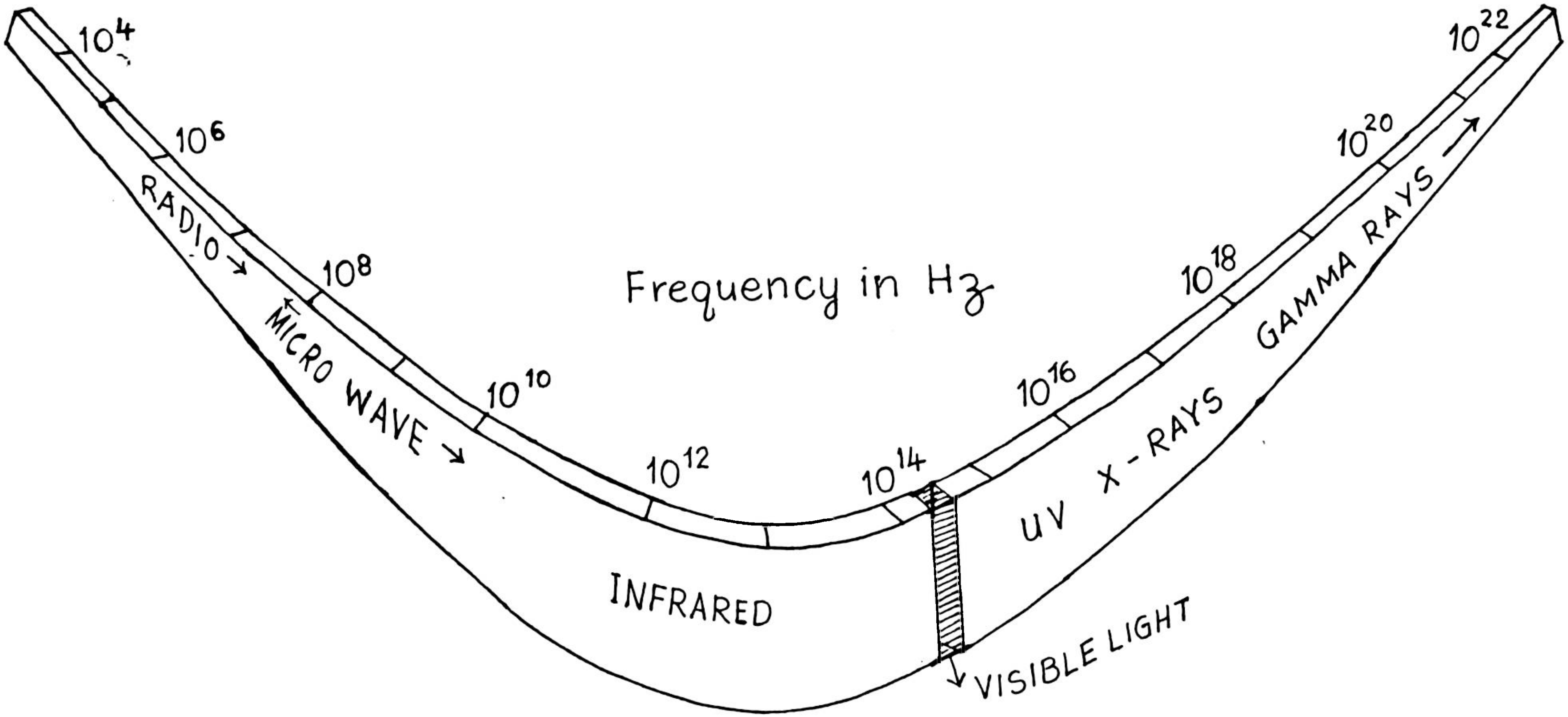

Fig 2.6 Frequency range of electromagnetic waves

Activity 2.8: Infrared and Ultraviolet rays:

Take an electric bulb fixed to a holder with two leads. Connect the leads to a variac and pass a suitable current through the bulb. First it becomes red hot. Later it becomes white hot. The heat radiation emitted when the filament of the bulb is hot is infrared radiation ~~and~~ cannot be seen. White light contains red to violet colours which can be seen by the human eye. It also contains ultraviolet and infrared radiation invisible to the human eye. The presence of infrared radiation can be demonstrated using a Crooke's radiometer kept in front of a hot iron or electric oven.

Detection of electromagnetic radiation:

Radio waves and micro waves can be detected using the radio receiver sets. Infrared rays can be detected by the rise in temperature of receiving body. Visible light can be detected by eyes and photographic emulsion. Ultra violet radiation can be detected by their phosphorescent effect and also by photography emulsions. X-rays can be detected by photographic effect and by their penetrating power. γ rays can be detected by their large penetrating power.

RADAR

Radar is an acronym for Radio Detection and Ranging. Radar is a general term used to include any system employing electromagnetic waves for the purpose of locating, identifying, navigating or guiding objects such as ships, aircraft, missiles, artificial satellites, etc.

The Radar works on the same principle as that of a SONAR but in this case the distances of the objects are usually quite large and electromagnetic waves in the microwave range are used. The radar system generates electromagnetic radiations of certain frequencies, in the microwave range. The output beam is made up of pulses. Distant objects which cross the path of the beam reflects the pulses back and are detected by a receiver. The distance of the object is measured bymeasuring the time interval between the emission of the pulse and the reception of the reflected pulse.

C. LIGHT WAVES

In this section, we will mainly discuss about electromagnetic waves which are in the visible region.

2.2 C TEACHING POINTS

1. Colours are classified as primary and secondary.

2. Primary colours are those which when suitably mixed produce secondary colours.

3. Influorescence, the substance emits light of wave-length longer than that of the incident light during the excitation.

4. In phosphorescence, the substance emits light of wavelength longer than that of the incident light, even after the exciting light is cut off.

5. The blue of the sky is due to the scattering of light by air molecules in the atmosphere.

6. In Raman Effect, the light scattered by transparent materials has wavelengths which are either shorter or longer than that of the incident monochromatic light.

7. In lasers, excited atoms emit light waves which are coherent and unidirectional.

2.3 C DEVELOPMENT

The primary colours are red, green and blue. Secondary colours are formed with suitable combination of two or more primary colours. For example, yellow colour is formed by the mixing of red and green; magenta colour is formed by mixing red and blue.

We can demonstrate using Newton's disc that seven colours when suitably mixed form white colour.

Activity 2.~~10~~9:

Cover half of the Newton's disc with blue paper and the remaining part with green paper. Rotate the disc with a different speed and see what colours result. Repeat the activity by changing (i) primary colours, either two or three at a time and (ii) the areas of the coloured regions on the disc.

Usually ultra violet radiation is used to produce fluorescence and phosphorescence effects. In both cases, a substance absorbs ultraviolet rays and emits light of longer wavelengths in the visible region. In fluorescence, emission stops as soon as the exciting light is cut off. Fluorescent lamp (i.e. tube light) is a common example of fluorescence. In this lamp, the tube is filled with a mixture of argon and nitrogen with traces of mercury vapour at low pressure. The inner wall is coated with fluorescent materials. The excitation of mercury produces both visible and ultraviolet light. These ultraviolet rays strike the fluorescent materials and produce fluorescence in the visible region of the spectrum. The efficiency of this lamp is higher because it utilises ultraviolet rays also.

Phosphorescence can be studied by using a sample which with the help of a stopper is alternately illuminated or cut off from the source. In this manner, the phosphorescence emission can be studied relatively free of interference from fluorescence and scattered lights. No phosphorescence can be observed in solution at room temperature, since the high collision rate between molecules deactivates the photo excited state. Usually spectra are recorded with compounds maintained at liquid nitrogen or lower temperatures.

Activity 2.~~11~~10:

Put a drop of red ink into water contained in a test tube. The colour of the water becomes pale red (orange). Shine light froman incandescent lamp on the test tube. We can also use a blue cellophane paper as a filter placed in between the source and the test tube. Observe in a direction perpendicular to the direction of the incident light and observe green fluorescence; when the incident light is cut off, there is no longer fluorescence (fig 2.~~8~~7).

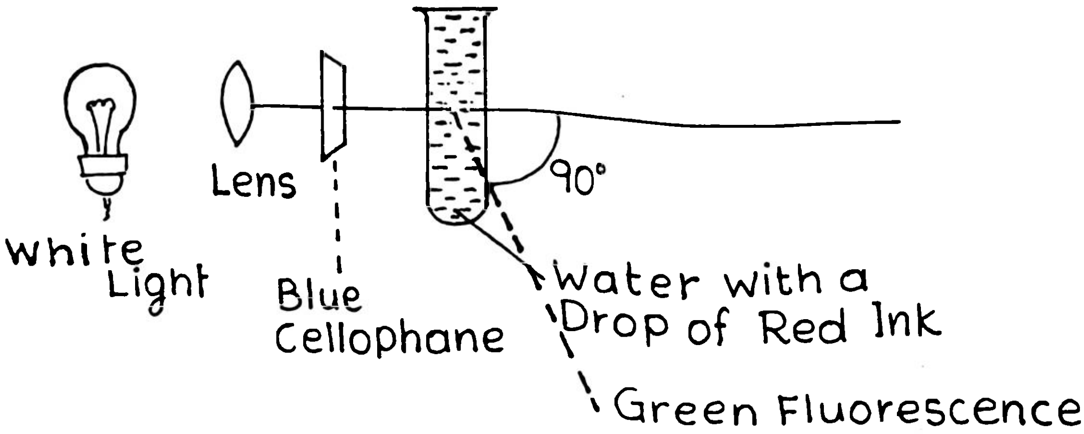

Fig 2.~~8~~ 7 To demonstrate fluorescence

Activity 2.~~12~~ 11:

Take commercially available phosphorescence sample such as zinc sulphide doped with copper or calcium sulphide doped with bismuth, etc. and excite it with ultraviolet light. Put off the exciting source and study the glow in a dark room. The sample glows for a long time, but the intensity rapidly decreases.

Activity 2.~~13~~ 12:

A rectangular tank is taken and a dilute solution of sodium thiosulphate (hypo) is poured into it. Then bright sunlight is allowed to pass through this solution and fall ona white screen placed on the other side. A few drops of concentrated sulphuric acid or dilute hydrochloric acid is added to it. Chemical reactions take place in the tank. Sulphur particles are formed in the solution. The white light seen on the screen gradually turns red. If we view perpendicularly, we can see the blue colour. From this experiment, we can infer that light rays get scattered by minute particles, and blue colour is scattered more than red colour.

The blue of the sky is due to the phenomenon of scattering of sunlight by the air molecules in the earth's atmosphere. The blue light is scattered about four times as effectively as red light, that is why the sky is blue.

Due to the same principle, the sea appears blue.

RamanEffect:

When a beam of monochromatic light is allowed to pass through a transparent liquid, free from dust particles, the scattered light is found to contain radiations of wavelengths different from that of the incident radiation; some of them are of longer wavelengths and some are of shorter wavelengths. Sir C.V.Raman, observed in 1928 that this phenomenon occurs in some liquids. He found that the frequency shift in the scattered radiation is characteristic of the liquid and does not depend upon the frequency of the incident radiation. This phenomenon is known as "Raman Effect". This effect is observed with transparent solids and gases also. The Raman Effect finds its application in the determination of the structure of molecules.

LASER

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. It is a very special source of light, different from incandescent lamps and fluorescent lights. It is characterised by a high degree of coherence, intensity and directionality.

Basic Principles:

LASER exploits the three fundamental processes, namely - absorption, spontaneous emission and stimulated emission, which occur when an electromagnetic wave (radiation) interacts with matter. According to quantum theory, electromagnetic radiation consists of packets or quanta of energy called photons.

Absorption: When the radiation of energy $h\nu = E_2 - E_1$ falls on matter (consisting of atoms or molecules), the atoms in the lower energy level (E_1 - ground state) absorb the energy and are excited to higher energy level E_2 ($E_2 > E_1$).

This is the process of absorption. The excited state of the atom is unstable and hence it falls back to stable ground state by emitting photons of energy $h\nu = E_2 - E_1$. This process of emission can take place either through spontaneous or stimulated emission.

Spontaneous Emission:

Consider an atom initially in the excited state (E_2). Since it is an unstable state, the atom falls down to the stable ground state emitting radiations on its own, spontaneously in about 10^{-8} s. This is called spontaneous emission. The photons thus emitted by different atoms will not have any correlation either in phase or in direction.

Stimulated Emission:

Now let us consider again an atom in the excited state (E_2). If a photon of energy $h\nu = E_2 - E_1$ is incident on such a system, the incident photon induces or stimulates the excited atom to fall to the ground state by emitting a photon of energy $h\nu$. It is called a stimulated emission. Since this process is forced by the incident electromagnetic wave. The photon emitted by the atom will be in phase with the incident wave, and the two will have the same direction.

LASER

Let us assume that the number of atoms in the two levels E_1 and E_2 are N_1 and N_2 respectively and $E_2 > E_1$. Under normal conditions, the lower energy level is more populated than the higher energy level i.e. $N_1 > N_2$. It is sometimes possible to reverse this situation by special means such that $N_1 < N_2$ i.e., the lower energy level is less populated than the higher energy level. Such a situation is referred to as 'Population Inversion'.

A material in which such a non-equilibrium condition has been achieved is called an 'active material'. When such an active material is kept in a resonant cavity (for example; in between two plane parallel highly reflecting mirrors) intensity increases because of successive reflections. Laser beam thus produced comes out from the mirror-end which is partially silvered. This is the basic principle of laser. It has the following properties:

1. **Highly directional:** This property is simply due to the fact that the active material is placed in a resonant cavity such as between plane parallel mirrors. Only an electromagnetic wave which propagates along the cavity direction or making very small angle with this direction will remain in the cavity, even after multiple reflection.

2. **Highly intense:** The brightness of a given source of light is the power emitted per unit area of the surface per unit solid angle. A laser of even moderate power (e.g. , a few milli watts) has brightness several orders of magnitude greater than the brightest conventional sources due to the highly directional property of the laser beam. In conventional source, light is emitted in all the directions.

3. **Highly monochromatic:** This is due to the fact that only an electromagnetic wave of frequency $\nu = (E_2 - E_1)/h$ is amplified. Also since the two plane parallel mirrors arrangement forms a resonant cavity, oscillations can occur only at the resonant frequency of the cavity (like any electronic oscillator).

4. __Coherence:__ If at a particular time the light has the same phase everywhere across a wave front, it is said to be completely spatially coherent. Also we can compare the phase of the light on one wave front (travelling) with its phase on the displaced wave front after it has travelled a distance 'd' in a time interval d/c. If these phases agree for all time intervals, the light is said to be completely time coherent. Thus a perfectly monochromatic wave, like a laser beam, is coherent both in space and time.

Pumping Schemes:

Population inversion is essential to get a laser beam. But how is this achieved? We have considered in the above examples, for simplicity, only two levels. E_1 and E_2. If an intense source of radiation of energy $h\nu = E_2 - E_1$ is incident on such two level systems, initially the absorption predominates the emission and thus more number of atoms are excited to the higher level. and a situation is reached when $N_2 = N_1$ i.e. the process of absorption and emission will compensate each other. This is referred to as 'Two level saturation'. Further increase in the population of the higher level is not possible. Hence, the population inversion can never be achieved with a two-level system.

Then, is it possible to use 3 or more available levels to achieve population inversion? The answer is YES. Accordingly, we speak of a 3-level system or a 4-level system.

In a 3-level system, as the name indicates, we make use of 3 energy levels (fig 2.~~9~~6). Due to absorption the atom is excited to level 3 from level 1. The atom goes over to the level 2 by collision. The level 3 acts as a reservoir to pump the atoms from level 1 to 2 (via 3). Level 2 has a longer life-time (10^5 s to several minutes) and is called meta-stable state. Thus a population inversion is achieved between levels 2 and 1 and lasing action takes place.

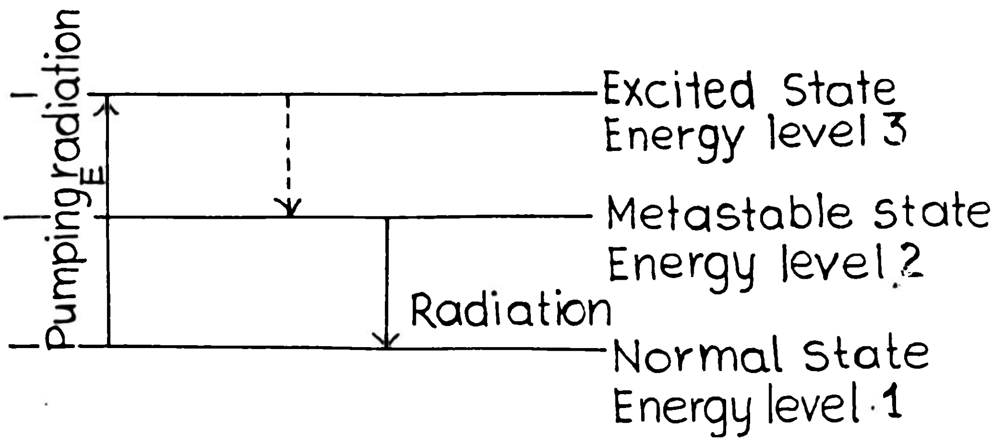

Fig 2.8 Three level energy system to obtain population inversion

The atoms can be excited (pumped) to higher levels by means of

1. Optical pumping (Solid State Lasers. dye lasers)
2. electrical pumping (Gas lasers, semi conductor lasers)

Ruby Laser:

Ruby is a crystal of Al_2O_3 doped with small quantities of Cr_2O_3 (0.03%). It is taken in the form of a rod of about 10 cm. in length and 0.5 cm in diameter. The ends of the rod are ground plane parallel and coated with highly reflecting dielectric; one end is made partially transmitting. It is kept along the axis of a spiral Xenon flash lamp. The light from the Xenon flash lamp is absorbed and after suffering multiple reflections, the red laser beams (6948 A) is extracted from the slightly less reflecting mirror end. fig 2.9).

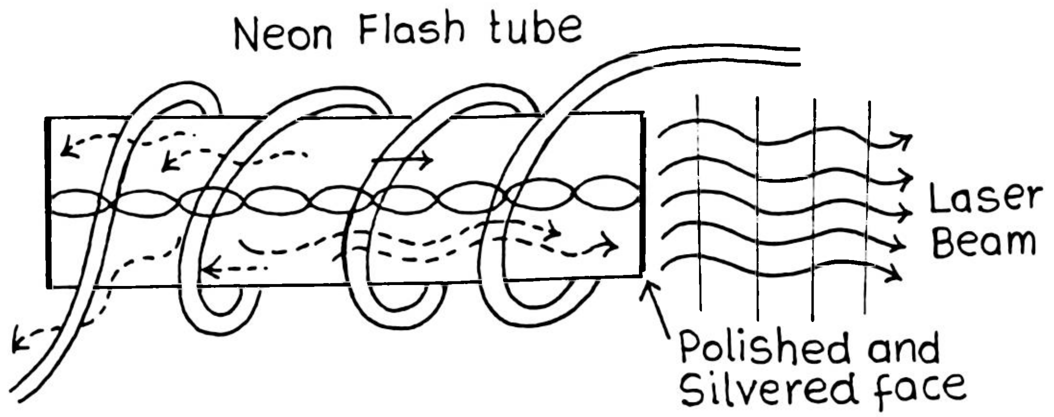

Fig 2.~~10~~ 9 Ruby Laser

He-Ne Laser:

A mixture of He-Ne gas in appropriate proportions is taken in a discharge tube, when electromagnetic radiation of appropriate frequency is passed, the He atoms are excited. When the He atoms collide with the Ne atoms the energy of excited He atoms is transferred to the Ne atoms and thus the Neon atoms are excited. Due to the transitions in Neon energy levels, Lasing action takes place. Here also multiple reflections takes place between two parallel mirrors. Actually, He-Ne system can lase at three wavelengths. Using appropriate set up, the system is made to lase at the required wavelength. The most commonly used He-Ne laser works at 6328 A.

Applications: Because of their high intensity and coherence, the lasers have many scientific, as well as technological applications as listed below:

1. Industrial-welding, cutting, measurement of actual length
2. Medical-welding of retina, tumour and cataract operations
3. Scientific-fibre optic communication, ranging, holography and Raman Effect.

2.4 EVALUATION QUESTIONS

1. As a rocket having a green tail-light moves away from the earth its tail will appear

   a) green b) yellow c) blue d) black

2. List three differences between ultrasonics and light waves.

3. The energy conversion in tape recording is from

   a) sound to magnetic

   b) magnetic to .electrical

   c) sound to mechanical

   d) electrical to sound

4. Calculate the wavelength of radio waves of frequency 300 KHz.

5. A radio station transmits waves of wavelength 50m. Calculate its frequency of transmission.

6. If λ is the wave length and C is the velocity ofan electromagnetic wave then its frequency is

   a) $C\lambda^{-1}$ b) $C^{-1}\lambda$ c) $C\lambda$ d) $C^{-1}\ \lambda^{-1}$

7. Influorescence there is

   a) increase in wave length

   b) decrease in wave length

   c) no change in wave length

   d) both increase and decrease in wave length

8. The blue light is scattered more than red light because

   a) the red light is totally absorbed by air.

   b) wavelength of blue light is shorter than that of red light

   c) wavelength of blue light is longer than that of red light

   d) there is more of blue component in the incident light

9. Sea appears blue. But when the sea water is taken in a cup it becomes colourless. Explain.

10. Beyond the atmosphere, the sky appears

    a) blue b) black c) red d) white

11, Raman Effect is due to the phenomenon of light

    a) scattering b) dispersion c) reflection d) refraction

12. Which of the following cannot be propagated in outer space?

    a)X-rays b) ultrasonics c) ultraviolet rays d) infrared rays

13. In vacuum radio waves,light rays, X-rays, and γ rays have the same

    a) wavelength b) frequency c) period d) speed

14. The wavelength of the green light is approximately the same as the

    a) size of the window

    b) diameter of a foot ball

    c) diameter of your eye

    d) thickness of a soap bubble

15. Earthquake does not produce

    a) electromagnetic waves b) sound waves

    c) seismic waves d) mechanical waves

16. Earthquake is caused by

    a) sudden shift of the earth's crust

    b) Slow movement of earth's crust

    c) movement of the surface layer of soil on the earth

    d) movement of the sea water

17. InRaman Effect, the wavelength of the scattered light is
    a) same as that of the incident light
    b) only longer than that of incident light
    c) only shorter than that of the incident light
    d) both longer and shorter than that of the incident light

18. Frequency shift in Raman Effect is characteristic of
    a) incident radiation only
    b) scattered radiation only
    c) the scatterer only
    d) both incident radiation and scatterer

19. What is population inversion?

20. A calcium line in the spectrum ofthe star α-Centuri line has a measured wave length of 3968.20 A. The same line in the solar spectrum has a measured wavelength of 3968.49A. What is the radial velocity of α-centauri relative to the solar system? Is it approaching or receding?

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III. ELECTRICITY AND MAGNETISM

3.1 INTRODUCTION

Till recently,magnetism and electricity were taught as if they were two independent units. Thus while explaining the concepts of magnetic poles and pole strength one used to mention that these poles lie at certain points within the magnet and that these could be located by drawing a few lines of force near the pole face and producing them backwards; similarly while defining the pole strength one used to assume the existence of an isolated unit poles. These statements are contrary to the reality.

Now-a-days, these concepts are developed on the basis of the magnetic effects due to electric currents. As we all know a solenoid carrying a current behaves like a bar magnet, and the magnetic field due to it is directly related to the strength of the current flowing in it. The study of the structure of the atom throws light on the magnetic properties of matter. The electron revolving around the nucleus of the atom is also equivalent to a current and this gives rise to the orbital magnetic moment associated with the atom; similarly, the 'spin' property of the electron which gives rise to the fine structure of spectral lines also contributes to the magnetic moment of the atom.

On the basis of the relation between the current flowing in a solenoid and the magnetic flux due to this current the concepts of magnetic moment and pole strength can be developed. These quantities are expressed in terms of the units, Ampere-metre^2 in the case of the magnetic moment, and Ampere-metre in the case of pole strength. The magnetic moment is also expressed in Weber-metre.

Matter is essentially electrical in nature, and the magnetic effects are all due to electrical charge contained with in matter. Therefore,it is only logical to treat electricity and magnetism as a single unified area of study rather than as two separate units.

In the case of electricity, it is possible to obtain isolated charges either wholly positive or wholly negative but in magnetism, one cannot obtain isolated poles. This difference has some important consequences. For example, the manner in which a magnetic field and an electric field exert a force on a charge is not the same. While it is only a moving charge which experiences a force due to a magnetic field, both stationary and moving charges experience force due to an electric field.

In the beginning of this chapter, we discuss some important concepts of electricity, and proceed subsequently to discuss some concepts of magnetism.

A. ELECTROSTATICS AND CURRENT ELECTRICITY

3.2 A TEACHING POINTS

1. Electrification is the process of establishing charge on a body.
2. Charges are of two kinds - positive and negative.
3. Unlike charges attract and like charges repel.
4. Force of attraction or repulsion between two charges depends on their magnitude and the distance between them.
5. Electric charge always resides on the outer surface of a conductor.
6. Distribution of charges on a conductor depends on the curvature of the surface.
7. A pointed conductor loses charge rapidly.
8. Materials which allow free flow of charges through them are conductors and those that do not, are insulators.
9. A charged body gives rise to an electric field in the region surrounding it.
10. Potential at a point in the field is the work done in bringing a unit charge from zero potential to that point in the field.

11. Positive charges flow from a region of high potential to a region of low potential.

12. Capacitor is an arrangement of conductors separated by air or any other insulating material to store charges.

13. Capacitance of a parallel plate capacitor, depends on the area of the plates, the separation between them and the dielectric constant of the medium between the plates.

14. Electric current is the directed flow of charges.

15. Electromotive force in a cell is its driving force.

16. Voltage increases in a series combination of cells.

17. Current in a circuit increases with a parallel combination of cells.

18. Resistance of a conductor at a particular temperature is a constant and is equal to the ratio of potential difference across it to the current flowing through it.

19. Resistance of a conductor depends directly on the length of the conductor and inversely on the area of cross-section.

20. Resistance varies with temperature.

21. Resistances are arranged in series to increase the net resistance and in parallel to decrease the net resistance of the circuit.

22. The rate at which heat is developed in a conductor depends on the square of the current flowing through it and on its resistance.

23. Chemical effects accompany the flow of charges in certain solutions.

24. Electric current through a conductor produces a magnetic field.

3.3A DEVELOPMENT

Electric Charges:

The Greeks, from their observations made over 2000 years ago, discovered that dust particles and small pieces of paper are attracted by a piece of amber rubbed with fur. The attraction between rubbed amber and the pieces of paper is due to electrification. In experiments in the early eighteenth century on electrical attraction, glass rods rubbed with silk and amber rods rubbed with fur were used.

Materials other than these such as plastics also exhibit electrification. For example, a plastic pen rubbed against wool and placed near small pieces of paper attracts them. However, for a successful result, the pen has to be absolutely dry; indeed in all experiments on static electricity, the apparatus must be dry and humidity must be less.

Activity 3.1:

a) Suspend a polythene rod from a wooden stand and charge it at one end by rubbing it with a piece of wool.

b) Charge a second polythene rod and bring this rod near the charged end of the suspended rod. Is the suspended rod attracted or repelled?

c) Rub a dry glass rod with a silk cloth and test it against the suspended polythene rod.

This activity can be more effectively demonstrated using a Whimshurst machine and a suspended pith ball. The result will be spectacular. Sometimes, the activities described above are not effective because of humidity in the air.

In all the above cases, what is observed is due to the bodies getting electrified by acquiring charges on account of friction.

Electric charges produced by friction are of two kinds. One kind is produced on polythene and another on the glass rod strip. Two charged polythene rods repel while a charged polythene rod and a charged glass rod attract each other. We can summarise these results by saying that

LIKE CHARGES REPEL, UNLIKE CHARGES ATTRACT

Many other substances can be tested for frictional electric charge, but the results always yield two types of charges. By convention, we say that the glass rod has acquired positive charges and the polythene rod has acquired negative charges. What then is the charge associated with silk and wool?

Coulomb's Law:

The Law according to which like charges repel and unlike charges attract was formulated by Coulomb. In his investigations a very sensitive balance is used to accurately measure the force between two small charged balls.

Based on his experimental observations, Coulomb concluded that the force between the charged balls is proportional to the product of the charges and inversely proportional to the square of the distance between them. If the charges on the balls are q_1 and q_2 and if the distance between them is r, then accordin g to Coulomb's conclusion the force F between them is given by

i) $F \propto q_1 q_2$ and

ii) F $1/r^2$. Combining and writing this in the form of a formula, we have

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

The constant ϵ_0 occuring in the formula is the permittivity of the free space. ($\epsilon_0 = 8.9 \times 10^{-12}$ Coulomb^2/Newton-meter^2). The charge on a body is usually expressed in terms of the Coulomb, which is the unit of charge.

Activity 3.2:

Take a hollow metallic sphere mounted on an insulated stand as shown in Fig 3.1.

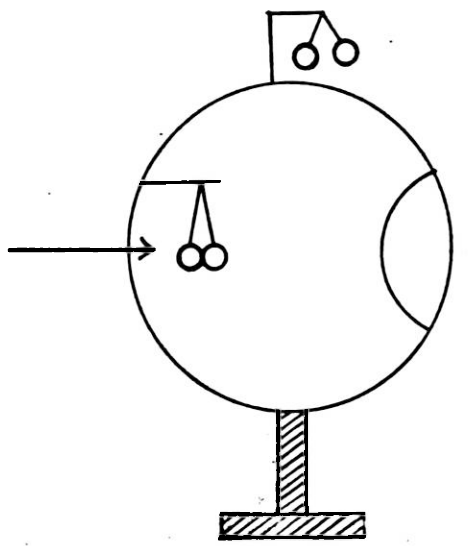


Fig 3.1 Distribution of charge in a hollow conductor

Suspend a pair of pith balls on the outer surface of the sphere by means of a metallic hook. Suspend another pair of pith balls using wet cotton thread on the inner surface of the sphere as shown in the diagram. Charge the sphere with a Whimshurst machine. The pith balls on the surface of the sphere diverge, whereas those inside the sphere remain unaffected. The divergence of the pith balls on the surface of the sphere indicates that the outer surface is charged. The absence of repulsion of the balls on the inner surface of the sphere indicates that the inner surface of the sphere is not charged. This shows that charges lie on the outer surface of the sphere.

Repeat the experiment by charging the inner surface of the sphere and observe both the sets of pith balls. How do they behave?

<u>Activity 3.3:</u>

Charge a metallic sphere A and another sphere B with a pointed end both mounted on insulated stands. Bring a candle flame near each of the spheres and observe what happens when the spheres are rotated (Fig 3.2).

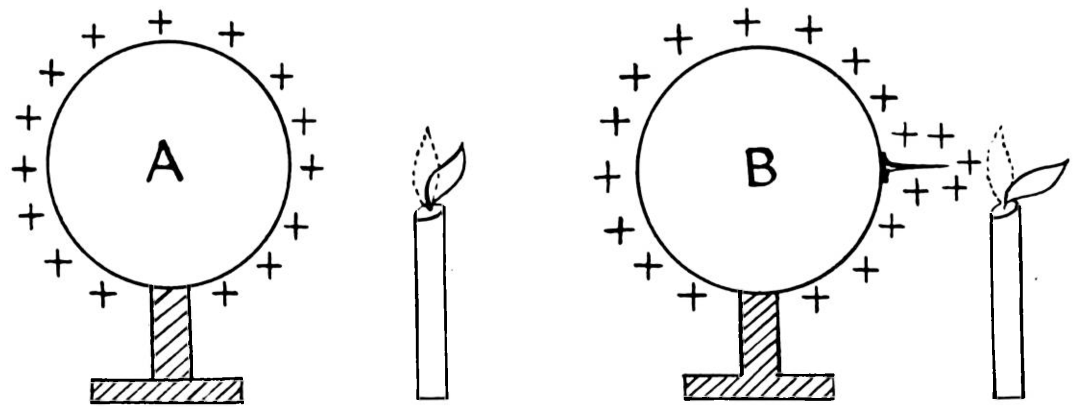


Fig 3.2 Discharging action of pointed ends

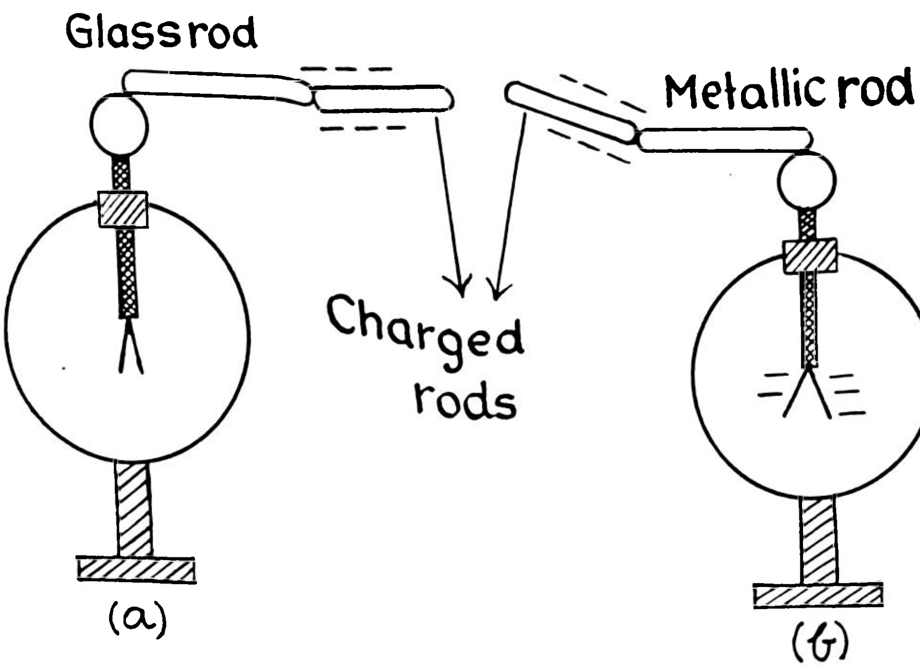


Fig 3.3 Insulators and Conductors

The flame gets deflected and when the pointed end of the sphere B is brought near the flame it gets deflected to the maximum extent. If the charged sphere is withdrawn, the flame comes back to its original position. This indicates that the flame deflects according to the strength of the charge on the surface facing it. The above experiment supports the fact that charge accumulation occurs to a large extent on surfaces with the least radius of curvature. The varying extent of the deflection observed can only be explained on the basis of the discharging action of pointed ends.

From the results of this experiment, it will be noticed that the charge is not, in general, distributed uniformly over the surface and that there is a concentration of charge wherever the surface is curved. The density of charge i.e., the charge per unit area is greater where the radius of curvature is less. (Fig 3.2b)

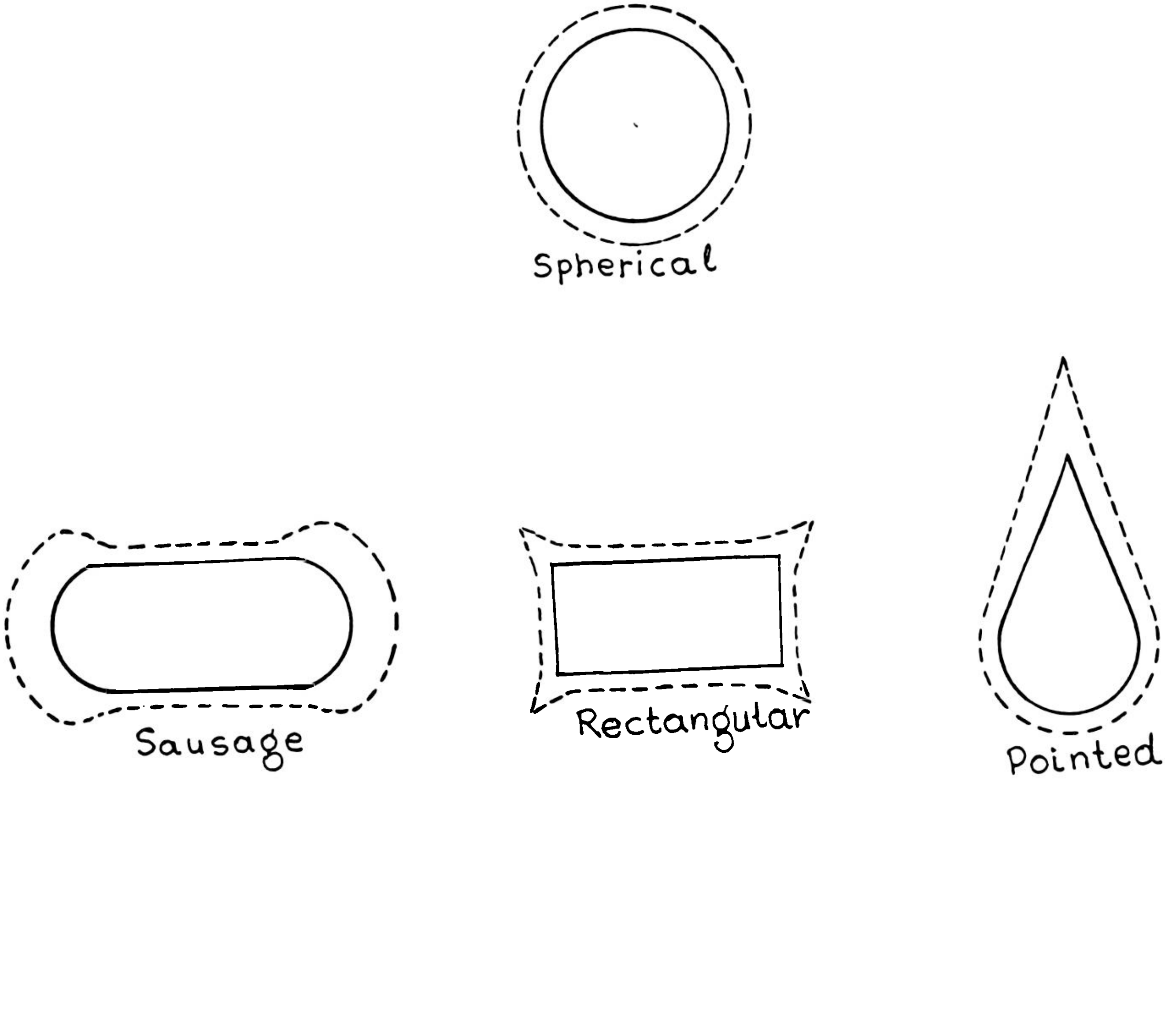


Fig 3.2 (b) Charge density is greater where radius of curvature is less

A pointed conductor rapidly loses its charge by the phenomenon of point-discharge. If a pointed conductor is raised to a very high positive potential, the rapidity of the discharge creates a current of air known as the "electric wind". This is strong enough to deflect the flame. Due to high charge density of the body at the pointed end positive charges which get leaked are repelled violently. The moving charges further create further charged ions by friction. This process increases the number of ions in a short time, and very soon a vast number of such positive ions move rapidly away from the point of discharge causing the electric wind. The role of the flame is only to indicate the movement of charges.

Good Conductors and Insulators:

Activity 3.4:

Mount a glass rod horizontally on an insulated stand. Arrange an electroscope such that one end of the glass rod is in contact with the knob of the electroscope. Bring an electrified object and keep it in contact with the other end of the glass rod. The leaves of the electroscope do not diverge Fig 3.3(a). This shows that no charge has been transferred to the leaves through the rod.

Repeat the experiment by replacing the glass rod with a metallic rod. The leaves of the electroscope diverge. This shows that charge has been transferred to the leaves through the metallic rod (Fig 3.3b).

Materials through which electric charges are easily transferred are called good conductors and those through which they cannot be transferred are called insulators. Examples of good conductors are silver, copper and aluminium and those of insulators are glass, mica, paraffin, rubber, dry air, shellac, silk and bakelite. Some solutions are also good conductors.

Metals have free electrons and these electrons which are in large numbers form a gas referred to as electron gas. The loosely held outermost electrons of the metal atoms can be considered to form the electron gas. These electrons which belong to the crystal as a whole are free to move throughout the crystal and they give rise to the high electrical conductivity commonly associated with metals.

A good metallic conductor has a large number of free electrons. For example, one mole of silver i.e., 108 g of silver contains 6.02×10^{23} atoms. Assuming that each atom contributes one valence electron the total number of free electrons per mole of silver will be 6.02×10^{23}, a very large number indeed! The free electrons inside the conductor spread throughout the material without giving rise to any local concentration of charges. If such a material is brought in contact with a charged body, the free electrons surge in a common direction. If the charged body is deficient in electrons, i.e. positively charged, this surge is in the direction of the object. If the charged object has an excess of electrons i.e., negatively charged, the surge is away from the object. In either case, the transfer of charge continues until a charge equilibrium is established.

In an insulator, we have relatively very few free electrons because even the outermost electrons are rather firmly held within the atom. In an insulator, therefore, the transfer of charge is usually negligible, and for this reason, their conductivity property is very poor.

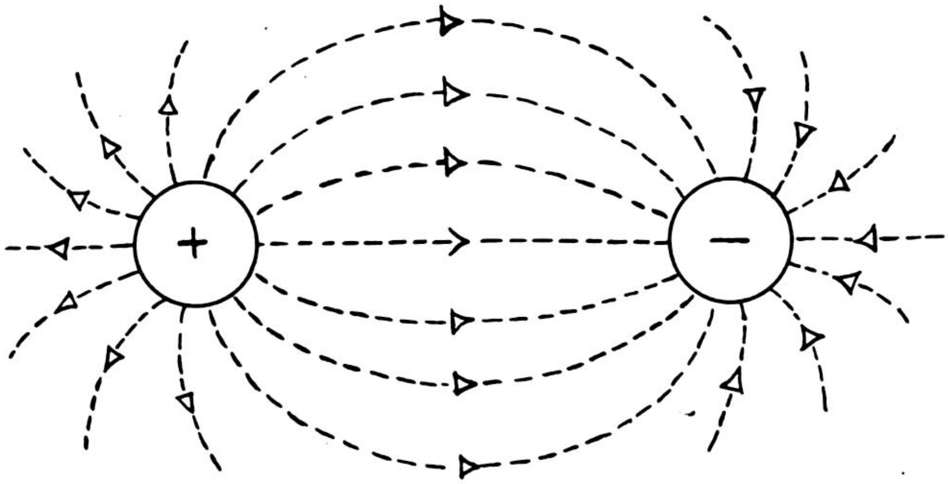
Electric Field:

The region surrounding a charged body exhibits a special property; if a second charge is brought into this region, it experiences a force. We say that the charged body gives rise to an electric field in this region. The direction of the electric field is given by the direction of the force on a positive charge placed in the field. Michael Faraday introduced the concept of lines of force with a view to explain the action of the electric field.

1. The direction of an electric field is the direction of the force on a positive charge placed in the field.

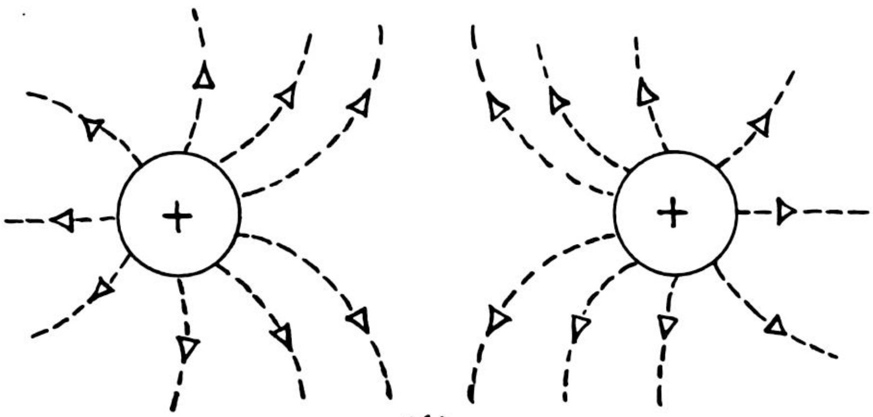
2. An electric line of force is a line in an electric field such that its direction at any point gives the direction of the electric force on a positive charge at that point.

In terms of the lines of force, a model of the electric fields between (a) unlike and (b) like charges can be drawn as shown in the figures below (Fig 3.4).



(a)

3.4(a) Lines of force between unlike charges



(b)

3.4(b) Lines of force between like charges

It may be noted that in the case of the like charges, the lines of force diverge.

In connection with the electric field concept the electric field intensity is defined in terms of the force in Newtons experienced by a unit charge i.e., one Coulomb of charge.

Electric Charge and Potential:

Activity 3.5:

a) Earth the case of an electroscope. Place a metal plate A on the brass cap of the electroscope (Fig 3.5a). Charge the metal plate A positively. Take a second metal plate B and earth it. Bring it over the metal plate A without touching it. One observes a fall in divergence of the leaves. Bring the plate B closer to A. the divergence decreases further. Remove the plate B completely from the vicinity of the electroscope; the leaves return to their original divergence.

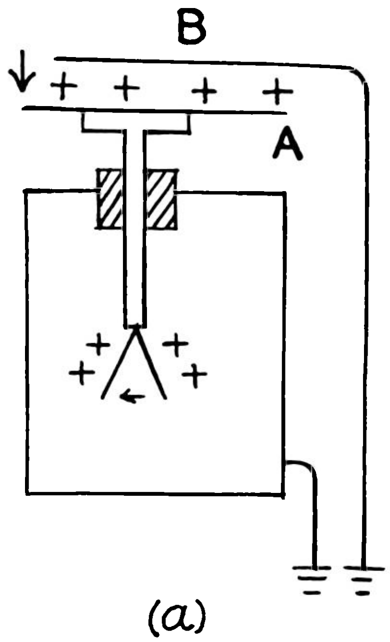


Fig 3.5(a) Measuring potential with an electroscope

This shows that the electroscope does not measure the charge on it as it remains the same throughout the activity.

What does the divergence measure?

In the first part of the activity earthing the case makes the charge, if any, to move towards the earth. Since both types of charges move towards the earth, earth may be supposed to be at zero potential.

(b-i) Earth the case of the electroscope and bring a positively charged perspex rod near the brass cap. By induction the brass cap will be charged negatively and the gold leaves positively. The leaves diverge (Fig 3.5b).

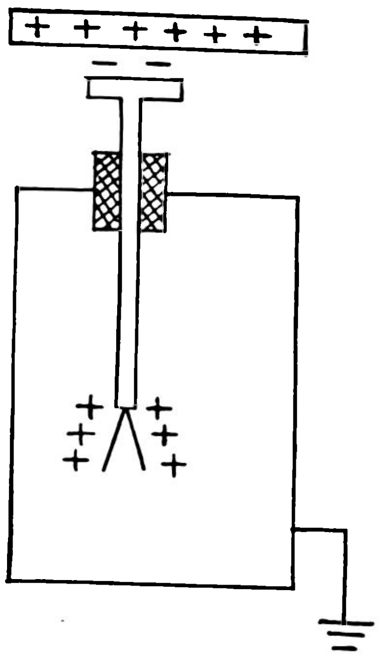


Fig 3.5(b) Potential causes divergence of gold leaf

(b-ii) Keep the electroscope on an insulating slab. Earth the brass cap. Bring a positively charged perspex rod near the case of the electroscope. The leaves diverge though they are earthed.

How do you explain the divergence when no charge can remain on the earthed electroscope?

(b-iii) Keeping the electroscope still on the insulating slab, connect the brass cap to the case of the electroscope. Bring a positively charged perspex rod near the brass cap. The leaves will not show any divergence even though they are charged by induction.

From these activities and observations it is clear that an electroscope divergence does not measure the amount of charge on it.

Reflecting on the activity (a) when the earthed plate B is brought near to the positively charged plate A the divergence decreases showing that the divergence is related to the earthed plate. Since we have assumed that the earthed plate is at zero potential, the divergence may be a measure of potential difference between the plate A and plate B. Greater the distance between them greater may be the potential difference. We shall see how this assumption that an electroscope measures the potential difference between the charged plate and the earthed plate holds good in the other activities.

In (b-i activity since the case is earthed, the divergence can be explained as the potential difference between the electroscope and the earthed case. Similarly, in (b-ii) activity, the divergence can be explained as the potential difference between the charged case and the earthed electroscope. In the last activity, case and the electroscope are connected together and none of them is earthed. The leaves and the case will be charged to the same extent by induction and the potential difference between them is zero. They will be at the same potential and hence no divergence.

The concept of electric potential and the gravitational potential are similar though their magnitudes are very different. In the gravitational potential one has to do work against the gravitational field in lifting a unit mass from zero potential level to that point. In the same way, we may define the electric potential as the amount of work one has to do against the electric field in bringing unit positive charge from zero potential level to that point. It should, however, be remembered that gravitational field is always inward whereas the electric field is always outward (we always consider positively charged body).

Thus it can be stated that an electroscope always measures the potential difference between the electroscope and the case. In general, the case is earthed and not the knob of the electroscope. The potential at a point in an electric field is the amount of work one has to do in bringing a unit positive charge from zero potential to that point. In the case of an isolated charged body where do you locate the zero potential point?

Capacitance

Activity 3.6:

Two cans of different sizes are charged with equal charges and placed on two electroscopes. The divergence of the leaves will be different. Obviously, the potentials of the cans are different even though equal amounts of charge are given to both the cans. The small can will have higher density of charge and higher potential and so causes more divergence. Now connect the two cans by means of a wire. Charges flow from the can at higher potential to the can at lower potential until the potential of both cans is the same. The divergence of the leaves in the two electroscopes will be the same. In the above, charges flow from smaller can to the bigger can and the charges on the two will not be different. The bigger can gains in charge and the divergence of the leaves increases. Since the divergence is a measure of the potential, it is obvious that the potential of the bigger can has also increased.

Therefore, we may conclude that

$V \propto Q$ or $Q = CV$

The analogy of two vessels containing water which can be connected to each other as shown in the fig 3.6 would serve to illustrate the above conclusion. The same volume of water is poured into the two vessels. However, because of the difference in dimensions of the two vessels the water settles to different heights h_1 and h_2 such that $h_1 > h_2$. On opening the interconnecting tap due to hydraulic pressure water flows from vessel 1 to vessel 2 until the pressures become equal i.e., the height of water h_3 will be the same in both vessels. However, each vessel contains different volumes of water. The hydraulic pressure which causes the water to flow can be compared to the electric potential and the quantity of water flowing to the quantity of charge.

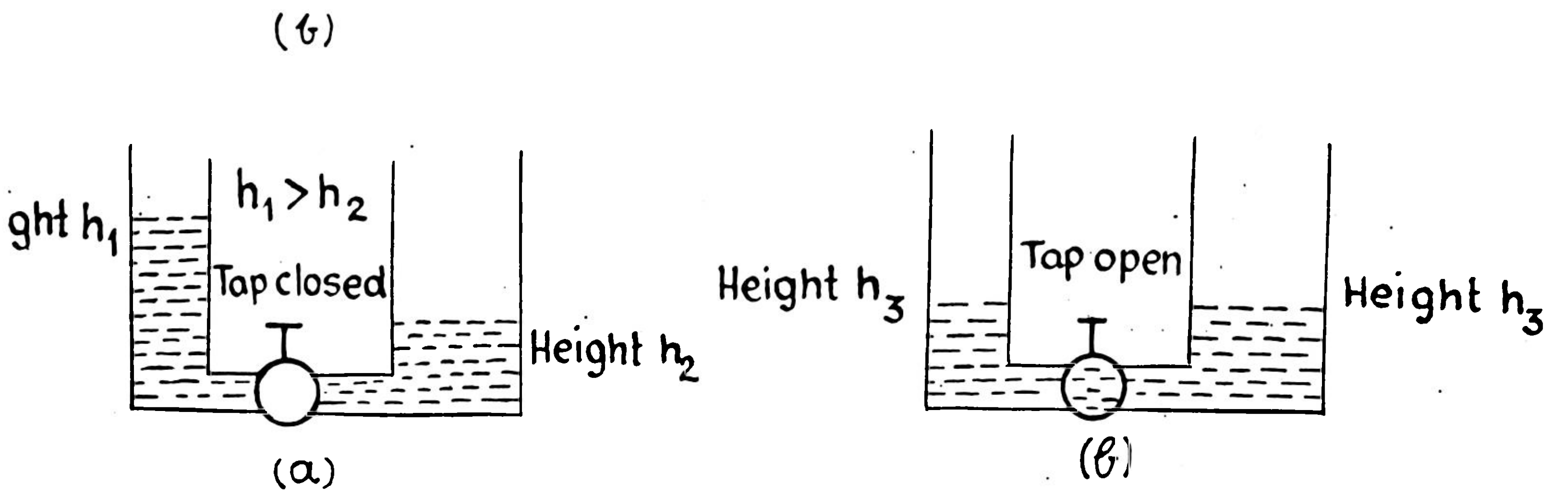


Fig 3.6 Interconnected vessels containing water

In the formula $Q = CV$, 'C' is referred to as the capacitance.

In activity 'A', to start with, the two cans carry equal charges but the smaller can is at a higher potential. Denoting the capacitance and the potential of the cans by C_1, V_1 and C_2, V_2 we have

$$Q = C_1V_1 = C_2V_2$$

$$\frac{C_1}{C_2} = \frac{V_2}{V_1}$$

but $V_1 > V_2$; therefore $C_2 < C_1$.

The unit of capacitance is the farad that is 1 coulomb/volt.

Activity 3.7:

a) Mount a metal on an insulating stand and connect it to an electroscope. Charge the metal plate and note the extent to which the leaves diverge (Fig 3.7).

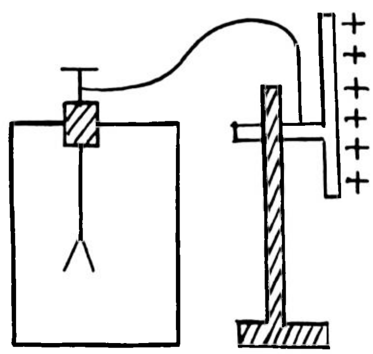


Fig 3.7 Charged conductor

b) Mount a metal plate on an earthed stand (iron). Bring this plate close to the charged plate. There occurs a large decrease in the divergence of the electroscope (Fig 3.8).

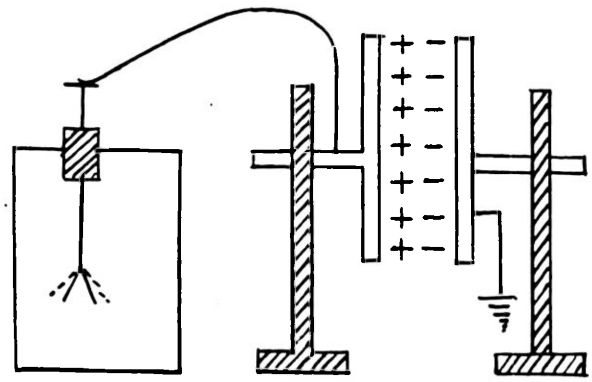


Fig 3.8 Earthed parallel plate capacitor

In the above capacity, a parallel plate capacitor has been formed which has one of its plates earthed. Any such arrangement of two conductors which stores electric charge is called a capacitor. The simplest type of capacitor is a parallel plate capacitor consisting of two plates.

Activity 3.8:

In this activity, use the parallel plate capacitor arrangement with one plate earthed as in activity 3.7. Move the earthed plate as shown in fig 3.9(a) so that the area of overlap increases.

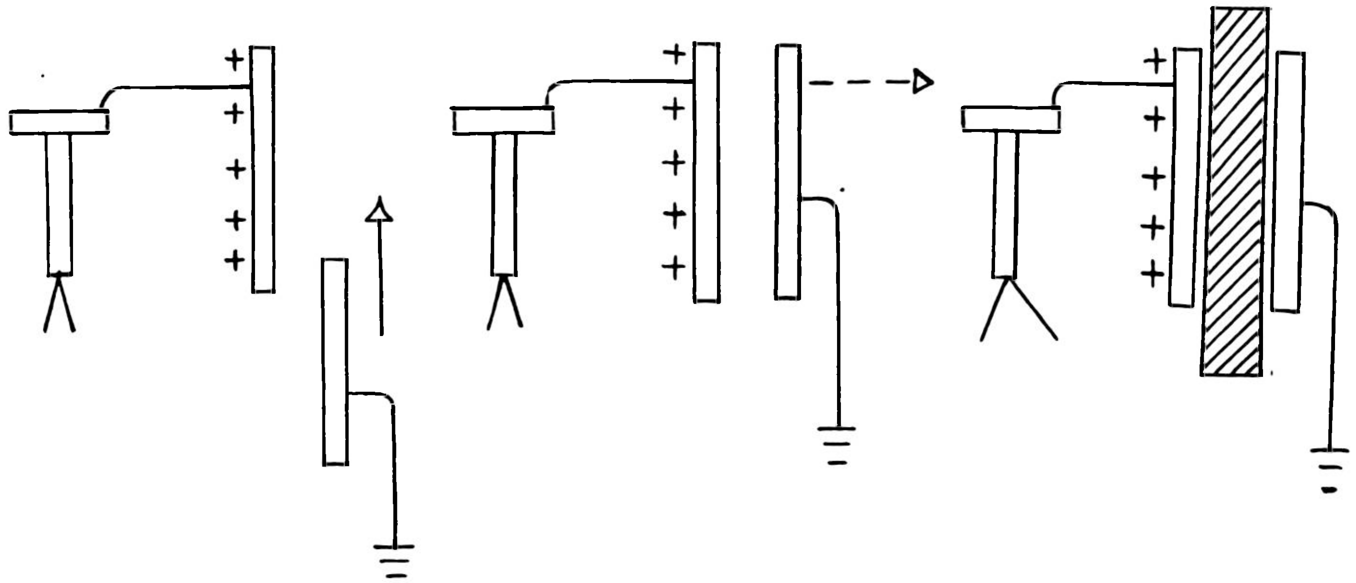


Fig 3.9 b   Factors affecting capacitance of a capacitor

Determine how the area of the plates affect the capacitance (Fig 3.9b). Now place the plates facing each other. Measure the distance between the plates and note the potential as indicated by the electroscope. Note the variation in potential as the distance between the plates is changed in steps of one cm. Find the variation of capacitance with the distance apart. Now repeat the above experiment by placing (i)a paraffin block (ii) a sheet of mica between the plates (Fig 3.9c). Note what happens to the divergence of the leaves.

The results of the above experiment indicate that the capacitance of a parallel plate capacitor increases directly with the area of overlap of the plates, inversely with the distance between the plates and also depends upon the material between the plates.

$C \propto A$

$C \propto 1/d$

or $C \propto A/d$ i.e. $C = K \varepsilon_0 \frac{A}{d}$

where K and ϵ_0 are constants. If there is vacuum between the plates of a parallel plate capacitor K = 1. The constant is called the permittivity of vacuum. K, the relative permittivity (dielectric constant) of a medium is also defined as the ratio of the capacitance of a given capacitor with the dielectric between the plates to the capacitance of the same capacitor with vacuum between them.

Current Electricity:

We define current as the rate at which charge flows.

$$\text{Current} = \frac{\text{charge}}{\text{time}}$$

The unit of current is the ampere. It is the current which corresponds to the flow of 1 coulomb of charge per second. The direction of the current is conventionally taken as the direction in which positive charges move to produce the observed current. Actual currents in conductors consist of the flow of electrons on a microscopic scale.

Activity 3.9:

Place a copper and a zinc plate in a beaker containing dilute sulphuric acid. Connect the terminals of copper and zinc plates to an ammeter and a switch as shown in the fig 3.10. Close the switch. The ammeter reading shows that current is flowing in the circuit.

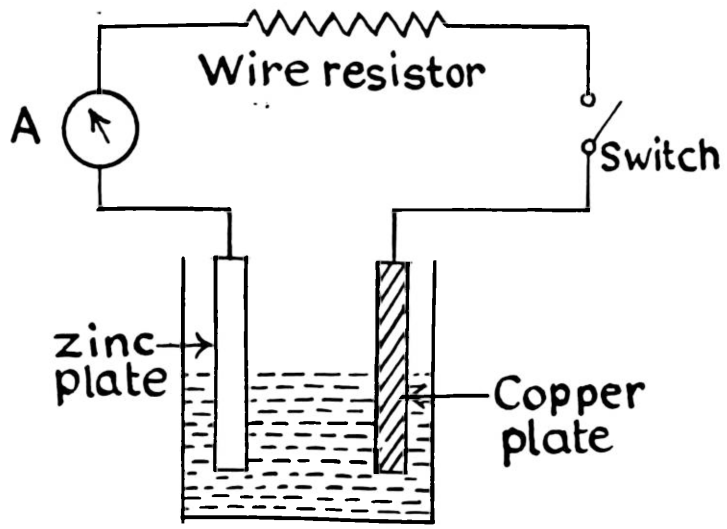


Fig 3.10 A simple primary cell

It can be explained as follows:
Sulphuric acid (H_2SO_4) when added in small amounts to water,dissociates as follows:

$$H_2SO_4 \rightleftharpoons 2H^+ + (SO_4)^{2-} \qquad (1)$$

when copper and zinc platesare introduced into this solution, the positive ions (two H^+ ions per molecule) and negative ions (one $(SO_4)^{2-}$ per molecule) in the solution near the plates react with the plates as follows:

a) $(SO_4)^{2-}$ ionises the zinc atoms (of the zinc plate), becomes zinc sulphate ($ZnSO_4$). That is $Zn = Zn^{2+} + 2e^-$

$$Zn^{2+} + (SO_4)^{2-} = ZnSO_4$$

The zinc plate is now left with $2e^-$ per molecule of $ZnSO_4$ formed.

b) The two H^+ ions, per molecule of H_2SO_4, ionises the copper atoms (of the copper plate. That is $Cu = Cu^{2+} + 2e^-$

$$2H^+ + 2e^- = 2H = H_2 \text{ (gas)}$$

The H_2 gas molecules, being very light (lighter than air), bubbles through the solution near the copper plate, copper, plate becoming positively charged. (One Cu^{2+} remains on the plate for every H_2 molecule formed).

So, the copper plate being positively charged will be at a higher potential than the zinc plate. The copper plate is called ANODE and the zinc plate is called CATHODE. When many molecules are involved in the above chemical reaction, a measurable potential difference is developed between the copper and zinc plates. When the cathode and anode are connected by a conductor (a wire) electrons from the zinc plate move towards the copper plate through the wire causing current. At the same time inside the cell, the chemical reaction drives the electrons from copper plate to the zinc plate. Thus a continuous flow of electrons is maintained both inside the cell and in the external circuit. It should be remembered that the flow of current in the external circuit is due to the potential differences whereas inside the cell it is due to the chemical energy. The electronflows from zinc to copper in the external circuit whereas inside the cell it flows from copper to zinc. In terms of conventional current that is the flow of positive charge, the current in the external circuit flows from a higher potential to a lower potential, but inside the cell it flows from a lower potential to a higher potential. The chemical reaction inside the cell drives the current from lower potential to the higher potential. This force is called the ELECTRO MOTIVE FORCE (e.m.f.) of the cell.

An analogy can be drawn between the action of a Voltaic cell and the pumping of water from a well, water is driven against the gravity by the pump and similarly, in the voltaic cell the current is driven against the potential gradient by the chemicalenergy of the cell.

Cells in Series and Parallel

Activity 3.10:

Very often in order to obtain large currents or longer e.m.f. it becomes necessary to combine a number of cells. Cells may be combined either in series or in parallel.

Connecta torch light bulb to a cell and observe the glow. Repeat the experiment using successively two cells and three cells in series connection as shown in Fig 3.11. It will be observed that the brightness of the glow increases. In the second and third case, the potential difference across the combination has increased and it will be equal to the sum of the p.d. of the individual cells. Therefore, in a series combination of cells, the voltage across the terminals increases.

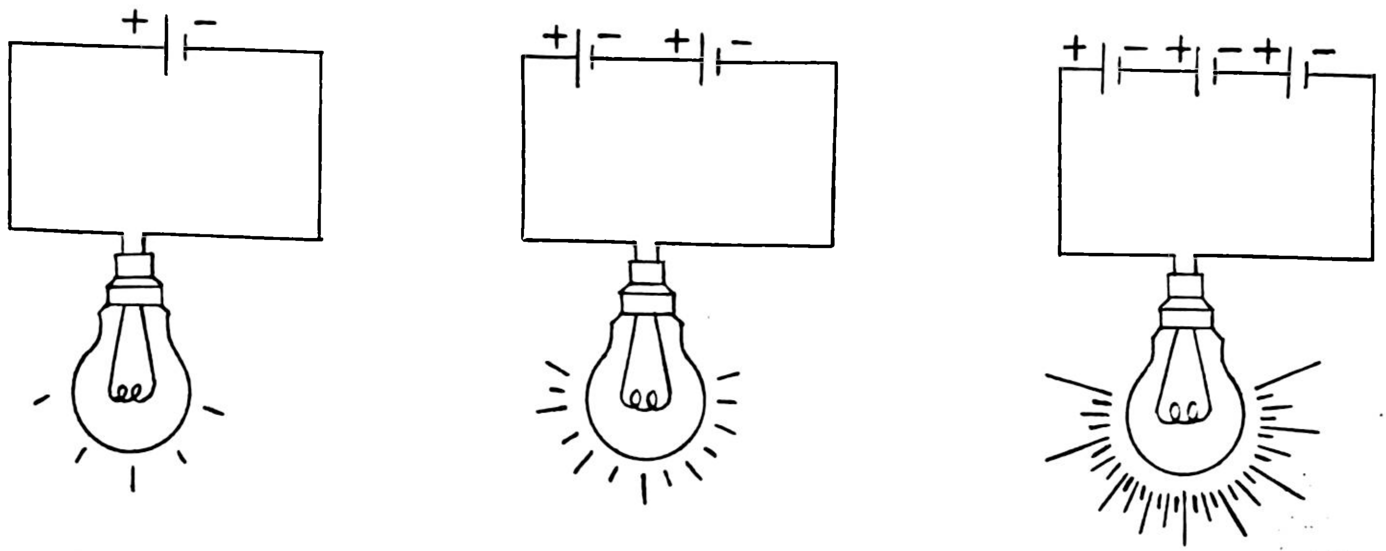


Fig 3.11 Cells in series

Assuming that the cells behave like electron pumps each cell aids in lifting the electrons to a certain level of potential energy. Hence, we can see that connecting the cells in series results in addition to the voltage of the cells. In a series connection the current inside each cell and in the external circuit is the same.

Now connect three cells of the same e.m.f. to a bulb and a key as shown in the figure 3.12 below. All the positive terminals are connected together and so also the negative terminals.

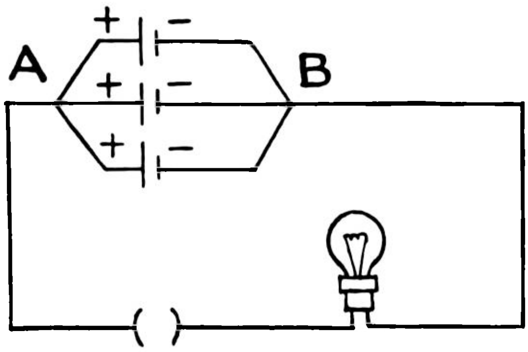
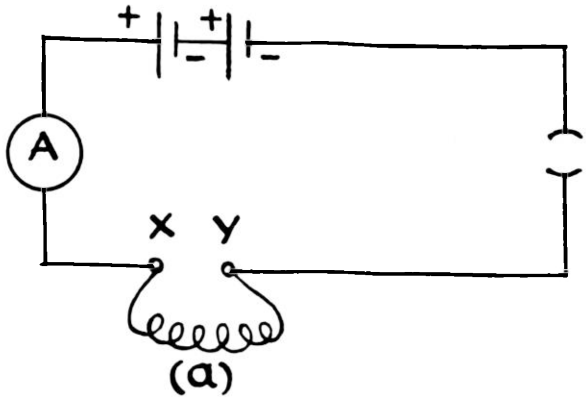


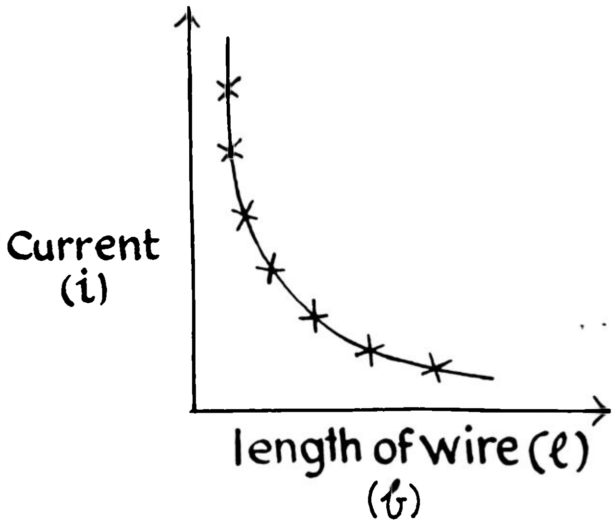
Fig 3.12 Cells in parallel

The cells are now said to be connected in parallel. From each cell there is a flow of electrons towards the junction B and all of them flow towards the positive terminal through the bulb. Hence the total number of electrons flowing through the bulb is the sum of the electrons due to the individual cells. Hence, in the case of a parallel combination the current in the external circuit increases. However, it can be shown that the e.m.f. of the combination will be the same as that of any one cell provided the resistance in the circuit is very large and cells have equal resistance.

Activity 3.11:

Connect a circuit as shown in fig 3.13(a) using a 4-volt accumulator. Across the gap connect nichrome wires of the same diameter but of different lengths one after another and record the current and lengths of the wires. Repeat the experiment this time using nichrome wires of same length but of different diameters. Repeat again the experiment using i) wires of different materials.





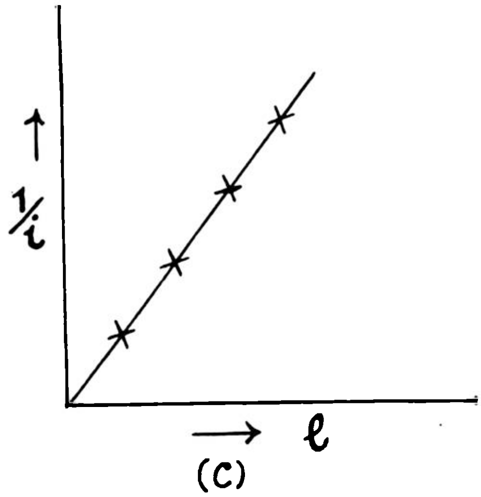


Fig.3.13(a) Circuit Diagram

Fig 3.13(b) Graph between length of the wire and the current flowing through it.

Fig 3.13(c) Graph of 1/i versus length of the wire

Draw a graph of length of the wire and the current flowing through the wire as in fig 3.13(b). It turns out to be a curve. Now plot 1/I against the length of the wire as in Fig 3.13(c). This turns out to be a straight line. Examine the readings obtained in the second experiment. It will be found that greater the diameter, greater the current. This shows that the resistance decreases with increase in diameter. The readings obtained in the third experiment will show that the resistance also depends upon the material of the conductor.

The results of the above activity show that the resistance of a wire

a) is proportional to the length of the wire.

b) decreases with increasing area of cross section.

c) depends on the material of the wire.

The relation between resistance and the above quantities was stated by Ohm as follows:

$$R = \rho \frac{\text{length of the wire}}{\text{area of cross section}} = \rho \frac{l}{A}$$

where ρ is called the resistivity of the material.

Activity 3.12:

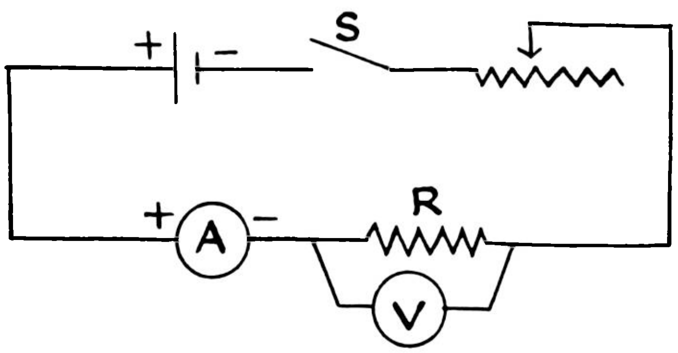


Fig 3.14 Verification of Ohm's law

Connect a 2 volt lead accumulator to provide the e.m.f. in the circuit shown infig 3.14. R is a resistance wire made of nichrome or manganin, 70 to 80 cm. in length and wound on a wooden cylinder without overlapping of turns. The ammeter has a range of 0-5A and the voltmeter a range of 0-5V. Close the switch and read the ammeter and voltmeter. Vary the current by adjusting the rheostat and note the ammeter and voltmeter readings. Repeat the experiment with different values of current and voltage. Record in a tabular form as shown below.

Sl No	Ammeter Reading (I)	Voltmeter Reading (V)	V/I = R
1			
2			
3			

Determine the ratio of the potential difference to the current. It turns out to be a constant for a given resistor.

V/I = constant

This constant is referred to as the resistance of the conductor. The unit of resistance is the Ohm.

In the above circuit, now replace the resistor by a bulb (12V) and a voltmeter with a range 0-15V. Repeat the experiment using a number of accumulators in succession. The brightness of the bulb increases as the voltage increases.

In this case, we find that the ratio V/I is not constant. We can, therefore, conclude that the constancy of this ratio depends on the temperature. Ohm stated the relation between the potential difference and the current flowing in a conductor in the form of a law. Ohm's law states that at constant temperature the current flowing through a conductor is proportional to the potential difference between its ends. According to this law, we have V = IR.

Activity 3.13:

Perform an activity combining two or three resistances i) in series ii) in parallel. Determine the effective resistance in both cases.

The effective resistance on combining resistors in series turns out to be the sum of the individual resistances i.e., $R = R_1 + R_2 + R_3 + \ldots$ and that in parallel $R^{-1} = R_1^{-1} + R_2^{-1} + R_3^{-1} + \ldots\ldots$

Activity 3.14:

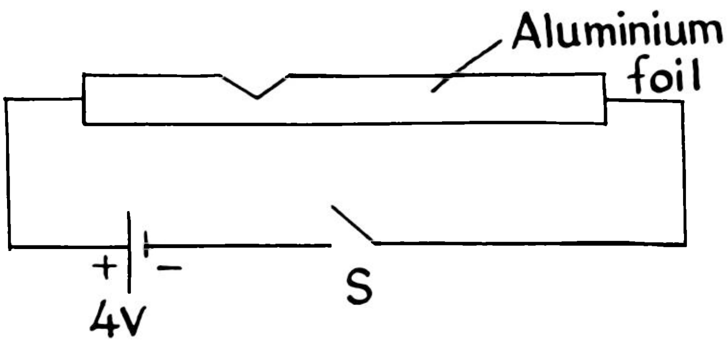


Fig 3.15 Heating effect of an electric current

Make a V-cut in analuminium foil and connect it to a 4V battery as shown in Fig 3.15. Switch on the circuit. The foil breaks at the V-cut. One can notice that heat is developed at the V-cut and this causes the foil to break. Maximum resistance is offered to the flow of current at the constriction due to the V-cut, and much heat is developed at this point. This shows that the flow of current through a conductor produces heat.

Activity 3.15:

Connect a circuit as shown in fig 3.16 using a coil of resistance wire of known length in the gap XY. Take 250 ml water of a beaker. Dip the coil in the beaker. Close the circuit. Pass current of 1A for 15 minutes. Note down the current, the potential difference across the coil and the final temperature of water. Using the same coil and taking the same quantity of fresh water in the beaker, repeat the experiment varying the current to about 1.5A but passing it again for 15 minutes. What do you observe? Similarly, repeat the experiment, but in this case, keep the current constant and pass the current for 15 min., 25 min. and 35 min. respectively. Repeat the first experiment also for coils of different resistances and using different potential differences.

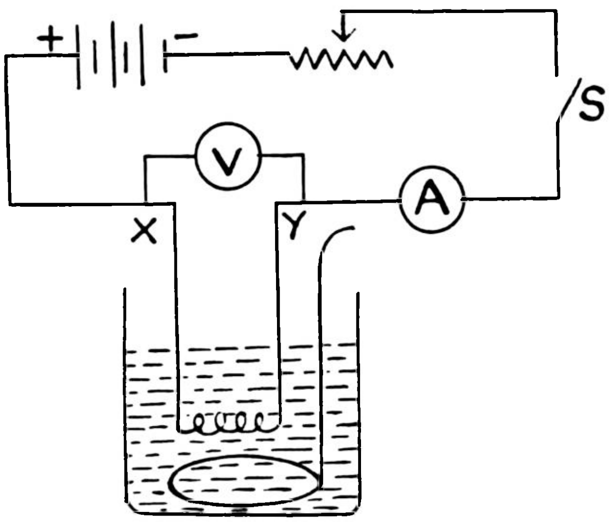


Fig 3.16 Joule's calorie meter

The results of the above experiment show that the amount of heat generated, Q, depends on the current, the potential difference and the time for which the current is passed.

$$Q = VI\ t$$

or $$\frac{Q}{t} = VI = I^2R$$

B. MAGNETISM

In the previous section, it was mentioned that the flow of an electric current produces a magnetic field. Now, we will investigate the properties of this field. Certain materials also produce magnetic fields and we call these materials magnets. We have temporary magnets and permanent magnets. Depending on their behaviour in a magnetic field the substances are classified as diamagnetic, paramagnetic or feromagnetic. Magnetic fields exert forces on current carrying conductors. They can produce electric current in a moving conductor. These and other interesting aspects of magnetism are discussed below.

3.2B TEACHING POINTS.

1. Magnets have the property of attracting iron filings and when suspended freely in air, they orient themselves along a particular direction.

2. The poles of a magnet are assumed to be near the two ends of the magnet where the force of attraction or repulsion is maximum.

3. Like poles repel and unlike poles attract.

4. North and south poles of a magnet are of equal strength.

5. Force acting between two magnetic poles depends upon the pole strengths and the distance between them.

6. A magnet gives rise to a magnetic field in the region surrounding it.

7. Lines of induction (lines of force) indicate the direction in which the magnetic force is acting: the tangent drawn to the line of force gives the direction of the magnetic field at that point.

8. The totalflux per unit area of cross section (magnetic flux density) is a measure of the magnetic field at that point.

9. Null points are points where the resultant magnetic field is zero.

10. Earth behaves like a magnet with its north seeking pole situated near the geographic south.

11. Magnetic field due to the earth at a given place (that is, in a small region) is uniform.

12. Electric current through a conductor produces a magnetic field.

13. A solenoid carrying a current behaves like a bar magnet.

14. A force acts between two parallel current carrying conductors.

15. A charge moving in a magnetic field experiences a force; which is perpendicular to both B and V

16. A current carrying coil experiences a torque when placed in a magnetic field

17. An e.m.f. is induced in a coil whenever the magnetic flux linked with it changes.

18. Materials are classified as dia, para and ferro magnetic depending on their magnetic properties.

19. A magnetic material consists of a very large number of tiny atomic magnets arranged at random.

20. Within the magnetic material groups of atomic magnets oriented in a particular direction constitute a domain.

21. In a permanent magnet, the domains are oriented in a particular direction.

22. The magnetism of a current carrying coil increases when its core is made of iron.

3.3 B DEVELOPMENT

Activity 3.16:

Spread out some iron filings on a sheet of paper. Take a bar magnet and tie it in the middle with an inelastic thread. Now holding the thread in hand, raise the magnet and place it on the iron filings spread on the paper containing the iron filings. When the magnet is raised again, you will notice maximum amount of iron filings sticking to the magnet at the two ends and practically nothing in the middle. This shows that in a magnet, the force of attraction of the iron filings is maximum at the two end-faces and practically zero at the mid-point. The poles of a magnet which are supposed to be responsible for the attraction of the iron filings are assumed to be located near the ends of the magnet.

The strength of the pole is denoted by m. It should be noted here that if one cuts a magnet into smaller and smaller pieces, then each piece will be found to be a magnet with two poles at its ends.

Will the pole strength of these smaller pieces be the same as the original magnet?

Activity 3.17:

When one suspends a bar magnet, it orients itself along a particular direction and the pole which directs towards the geographic north is known as north-seeking pole and the other south-seeking pole. Mark the poles. Mount a magnetic needle. Bring the north-seeking pole of the bar magnet near the north-seeking pole of a mounted magnetic needle. Notice the effect. Now bring the north-seeking pole of the bar magnet near the south-seeking pole of the needle.

What do you notice? Draw your inference.

MAGNETIC FIELD

Activity 3.18

Suspend a magnet from a wooden stand by means of a thread. Hold a small magnetic compass at different points around the magnet. i.e.at points lying sideways with reference to the magnet and above the magnet, as well as at points, the magnetic compass shows a deflection indicating that a magnetic force is felt in the region around the magnet. This region around the magnet has a special property, namely, a compass needle placed in this region shows a deflection indicating the presence of a force due to the magnet. We say that the magnet gives rise to a magnetic field in this region.

Will the deflection remain the same at all points? Perform this activity and draw inference regarding the nature of this magnetic field.

Activity 3.19

Suspend a bar magnet with the help of a wooden stand and thread. It comes to rest pointing North-South. A small wooden bench is placed near the north pole of the magnet along the east-west direction. The height of the bench must be the same as the height of the suspended magnet. Mark distances on the wooden bench, the distances being measured from the N-pole of the suspended magnet. A second magnet is placed on the bench with its N-pole at a distance 3 cm from the end of the suspended magnet. What do you notice?

Repeat with another magnet slightly stronger than the previous one but keeping it at the same distance of 3 cm.

Why does the magnet show a different deflection? Repeat with a third magnet at distances of 5 cm and 7 cm from the suspended magnet.

These two activities show that the force of repulsion depends on the product of pole strengths. Also the force is seen to decrease with the distance and it can be shown through more sensitive experiments that it is inversely proportional to the square of the distance.

$$F \propto m_1 m_2$$

$$F \propto \frac{1}{d^2}$$

$\therefore \quad F = K \dfrac{m_1 m_2}{d^2}$ where K is a constant. In SI units,

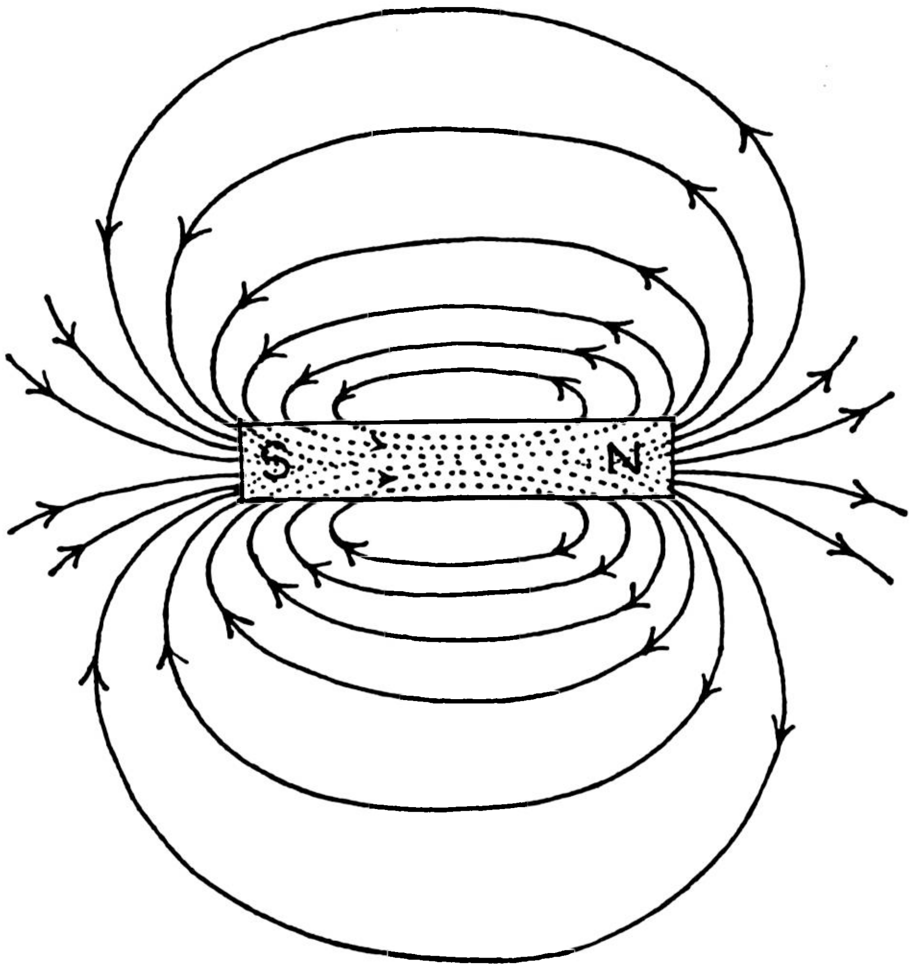
$$K = 10^{-7}\ N\ A^{-2}.$$

Will the magnetic field pass through glass sheet, wooden plate and books. etc.? Perform the above activity and see that magnetic field passes through these media but becomes weaker. We say that the permeability of the media are different and denote it by μ

Activity 3.20

Fix a sheet of paper on a drawing board. With the help of a pencil, mark the boundary of the bar magnet kept on the paper. Take a small compass needle and place it very close to the pole (N pole) of the magnet. Mark the positions of the north and south poles of the needle. Move the compass forward such that its south pole now occupies the position of its earlier north pole. Repeat the activity till the compass needle is shifted to the south pole of the magnet. These points can be joined by a free-hand curve and call such a line starting from the N pole as a line of force. (LINE OF INDUCTION). We may draw similar lines starting from a new point close to the N pole of the magnet. (Fig.3.17

When we study these lines of induction around a magnet, we notice that (a) the lines appear to originate from the north pole and move towards the



3.17 Magnetic lines of induction due to a bar magnet

the south pole. (b)The lines are more crowded at the two poles and less crowded elsewhere. (c)The lines show the direction in which the magnetic force is acting. (d)If one draws a tangent at any point to a line of force, the direction of the tangent will show the direction of the magnetic field at that point. The direction in which a north pole would tend to move along the line of force is taken as the direction of the magnetic field.

Will there be any lines of induction inside the magnet?

The study of magnetic properties of matter has made us conclude that these lines of induction pass through the south pole into the magnet and move towards the north pole. This means that the lines of induction are all closed curves originating from the north pole moving towards the south pole outside the magnet and then through the magnet moving towards the north pole.

Will any two lines of induction cross each other?

The very idea of lines of induction crossing each other makes us believe that magnetic field at a point will have more than one direction as one can draw tangents to two lines of induction at the point of intersection. This is not possible.

<u>Activity 3.21</u>

When we draw a number of lines of induction all round the magnet, we notice concentration of lines at the two poles and fewer lines of force at other points, Fig.3.17.

What does this concentration of lines of induction at the two poles indicate?

We have already seen that the magnetic force of attraction at the two poles is maximum. Evidently, the concentration of the lines of induction at the poles can be linked with the maximum force of attraction at the poles. The number of lines of induction across a unit area of cross-section can be taken as a measure of the magnetic field strength. The total number of lines of induction across a surface is generally called the magnetic flux denoted by Φ and the flux across unit area generally called the magnetic flux-density or simply magnetic induction. It is denoted by B and measured in Weber per meter^2 (Wb/m^2. In S.I. units, this unit is given the name Tesla.

Earth's Magnetic Field

Activity 3.22:

Fix a sheet of paper on a drawing board. With the help of a compass, mark the north-south direction at the centre of the paper. Place a bar magnet along this line with its north pole pointing north. Draw the boundary of the magnet. Start with a point close to the N pole of the magnet and draw lines of force with the help of a small compass needle. Draw a number of such lines of force all round the magnet. Start drawing a few lines of force away from the magnet on either side of the magnet. These lines which are almost parallel will be due to earth's field. If we move the compass needle from the mid point and normal to the bar magnet, it will be noticed that the direction of the compass needle changes suddenly at a certain point. Two such points on either side will be found for a bar magnet (fig 3.18).

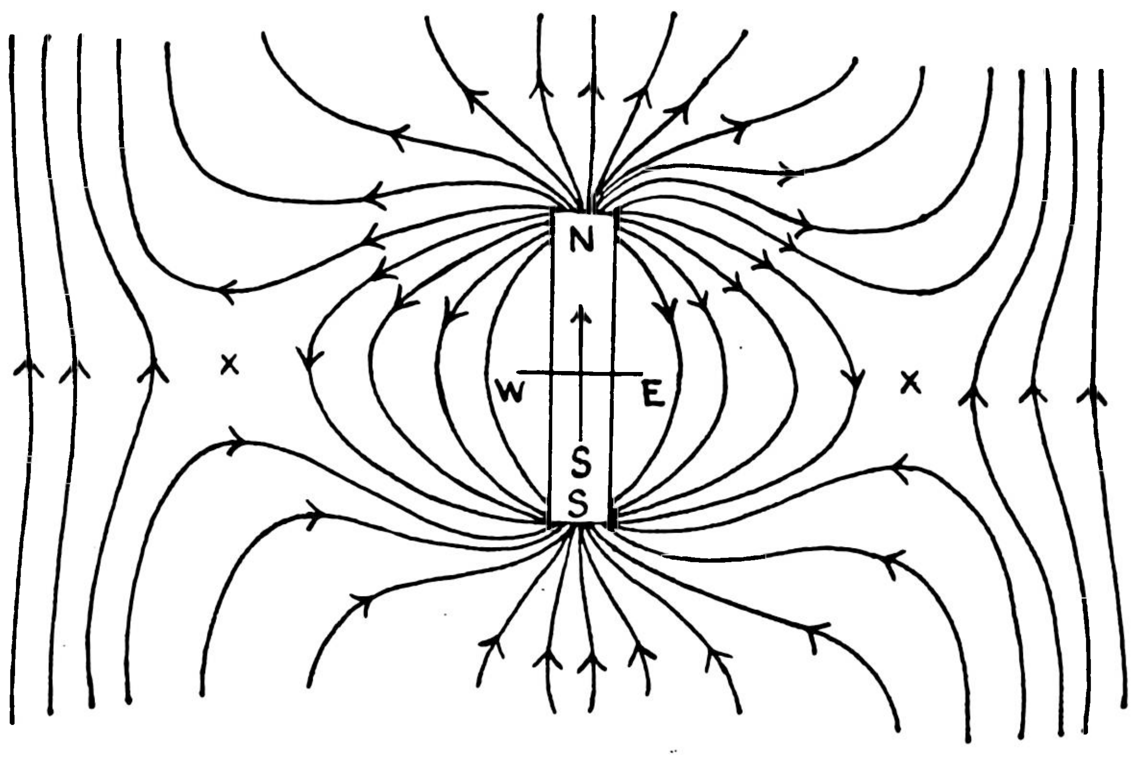


Fig 3.18 Null Points due to a bar magnet kept with its N-pole pointing north

These points are called null points since the resultant magnetic field at these points is zero. At the null points, the magnetic field due to the bar magnet and the earth's field are equal and opposite and the compass needle comes to rest in any direction since the resultant field is zero.

Now perform the same type of activity with a new sheet of paper but keep the bar magnet such that its north pole now points south and try to observe the null point.

Activity 3.23:

From the previous activity, we know that like poles repel and unlike poles attract. Why does a freely suspended bar magnet come to rest pointing north-south? This can be explained by assuming that the earth behaves like a magnet with its north-seeking pole situated near the geographic south and the south-seeking pole near the geographic north.

Activity 3.24:

Fix a sheet of paper on a drawing board. Mark about five to six points on the sheet at a distance of about 1 cm. Using a compass needle, draw a few lines of force of the earth's magnetic field. Take a compass and adjust its position such that one of its poles is at the first marked point. Mark the position of the other pole. Now move the compass such that its earlier pole is at the marked point. Repeat the activity and draw a line indicating the movement of north pole of the compass. Repeat the same with reference to the second, third, fourth and fifth marked points. These lines of induction of earth's magnetic field, will be found to be parallel to each other.

What does this indicate?

From the definition of magnetic flux density, i.e. , lines of induction across a unit area, one can infer that the earth's magnetic field at a given place is uniform.

Will the magnetic field remain the same at all places? Obviously not.

Magnetic Field of a Current Carrying Conductor

Activity 3.25:

Mount a magnetic needle on a pivot. It will point north-south. Take a copper conductor, about 50cm long. Holding it parallel to the magnetic needle and just above it connect its two ends to a pair of cells.

One will notice a deflection of the magnetic needle. Reverse the direction of the current.

Why does the deflection now change its direction?

Perform the same activity by keeping the wire close to but just beneath the needle. The deflection of the needle in all these cases will make one to conclude that an electric current in a conductor produces a magnetic field around the conductor.

Activity 3.26:

Prepare a solenoid by winding a thin copper DCC (double covered cotton), wire over a glass rod or a small test tube. Pass an electric current through the solenoid using a battery and an adjustable resistance (rheostat) and a key. If now one brings some iron pins near one end of the solenoid we may observe the attraction between the current carrying solenoid and iron pins; this will happen at the other end also. When no current passes through the solenoid one can see that the force of attraction ceases. This shows that a current carrying solenoid behaves like a magnet.

The direction of the field is given by Ampere's rule. Grasp the coil in the left hand with fingers circling the coil in the direction of the electron current. The extended thumb will point in the direction of the N pole of the core (fig 3.19).

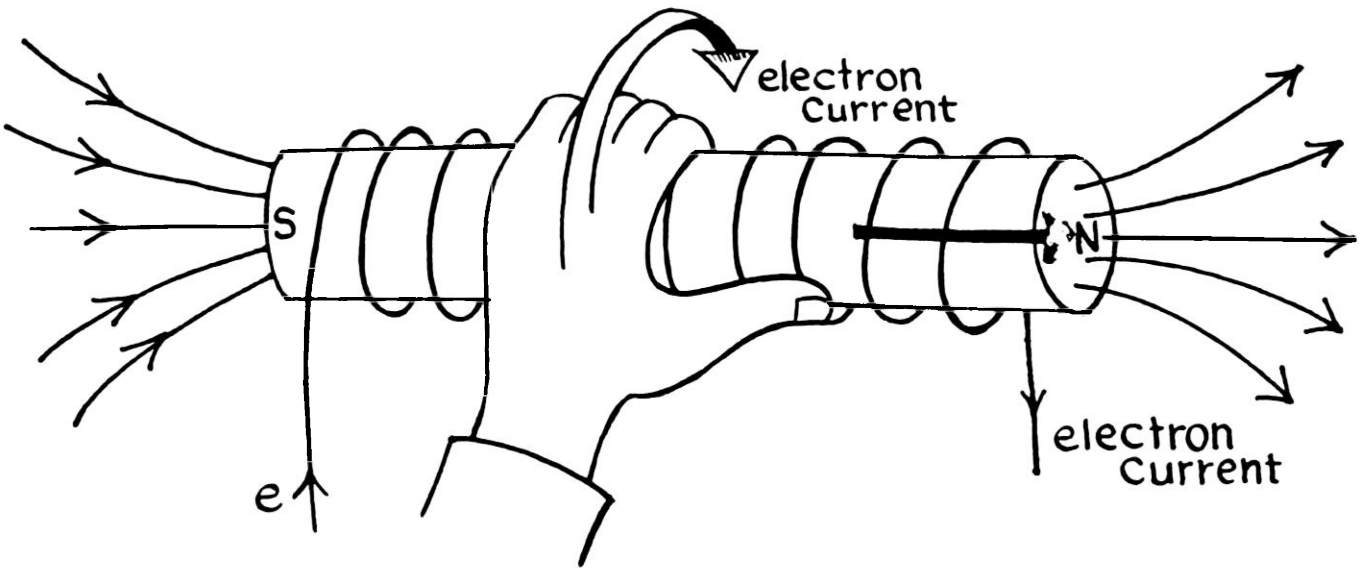


Fig 3.19 A current carrying solenoid

This activity, therefore, establishes a relationship between the magnetic field and the electric current. On account of this relationship, properties of magnetism are now-a-days explained in terms of current. The magnetic pole strength 'm' is also measured in Ampere-meter and magnetic moment in Ampere-meter^2. As in a bar magnet, the force of attraction is maximum at the two ends of the solenoid.

Activity 3.27:

We have seen that a current-carrying conductor produces a magnetic field and if a magnetic needle is kept close to such a conductor, it will show a deflection. Noting the direction of the deflection of the N pole of the magnetic needle, it is possible to fix the direction of the magnetic field. The following rule helps to obtain the direction of the field. If the wire is grasped by the right hand, with the thumb pointing in the direction of current, then the folding fingers point in the direction of the lines of force of the magnetic field. These will be concentric circles round the conductor (Fig 3.20).

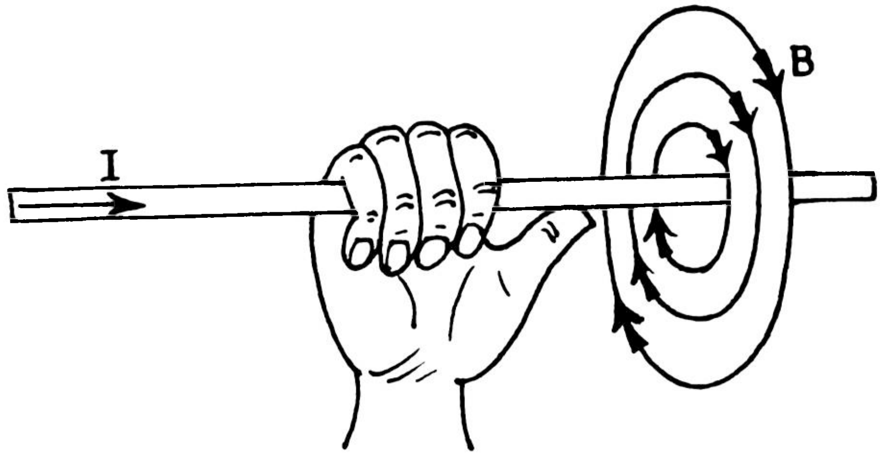


Fig 3.20 Magnetic field due to a current carrying conductor

We have seen that a freely suspended magnet will be deflected if another magnet is brought near it.

Will two current carrying conductors kept close to each other experience any force?

Since each of them behaves like a magnet, we may expect a force of interaction between them. The direction of the two magnetic fields due to the conductors will depend on the direction of the current. If the currents are in the same direction from the above rule, then their lines of force will be as shown in the fig 3.21.

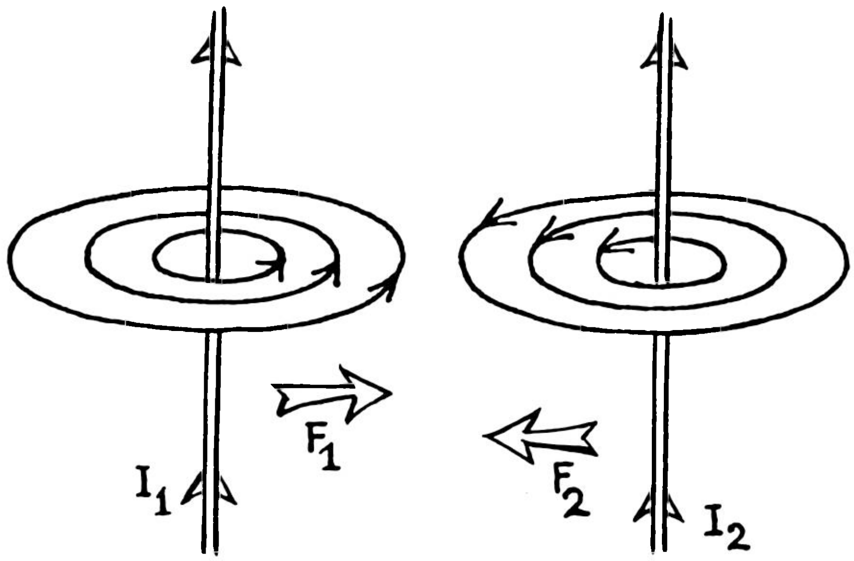


Fig 3.21 Attraction between two parallel wires carrying current

From this one can clearly see that there will be a force of attraction between the two conductors.

What would happen if the currents are flowing in the opposite direction?

Moving Charge in a Magnetic Field

Activity 3.28:

Take a cathode ray tube. The beam of cathode rays can be made visible using a fluorescent plate mounted close to the electron beam. Bring a bar magnet with its north pole pointing downwards. It can be seen that the beam now gets deflected at right angles to the magnetic field as well as to the original direction of flow of electrons.

If the electrons are moving towards the right (this is equivalent to movement of positive charge to the left) and the magnetic field is downward, then the force will be acting towards the observer. Refer to fig 3.22 to locate the direction of v, B and F. One can make use of Fleming's left-hand rule to determine the direction of the force. If the forefinger, the middle finger and the thumb of the left hand are stretched so as to be mutually perpendicular to one another and if the middle finger points in the direction of motion of positive charge, the forefinger in the direction of the magnetic field B, the thumb will indicate the direction of magnetic force F. Note that the force F will be perpendicular to both B and v. When B and v are perpendicular to each other, the force: on a charge q is given by Bq v (Fig 3.22).

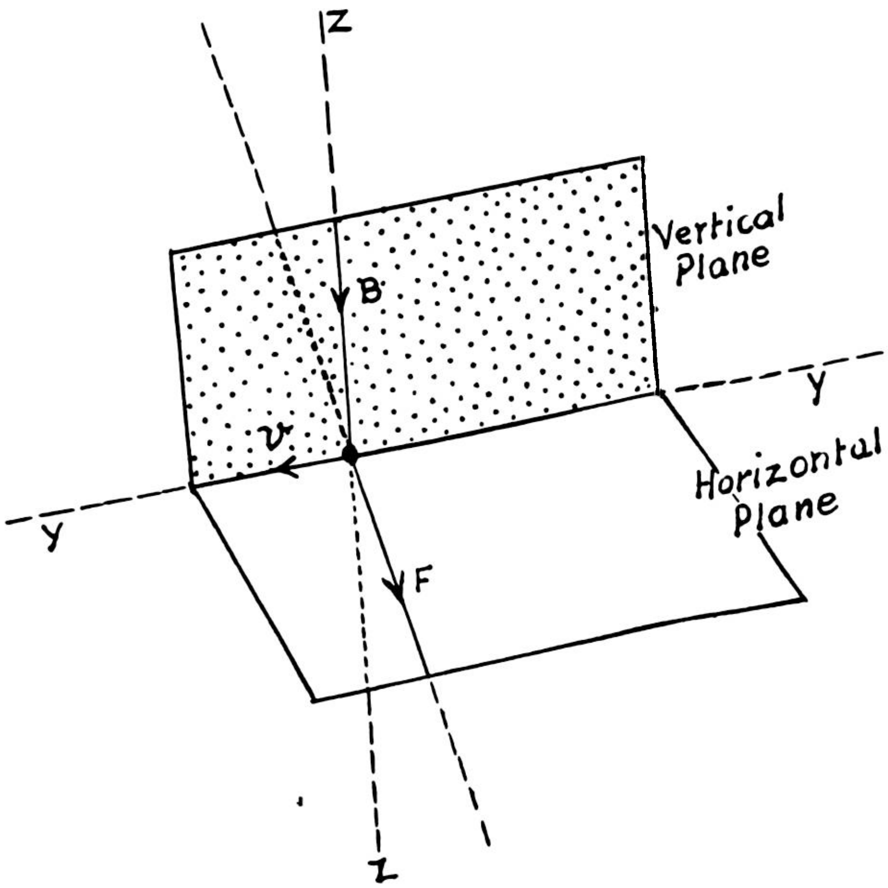


Fig 3.22 Force on a moving positive charge in a magnetic field

Activity 3.29:

Take an empty cigarette packet and cut out a width of about 1 cm. Over this, wind thin enamelled copper wire of about 10 turns. Suspend the coil with the help of a thin string, from a wooden stand. Mount two strong magnets on either side of the coil with opposite polarities facing each other and also in line with the coil. The pole faces must be normal to the cross-section of the coil.

Pass a current through the coil by connecting the two free ends of the coil to a pair of cells through a rheostat and a key. The coil gets deflected and will now orient itself making an angle with the magnetic field (Fig 3.23). Repeat the same activity with reverse current.

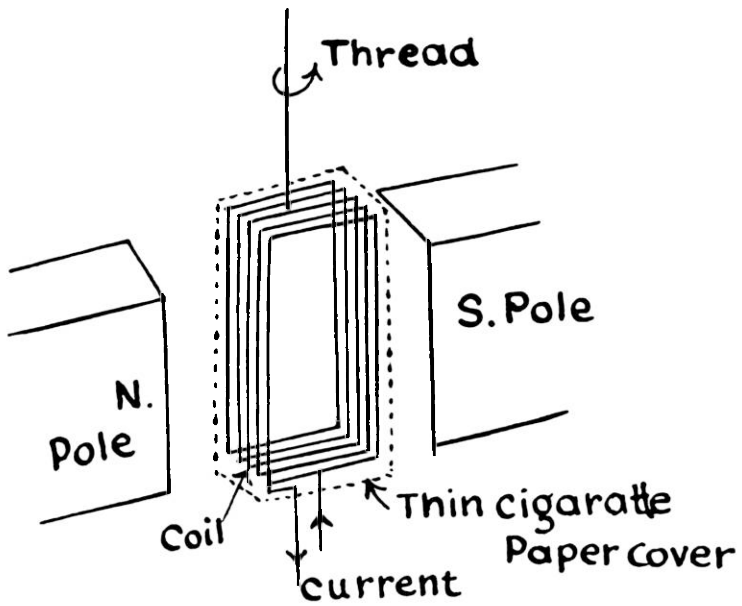


Fig 3.23 Tongue on a current carrying loop of wire kept in a uniform magnetic field.

How do you explain the deflection of the coil?

The current carrying conductor consisting of moving charges will experience a force due to the magnetic field produced by the magnets. Each element of the coil will experience a force due to the magnetic field, the direction of the force being given by Fleming's rule (Fig 3.24).

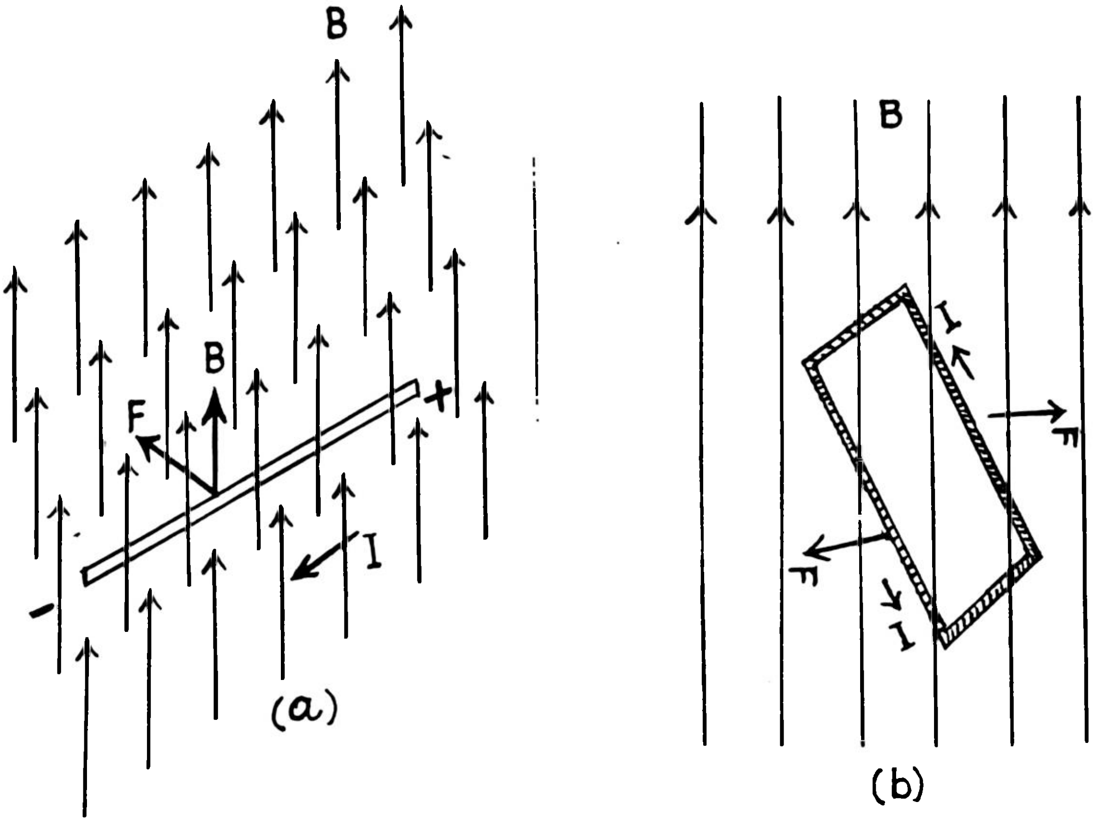


Fig 3.24 (a) Force on a current carrying conductor in a magnetic field

Fig 3.24 (b) Couple acting on a current loop kept in a uniform magnetic field

If we consider two such diametrically opposite elements they will experience equal forces but in opposite directions. These two forces give rise to a couple. Considering that the coil consists of many such elements, we can show that the coil as a whole experiences a torque. The coil gets deflected due to this couple and comes to rest when the torque due to the flow of the current is equal to the restoring couple due to the twist in the suspension. It has been found that this torque depends on the strength I of the current.

N, the number of turns of wire;
A, the area of the coil and
B, the magnetic field strength. Torque = NIAB

Current due to varying Magnetic Field

Activity 3.30:

Soon after the discovery that electric current in a conductor produces a magnetic field scientists wondered whether it is possible to produce current by using a magnetic field. Faraday discovered that when a bar magnet is moved rapidly through a coil of many turns, a current is produced in the coil, which could be detected with the help of a galvanometer. No induced current is produced if the magnet is kept stationary with respect to the coil. Similarly, when the magnet is moved in the backward direction once again current is induced in the coil but in the opposite direction.

Repeat the activity by keeping the magnet stationary and moving the coil rapidly towards the magnet or away from it. In this case also, a current is induced in the coil. One can infer that an e.m.f. is induced when there is a relative movement between the magnetic field and the coil. Faraday showed that this induced emf is directly proportional to the rate of change, of the magnetic flux linked with the coil. If Φ is the total flux linked with the coil, the emf induced in the coil is given by

$$\mathcal{E} = -\frac{d\Phi}{dt}$$

It should be noted that we are not getting induced emf for nothing. One cannot create electrical energy without doing work. Teachers may note that by thrusting the N pole of the magnet towards the coil, a current is induced in the coil. The coil in which a current is now flowing develops N polarity in the end initially closer to the N pole. There will be a force of repulsion and one has to do work against this force. Similarly, when one removes the magnet, we move the N pole in opposite direction which in turn produces a current in the opposite direction. This means you are producing S polarity on the end which had N polarity before. In all these cases, work is done against the force, (fig 3.25) .

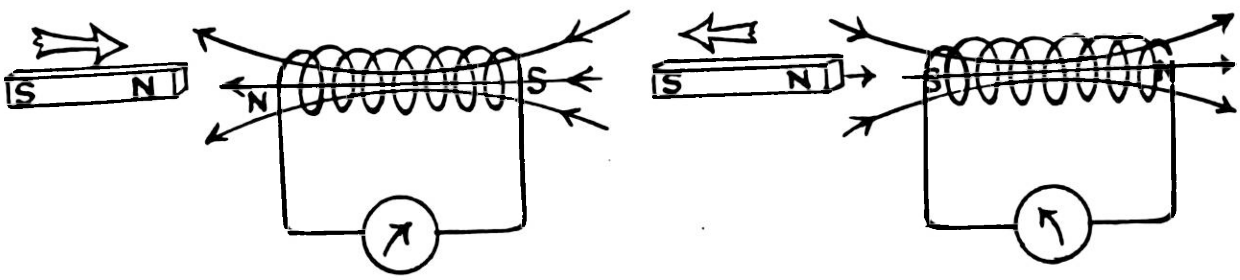


Fig 3.25 An emf is induced when magnetic flux linked with the coil changes

Another point to be noted is that from the point of view of conservation of energy, the induced emf has to be in a direction which tends to oppose the rate of change of flux.

Perform another activity using two independent coils lying close to each other. Connect one of them to a battery through a key and the other to a sensitive galvanometer. See that the coils are well insulated. Observe what happens when the primary circuit is closed and later when the primary circuit is opened (Fig 3.26).

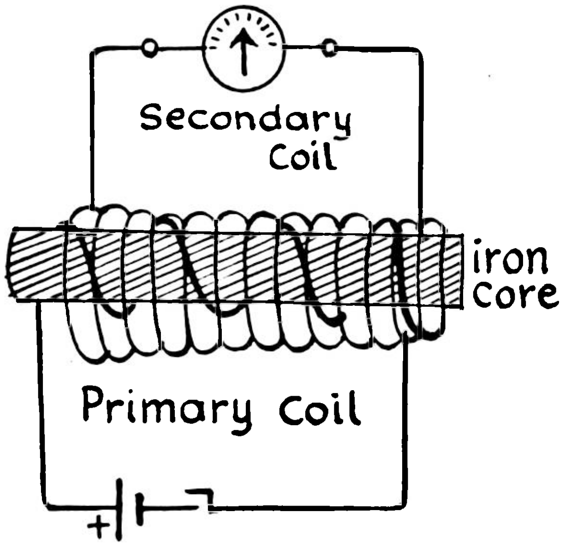


Fig 3.26 Induced emf in the secondary due to make and break of the primary circuit

Why does the galvanometer show a deflection only when the circuit is closed or when it is opened?

Dia-, Para- and Fero-Magnetism

Activity 3.31:

One wonders why an ordinary piece of iron is normally not a magnet but acquires magnetism when magnetised. All materials are electrical in nature. The structure of the atom shows that electrons revolve around the nucleus with very high speeds. In the case of hydrogen atom which is the simplest in structure the electron revolves in an orbit with a speed of about $2.2 \times 10^6 ms^{-1}$. The revolving electrons give rise to a current and on account of this current, a magnetic moment may be associated with the atom. This is referred to as the orbital magnetic moment. Similarly, scientists have shown that electrons possess 'spin' by virtue of which they contribute to magnetic moment. In some substances, the total magnetic moments-due to both the causes will be zero and they are called diamagnetic and in some cases, they give rise to weak magnetic moments due to 'spin' and they are called paramagnetic. But in the case of iron, the paramagnetic effect is highly enhanced due to the neighbouring atoms acting cooperatively. Such materials are called ferromagnetic substances. This results in the formation of DOMAINS, that is, assembly of group of atoms with their magnetic moments aligned. But in ordinary iron piece, these domains are randomly arranged. Once the iron piece is influenced by an external magnetic field, these different domains tend to align themselves in the direction of the external field (Fig 3.27).

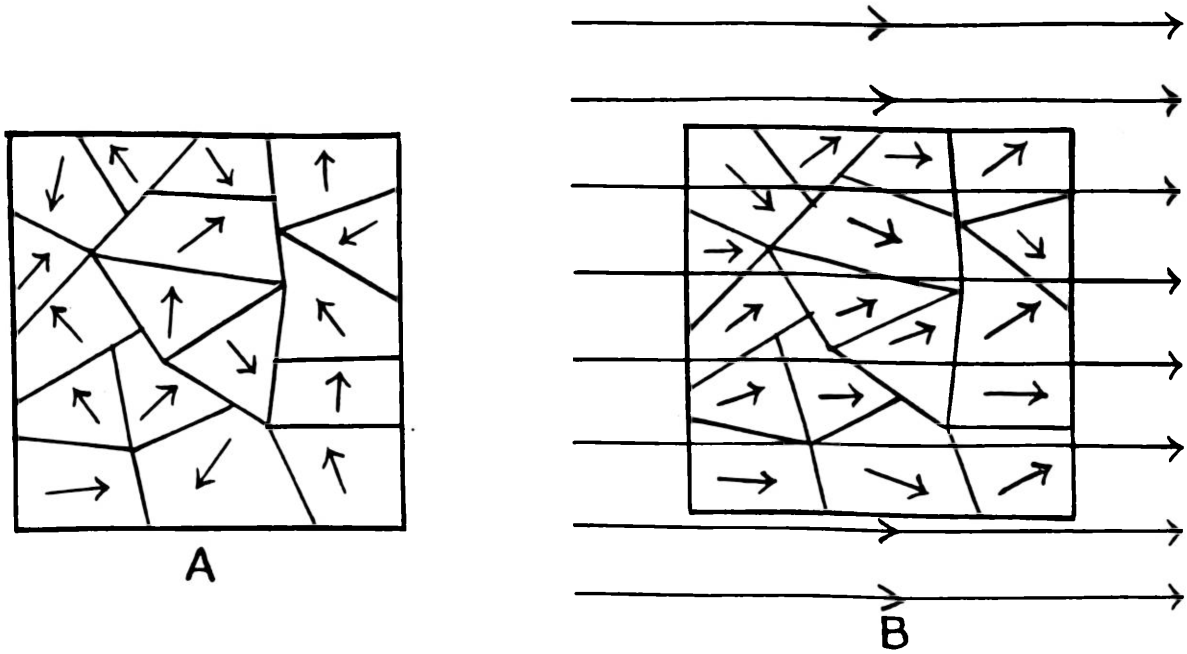


Fig 3.27 Domains in an unmagnetised iron sample

Electromagnetism

Activity 3.32:

Ordinary iron consists of very large number of domains. The magnetic moments within a domain are parallel to one another but different domains have their magnetic moments in different directions. In the presence of a powerful magnet the domains rearrange themselves such that they orient nearly along the direction of the external field. But once the external field is removed, the domains return to random orientation, and the piece of iron returns to the original position. This property has been used in the production of electromagnets.

In the case of steel, the picture is different. Once the domains orient themselves along the direction of external field, they try to retain that orientation unless subjected to mechanical stress, etc. Therefore, steel is used in the preparation of permanent magnets.

Activity 3.33:

We have seen that a solenoid behaves like a bar magnet when it carries a current. It can be shown that magnetic field strength increases tremendously if its core is made of iron. Prepare a solenoid by winding DCC copper wire over a small test tube. Wind a secondary coil (DCC) over the primary having slightly more number of turns per unit length. Connect the secondary to a galvanometer and the primary to a 2V cell through a key. Close the primary circuit and note the momentary deflection. Disconnect the primary. Now introduce an iron core into the test tube. Close the primary circuit. You will notice a larger deflection in the galvanometer. This activity shows that the induced emf in the secondary has increased due to the formation of strong magnetic field. The large change in the flux on introducing the iron core can be explained as being due to the high permeability of iron.

Additional activities to be performed:

1. Suppose you are given two identical iron rods, one of which is a magnet and the other ordinary iron. Without suspending or using other magnetic materials, how are you going to identify which one is a magnet?

   Hint: In a magnet, the attraction is maximum at the ends and least or practically nil at the middle point.

2. Trace the lines of force using a magnet and iron filings.

   Hint: For a good distribution of the iron filings along the lines of force, tap gently the board on which the magnet is kept and iron filings are spread.

3.4 EVALUATION

1. What type of charges are developed when an ebonite rod is rubbed with flannel?

2. When a hollow metallic sphere is charged from outside the charges will be distributed.

   a) on both the surfaces

   b) on the inner surface

   c) on the outer surface

   d) at the centre

3. When a hollow metallic sphere is charged through the inner surface of the sphere, the charges will be distributed

a) on both the surfaces

b) on the inner surface

c) on the outer surface

d) at the centre

4. Materials which freely allow electric charge to pass through are called

a) conductors b) insulators c) resistors d) capacitors

5. Slabs of materials with different dielectric constants (K) are placed in between the plates of a parallel plate capacitor. The capacitance of the arrangement is greatest

a) when the slab has K = 6.5

b) when the slab has K = 5

c) when the slab has K = 2

d) when there is no slab between the plates

6. If the distance between the plates of a capacitor is increased its capacity

a) increases b) decreases c) becomes zero.

d) remains unaltered

7. When two dry cells each of e.m.f. 1.5 V are connected in series then effective e.m.f. is

a) 3V b) 1.5V c) zero d) more than 3 V.

8. When two dry cells each of e.m.f. 1.5 V are connected in parallel then effective e.m.f. is

a) 3V b) 1.5V c) Zero d) more than 3V

9. When a metallic conductor is charged, the part with the pointed edges will have

a) a uniform charge density

b) small amount of charge density

c) no charge density

d) maximum charge density

10. A galvanometer is converted into an Ammeter by connecting a

a) high resistance in series with it

b) low resistance in parallel with it

c) high resistance in parallel with it

d) low resistance in series with it

11. When an electric current is passed through a conductor, the heat generated depends on the

a) square of the current

b) first power of the current

c) square of the e.m.f.

d) reciprocal of the current value

12. While transferring charges from a fully charged ebonite rod to an electroscope does it make any difference if the

a) tip of the rod touches the knob of the electroscope?

b) the whole rod touches the knob?

13. Determine the missing values for the Resistor, current, voltage in the table.

Sl.No.	R	V	I
1.	15	30	-
2.	15	-	3
3.	--	234	117

14. Which of the following statement is not true?

a) Insulator does not contain free electrons.

b) Some of the electrons in a conductor are free to move.

c) Conductors always contain more electrons than insulators.

d) Conductors are always solid metals.

15. A gold leaf electroscope is charged positively and its case is earthed. When a negatively charged rod is brought near the knob of the electroscope the divergence

a) decreases as the total charge on the electroscope decreases.

b) increases as the total charge on the electroscope decreases.

c) decreases as the potential difference decreases

d) increases as the potential difference increases

16. A parallel plate capacitor is charged and the charged plate is connected to a gold leaf electroscope. If a polythene block of dielectric constant 2.3 unit is introduced in between the plates of the capacitor without touching them, the divergence of the leaves will

a) increase as the capacitance increases.

b) increase as the potential increases due to an increase in its capacitance

c) decrease due to a fall in its potential

d) decrease as the total charge on the capacitor decreases

17. What is the difference between the lines of force around a horse shoe magnet and the lines of force due to earth's magnet?

18. What would happen if we pass an alternating current through a coil kept in a magnetic field?

19. A cathode ray beam is projected horizontally from left to right. A straight conductor is placed parallel to the beam. If a current is now passed from left to right through the conductor, what would happen to the electron beam?

20. State the principle of the working of a galvanometer.

21. The magnetic property of a matter is basically from the spin of the electrons, each spinning electron acting as a tiny magnet. What would happen if a pair of electrons spin in opposite directions?

22. If a coil of many turns is rotated rapidly in a magnetic field, it will produce an induced emf. What would be the nature of this induced emf?

23. While drawing the lines of induction of a magnet in the earth's field to locate the null points, we notice that the stronger the magnet, the null points will be

    a) farther away
    b) nearer
    c) unchanged
    d) farther on the N-side than on the S-side

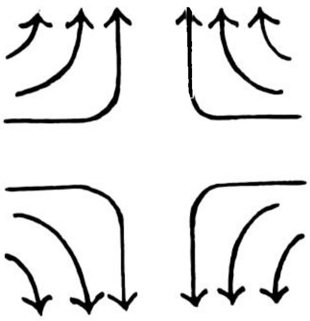
24. Magnetic lines of force due to a bar magnet are

    a) confined to a horizontal plane
    b) confined to a vertical plane
    c) around the magnet in all directions
    d) only along the magnetic meridian

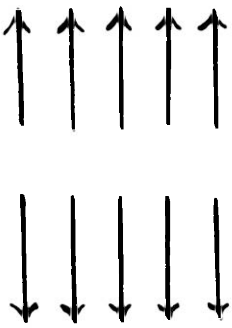
25. A magnetic needle comes to rest pointing N-S direction. If we perform the activity at the geographic north pole the needle will

    a) point N-S direction
    b) point in any direction
    c) be vertical with the N-pole upwards
    d) be vertical with the S-pole upwards

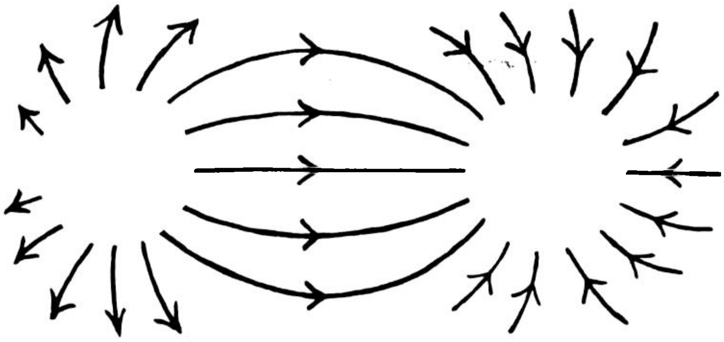
26. Note the markings of lines of induction as shown below (fig 3.28).



II



III



IV

The pattern that arises from two poles separated by a finite distances are

a) II only   b) II and IV only

c) IV only   d) III only

27. If two bar magnets of different lengths have equal magnetic moments then one can infer that

a) the shorter magnet is weaker

b) the shorter magnet must have greater pole strength

c) the longer magnet must have greater pole strength

d) the magnets have equal pole strengths

28. The earth's magnetic field can be explained in terms of

a) gravitational attraction between the earth and the sun.

b) cosmic rays coming from outer space

c) moving charges inside the molten core

d) radioactive substances inside the earth

29. When an unmagnetised iron bar is magnetised

a) electrons are added to it

b) poles are added to it

c) molecules of the iron arrange themselves along a particular direction

d) electrons are removed from it.

30. Current is nothing but flow of charges; so when a conductor carrying current I and of length l is kept in a magnetic field of induction B, it experiences a force which is given by

    a) B I newtons

    b) BIV newtons, V is the velocity of the charges

    c) BIl newtons

    d) Bql newtons, where q is the charge

31. A compass needle will be deflected if it is kept near a

    a) positively charged body at rest

    b) negatively charged body at rest

    c) charged body in motion

    d) chargedcondensor

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IV MODERN PHYSICS

4.1 INTRODUCTION

In this chapter, we deal with a few important topics of modern physics, such as the structure of the atom, X-rays, radio-activity and nuclear physics. The story of modern physics may be said to have commenced with the systematic study of discharge of electricity through gases at low pressure undertaken by Crookes and others during the last decade of the nineteenth century. This study finally led to the discovery of the electron by J.J.Thomson in 1897. This epoch-making discovery may be said to mark the beginning of modern physics. Almost at about the same time, the phenomena of radio activity and X-rays were discovered.

The discovery of the electron triggered off a number of investigations, both experimental and theoretical, which finally led to the emergence of a definite model of the structure of the atom. The investigation connected with the radio-activity of certain substances led to developments concerning the structure and composition of the nucleus. It was discovered that the nucleus consisted of protons and neutrons held together by a very strong binding force. The discovery of fission of uranium atom led to the development of the atom bomb and establishment of a number of nuclear reactors. All these and a few other important topics of modern physics are dealt with in this chapter.

A. ATOMICITY AND DISCHARGE OF ELECTRICITY THROUGH GASES

4.2 A TEACHING POINTS.

1. All substances are made up of minute particles called atoms.
2. An atom is the smallest particle of matter, which can exist alone or in combination with others of the same or another element.
3. A molecule is the smallest particle of an element or compound capable of stable independent existence..
4. At ordinary pressures, gases do not generally conduct electricity.
5. At extremely low pressure gases can be made to conduct electricity by the application of high voltage.

6. Ions are formed when an atom loses or gains one or more electrons.

7. The formation of ions results in the flow of electricity through gases.

8. In a discharge tube, cathode rays are emitted perpendicular to the surface of the cathode.

9. Cathode rays consist of a stream of electrons.

10. An atom consists of a positively charged nucleus surrounded by electrons.

11. The hydrogen atom contains one proton and one electron.

12. The maximum number of electrons in any shell of the atom is equal to $2n^2$ where n is the quantum number of the orbit.

13. The nucleus of an atom contains neutrons, in addition to protons, the total number of nucleous-neutrons and protons-being given by the mass number.

14. The number of protons in the nucleus gives the atomic number; the number of electrons in the un-ionised atom will be equal to this number.

15. The atomic mass unit is equal to 1/12th of the mass of the carbon-12 (C^{12}) atom.

4.3 A DEVELOPMENT

Activity 4.1:

The lesson may be started by having a discussion on the size of the things around us. One can start by comparing the size of an ant with that of an elephant. We can proceed further by comparing the sizes of a grain of sand with a mud particle or a fine dust particle. Show the students samples of fine saw-dust, (these may be collected from a saw-mill of your town) and ask the students these questions. What is saw-dust? How is it obtained? What is the fine dust particle? They would be able to infer that saw-dust is nothing but a collection of many minute particles of wood.

Activity 4.2:

Imagine that we are breaking up crystals of sugar or crystals of salt into smaller bits. If the process is continued we get smaller and smaller parts. If we imagine the process to be continued further we will reach the stage of the smallest unit which will retain the properties of sugar/salt.

This unit will not retain the characteristics of sugar/salt if divided further. This smallest unit of a substance which is capable of stable independent existence is called a molecule. In the earlier example of saw-dust each of the particles can be divided further andwe are bound to reach the stage of the "molecules".

Activity 4.3:

Ask the question - What is a molecule? Surely we cannot say that a molecule is the ultimate stage in the division of matter.

Imagine now, that we are dividing a sugar molecule. It will be found that it consists of particles of three simple elements. The individual particles of these elements are called atoms. Thus, it is possible to observe that sugar contains atoms of carbon, hydrogen and oxygen. An atom is the smallest particle of an element. Atoms can exist either alone or in combination with other atoms of the same or of another element.

Activity 4.4:

Can we see an atom or a molecule with our naked eyes? They are too small to be seen by even the most powerful optical microscope. Imagine that we magnify a drop of water, which really consists of a very large number of molecules, to the size of the earth. Then each of the molecule of water would be about one meter in diameter. (For a discussion on the size of the molecules, and for an estimation of its size see "Physics Resource Material" Vol.II Activity 17.9.

Since atoms make up molecules we would expect atoms to be smaller in size than molecules. The hydrogen atom which is the smallest has a diameter of about 0.8 Å ($1\ \text{Å} = 10^{-10}$ m). The size of other atoms varies from about 1.5 Å to 4.5 Å in diameter.

Model of the Structure of the Atom:

The conclusion that electrons are present in all kinds of matter (Refer to the following section of Discharge of Electricity Through Gases), that is, in all kinds of atoms, raises the question of the composition and structure of the atom. Normally, the atoms are electrically neutral, and therefore, it is obvious, that, in addition to the electrons, there must be within the atom another constituent part which carries the requisite amount of positive charge. The electrons contribute very little to the mass of the atom, and, therefore, this constituent part must be relatively massive. The mass of an electron is 9.109×10^{-31} kg and that of a proton is 1.673×10^{-27} kg.

How are the electrons and the positively charged massive part arranged within the atom? Almost immediately after the discovery of the electron, Thomson put forward a model for the structure of the atom in which he said that positive charge is uniformly distributed inside the atom. Thomson's model held the field till 1911. This model was found unsatisfactory, because of its inability to account for the occurrence of discrete lines in the spectrum of hydrogen, helium and other elements.

The experiments conducted by Rutherford and his collaborators during the years 1911-13 on the scattering of α-particles by thin metal foils led to a very important conclusion. The results of the experiment established the fact that inside the atom, the positively charged massive portion of the atom is concentrated within an extremely small region and that the electrons lie distributed in some manner around this region. After this, one could say that the atom consists of a centrally located nucleus surrounded by electrons.

Bohr's Model of the HydrogenAtom:

The exact configuration of the nucleus and the electron was elucidated in the case of hydrogen by Niels Bohr in the year 1913 by introducing some new concepts and postulates. According to Bohr, the hydrogen atom consists of a centrally located nucleus carrying a single unit of positive charge with an electron going round the nucleus in a circular orbit of suitable radius. On the basis of this model, Bohr was able to explain the occurrence of four spectral lines - H_α, H_β, H_γ and H_δ - in the visible portion of the spectrum of hydrogen. The nucleus of the hydrogen atom was found to be an elementary particle of mass 1.672×10^{-27} kg carrying a positive charge of 1.602×10^{-19} coulomb. This particle was called the proton.

Distribution of electrons inside the atom:

Bohr's theory of the hydrogen atom served as the starting point for the subsequent attempts to elucidate the structure of more complex atoms. As a result of these attempts, it became clear that the atom of an element consists of a nucleus carrying a positive charge +Ze, and Z electrons distributed around the nucleus in circular orbits where 'e' stands for the charge on the electron, and 'Z' denotes the atomic number of the element. The electronic orbits within the atom are characterised by a certain quantum number 'n' and are referred to as shells. It can be shown that the maximum number of electrons which can be accommodated in a shell is equal to $2n^2$. According to this formula, the first shell can accommodate a maximum number of 2 electrons, the second shell a maximum number of 8 electrons, the third shell a maximum number of 18 electrons and so on.

The nucleus of the atom:

Mass of an atom is practically equal to the mass of its nucleus.

Except in the case of hydrogen, the 'Z' protons in the nucleus cannot fully account for the mass of the nucleus. Thus, if we consider an atom of oxygen of mass number 16, its nucleus contains 8 protons; these eight protons will approximately contribute 8 units of mass on the atomic mass unit scale, leaving unaccounted another eight units of mass. From this, it is obvious that the nucleus must contain, in addition to protons, another type of particle which contributes to the mass but are electrically neutral. This type of particle appropriately named neutron was discovered by Chadwick in 1932. With the discovery of neutron, it became clear that the nucleus consists of protons and neutrons. The number of protons in the nucleus of an atom will be equal to the atomic number Z, and the number of neutrons will be equal to (A-Z) where 'A' is the mass number.

Nuclear Force:

Protons and neutrons within the nucleus are together referred as nucleons. These nucleons, 'A' in number, lie together in an extremely small region of the size of 10^{-15} metre. Extraordinary strong forces acting between these nucleons hold them together within the nucleus. These forces are called nuclear forces. In the case of protons, these binding forces are capable of overcoming the strong electrical forces of repulsion between a proton and a proton. It is to be emphasised that these binding forces are short-range forces operating over extremely short distances. They are independent of the charge and nature of the particle.

The atomic mass unit:

The masses of the individual atoms are usually expressed in terms of what is known as the atomic mass unit (a.m.u). Now-a-days instead of the mass of the oxygen atom O^{16} the mass of the atom of the carbon isotope C^{12} is taken as the standard and 1/12th of the mass of the atom of this isotope is taken as the atomic mass unit. On this scale, the mass of the hydrogen atom is equal to 1.007826 a.m.u. The value of one a.m.u. is equal to 1.660×10^{-27} kg.

Activity 4.5:

Use two or three torch light cells each of 1.5 V) and a torch light bulb to make a circuit as in Fig 4.1.

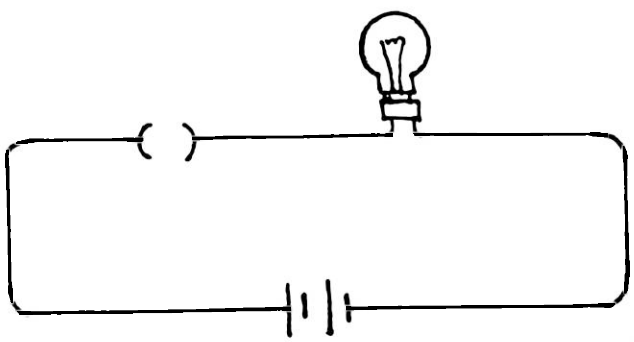

Fig 4.1 A simple circuit - When the switch is closed the bulb glows

When the switch is closed, the bulb glows and the students infer that a current passes through the circuit.

Activity 4.6:

Use the same components as in Fig 4.1, but now take out the key and dip the two open ends of the wires in a beaker containing freshly prepared distilled water. (If insulated wires are being used, remove the insulation from the ends of the wire). Now, the bulb does not glow.

Add a few drops of dilute sulphuric acid (H_2SO_4). Now the students see that the bulb glows, which indicates a flow of current through water. What causes the conduction now? Pure water does not conduct electricity. When sulphuric acid is added, water conducts electricity due to the presence of positive and negative ions.

What will happen if the twoends of the wires are kept in an empty beaker separated by a distance? Now the medium is air. Ask the students to predict the result. Later perform this activity and show that ordinarily air does not conduct electricity.

Discharge through Gases:

Discuss how the possibilities of a 'conduction' through air under conditions which are not 'normal'. What happens in a lightning?

In lighting an enormous electric discharge takes place between two clouds which are oppositely charged and this discharge is due to a very large potential difference existing between the two clouds. It is possible to produce such a discharge in the laboratory between two charged electrodes.

Towards the end of the last century, a systematic study of discharge of electricity through gases was undertaken by Sir William Crookes. The experimental set up consisted of a long glass tube about 4cm in diameter and 1.5m long with two electrodes fitted at the ends. Through a side tube air was continuously evacuated using a vacuum pump. The two electrodes were connected to the secondary terminal of an induction coil. The induction coil could give voltage upto fifteen thousand volts. Fig 4.2.

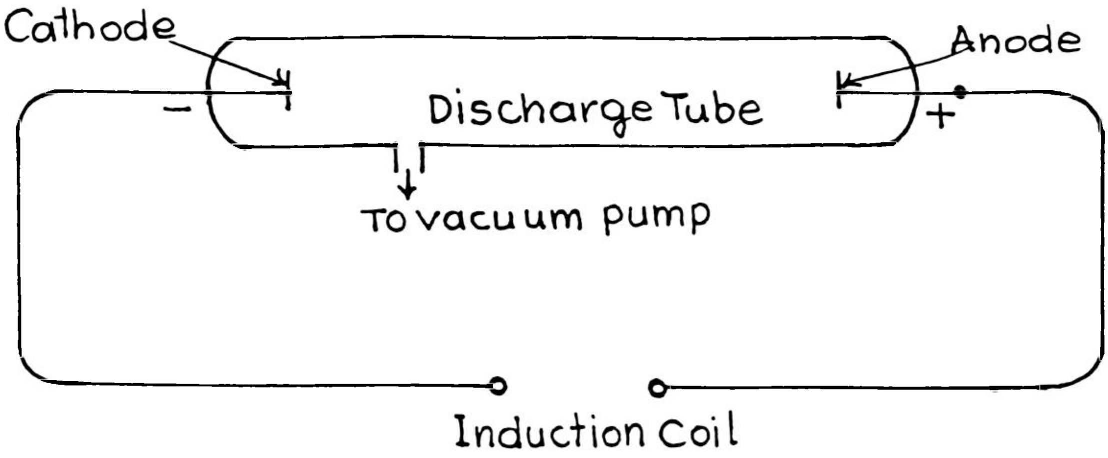

Fig 4.2 Schematic diagram of a discharge tube experiment

Activity 4.7:

Set up the above apparatus with a tube of length 0.5 m. As the air inside is slowly being pumped out the following effects takes place.

The first discharge in the form of long, thin, bluish coloured streamers occurs when the pressure is about 8 mm of mercury (Fig 4.3a). At a pressure of about 5 mm of mercury, the colour of the discharge changes to pink (Fig 4.3b) and it also widens and fills the tube. At a still lower pressure of 2 mm a dark region appears near the cathode (Fig 4.3c). This splits the discharge into a long pinkish section and a short bluish section near the cathode with a dark space in between. The former is called the positive column and the latter, the negative glow.

The dark space is called the Faraday Dark Space. As the pressure drops still further, the Faraday dark space grows in size and the negative glow moves away from the cathode. The new dark space appears between the cathode and the negative glow. This second dark space is known as 'Crooke's dark space'. It is also seen that at this stage, the positive column divides into a number of equally spaced layers. These layers are called "striations". As the pressure is reduced further, the Crookes dark spacewidens. At a pressure of about 0.01 mm, the Crooke's dark space fills the entire region between cathode and anode and the whole tube glows with a faint greenish light.

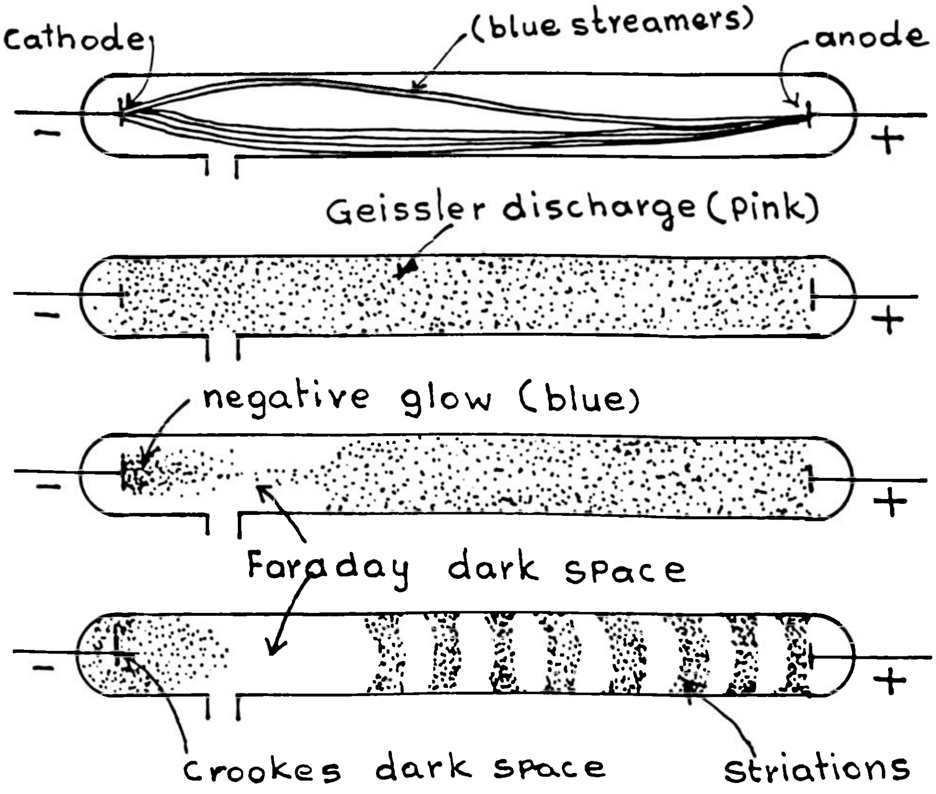

Fig 4.3 The different stages in the discharge of electricity through gases
a) At a pressure of the order of 8 mm of mercury
b) At a pressure of the order of 5 mm of mercury
c) At a pressure of the order of 2 mm of mercury
d) At a pressure of the order of 0.01 mm of mercury

This greenish glow obtained during the final stage (at pressures of about 0.01 mm) is due to the fluorescence of the glass tube. It was thought that the fluorescence was due to some kind of rays coming from the cathode. These rays were called "cathode rays". In this case, the conduction of electricity from one electrode to the other is due to the formation and movement of ions in addition to the movement of electrons. The extremely low pressure of the gas and the high voltage between the electrodes cause the electrons to become energetic. Due to collisions between the electrons and the atoms the atoms lose one or more electrons and become ions.

Cathode Rays:

Having discovered the "Cathode rays", the next important task is to establish the properties and nature of these rays. With the help of a Crooke's discharge tube, some of these can be demonstrated.

Cathode rays travel in straight lines. The Crooke's tube will be very useful for this demonstration. An object in the form of a cross kept in the path of the cathode rays casts a clear shadow on the wall of the glass tube.

The cathode rays have momentum and kinetic energy. To demonstrate this, Crookes made the following modification in the tube. A pin-wheel was supported on two long rails. If the wheel is pushed gently, it will roll over the rails from one end to the other. This assembly was introduced into the discharge tube. It was found that the cathode rays striking the wheel made it to roll over the rails towards the anode. From this experiment, Crookes concluded that the rays possess momentum and hence, kinetic energy.

In the year 1895, the French scientist Jean Perrin investigated the nature of cathode rays. He obtained a thin pencil of cathode rays by placing a narrow slit near the cathode. A long fluorescent screen is kept inside the discharge tube in such a way that the cathode rays graze the screen; this makes the path of cathode rays visible. The rays travel in straight lines. When Perrin brought a magnet near the beam of the cathode rays as shown in the fig 4.4, the beam was deflected downward.

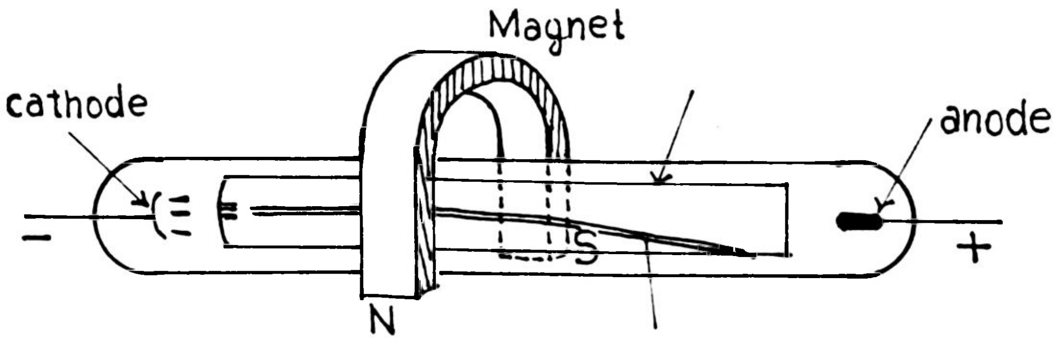

Fig 4.4 Deflection of Cathode rays in a magnetic field

We have seen earlier that only a beam consisting of charged particles can be affected in this way. Light and other electromagnetic radiations do not show this behaviour. Thus, Perrin was able to prove that the cathode rays consist of charged particles and further, from the direction of deflection he inferred that these particles are negatively charged.

J.J.Thomson used both electric and magnetic fields to study the deflection of these particles and was able to measure the ratio of charge to mass of the particles. Using different materials as electrodes and using different gases inside the discharge tube he was able to establish that this ratio has the same value in all the cases. From these results, he was able to establish that these particles are present in all kinds of matter. He called these particles 'electrons'. We may now conclude that the so-called cathode rays are nothing but a stream of fast moving electrons.

The discharge tube used by J.J.Thomson is schematically shown in fig 4.5.

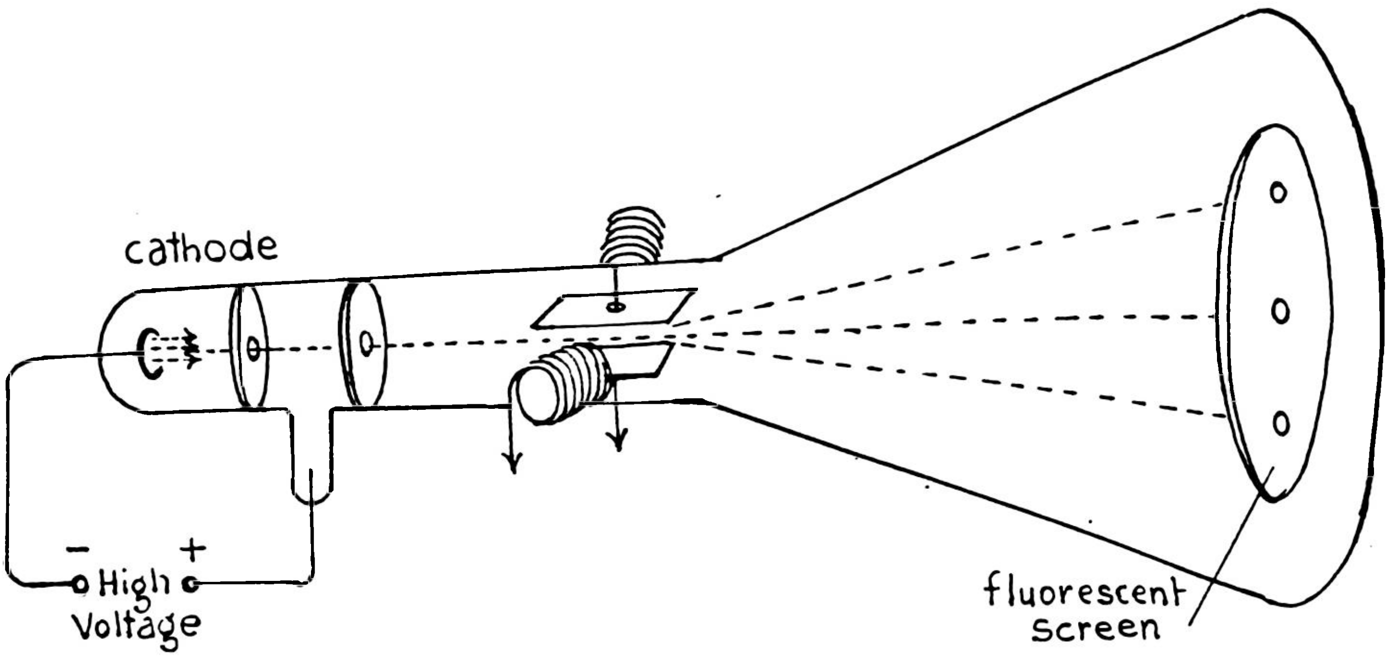

Fig 4.5 Diagram of discharge tube used by J.J.Thomson to measure the velocity of cathode rays

Subsequent to the discovery of the electron, the value of e/m (charge to mass ratio) has been determined very accurately by various methods. The currently accepted value of the e/m of electrons is 1.759×10^{11} coulomb per kilogram. The charge on the electron can be determined by Millikans oil-drop experiment. It is equal to 1.602×10^{-19} coulomb (abbreviated asC). Knowing the value of e and of e/m, one can calculate the value of m, the mass of the electrons as $m = 9.108 \times 10^{-31}$ kg.

B. X-RAYS

4.2B TEACHING POINTS

1. When the fast moving electrons are suddenly stopped by heavy metals, X-rays are produced.

2. X-rays are electromagnetic radiations of very short wavelength.

3. X-rays are capable of penetrating through matter.

4. X-rays cause ionization when they pass through matter.

4.3B DEVELOPMENT

Activity 4.8:

Collect some X-ray photos of bone fracture. Explain why some parts of our body are transparent, and some parts are opaque to ordinary X-rays.

In 1895, Rontgen, a German scientist experimenting with a discharge tube of high vacuum of the order of 0.01mm and more found, to his great surprise, that a fluorescent screen in the neighbourhood of the tube became luminiscent as though exposed to ordinary light. Likewise a photographic plate lying nearby was affected, although it was wrapped up completely in black paper. interposing a thick plate between the tube and the fluorescent screen, a dark shadow was produced on the screen. Substances such as paper, wood and thin aluminium sheet cast less distinct shadows on the screen. Rontgen attributed these effects to some kind of invisible rays given out by the discharge tube. Since the nature of this radiation was unknown, he called them X-rays.

Production of X-rays:

It is found that whenever fast moving electrons are stopped by metals X-rays are produced. One generally obtains fast moving electrons in discharge tube by subjecting them to a very high accelerating voltage. When these energetic electrons strike a metal target and are brought to rest, considerable amount of heat is generated. The target metal, therefore, must have a high melting point. Cooling arrangements are also made by circulating running water.

If the voltage applied to the X-ray tube is very high, then the X-rays of short wavelength and high intensity are produced. These X-rays are known as hard X-rays. If the voltage applied between the cathode and anode is less, soft X-rays are produced. The nature of the X-rays also depends upon the target used in the X-ray tube.

COOLIDGE TUBE

In 1913, Coolidge designed a new type of X-ray tube which superceded the earlier type of tube used by Rontgen and others.

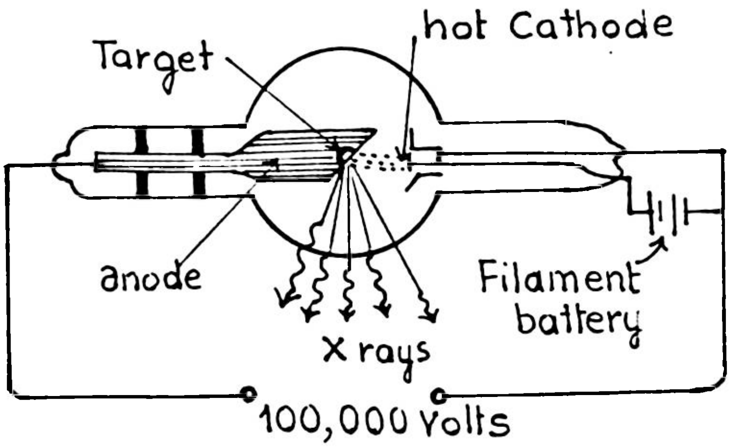

Fig 4.6 Coolidge Tube

The cathode is a filament of tungsten F heated by a small battery B and made to emit thermionic electrons Fig 4.6. These electrons are accelerated by means of a high potential difference maintained between F and the target T. The tube is evacuated to a high vacuum, of the order of 0.001 mm. The fast moving electrons striking the target produce X-rays. Usually, the filament is placed inside a metal cup G for focussing electrons onto the target. The target is fixed to a copper rod which projects outside the tubeand is water cooled, since there is a considerable development of heat when the tube is operated for a long time.

X-rays are electromagnetic radiations. This is evident from the fact that they are not deflected either by electric or magnetic fields.

Properties and Uses of X-rays

These rays are capable of penetrating through solid matter, such as paper, wood, flesh, thin sheets of metals, etc. But the penetration is poor in the case of materials like bone, brass, steel, gold,etc. Depending on the penetrating ability of these rays, they are divided into soft X-rays and hard X-rays. Generally voltages varying between 50,000 volt and 100,000 volt applied between the filament and the target gives rise to soft X-rays. Higher voltages of the order of 10^6 volt are required for producing hard X-rays. The wavelength of X-rays are from 10^{-8} to 10^{-12} m.

When X-rays pass through gases they cause ionization. When they are allowed to pass through a charged electroscope, the leaves collapse suddenly. This can be explained on the basis of the ionization of air caused by X-rays. Continuous exposure of skin to X-rays causes burns or wounds.

Uses of X-rays:

1. By means of X-ray photographs, we can detect malformation, fracture of bones, development of malignant tumours and presence of foreign bodies. Soft X-rays are used for these purposes.

2. Cancer and skin diseases of certain types can be cured by exposing the affected portion to X-rays.

3. X-rays are useful in determining the structure of crystals.

4. Very hard X-rays (also Gamma rays) are used in industry for detecting defects in metal castings.

C. RADIO ACTIVITY AND NUCLEAR ENERGY

4.2 C ~~CONCEPTS~~ TEACHING POINTS.

1. Radioactivity is a spontaneous and irreversible kind of nuclear activity.

2. Certain heavy nuclei exhibit spontaneous radio activity.

3. Radio active substances emit three types of radiations α and β particles and γ rays.

4. α particles or α rays are helium nuclei.

5. β particles or β rays are fast moving electrons.

6. Emission of an alpha particle results in a nucleus with the atomic number reduced by two and mass number reduced by four.

7. Emission of a beta particle results in a nucleus with atomic number increased by unity but mass number remaining the same.

8. The time taken for the radioactive substance to decay to one-half of its original number of atoms is the half-life period of that substance.

9. Mass can be converted to energy.

10. The difference between the mass of the nucleons in the nucleus and the mass of the nucleus is a measure of the binding energy of the nucleus.

11. A uranium nucleus capturing a neutron breaks up into two different nuclei, with the release of a large amount of energy.

12. Release of energy from nuclear fuel due to fission can be controlled.

13. Moderators slow down the neutrons released in a nuclear fission.

14. The nuclear reactors are suitably shielded for protection from radiation hazards.

4.3C DEVELOPMENT

Discovery of Radio-Activity:

In 1896, Henri Becquerel, a French scientist found that the uranium ore (pitchblende gives off an invisible radiation which affects an unexposed photographic plate. Elements which spontaneously emit such radiation are called radioactive substances.

Elements with atomic number greater than 83 exhibit the property of radioactivity. Even elements with lower atomic number, viz. sodium, potassium, rubidium, etc. can be made to show radio-activity. This kind of radio activity is called induced radio-activity. Radio active substances emit three distinct kinds of radiation, known as the alpha (α), beta (β) and the gamma (γ) radiations. Radio activity is a spontaneous nuclear activity unaffected by an external agent whether physical or chemical.

The fact that radio-active substances emit three different kinds of radiation was established by Rutherford by conducting a simple experiment. A narrow beam of rays from a sample of radius was obtained by placing it at the bottom of a hole drilled in a block of lead. This beam was subjected to the action of an electric field/magnetic field. It was found that some rays were bent to the left, some to the right while some were not bent at all (Fig 4.7). This shows that the beam consists of (i) a group of positively charged particles called α rays (ii) another group of negatively charged particles called β rays and (iii) yet another group which is neutral called γ rays. From a study of the extent of deflection one can infer that the α particles are much heavier than the β particles.

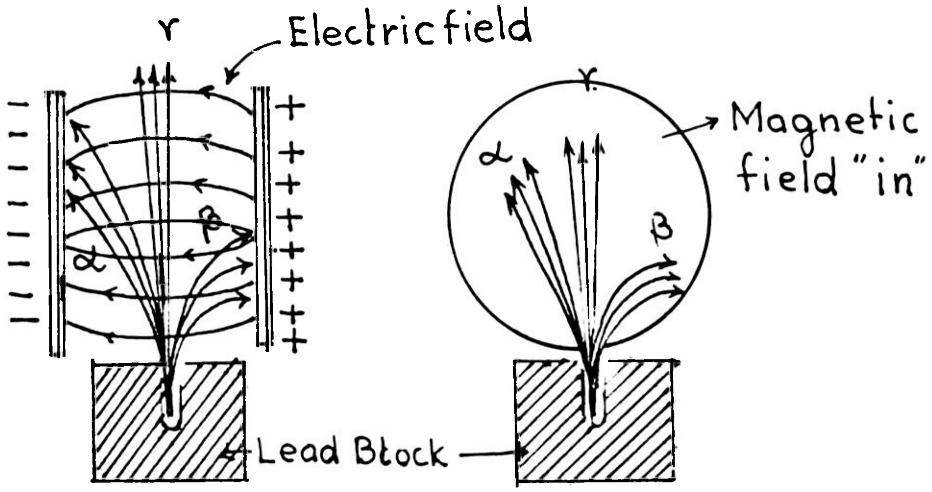

Fig 4.7 Deflection of α, β and γ rays in an electric and a magnetic field

Alpha Rays:

These are positively charged particles. It has been established from experiments that α particles consist of two protons and two neutrons. Thus they can be considered as the nuclei of helium atoms. When a radio active element emits an α particle, a new nucleus whose atomic mass is less by 4 units and atomic number less by 2 units, is formed. For example, when radium (${}_{88}Ra^{226}$) emits an α particle, it becomes randon ${}_{86}Rn^{222}$).

$${}_{88}Ra^{226} \longrightarrow {}_{86}Rn^{222} + {}_{2}He^{4}$$

The mass of an α particle is 6.664 x 10^{-27} kg , a mass four times that of the hydrogen atom. They travel a few centimetres in air and a few tenths or hundredths of a millimeter through solids before being absorbed. While passing through air or a gas, α particles cause ionization, the extent of this ionization being much greater than that produced by the other two rays. The velocity of α particles is about 2 x 10^7 m/s i.e. nearly 1/15 of the velocity of light.

Beta Rays:

These are negatively charged particles, having the same charge and mass as that of an electron. They have more penetrating power as compared to α rays but less ionising power (about 1/100). Beta rays come out with a very high velocity, comparable to that of light and in some cases, it is as high as 0.99 times the velocity of light. When a β particle is expelled a new nucleus whose mass number is the same as the original atom but whose atomic number is greater by one unit is formed. For example, when lead isotope $_{82}Pb^{214}$ emits a β particle it becomes bismuth $_{83}Bi^{214}$.

$$_{82}Pb^{214} \longrightarrow {}_{83}Bi^{214} + e^-$$

Gamma Rays:

These are electromagnetic waves having wavelengths shorter than those of X-rays. They have very poor ionising power and a very high penetrating power. They are capable of penetrating several centimetres of lead without being absorbed.

When excited nuclei come down to ground state they emit γ -rays

$$_{38}Sr^{87*} \longrightarrow {}_{38}Sr^{87} + \gamma$$

Radioactive Disintegration:

The nuclei of radioactive substances undergo decay at random. However, for any radio-active substance, the rate of decay, i.e. the number of nuclei which disintegrate per second is proportional to the number of radio-active nuclei present at that instant.

If N be the number of radio-active atoms at any instant t, then the rate of disintegration is proportional to N. i.e. $-\frac{dN}{dt} \propto N$

or $\frac{dN}{dt} = -\lambda N$ where λ is a constant.

λ is called the decay constant or disintegration constant.

Half-life Period:

The half-life period (T) is defined as the time in which half the original radio-active nuclei decay into new nuclei. (Fig 4.8). The half life period is related to the decay constant by the formula $T = \frac{0.693}{\lambda}$. The half life of radium $_{88}Ra^{226}$ is 1600 years while that of bismuth $_{83}Bi^{210}$ is 5 days.

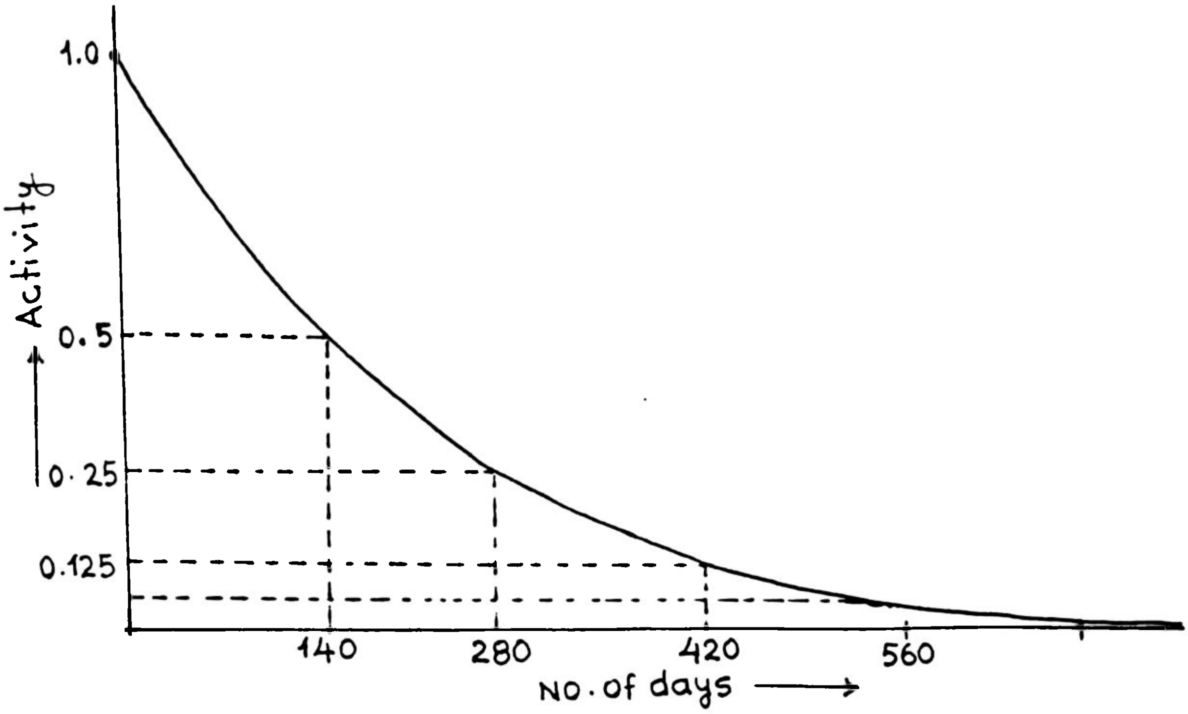

Fig 4.8 Radioactive decay curve

Unit of Radio Activity:

The Curie is the unit of radio-activity and is defined as the quantity of any radio-active element in which the number of disintegrations per second is 3.7×10^{10}.

1 Curie = 3.7×10^{10} disintegrations/sec.

1 millicurie (1mc) = 10^{-3} curie

1 microcurie (1 μc) = 10^{-6} curie

Table 4.1 Half-life Period of some Elements

Mass Number	Atomic Number	Element	Radiation	Half life
238	92	Uranium	α	4.5×10^{9} years
234	90	Thorium	β	24.5 days
234	91	Protoactinium	β	1.14 min.
234	92	Uranium	α	3.0×10^{5} years
230	90	Thorium	α	8.3×10^{4} years
226	88	Radium	α	1600 years
222	86	Radon	α	3.82 days
218	84	Polonium	α	3.05 min.
214	82	Lead	β	26.8 min.
214	83	Bismuth	β	19.7 min.
214	84	Polonium	α	10^{-6} sec
210	82	Lead	β	22 years
210	83	Bismuth	β	5 days

Activity 4.9:

About 1000 small wooden cubes are made and one of the six faces of each cube is painted. They are placed in a large box and jumbled. They are thrown on a table. Collect the cubes with the painted face up and count them. The remaining cubes are placed in the box, jumbled and thrown on the table. Again as before the cubes with the painted surface up are counted. The process is repeated until there are no more cubes. A graph is plotted by taking the number of cubes collected every time along the y-axis and the number of the trial conducted on the X-axis. The curve obtained is called a distribution curve. A similar graph can be obtained in the case of the decay of a ratio active element. Such processes are called random events.

MASS DEFECT

Einstein established the mass-energy equivalence, this equivalence being given by the relation $E = mc^2$ where E is the energy, m is the mass and c the velocity of light. This disclosed the possibility of mass being converted into energy and vice-versa. Such a possibility is actually realized in a number of nuclear phenomena. In fact, we may say that many of the present day developments relating to structure of nucleus, stability, fission and fusion processes are due to a knowledge of this mass-energy equivalence.

Activity 4.10:

In the bombardment of lithium by protons, helium nuclei are formed according to the following equation.

$$_1H^1 + {_3Li^7} \longrightarrow {_2He^4} + {_2He^4}$$

The sum of the masses of the two helium nuclei is smaller than the sum of the masses of the proton and the lithium nucleus.

Mass of $_1H^1$ + mass of $_3Li^7$ = 1.007825 + 7.016005 amu = 8.023830 amu.

Mass of two helium nuclei = 2(4.002604) amu = 8.005208 amu.

Mass defect = 0.018622 amu.

This mass gets converted into energy. Convert this mass into kg and using the relation $E = mc^2$, calculate the energy into joules (1 amu = 1.660×10^{-27} kg).

Activity 4.11:

The nucleus of the ordinary hydrogen consists of a single proton. The nucleus of deuterium, an isotope of hydrogen, consists of a proton and a neutron. The sum of the mass of the two is equal to 2.016490 amu, but the actual mass of the deuterium nucleus is equal to 2.014103 amu. We thus see that in this case, there is difference between the sum of the masses of the nucleons, and the mass of nucleus formed by the nucleons. This is also true of the helium nucleus, which consists of 2 protons and 2 neutrons. The mass of the two protons is equal to 2.015650 amu and the mass of two neutrons is equal to 2.017322 amu. The total mass of the four nucleons is 4.032972 amu. But the mass of the helium nucleus is equalto 4.002604 amu. In this case also, there is a mass defect. This is, in general, true of all nuclei. The difference between the mass of the nucleus and the sum of the masses of the nucleons which go to make up the nucleus is called the mass defect.

Earlier we have remarked that the nucleons of a nucleus are held together by very strong short-range forces. A measure of the strength of these forces and also of the binding energy is given by the mass defect. In the case of deuterium the mass-defect is equal to 0.002387 amu. Calculate the energy using the mass energy relation. This will be its binding energy.

NUCLEAR FISSION

In 1939 Otto Hahn, Meitner and Strassmann in Germany discovered that when uranium was bombarded with neutrons, the uranium nucleus split into two parts which were identified as $_{56}Ba$ and $_{36}Kr$. During this process, a large amount of energy is also released. The splitting of heavy nuclei into two or more lighter nuclei is known as nuclear fission.

During such fission, a comparison of the total mass of the particles involved before fission and the total mass of the fission products shows that there is some mass defect. This mass appears in the form of energy. The amount of energy thus released can be calculated according to Einstein's mass energy relation $E = mc^2$.

The products of fission depend upon the energy of the neutron captured. Thus when a U^{235} captures a slow neutron, the products of fission are found to be ${}_{38}Sr^{94}$ and ${}_{54}Xe^{139}$.

$$ {}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{38}Sr^{94} + {}_{54}Xe^{139} + 3{}_{0}n^{1} + \text{energy} $$

NUCLEAR FUSION

Very light nuclei may be built up from even lighter components. This process is called fusion. During fusion, a very large amount of energy is released.

The possibility of direct conversion of 4 protons into a helium nucleus has been realized.

$$ {}_{1}H^{1} + {}_{1}H^{1} \longrightarrow {}_{1}H^{2} + e^{+} + \text{energy} $$

$$ {}_{1}H^{2} + {}_{1}H^{1} \longrightarrow {}_{2}He^{3} + \text{energy} $$

$$ 2He^{3} + 2He^{3} \longrightarrow {}_{2}He^{4} + 2\,{}_{1}H^{1} + \text{energy} $$

Such reactions would require very high temperature which is obtained through a fusion process. In the interior of the sun, this type of fusion continuously takes place giving rise to a very high temperature of the order of 10^6 K.

NUCLEAR REACTOR

When the nucleus of uranium undergoes fission by the capture of a neutron, apart from the fission products such as barium and krypton or strontium and xenon a few neutrons are also released at an average of 2.5 neutrons per fission. Each of these neutrons can cause further fission of uranium present in the sample. Such a chain reaction will go on progressively and in an extremely small fraction of a second billions of uranium nuclei undergo fission. This results in an uncontrolled release of a tremendous amount of energy, as happens in the case of an atom bomb. It isalso possible to achieve controlled release of this energy and use itfor peaceful purposes. This is realized in a nuclear reactor.

In a nuclear reactor, this control is achieved by regulating the chain reaction. For this control rods made of neutron absorbing boron-steel or cadmium are inserted in the reactor in an appropriate manner.

The Uranium isotope U^{235} is more readily fissionable than its other isotopes. It is for this reason that enriched uranium which has a high percentage of U^{235} is used in nuclear reactors. But it is only the slow neutrons which can bring about fission in U^{235}. To slow down the neutrons released in a fission reaction, it is necessary to use a moderator. The moderator must be a material containing atoms of low atomic weight such as graphite or heavy water. When the fast neutrons collide with these light atoms it loses much of its momentum to these atoms and its velocity is brought down to the required level.

A large quantity of radiation is given out by the reactor due to contamination by the fission products which are radioactive. Such radiations from radio active materials are harmful to living beings. As a protection against this, the reactor is usually surrounded by thick lead-lining which in turn is surrounded by a heavy concrete wall.

The fig 4.9 shows the essential parts of one type of power reactor. The core of the reactor contains enriched uranium rods surrounded by a suitable moderator. The control rods can be raised or lowered into the core. The heat generated in the reactor can be suitably made use of ingenerating electricity.

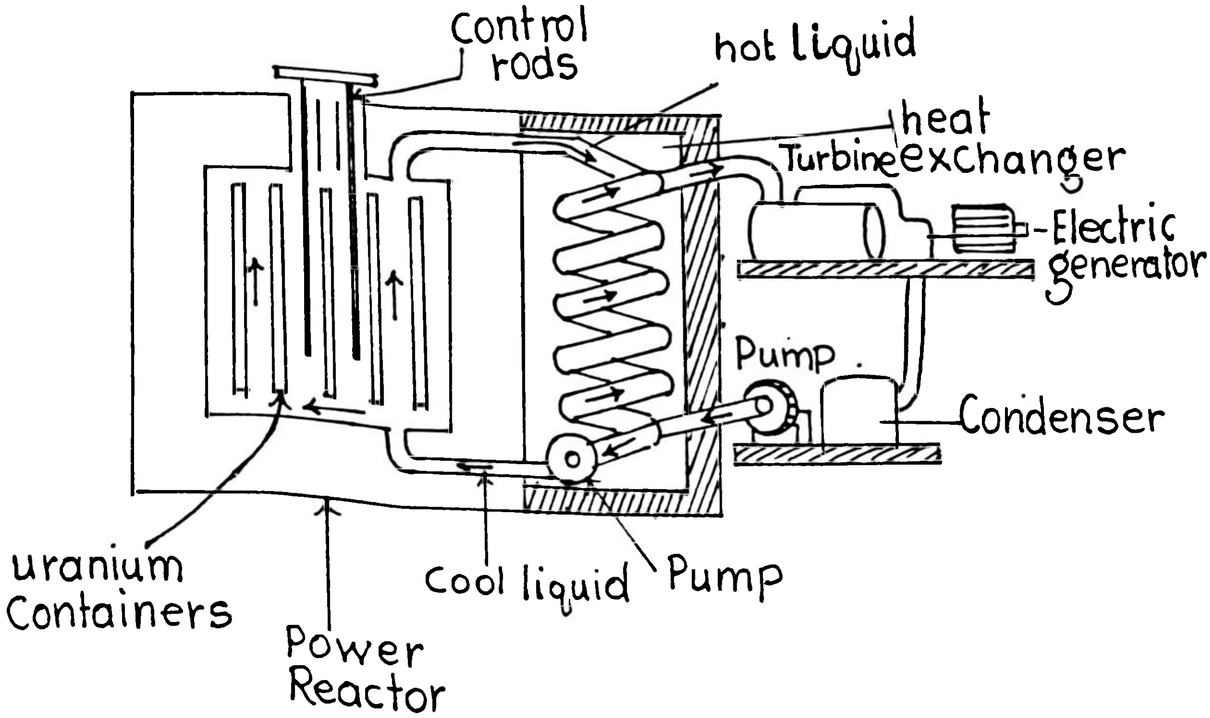

Fig 4.9 Schematic diagram of a typical nuclear power generator

4.4 EVALUATION

1. Using a modified electronic discharge tube 'CANAL' rays were discovered. They were found to have positive charge and were massive.

   a) How are they produced?

   b) Will these rays have the same property if one uses different gases?

2. Explain how low pressure and high voltage help in the discharge of electricity through gases.

3. A beam of cathode rays were found to bend down when a magnetic field is introduced normal to the beam. Is it possible to bring back the beam to its original position without altering the magnetic field? Explain.

4. Making use of Bohr's model of atom, draw the electron distribution in the case of oxygen (Z=8), Sodium (Z=11) and mercury (Z=50).

5. What is the ratio of the number of neutrons to the number of protons in the nucleus S^{32}, C^{14} and U^{238} ?

6. What is the difference between K^{39} and K^{42}; Cl^{35} and Cl^{37} ?

7. What happens to the nucleus if it emits an e^{+}(positive)?

8. Fill in the blanks in the following disintegration reactions. (Make use of the Periodic Table).

$K^{42} \longrightarrow \qquad + e^{-}$

$U^{238} \longrightarrow \qquad + 2He^{4}$

$Th^{233} \longrightarrow \qquad + 2e^{-}$

$O^{14} \longrightarrow \qquad + e^{+}$

$H^{1} + O^{16} \longrightarrow \qquad + 2He^{4}$

9. An electron (charge $e = 1.6 \times 10^{-19}$ coulomb) when accelerated through a potential difference of 1 volt is said to acquire an energy 1 electron volt 1.6×10^{-19} J. Express the energy released in the reaction given below in terms of million electron volts (1 MeV = 10^{6} eV).

$${}_{3}Li^{7} + {}_{1}H^{1} \longrightarrow {}_{2}He^{4} + {}_{2}He^{4} + 28 \times 10^{-13} \text{ Joules}$$

10. A certain radioactive disintegration results in the release of energy of 20 MeV. Calculate the mass equivalent of this energy.

11. If a cathode ray tube is coated from outside with a thin layer of wax opposite to the cathode, it will

a) melt due to the fast motion of electrons.

b) melt due to the heat produced by the impact of electrons.

c) give rise to fluorescent light

d) give rise to more ions

12. Two different X-ray tubes are working with accelerating potentials of 100,000 and 2000,000 volts respectively. The X-rays thus produced are found to have

a) higher frequency from the first tube.

b) longer wavelength from the second tube.

c) longer wavelength from the first tube.

d) higher frequency from the second tube.

13. A charged gold-leaf electroscope is kept at about 3 to 5 m away from an X-ray tube; the leaves of the electroscope collapse when the X-ray tube is turned 'on'. This shows that X-rays

a) have very high penetrating power

b) carry negative charges

c) take away charges from the gold leaves

d) have high ionising power

14. A nucleus of atomic number Z and mass number A emits an alpha particle. The resulting nucleus Y may be represented

a) $_{Z}Y^{A-2}$ b) $_{Z-2}Y^{A-4}$

c) $_{Z-2}Y^{A}$ d) $_{Z-2}Y^{A-2}$

4.5 REFERENCES

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2. Modern Physics - Charles E. Dull, H.Clark Metcalfe and John E.Willians (Holt,Rinehart and Winston, Inc. New York).

V ELECTRONICS

5.1 INTRODUCTION

Thomas Alva Edison, the inventor of incandescent lamp, in 1883 was plagued by the frequent burning out of the carbon filament with an accompanying black deposit inside the bulb. While attempting to overcome this difficulty, he sealed a metal plate inside the lamp near the filament and connected it to a battery, the other terminal being connected to the filament. He observed that current would flow in the plate circuit if the positive terminal of the battery was connected to the plate. However, no current would flow if the negative terminal of the battery was connected to the plate. This discovery, called Edison effect formed the basis of vacuum tubes.

In 1904, Sir J.A.Fleming used the Edison effect to develop the first diode for detecting radio signals. Fleming's valve was crude and insensitive and it did not find immediate application. Yet, it was an important link in the evolution of the vacuum tubes which utilize the flow of free electrons emitted by the filament.

Lee de Forest, in 1906, placed a third electrode in the form of a grid of fine wire between the filament and the plate of the diode and found that a small variation in voltage applied to the grid produced a large variation of current in the plate circuit of the tube. This triode was immediately used for amplifying feeble radio signals from an antenna. The success led to the development of a family of vacuum tubes which are used in circuits to perform functions such as rectification, mixing, detection, amplification, generation of electrical oscillations, etc. The development of electron tube produced a new branch of engineering called electronics, which made possible long distance communication, public address systems, modern broadcasting, television, radar, guided missiles, computers and a multitude of controlling and switching devices.

Yet another discovery in 1940's further revolutionised electronics. After nearly ten years of fundamental research in the physics of semi conductors a team of physicists at the Bell Telephone Laboratories in 1948 developed transistors - crystals of silicon or germanium containing traces of certain impurities.

These tiny, rugged structures which require very small power were found to perform functions of vacuum tubes. The great reduction in power consumption and size, and the longer life made transistors preferable to vacuum tubes in many circuits. Electronic appliances are now increasingly used at home and in industry and are coming into increasing use in medical diagnosis. These days electronic devices soar with space vehicles through unimaginable distance to probe, examine and send back pictures and reports from outer space.

Vacuum tubes still find application in circuits involving large power such as radio and television. In this chapter, we look at some of the principles of vacuum tubes - diode and triode; in order to develop a general understanding of the principles of radio, television and radar.

A. THERMIONIC EMISSION:

5.2A TEACHING POINTS

1. Metals when heated emit electrons.
2. Free electrons inside a metal need a definite amount of energy to escape from the metal.
3. The rate of thermionic emission of electrons from a surface depends upon the material of which it is composed and increases rapidly with increase in temperature.
4. A diode consists of a cathode that emits electrons and a plate that collects the electrons.
5. A diode conducts only when its plate is at a positive potential with respect to the cathode.
6. Space-charge is the cloud of electrons between cathode and the anode.
7. Plate current is a function of the plate voltage and the temperature of the filament.
8. A diode as a circuit element behaves like a variable resistor.
9. Rectification is the process of converting an alternating current or voltage into a unidirectional current or voltage.
10. Detection is the process of separating the audio or video component from a complex signal.

11. A triode can be considered as a diode to which is added another electrode called grid in between the cathode and the plate.

5.3A DEVELOPMENT

Edison Effect:

In the circuit shown in Fig 5.1, D is the vacuum diode. It consists of a filament F made of a conducting material and another metal electrode P called plate (or anode). The two ends of the filament are connected to a battery B_1. The plate P is connected in series with a galvanometer to the positive terminal of another battery B_2 and the circuit is completed as shown.

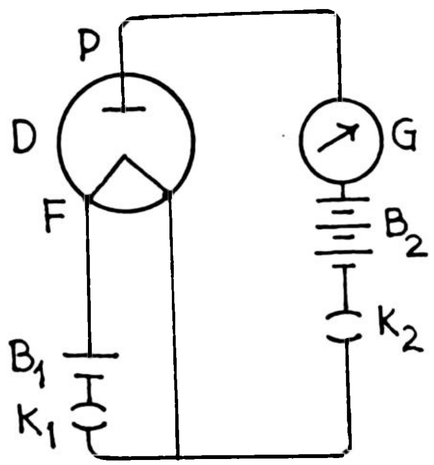


Fig 5.1 Circuit to demonstrate Edison effect

The switch K_1 is closed. The filament gets heated and after a while, appears red hot. Now, close switch K_2. A deflection in the galvanometer is observed. Note the direction of conventional current in the circuit. It is from plate to the filament in the diode. Recall that the current is due to the drift of charges. The potential of plate is positive with respect to the filament. Therefore, the current in the diode is due to negative charges emitted by the filament. It can be confirmed by reversal of the polarity of battery B_2. The galvanometer does not show measurable deflection. In this case, the plate being negative with respect to the filament repels the negative charges emitted by the filament. Hence, current in a diode is almost unidirectional. The above phenomenon is known as Edison effect.

Thermionic Emission:

What are these negative charges emitted by the filament?

The filament, being a conductor has a great many electrons which at the moment are not definitely attached to any particular atom or molecule. These 'free electrons', like gas molecules are in continuous random motion with various speeds (or kinetic energies) that increase with temperature. However, these free electrons cannot escape from the surface due to the attractive forces exerted by the positive charges at the surface. They have to perform work against these attractive forces in order to escape from the surface. The energy needed to perform this work is so large when compared to their available kinetic energies at ordinary temperatures that for all known substances no electron can escape from the surface at room temperature. Therefore, in order to liberate electrons from a surface, energy has to be supplied. The amount of energy that has to be supplied in order that the free electron overcomes the attractive forces at the surface and escapes with almost zero velocity is called the work-function of the material. This is different for different materials. This is expressed in electron-volt units (1 electron volt is the energy acquired by an electron when it moves across a potential difference of 1 volt and is equal to 1.6×10^{-19} J). The energy is supplied by the battery B_1 which sends a current through the filament. When the temperature of the filament is increased to a value at which the kinetic energy of the free-electron exceeds the work function, it can escape from the surface and become a 'thermion'. The current in the diode is due to thermions, escaping from the filament surface. The phenomenon is called thermionic emission and is analogous to the evaporation of molecules from the surface of a liquid. In the case of vapour, the evaporated molecules are the ones that have obtained sufficient kinetic energy to overcome the restraining forces at the surface of the liquid and the number of such molecules increases with increase in temperature. The thermionic emission of electrons can be considered as evaporation of electrons from the heated metals.

The rate of emission from a surface depends upon the temperature of the filament and upon the material of which it is composed. Once the temperature is sufficient to cause significant emission, the rate of emission increases rapidly with increase in temperature, as shown in Fig 5.2, for various common emitters, A,B, C, etc. The rate of emission per unit area I is given by the relation

$$I = a\,T^2\,e^{-b/T}$$

where a is a constant, the value of which may vary with the type of the emitter, T is the absolute temperature of the material and b is 11,600 times the work function in eV. The rate of emission does not depend on the plate voltage provided it is not too large.

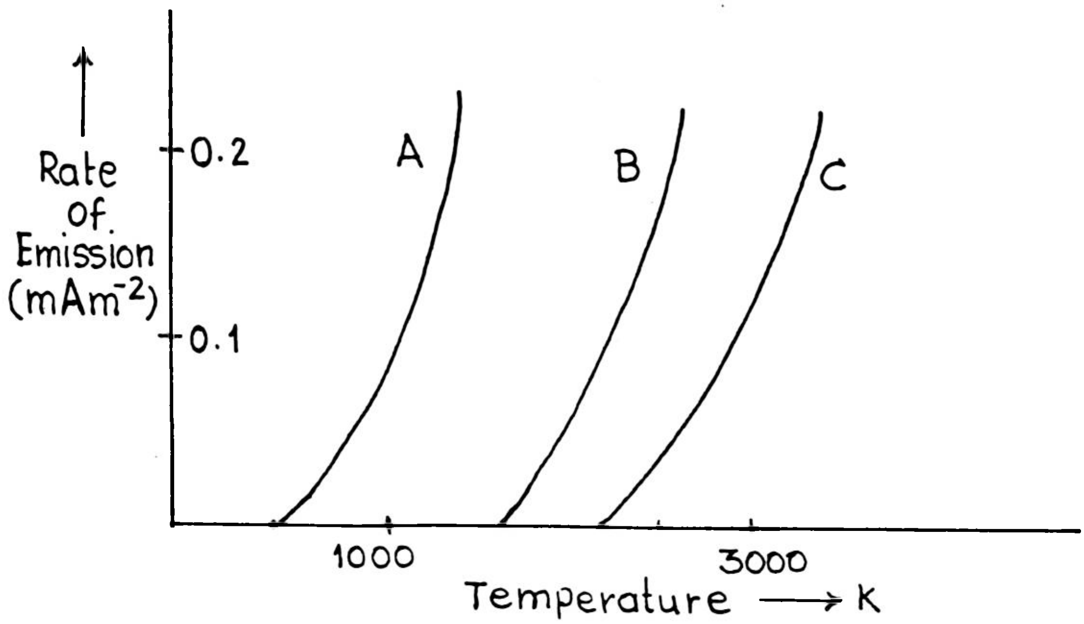


Fig 5.2 Variation of electron emission for common emitters

<u>**Practical Emitters:**</u>

The characteristics required of a good emitter are low work-function and greater life (i.e. mechanical stability at high working temperature). Few substances satisfy these requirements. Tungsten, thoriated-tungsten and oxide-coated emitters are commonly used in vacuum tubes.

Tungsten, in spite of its high work-function (4.52 eV) is virtually the only material that can be used successfully as an emitter in tubes associated with high plate voltages (more than 10,000 volts) required in communication transmitters. Its operating temperature ranges from 2500 K to 2600 K and its emission efficiency (ratio of emission current in milliampere to the heating power in watt) is not high.

It is found that the work-function of tungsten is reduced by a coating on the surface of some material of lower work-function,such as thorium oxide. Thoriated-tungsten emitters consist of tungsten containing a reducing agent (ordinarily carbon) and a small quantity (1 to 2%) of thorium oxide. Their working temperature ranges from 1000 K to 2000 K and emission efficiency is considerably higher than that of pure tungsten and are extensively used in medium to large power tubes (plate voltage 10,000 volt or less).

During operation, thorium is continously evaporated from the surface layer, but is replenished by diffusion from the interior of the tungsten. Thoriated-tungsten emitters are always carbonized by converting the surface to tungsten carbide. Thorium adheres much more firmly to a tungsten carbide surface than it does to tungsten. So,carbonization results in reduction of the rate of evaporation of thorium. However, tubes employing thoriated-tungsten must have high vacuum. Otherwise, positive ions, produced as a result of ionization by collision of the electrons with the residual atoms in the tube bombard the emitter. This results in stripping off the thorium layer affecting the electron emission. Carbonizing reduces this tendency to some extent.

The oxide-coated emitter consists of a mixture of barium and strontium oxide coated on the surface of a suitable metal, commonly nickel or nickel alloy. It emits electrons profusely at a temperature in the range from 1000 K to 1200 K. The increased emission, it appears, is due to the free electrons in the oxide coating. It gives more emission per watt of heating power than any other type of emitter and therefore, is used in low power tubes (plate voltages about 1000 volt or less). In tubes designed to generate short pulses of high power, such as radar transmitting tubes, oxide-coated emitters have an advantage as they give very high instantaneous electron emission for brief periods. This high transient emission, however, drops off in a comparatively few micro seconds and then is not fully restored until after a rest of at least a few hundred micro-seconds. The oxide-coated emitters are 'poisoned' readily by impurities and deteriorate more rapidly than does thoriated-tungsten when subjected to bombardment by high energy positive ions. In most of the vacuum tubes, the electron emission takes place from a metal cylinder called the cathode which is heated by a separate filament enclosed within. Such a tube is called an indirectly heated tube.

Space-charge:

The electrons that leave the cathode make the latter positively charged. The cathode, then exerts an attracting force on the electrons moving away from it. Some of them may stop moving and others may return. A cloud of electrons, called space-charge, thus forms in the space between the cathode and plate. As more electrons enter the cloud this region becomes more negatively charged and repels electrons from the cathode. When the space charge becomes dense enough it can return electrons at the same rate at which they are emitted by the cathode, giving a net zero emission.

How does the situation change if a potential difference were to exist between the cathode and plate?

Diode Characteristic:

Fig 5.3 gives the relation between plate voltage and the current flowing to that plate. It has three distinctive regions AB, BC and CD.

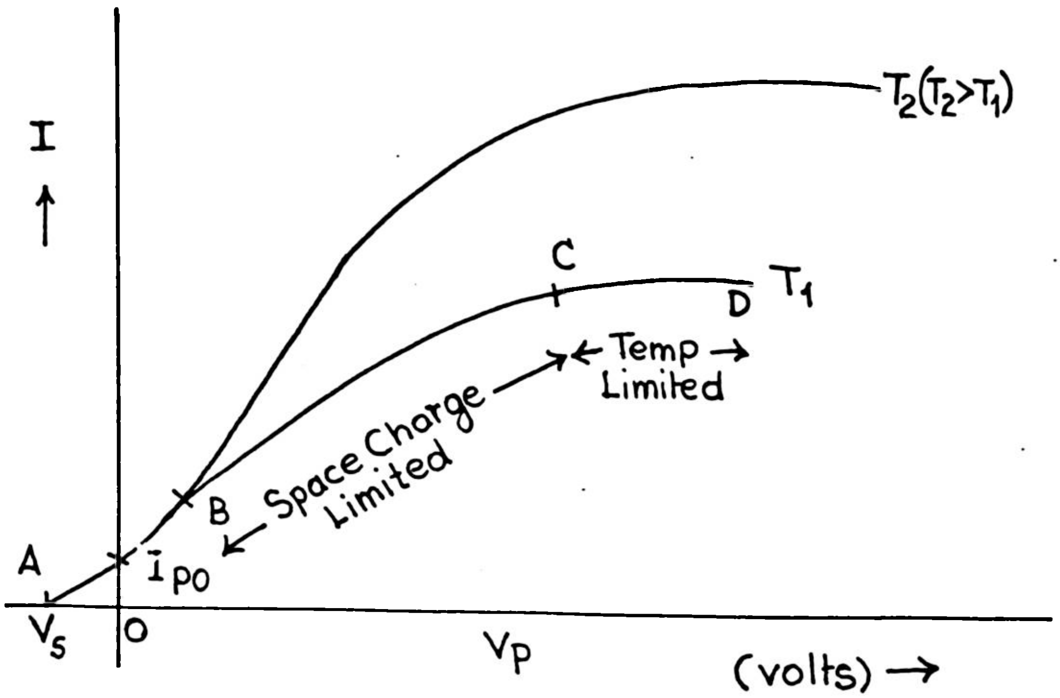


Fig 5.3 Variation of plate current with plate voltage for a diode

Region AB:

It shows that the current is not zero when V_P is zero. This can be explained by the fact that a few of the emitted electrons may possess sufficient kinetic energy to overcome the repelling force of space-charge and may reach the plate, giving rise to a current I_{PO}. In fact, to stop the current completely the plate has to be at slightly negative potential V_S with respect to the cathode. However, I_{PO} and V_S are nearly zero.

Region BC:

When the plate is made positive with respect to the cathode, electrons will be attracted to the anode registering a certain plate current. Space-charge is reduced. This permits more electron emission. Plate current increases. However, the rate at which plate collects the electrons is less than that emitted by the cathode due to the space-charge present. Thus in this region plate current is limited by the space- charge and is given by

$$I = K \ V_p^{3/2}$$

where K is a constant determined by the geometry of the tube and V_p is the plate voltage with respect to cathode.

Region CD:

When the plate voltage is sufficiently large electrons are drawn away from the cathode as rapidly as they are emitted. The plate current attains a maximum value which is determined by the cathode emission capacity and hence on the temperature of the cathode rather than on plate voltage. However, if the cathode temperature is increased to a higher value T_2 the saturated plate current increases as shown by the second curve. The plate saturation effect depends upon the type of the emitter.

A potential on the plate affects the resistance of the diode. This is called plate resistance and is a measure of the opposition to the flow of electrons from cathode to plate. The static or d.c. plate resistance R_p of the diode is defined as

$$R_p = \frac{V_p}{I_p} \quad \text{for a given } V_p$$

The dynamic or a.c. plate resistance r_p is defined as the ratio of infinitesimal change in plate voltage to a corresponding infinitesimal change in plate current.

$$r_p = \frac{d\,V_p}{d\,I_p} \quad \text{for a given } V_p$$

This corresponds to inverse of the slope of a tangent at a point on the voltage-current characteristic. As the slope varies from point to point on the curve, r_p has variable value and should be stated along with the value of current, for example r_p = ... ohm at I_p = ...mA. Therefore, the diode as a circuit element appears as a variable resistor.

Temperature Saturation:

The variation of plate current with filament voltage is shown in fig 5.4. When the filament voltage is zero, and is at room temperature no electron emission will be possible. Plate current is zero.

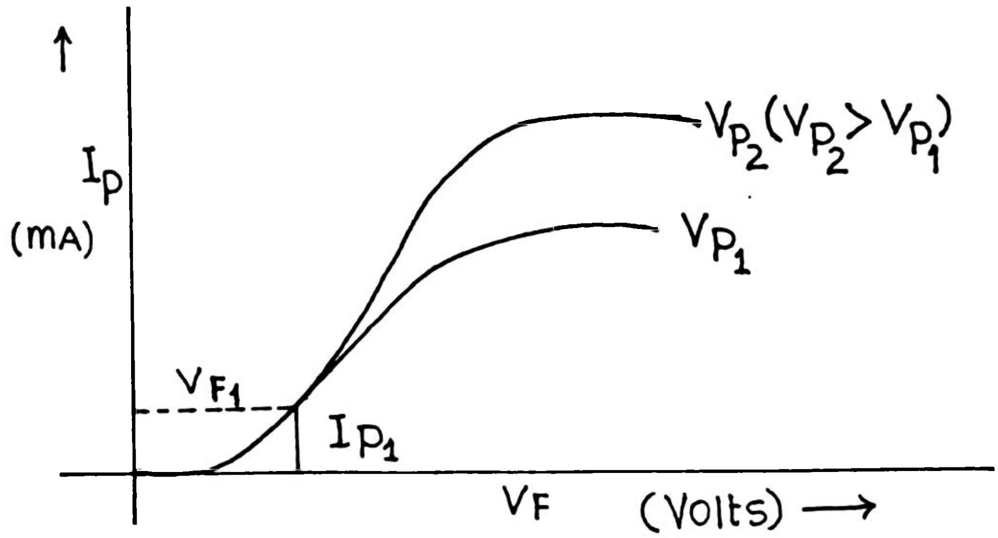


Fig 5.4 Variation of plate current with filament voltage for a diode

Suppose that the filament voltage is V_{F1}. It sends a current through the filament. The temperature of the filament is raised, the cathode emits electrons which move towards the plate by the electrostatic field established by the plate voltage. Plate current I_{P1} is registered. As the filament voltage increases, its temperature increases increasing (not linearly) the rate of emission of electrons. More electrons reach the plate increasing the plate current. This tendency will continue until the cathode attains a temperature at which it emits electrons at a rate equal to that collected by the plate. The plate current reaches a saturation value limited by the plate voltage and the phenomenon is called temperature saturation. No further increase in plate current can occur even if the temperature of the cathode (or filament voltage) is further increased.

However, if plate voltage is increased, the plate can pull more electrons thus increasing the plate current as shown in the curve for a higher plate voltage V_{P2}, (fig 5.4). At this plate voltage the filament voltage has to be further increased to obtain temperature saturation.

Activity 5.1:

Take a worn-out diode valve. Cover it with thick cloth to avoid any injury and break the glass covering. Show its parts.

Triode:

Control of space-charge:

It isclear that because of space-charge only the more energetic electrons can pass through to be collected by the plate. Can the number of electrons in transit through space-charge be controlled, say, by establishing an additional field? What should be the nature of such an arrangement?

In 1906, Lee De Forest inserted a spiral like third electrode (this would present negligible physical barrier to electrons in transit) in between cathode and plate, but nearer to cathode. He succeeded an amplifying feeble radio signals. Such a tube is called a triode.

A triode is a three element electron tube containing a cathode (emitter), plate (collector) and a control grid placed between the cathode and plate, (fig 5.5).

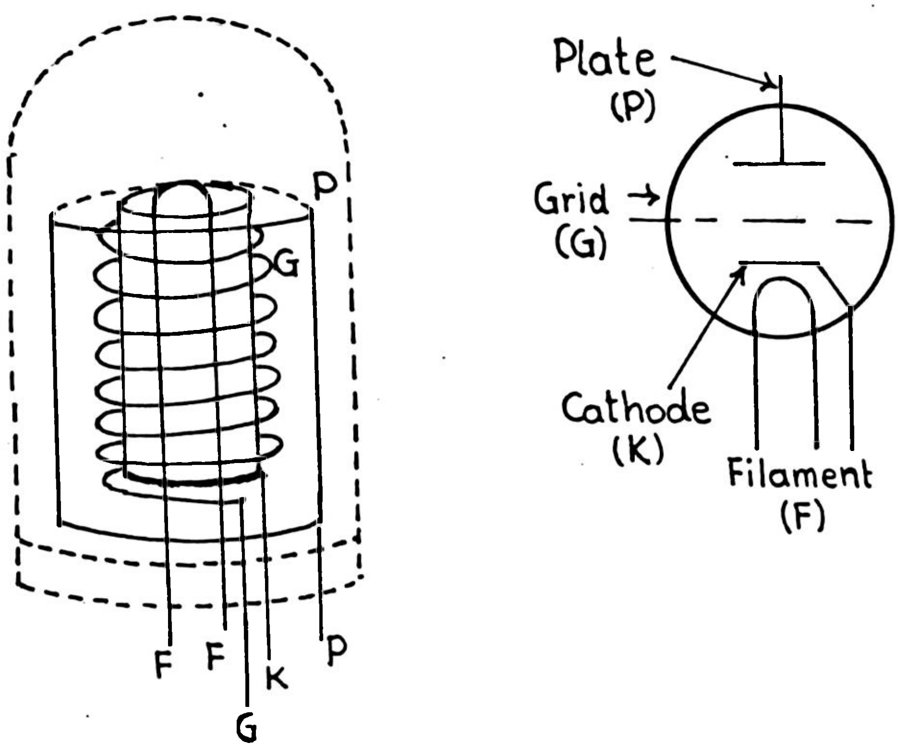


Fig 5.5 Construction and circuit symbol of a triode

Let the anode be given a positive potential compared to the cathode which is usually at zero or negative potential. The electrons emitted from the cathode are attracted towards the anode and a current flows in the anode circuit. The grid is nearer to the cathode than the plate and hence can affect a greater control over the electron flow compared to that by the plate. If the grid is given a very high negative potential, the electrons due to their negative charges experience a very high repulsive force and find it impossible to get across the grid to the plate. The plate current then will be zero. As the potential of the grid is increased from this negative value, the plate current increases and reaches a saturation value.

If an oscillatory potential say an a.c. voltage is applied between the grid and cathode, the plate current too will be oscillatory. Usually the normal d.c. potential on which the a.c. signal is impressed is called the grid bias. The flow of electrons from the cathode to the plate is equivalent to a flow of positive charges (conventional electric current) in the reverse direction.

B. SEMICONDUCTORS AND THEIR APPLICATIONS

5.1B INTRODUCTION

Semiconductors are usually crystalline solids whose resistivity lies between those of metals and insulators. Also the resistivity is strongly determined by even minute traces of impurities, intentionally or otherwise added to them. A discovery of this class of solids revolutionised the field of electronics.

Crystals of germanium, silicon, selenium are some commonly used semiconductors. These are tetravalent and are strongly covalently bonded, i.e. some energy is required to break these bonds. At room temperature, they are stable solids, since adequate energy is not available for breaking the bonds. However, occasionally, some bonds do break due to thermal agitation. An electron from the bond is released. The bond, that has released the electron has a vacancy, indicating the loss of an electron or a negative charge. This vacancy, for all practical purposes, behaves like a real positive charge and is called a HOLE. Thus a breaking of a single bond makes a free electron and a hole available for the crystal. This is referred to as an electron-hole pair. The free electron, being not attached to any bond moves across the crystal and can act as a current carrier. Due to thermal agitation, an electron from a neighbouring bond, being attracted by the positive charge of the hole, moves towards this 'hole' and fills up the hole i.e. the electron moves from the neighbouring bond towards that bond which broke due to thermal agitation. It appears that a fresh hole is created in the neighbouring bond due to release of an electron. It can also be said that effectively the 'hole' has moved in a direction opposite to that of the electron, and in the process can act as a current carrier.

Thus, for every bond that is broken, an electron hole pair is created in the crystal. Current is carried both by holes and electrons. There are as many holes as there are electrons released from the bonds.

As temperature increases, the number of electron - hole pair increases due to increase in supply of thermal energy which results in more bonds being broken. The current carried by holes and electrons increases. Such pure crystals whose electrical conductivity is closely determined by their temperature alone are called INTRINSIC semiconductors.

Germanium and silicon, the most frequently used crystals can form four covalent bonds with their adjacent atoms. This is because they have four electrons in their outermost shell.

If an atom like arsenic or phosphorous containing five electrons in the outermost shell is added to germanium, four outermost electrons are engaged in forming its four covalent bonds and the fifth electron is released free. Thus there will be a 'free' electron in the atom, which can move within the crystal and can carry current. The current is mainly due to electrons or negative charges, which outnumber the positive charges. Such crystals are called N-type semi-conductors.

If an atom like aluminium, or indium which has three electrons in the outermost shell is added to germanium only three covalent bonds can be formed and the fourth bond is left vacant. This vacancy, short of an electron or a negative charge acts like a hole. An electron from a neighbouring bond moves towards this and a fresh hole is created there. Thus, it appears that the holes outnumber the electron in this case moving across the crystal. Current is mainly carried by holes moving in a direction opposite to that of electrons. Such crystals are referred to as P-type semiconductors.

5.2B TEACHING POINTS

1. A PN junction offers very low resistance for the flow of current in one direction a very high resistance in the opposite direction.
2. A NPN or PNP transistor can be considered as two PN junctions fused back to back.
3. Rectification is the conversion of alternating current/voltage to direct current/voltage.
4. A single diode converts only alternate half cycles of the alternating current into unidirectional current (half-wave rectification).
5. In full wave rectification, every half cycle of the alternating current flows in the same direction.
6. An amplifier is an electronic circuit whose output is a magnified version of the input signal and it draws its power from the plate voltage.
7. An electronic oscillator circuit converts direct current power into alternating current power.

8. In an electronic oscillator circuit, electrical energy is made available to the tank circuit and sustained electrical oscillations are present.

Activity 5.2:

Make the students sit close to one another in a circle leaving one vacant place in between. Ask the one sitting besides the vacant place to occupy it and ask the next one to occupy the new place and so on. When looking from a distance one can see that the vacant space is moving in the direction opposite to the movement of students. The teachers can tell the students that the vacant space represents a hole and students represent electrons. Even though this is not a correct representation, they may get some idea about the movement of holes.

Activity 5.3:

Tell the students about transistor and diodes. Then give them different kinds of transistors (For eg. AC 128, BC 107, BF 148, 2N 3055 etc) and diodes (e.g. OA 79, SR 100, DR 25, BY 126, etc) which are available in the market. Ask them to separate diodes and transistors.

Generally, there will be three leads in transistors and two leads in diodes. But among the items listed above, even though 2N 3055 has only two leads it is a transistor and not a diode. It is a transistor with the body acting as collector.

Activity 5.4:

Give a few diodes which are available in the market and are in common use (eg. OA 79, SR 100, DR 25, BY 126, BY 100, CD 31, etc.). Ask the students to identify cathode and anode with the help of the marking on it and the shape of it.

Identification of some typical commercial diodes are given in fig 5.6.

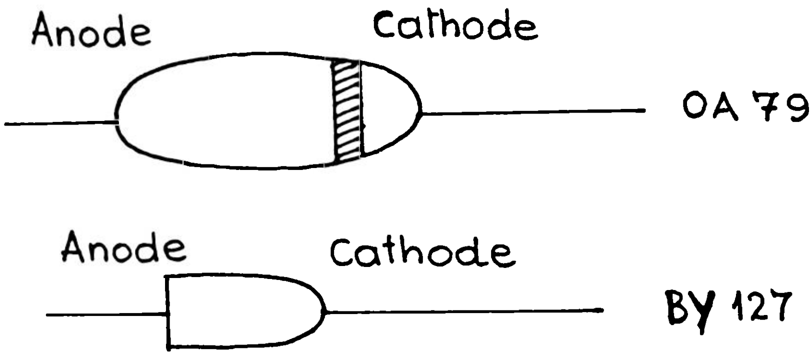


Fig 5.6 Commercial diodes

Activity 5.5:

Give a few transistors available in the market that are in common use (eg. BC 148, AC 128, AC 126, BC 107, BC 108, BC 109, BC 147, BF 115, CIL 471, AF 115, 2N 3055, etc.). Ask the students to identify the emitter, base and collector terminals using manufacturer's guide (fig 5.7). In some transistors colour dot indicates the collector but in some it indicates the emitter.

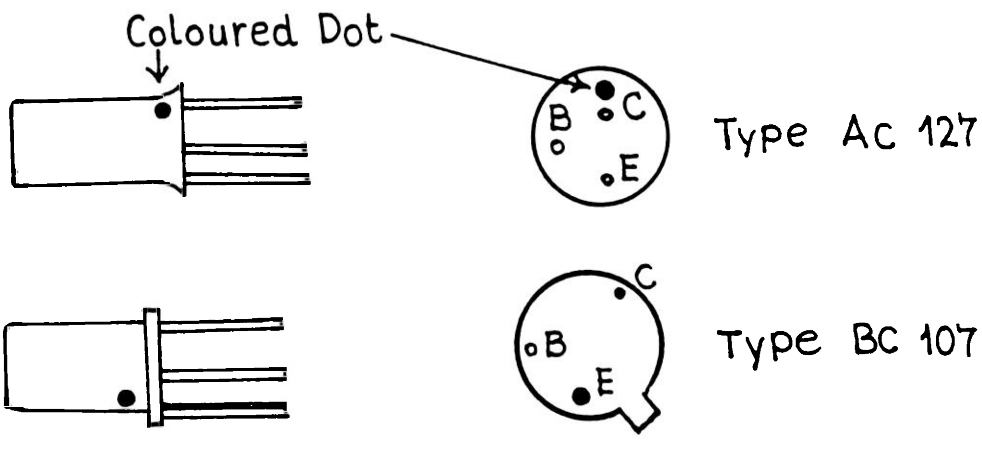


Fig 5.7 ommercial Transistors

PN-junction Diode:

Reversing the polarity of a battery connected to a P- or N-type semiconductor does not affect the flow of current. The current flows equally well in either direction. But the situation changes drastically when a P-type germanium (or silicon) is joined to a N-type germanium (or silicon). Such a combination is a P-N junction. One of the ways of preparing a PN junction is to press a small dot of P-type material on an N-type material. After heat treatment P-type material fuses to the surface of the N-type material, forming a P-N junction.

P-N junction with forward bias:

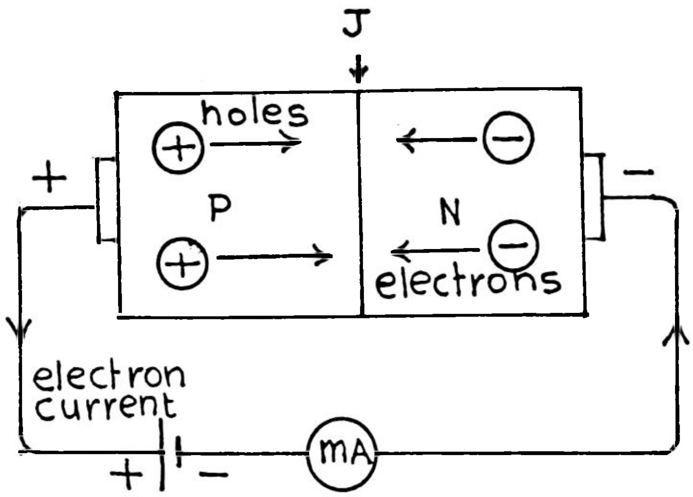


Fig 5.8 P-N junction with forward bias

In this case, the P-type germanium is connected to the positive terminal of a battery and the N-type to the negative terminal. Now positively charged holes migrate from P type to N-type region. Electrons in the N-type crystal drift towards the P-type material. This constitutes a current (fig 5.8). The electron current flows from P-type to N-type material in the external circuit i.e., the conventional current flows from N-type to P-type in the external circuit. At the junction, the holes and electrons recombine. But, a continuous loss of charge carriers at the junction is compensated by continuous supply of holes in the P-type material, i.e., electrons from P-region are drawn towards the positive terminal of the battery. Similarly, electrons arriving from the battery enter the N-type crystal and replace the electrons lost during recombination with the holes. A minimum voltage of about a fraction of a volt produces a current. The current increases rapidly with the increase in the applied voltage across the junction. The current is of the order of a few milliamperes. The junction thus facilitates an easy current flow and the junction is said to be in forward bias. The resistance is low in this case. Reversal of the battery terminals results in an entirely new situation which is of great importance.

PN junction with reverse bias:

The PN junction is said to be in reverse bias when the negative of the battery is connected to the P-type material and the positive connected to the N-type material. Now the holes at the junction are drawn away towards A and the electrons towards B. At the junction, therefore, there will be no holes of electrons. In other words, the junction region is depleted of charge carriers. In the absence of charge carriers at the junction, the current stops flowing. However, a very small current (of the order of a few micro ampere) flows in the circuit. This is due to breaking of some covalent bonds in both the N and P type materials due to thermal agitation. Consequently, holes migrate towards A and electrons migrate towards B. This is illustrated in the Fig 5.9.

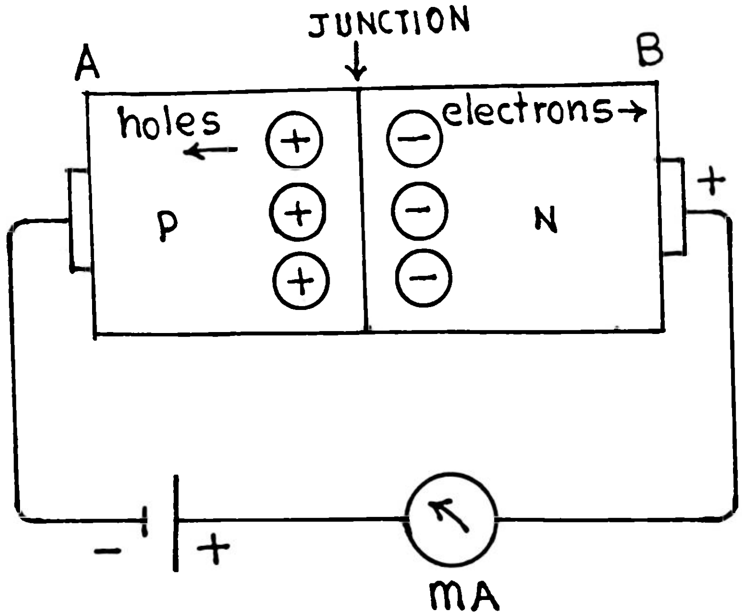


Fig 5.9 P-N junction with reverse bias

Thus, a PN-junction offers a negligible resistance in one direction (forward bias) and a very high resistance in the opposite direction (reverse bias).

Activity 5.6:

Give some n-p-n and p-n-p transistors, one dry cell and one torch bulb with very low wattage. Ask the students to find out the n-p-n and p-n-p transistors.

Hint: Find out the base of a transistor. Make a connection between the base and collector or emitter through a torch bulb having very low power and a dry cell in series. The bulb will glow when the base is connected to the negative (positive) terminal of the battery if the transistor is p-n-p (n-p-n). .For the safety of the transistor, a resistor in serieswith the battery may be used. The same experiment can be done using a galvanometer and resistor in place of the bulb. Draw the corresponding circuit diagrams.

TRANSISTORS

The junction transistor (a three element device) succeeded the PN junction diode. This device is widely used as an amplifier and oscillator in electronic circuits.
A typical PNP transistor consists of two P-type semi-conductors with an N-type material sandwiched (fig 5.10). Similarly, an NPN transistor has two N-type semi-conductors with a P-type material in between. The inner semi conductor is very thin (fig 5.11).

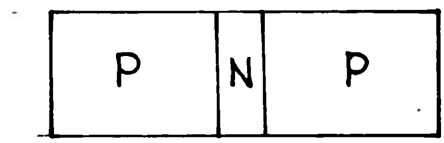


Fig 5.10 P-N-P transistor

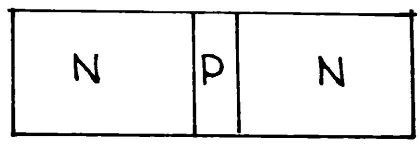


Fig 5.11 N-P-N transistor

A typical transistor circuit is connected as shown in fig 5.12.

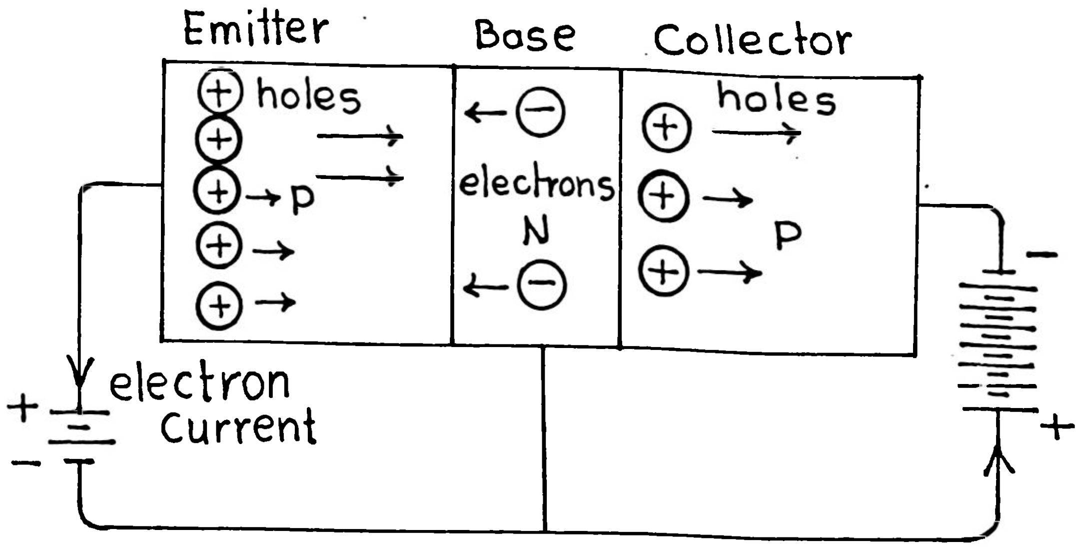


Fig 5.12 A typical transistor (p-n-p) circuit

Notice that a transistor can be considered to be two junction diodes connected back to back. One set of junctions shown at the left is the emitter base junction (known as the emitter junction). The other set shown at the right is the base-collector junction (known as the collector junction). We observe here that the emitter-base junction is forward biased, whereas the base-collector junction is reverse biased.

Holes created in the P-region at the left drift towards the base. A few of these holes recombine with the electrons drifting from the base region (N-type). But a majority of the holes succeed in penetrating the base and enter the collector region. This is so because the base is extremely thin (almost porous).

About 95 percent of the holes penetrate the base and enter the collector. Each hole reaching the collector combines with an electron arriving from the negative battery terminal. The loss of holes at the emitter region is compensated by a continuous pulling out of electron by the positive terminal of emitter battery. Therefore, a continuous supply of holes is made by the emitter which will be gathered up by the collector. Thus in a PNP transistor conduction is through the holes, but conduction in the external circuit is of course always by electrons. Collector current is less than the emitter current by a factor equal to the charges lost by recombination in the base.

As the emitter-base junction is forward biased, a very small emitter voltage (0.1 to 0.5 volt) produces an appreciable current. A large fraction of this current flows out through the collector. As the collector voltage is quite high (upto 30 volts), large output power is possible. Thus, a large power at the output (collector) can be controlled by a small power at the emitter.

A transistor can therefore, be compared to a vacuum tube triode, the input signal is applied between emitter and base output being obtained at the collector. Therefore, the emitter, base and collector can be compared to the cathode, grid and plate of a triode.

In the NPN transistor the action is similar, except for the fact that conduction through the transistor is by electrons. The battery connections are just reversed (fig 5.13). The circuit symbols for the two types are as shown in fig 5.14.

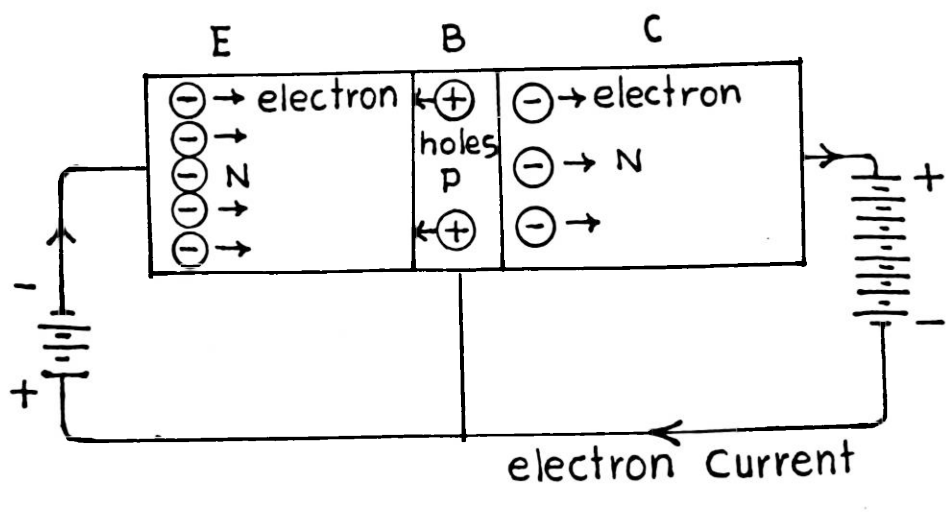


Fig 5.13 N-P-N transistor circuit

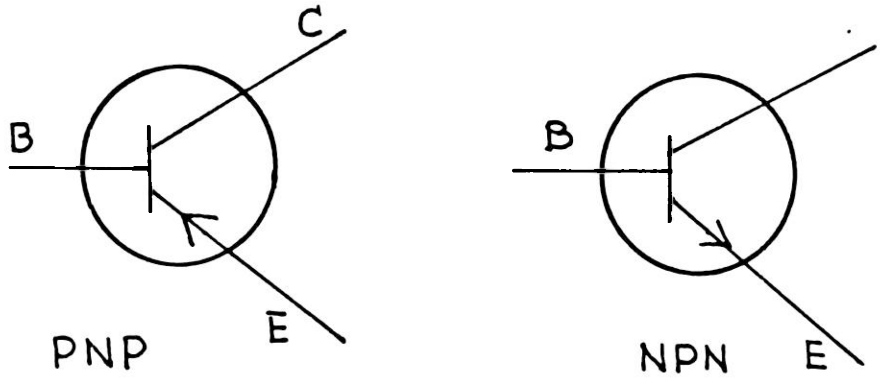


Fig 5.14 Circuit symbols for N-P-N and P-N-P transistors

AMPLIFIER

An amplifier is an electronic set up in which a small variation in voltage across the input will produce a fairly large variation in the voltage across the out-put end. A PNP or an NPN transistor can be employed for such amplification of voltages or power. The circuit of a typical transistor amplifier is given in fig 5.15.

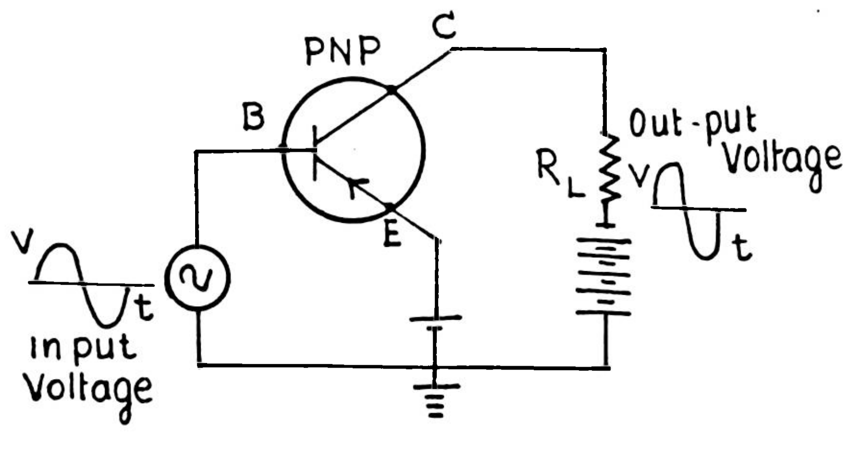


Fig 5.15 Transistor Amplifier

It is noticed from the above diagram that the emitter-base junction is forward biased and the collector-base junction is reverse biased. Note that the emitter is a P-type sample, base an N-type and the collection is again a P-type one.

As already stated, a P-N junction that is forward biased has negligible resistance. Thus the emitter circuit where the input voltage - a small signal voltage, is impressed has least resistance and allows a large emitter current to flow through. The output voltage is tapped out at the collector circuit which is reverse-biased, offering high resistance. The emitter current, after flowing through a thin slice of the N-type i.e. the base, flows through the collector and is of almost the same magnitude as that in the emitter. This current flowing through the high resistance of the collector circuit develops a large voltage or power across the output terminals in the collector circuit. This is considerably large when compared with the small signal applied across the input terminals in the emitter circuit. A transistor thus helps in amplifying a voltage or power. A small alternating voltage in the emitter-base circuit (input) produces a large change in collector current. This variable current, when passed through a load resistor gives rise to a large variable output voltage across the resistor. This is shown in Fig 5.16.

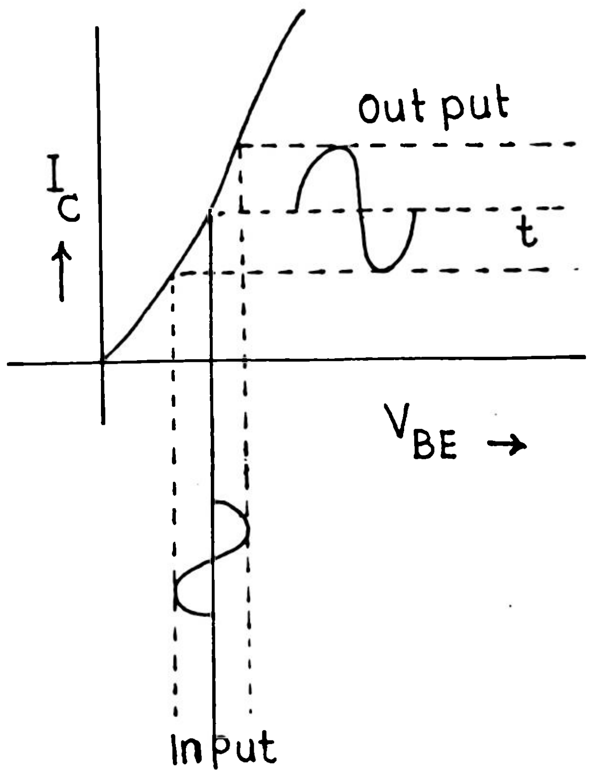


Fig 5.16 Variation of collector-base current with emitter base current in a transistor

The ratio of the output voltage to the input voltage is called the voltage gain. Similarly, the power gain is also defined. Usually voltage gains of the order of 50-100 can be achieved using such transistors.

An NPN transistor can also be used as an amplifier. It is to be noted that the input circuit has to be forward biased and output circuit has to be reverse biased. In early days triode amplifiers were employed, input being applied in the grid circuit; the output, appearing across a resistor in the plate circuit.

RECTIFIER

Half wave rectifiers change alternating current into a pulsating direct current (unidirectional current) by the suppression of alternate half-waves. An ideal half wave rectifier acts like a switch that closes a load circuit during the alternate half waves and opens the circuit during the other half-waves. Diodes provide unilateral conduction since the current can flow in one direction only from anode to cathode in the diode. Full wave rectifiers invert alternate half-waves of the alternating current to obtain direct current.

Diodes are available in the form of evacuated or gas filled electron tubes, and copper-oxide or selenium metallic rectifiers. In fig 5.17, is shown a simple half-wave rectifier circuit using a junction diode. In the early days, vacuum tube diodes were in use for rectification. The PN junction conducts when it is in forward bias; in the other half of AC cycle it is reverse biased. Hence there will be no conduction.

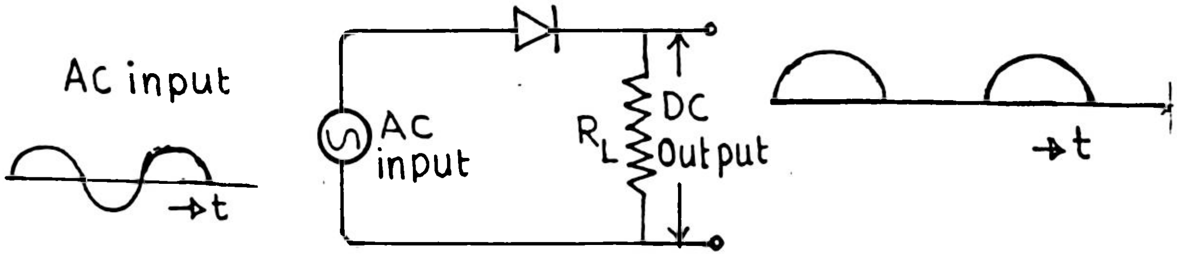


Fig 5.17 A junction half-wave rectifier

A circuit diagram of a full-wave rectifier is shown in fig 5.18.

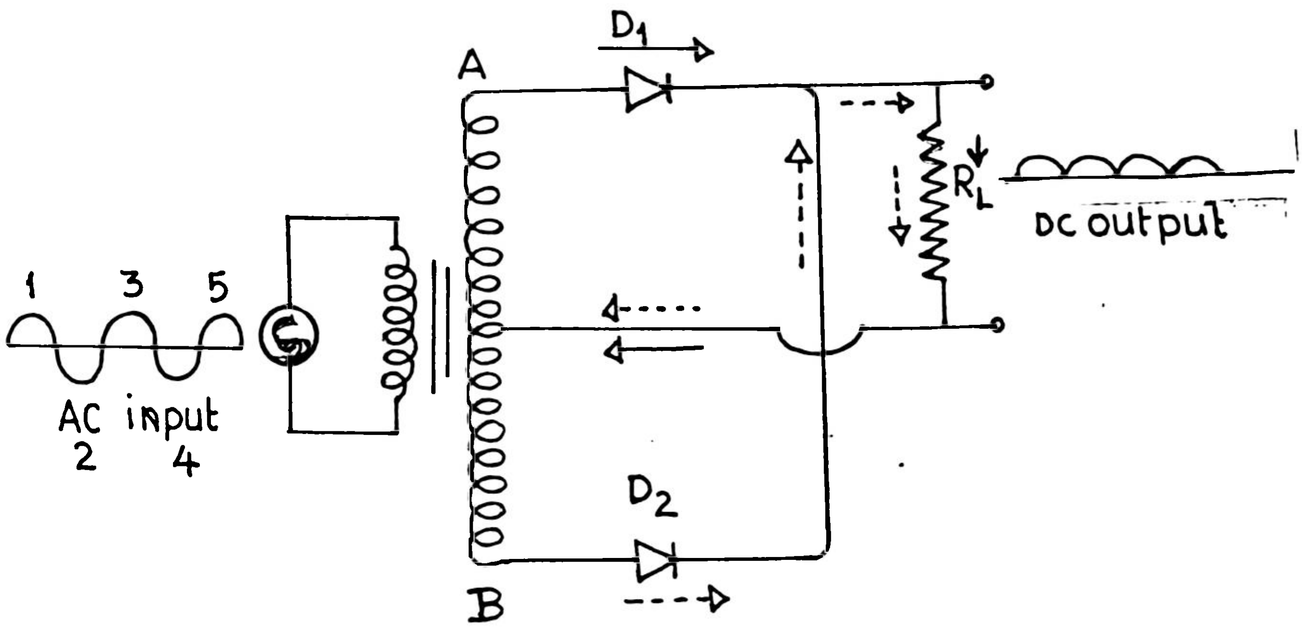


Fig 5.18 A full-wave rectifier

D_1 and D_2 are two junction diodes,connected to the ends of the secondary of a transformer having a centre tap. During the alternate half-cycles namely 1,3,5,...D_1 will be in conducting state as the end A is positive. In the alternate half cycles 2,4,6,...D_2 conducts as B is positive. Note that while D_1 is conducting D_2 is not and vice versa.

The full wave rectifier circuit shown in fig 5.19 where 4 diodes are used does not require a centre tap for the transformer. During the half-cycles when the point **A** is positive diodes 4 and 2 conduct and during the other half diodes 1 and 3 conduct sending a unidirectional current through R_L during both halves of the cycle.

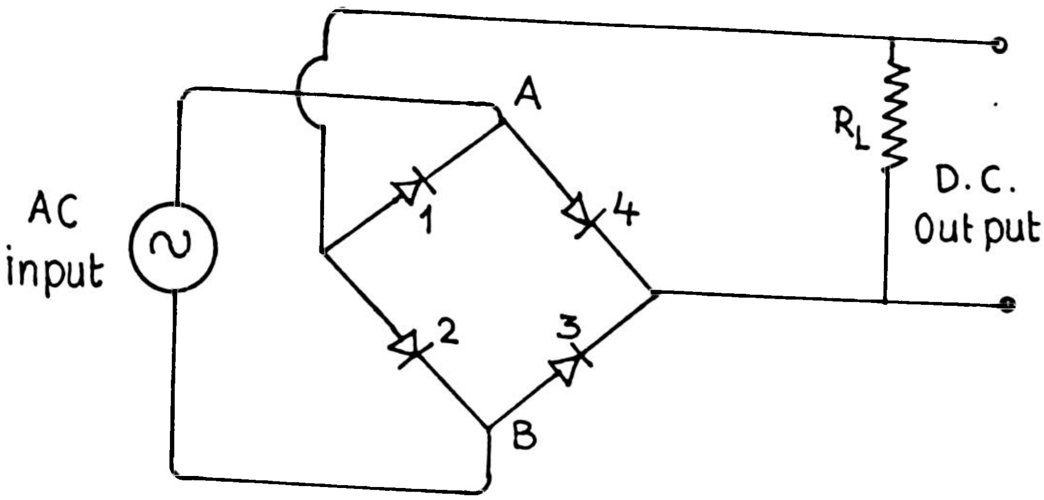


Fig 5.19 A bridge full-wave rectifier

OSCILLATOR:

A voltage that changes with time, periodically, as the function $V = V_0 \sin 2\pi ft$ ft or as the function $V_0 \cos 2\pi ft$ is called a sinusoidal voltage (V_0 is the maximum voltage; t is time and f is the frequency) (fig 5.20).

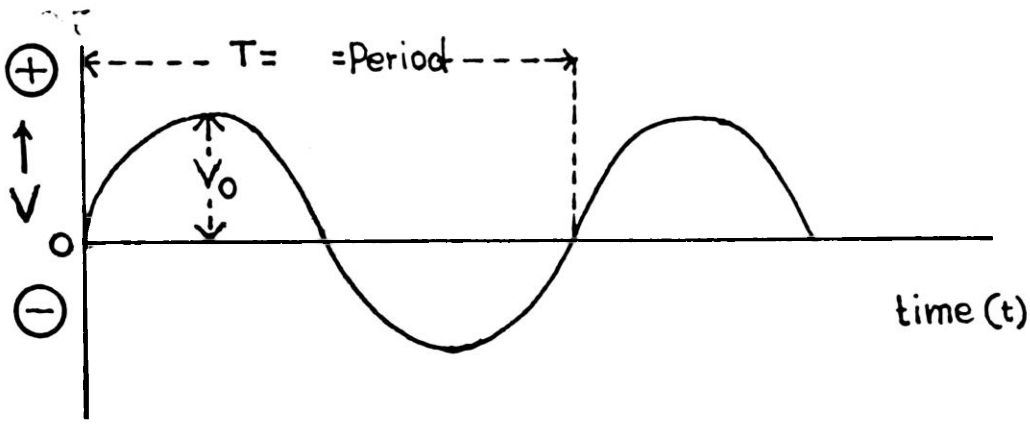


Fig 5.20 A sinusoidal voltage

We are supplied with this type of alternating electric voltage by the electricity board for consumption of electric power,both for domestic and non-domestic purposes. Whenever a direct current is required, we use a rectifier to convert alternating current into direct current (along with the step-up or step-down transformer wherever necessary). An oscillator works the other way. It converts direct current/voltage into alternating current/voltage. Here we discuss oscillator which converts direct voltage into a sinusoidal alternating voltage.

Consider a mechanical oscillator such as a simple spring pendulum, consisting of a mass suspended from one end of a coiled spring. If the mass is pulled down from its rest position, thereby supplying energy, and then released, it will oscillate up and down. Here, the amplitude of the oscillations decreases with time exponentially due to frictional losses and the oscillator gradually comes to rest. Such oscillations, the wave forms of which are shown in fig 5.21 are called damped oscillations. However, sustained oscillations (undamped oscillations) with constant amplitude can be produced by supplying energy at regular interval at proper time i.e. in proper phase. This supply of energy replenishes the frictional losses.

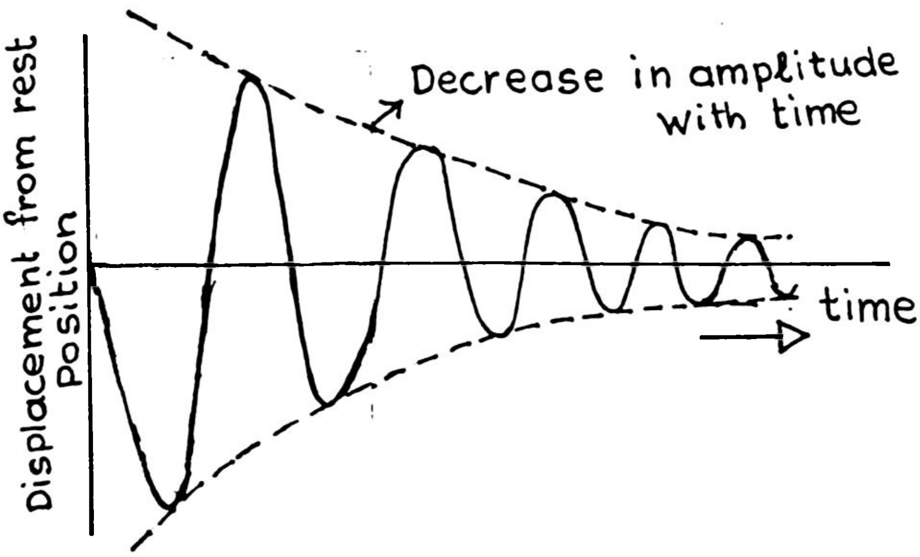
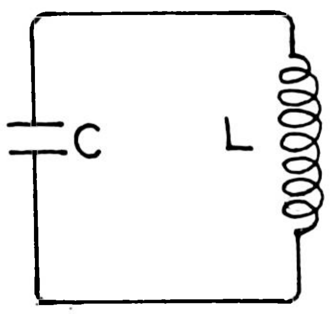


Fig 5.21 Damped oscillations

A tank circuit consisting of a capacitor and an inductance in parallel (fig 5.22a) is the simplest type of an electrical oscillating system. It can generate damped oscillatory current when excited and left free. The damping loss is due to the resistance of the circuit. With reference to fig 5.22b the tank circuit can be initially supplied with electrostatic energy by putting the SPDT (single pole double throw) switch to position 1 thereby, allowing the capacitor to get charged. When the switch is put to position 2 we have the LC tank circuit as shown in fig 5.22a with energy supplied to it. Due to the voltage across the capacitor, current (discharging current) flows through the inductor (fig 5.23a) establishing magnetic energy due to the magnetic field created around the inductor. When the capacitor completely loses its charge (due to the discharge through the inductor), the current through the inductor reaches a maximum and at this stage, the electrical energy is completely converted into magnetic energy (fig 5.23b).



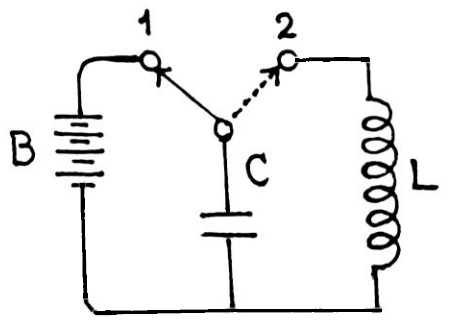


Fig 5.22a Tank circuit

Fig 5.22b Sequences of charging and discharging of a capacitor through inductance

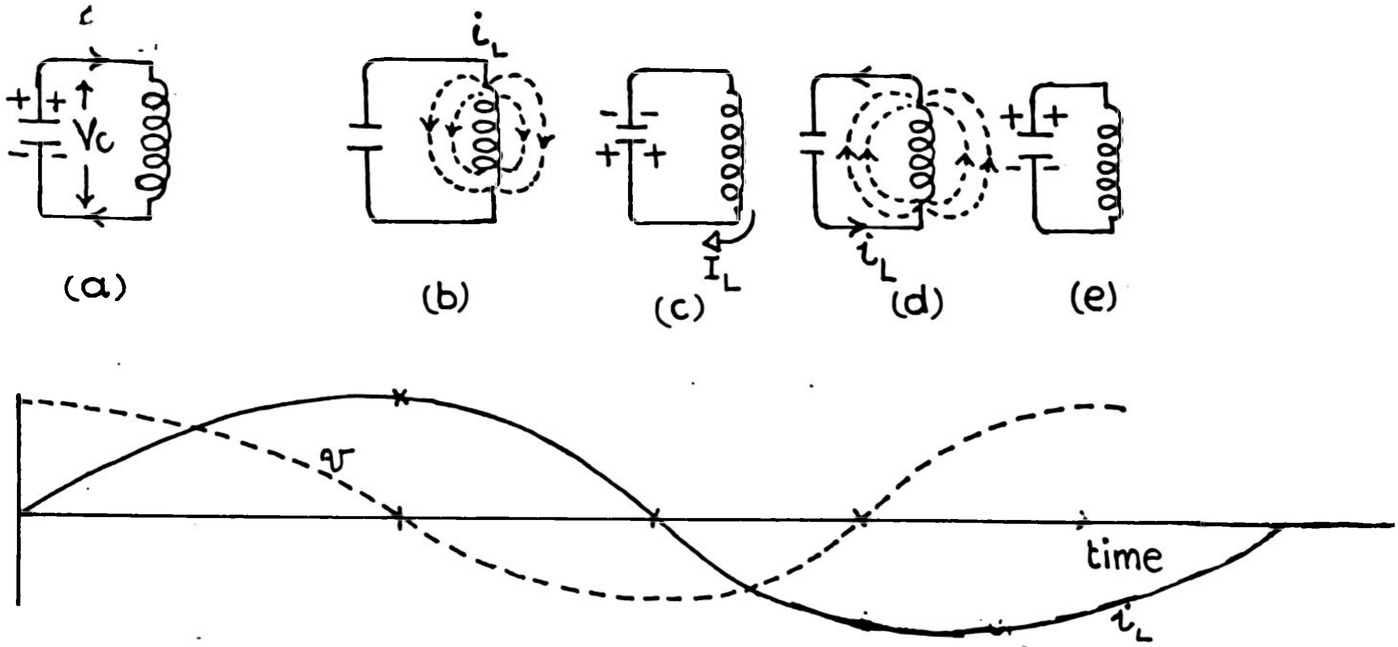


Fig 5.23 Working of a tank circuit

Next, the current through the inductor continues to flow in the same direction (recall Lenz's law) with decreasing amperage, charging the capacitor in the reverse direction. This builds up voltage across the capacitor, this time with opposite polarity, re-establishing electric energy stored in the capacitor. As the current drops to zero,magnetic energy completely gets converted into electrical energy (fig 5.23c). Thus, once again current starts to establish through the inductor, but this time in the opposite direction (fig 5.23d). A cycle is completed when the capacitor is again fully charged to the initial polarity (fig 5.23e). The sequence of charging and discharging results in an oscillating current and eventually the oscillations die (damped oscillations) down,due to the I^2R losses in the form of heat. The frequency of oscillations is $f = \dfrac{1}{2\pi\sqrt{LC}}$

The block diagram of an electrical oscillator is given in fig 5.24. It consists of the following:

i) An oscillatory (resonant) circuit, containing inductance L and capacitance C which determines the frequency of oscillation. Such a circuit is called a tank circuit. This is analogous to a simple mechanical harmonic oscillator.

ii) A source of d-c energy to replenish losses in the tank circuit. This is the actual energy reserve from which a-c energy/ voltage is derived.

iii) A basic amplifier element has a feedback circuit, the feedback being from the ac output. The feedback (a) senses the phase of the output ,(b) draws energy from the d-c source, (c) replenishes in the right phase, the energy loss (due to joule heating) at the tank circuit. This is to maintain the oscillations. Such a feedback is said to be regenerative. For a given feedback, the amplification must be such as to transfer sufficient energy from the d-c source to the oscillating tank circuit to compensate for the energy loss. Fig 5.24 shows a block diagram of an electrical oscillator.

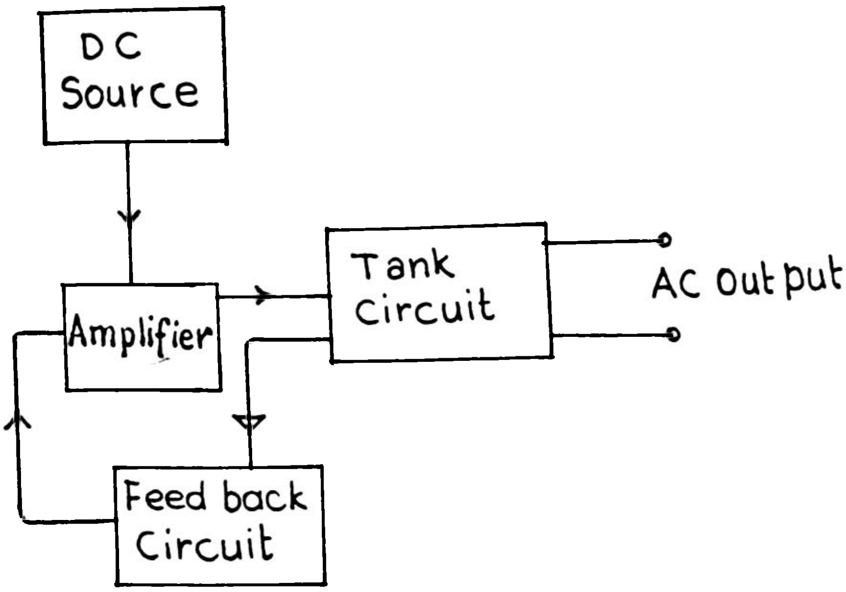


Fig 5.24 Block diagram of an electrical oscillator

In fig 5.25, is shown a simple electrical oscillator circuit.

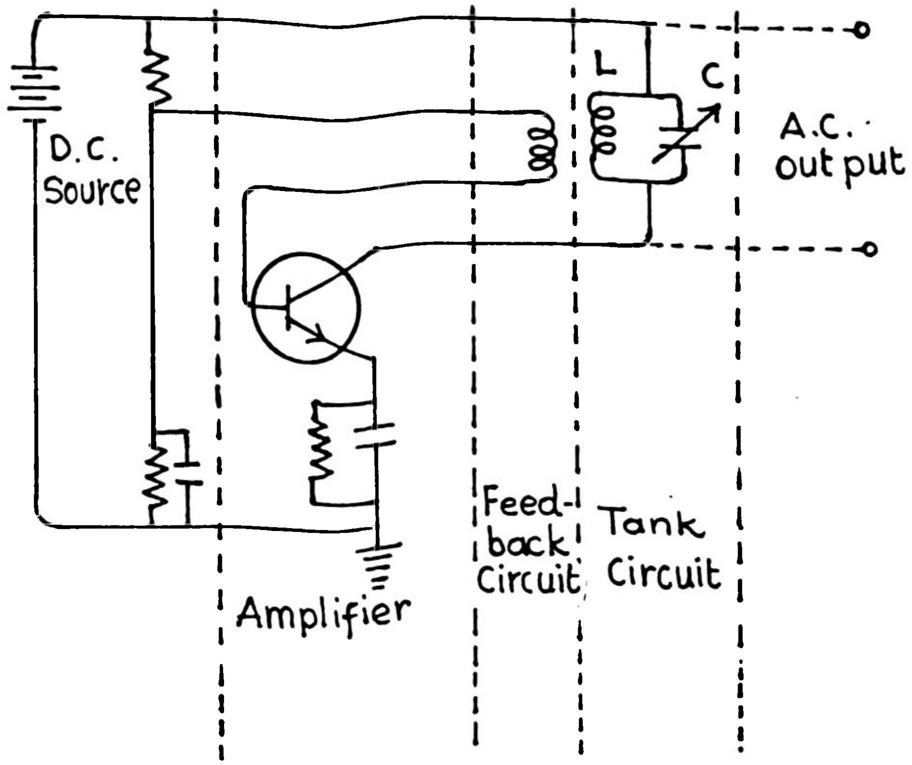


Fig 5.25 A simple electrical oscillator

Activity 5.7:

Action of a Diode:

The rectification action of a diode can be illustrated with the help of the circuits shown in fig 5.26.

Make the circuits as shown in fig 5.26. Observe the change in intensity of the glow of the neon lamp. Take care to see that the A.C. mains supply is switched off while making the changes in the circuit. The student will be able to reason out, that the reduction in the intensity, andthe flickering of the neon lamp (figs 5.26b and 5.26c) is due to the interruptions in the supply of voltage to the bulbs as given in the output waveform of half-wave rectifier.

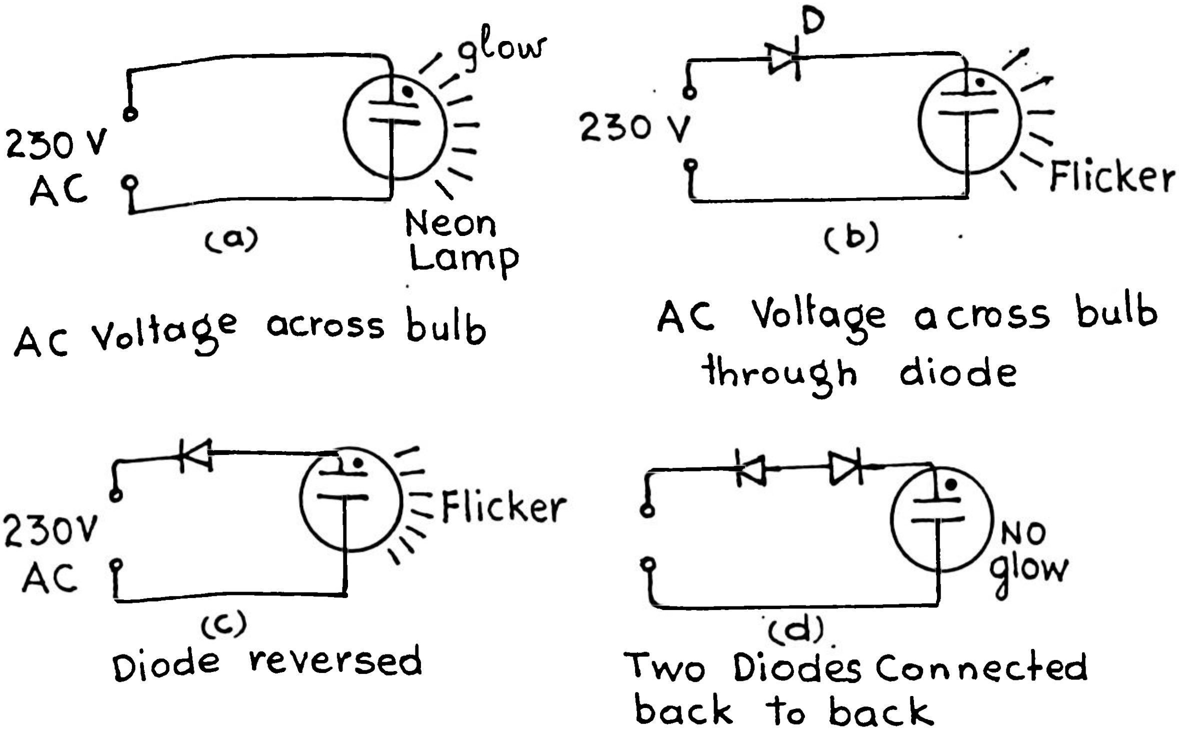


Fig 5.26 Circuits to demonstrate rectification action of a diode

Activity 5.8:

Connect the circuit as shown in fig 5.26d. The neon lamp does not glow. It could be explained as follows:

a) During one half cycle of the A.C. supply, when diode 1 is forward biased, the diode 2 is reverse biased disallowing the current to flow. b) During the second half cycle diode 2 is forward biased but diode 1 is reverse biased and hence no current in the circuit.

Activity 5.9:

The circuits shown in fig 5.27 may be used to demonstrate the amplifying action of a transistor.

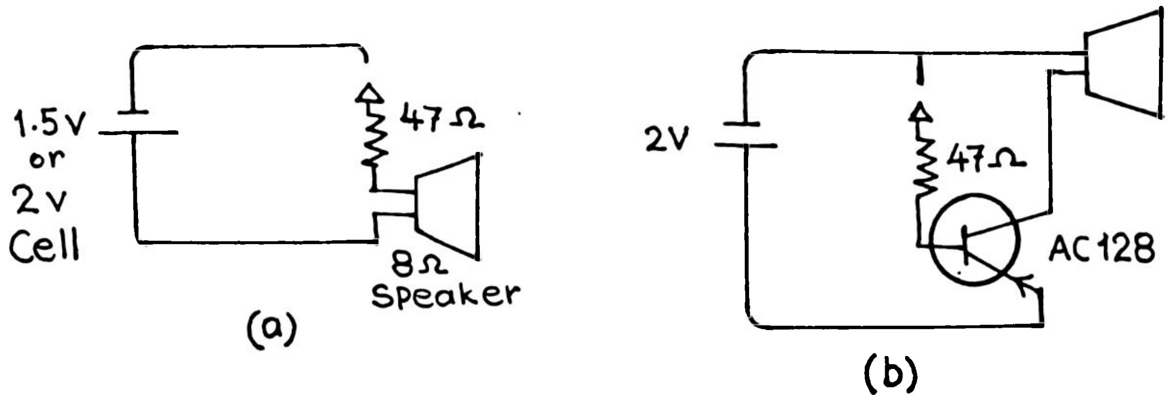


Fig 5.27 Circuits to demonstrate amplifying action of a transistor

When the open-end of the wire in fig 5.27a is scratched against the cell terminal shown, it provides changing current through the circuit, for the speaker to give a noise signal. Notice the amplified noise in the speaker in fig 5.27b.

Amplification of a.c. currents can be demonstrated by replacing the speaker by a milli-ammeter. The resistance may have to be changed to suit the range of the milli-ammeter. In this case, wire may be directly connected to (-ve) terminal of the cell.

C. RADIO BROADCASTING AND RECEPTION

5.1 C INTRODUCTION

Radio is a means of wireless communication. Radio waves are electromagnetic waves travelling with the speed of light. These waves can propagate through matter without appreciable absorption except in conducting media. Sound waves (20Hz to 20 kHz) cannot be propagated over large distance due to heavy absorption.They never propagate in vacuum. In order to transmit them over long distances, they are converted into electrical waves. These waves are superimposed over carrier electromagnetic waves and transmitted through an antenna. At the receiving end, these waves are picked up by an antenna and converted into audio waves.

5.2C ~~CONCEPTS~~ TEACHING POINTS.

1. The audio frequency waves when imposed on the carrier wave of radio frequency can travel a long distance with less absorption.

2. The frequency/amplitude of the wave is 'modulated' in propportion to the microphone current when the amplitude/frequency of the wave is kept constant.

3. For long distance transmission of the signal, the waves have to be suitably amplified.

4. The receiving antenna picks up the modulated electromagnetic signal which induces a current in a tuned L C circuit.

5. The receiver set demodulates the signal received by the antenna and the low frequency of audio waves are separated from its carrier wave.

5.3C DEVELOPMENT

Radio Transmitter:

The basic elements of a radio transmitter (fig 5.28) are described below.

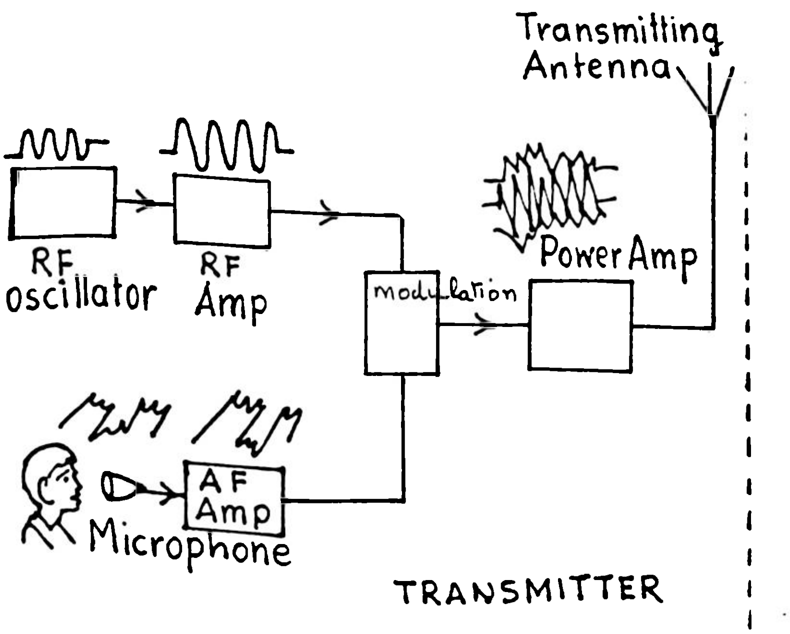


Fig 5.28 Basic elements of a radio transmitter

Microphone:

This converts sound waves into electrical waves. The wave characteristics are maintained in this conversion.

R.F.Oscillator:

RF waves whose frequencies (20 kHz to 10^5 MHz) are considerably higher than the frequency of the sound waves (audible signal) are used as carrier waves to carry the message. The carrier wave of high frequency is 'modulated' by the information signal (obtained from sound waves through microphone) for effective transmission. Modulation is the process of, changing either the amplitude or frequency of the carrier wave in proportion to the voltages of the information signal. The frequency of the carrier wave maintains the identity of a particular transmitting station.

The electrical impulses obtained from the microphone are amplified in an audio amplifier and superimposed on the amplified RF carrier so that the amplitude of the carrier changes in proportion to the instantaneous voltage of the audio frequency signal. This is further amplified in a power amplifier.

Transmitting antenna (aerial):

The output of the transmitter is fed into the transmitting antenna to radiate the electrical waves into space as electromagnetic waves.

RECEIVER

The basic elements of a radio receiver (fig 5.29) are described below.

Receiving Antenna:

When the modulated electromagnetic wave propagated from the transmitting antenna sweeps across the receiving antenna, a feeble alternating current is induced in it. This induced current contains the information signal superposed over the carrier wave.

Tuner:

A coil in the antenna branch induces by mutual induction a voltage proportional to the modulated carrier signal in an L-C circuit. This circuit has an inductance and variable capacitor in parallel. When the capacitance is varied the natural frequency of the L-C circuit changes and when this frequency is set to be equal to the carrier frequency, resonance occurs. Then a large voltage corresponding to the desired carrier frequency alone is induced in this circuit. The process is known as 'tuning'. The signal is further amplified.

Demodulation:

If the signal is directly fed to the loudspeaker, due to inertia and the high frequency of the modulated signal there will be no response. Hence there is a need for separation of the low frequency information component from the carrier component. This process of separating the AF component from the modulated carrier is detection or demodulation. The audio component is amplified and fed to the loudspeaker.

Loudspeaker:

The loudspeaker converts the electrical impulses into sound waves corresponding to the transmitted information.

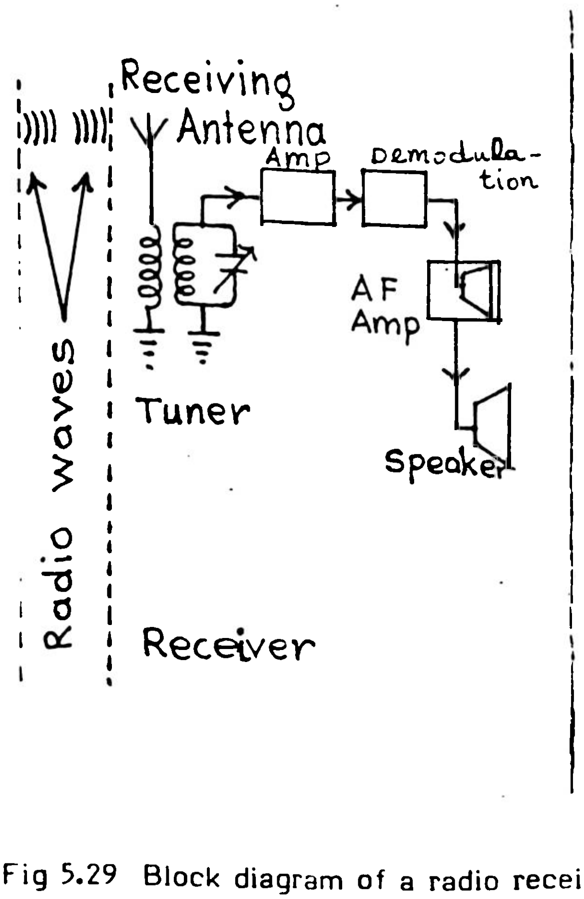


Fig 5.29 Block diagram of a radio receiver

5.D TELEVISION AND RADAR

5.3C INTRODUCTION

Television means to see at a distance. This is accomplished in a camera tube. First, an electrical image of the picture is obtained employing the principle of either photoconduction or photoemission. Next, the electrical image is scanned by a beam of electrons to produce varying voltages called video signals, corresponding to light intensity variations in the picture. The signals, after amplification, modulate the amplitude of a radio frequency carrier wave. The sound accompanying the picture, as in radio, is converted into varying voltages which after amplification modulates the frequency of a carrier, whose frequency is 5.5 MHz greater than that of the picture carrier. Obviously, two transmitters are necessary, one for sound and one for picture. The outputs of both these transmitters are radiated in all directions through a single antenna as two carriers differing by 5.5 MHz. (Fig 5.30)

A television receiver is a complex combination of an a-m-receiver for picture, a f.m. receiver for sound and a highly specialized cathode-ray tube (called the picture tube or kinescope). The picture is reproduced upon the face of a large fluorescent screen of the picture tube. A beam of electrons shot out of an electron gun scans the screen in step with the scanning of an electrical image of the picture in the T.V. camera tube. When the electron beam strikes a spot on the screen, the fluorescent material absorbs the kinetic energy of the high speed electrons that strike it. Some of this energy, instead of being changed into heat, is given off by the atoms of the phosphors in the form of visible light. The more intense the electron beam, the greater is the intensity of the light given off by the screen where the beam strikes it. The number of electrons striking the screen at a time depends upon the video signal received. In this manner, the picture that was taken apart bit by bit is reassembled in the same sequence on the face of the picture tube. The accompanying sound signal is processed as in radio.

In the receiver, the carrier signal is mixed with the output from a tunable oscillator (known as local oscillator). This mixing results in the formation of a signal whose frequency is the difference of the two frequencies. This frequency

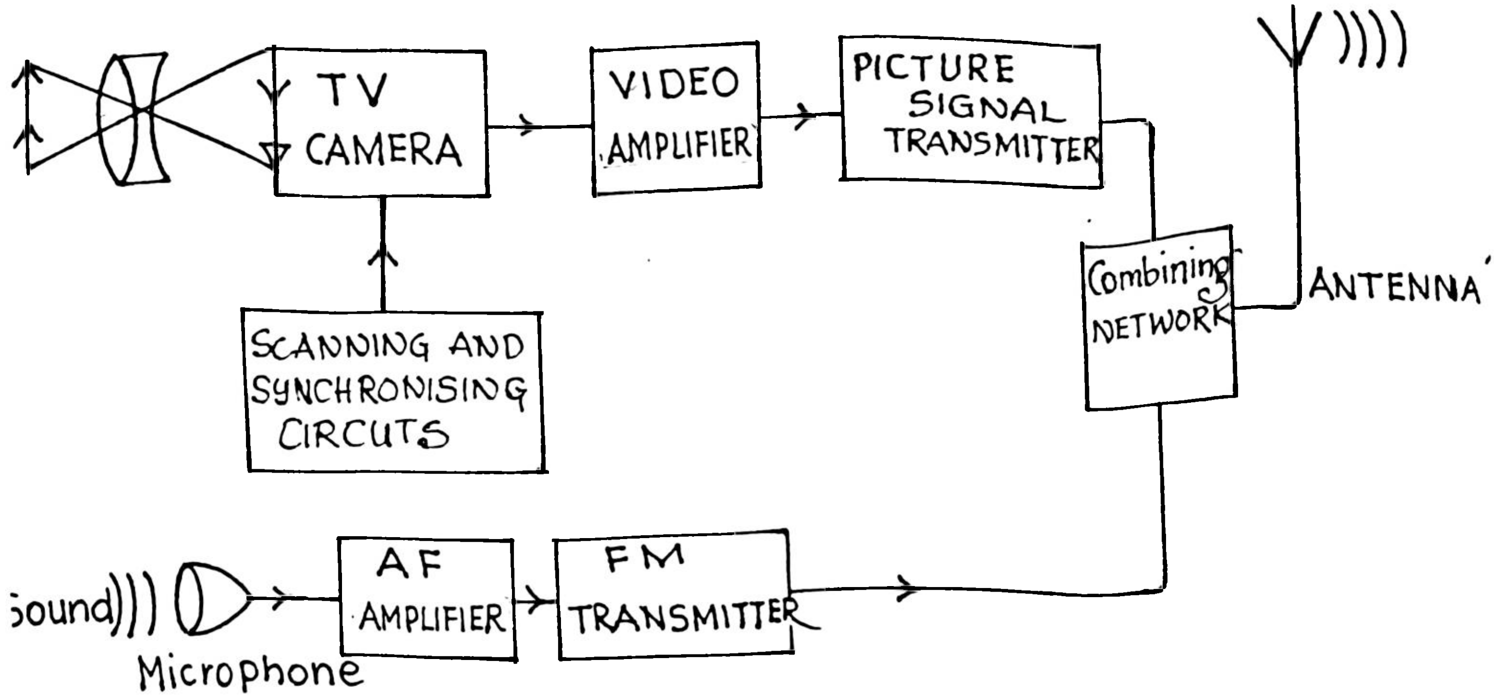


Fig 5.30 Block diagram of a T.V. transmitter

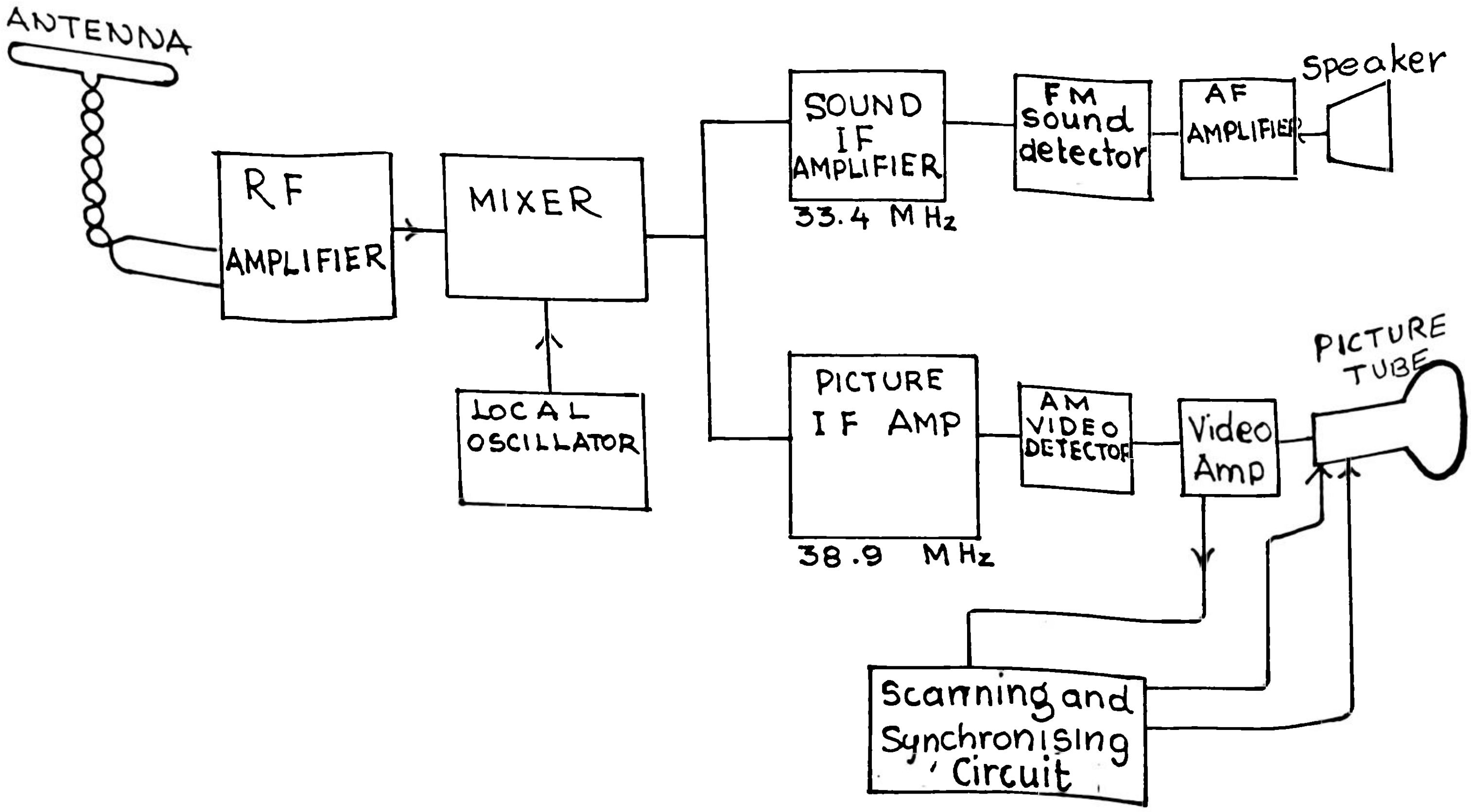


Fig 5.31 Block diagram of a T.V. receiver

is known as the intermediate frequency (IF). This is 33.5 MHz for sound and 38.9 MHz for picture. All the later circuits are tuned to these frequencies. (Fig 5.31)

5.2D TEACHING POINTS.

1. Television is a system of communication in which high frequency radio waves are used to obtain visual and sound reproduction at distant places.

2. The picture is broken into a large numberof elements at the transmitter and at the receiver, they are reassembled in the same sequence.

3. Scanning is the process where a narrow beam of electrons sweeps across a rectangular area containing the picture.

4. In a T.V. camera tube, the optical image formed on a screen is first converted into its electrical image by the phenomenon of photoconduction, or photoemission.

5. Scanning of the electrical image results in the production of varying voltages in accordance with the nature of the picture elements.

6. The scanned signal when incident on the fluorescent screen of the picture tube reproduces the picture.

7. Intensity of the visible light emitted by the phosphors depends on the number of electrons striking it, which in turn depends on the strength of the signal.

8. In general, in a television system illusion of continuous motion in the picture is obtained by presenting 25 frames per second.

9. Interlacing is a method of dividing the number of scanning lines associated with a frame into two groups- odd numbered and even numbered, in order to present to the eye 50 fields per second for avoiding flicker.

10. In order to have high-fidelity in the reproduced picture a frame must have a large number of horizontal scanning lines.

11. Synchronizing pulses enable the scanning at the receiver to keep step with the T.V. camera tube.

12. Horizontal and vertical retraces are blanked out by transmitting respective blanking pulses.

13. The composite video signal includes camera signal with picture information synchronizing pulses for time scanning and blanking pulses to blank out retraces.

14. The picture carrier is amplitude modulated by the composite signal and the sound carrier is frequency modulated by audio signal.

15. The propagation of T.V. waves from the transmitter to the receiver antenna is along the line-of-sight direction, as sky waves emitted are not returned to the ground by ionosphere.

16. Satellites are used to relay T.V. signals for longer distances.

17. The colour T.V. involves the breaking down of light from a scene to be telecast into its primary colours (red, blue and green) and recombining them at the receiver suitably designed for this.

18. The red, green and blue signals from the colour camera tube are suitably combined to form luminance (Y) and chrominance (G) signals.

19. The luminance signal has black and white information for monochrome receivers and brightness information for colour receivers.

20. The chrominance signal has no effect in monochrome receivers but provides colour information to colour receivers..

21. Compatibility is the ability of monochrome receiver to use luminance signal to produce black and white version of colour telecast.

22. Colour picture is reproduced when electron beams controlled by red, blue and green signals strike the respective phosphor dots coated on the fluorescent screen.

23. Radar is a microwave communication system of transmitting and receiving the reflected pulse at the same place.

24. Range is determined by measuring the time elapsed between sending a pulse and receiving its echo.

25. Direction is given by the orientation of the antenna when it scans the horizon or sky.

26. Comparison of the frequency of the reflected pulse with that sent indicates the relative velocity of the object. The object is receding if the reflected pulse has a lower frequency than that of the transmitted pulse and vice versa.

27. Suitable indicators are designed to give continuously the instantaneous distance, direction and relative velocity of the object.

5.3D DEVELOPMENT

Television Channels:

In India, CCIR (International Radio Consultative Committee) standards are followed. The frequencies assigned are as follows:

Type	Range	Channel No.
Very high frequency	40MHz to 47 MHz	1
	47MHz to 54 MHz	2
	54MHz to 61 MHz	3
	61MHz to 68 MHz	4
	81MHz to 88 MHz	5
	174MHz to 230 MHz	6 to 13
ultra high frequency	470MHz to 960 MHz	14 to 83

Very high frequency range from 88 MHz to 174 MHz is reserved for F.M. broadcasting.

A T.V. channel is 7 MHz wide. The picture carrier is 1.25 MHz above the low frequency of the band assigned to a station. A frequency band upto 5.5 MHz wide is available for video signals.

Range of telecast:

Telecast involves very large frequencies. The sky waves radiated from the transmitting antenna are propagated through the ionosphere and do not return to the ground. Television waves, therefore. cannot be transmitted farther than the 'line of sight' distance because they are intercepted and absorbed by the curvature of the earth.

Reception of television signals beyond horizon is possible with a tall receiving antenna.

To obtain a large range, the transmitting antenna must be located on a high tower atop a tall building, hill or a mountain peak. The greater the power of the transmitter, the more is the range of coverage.

The range of television coverage can further be increased by the use of transmission relay towers, strategically located across the length and breadth of the country. Microwaves are beamed from tower to tower, relaying transmitted programmes. Towers are connected to their relay centres by coaxial cables, (a cable containing a conducting wire in the centre of a conducting tube, but insulated from it).

The range of television transmission can be further increased beyond normal range by using communication satellites placed in geo-stationary orbits (fig 5.32).

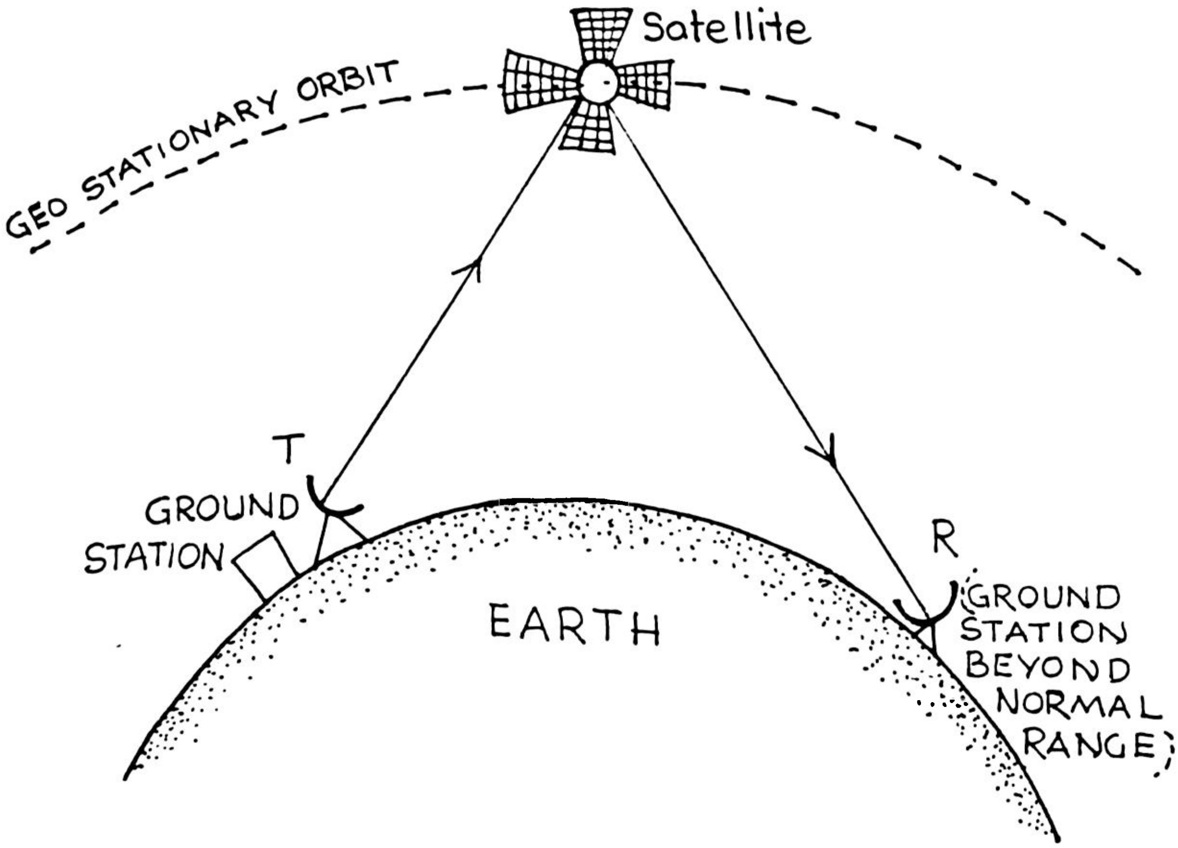


Fig 5.32 How to increase the range of TV transmission?

The satellite, energised by solar cells has aerials and equipment to receive transmission (sky waves from transmitting antenna) from a ground station and retransmit them in a changed frequency in a different direction. The frequency changing is necessary to convert the incoming signals (to the satellite) into a form suitable for the conventional television receiver. The retransmitted signals are received on the ground very far away by a large paraboloidal aerial. The signals are focussed to a pick-up point. These aerials are much more efficient than an ordinary aerial and the receiver has high sensitivity.

Scanning:

It is impossible to convert a whole picture, all in one instant into electrical signals. So, a picture is transmitted bit by bit and then put back together in the same sequence, at the receiving end. In a camera tube, an electrical image is obtained by the phenomenon of either photoconduction or photoemission. A beam of electrons explores different portions of the electrical image,developing a voltage at each instant proportional to the light intensity of the portion of the picture under examination. This process by which a beam of electron spot is made to move across a rectangular area in a sequential manner is called scanning.

Any motion in the scene to be telecast must appear on the receiving screen as a smooth and continuous change. For this, the property of the human eye known as persistance of vision is used. For illusion of motion, it is necessary to present more than 16 pictures of frames per second to the eye. In Indian television system, the frame repetition frequency is 25 (in motion picture it is 24). This frame repetition frequency is still not rapid enough to overcome the problem of flicker at the light levels encountered on the picture tube screen. For this, each complete picture or frame is divided into two fields so that 50 views of the scene are presented to the eye during each second. This repetition rate is fast enough to eliminate flicker. The choice of 25 complete pictures or frames enables the field rate to be exactly equal to power line frequency of 50 Hz.

The division of a frame into two is accomplished by a method of scanning of interlaced horizontal lines. This method divides the total number of lines that form a complete picture into two groups of lines called fields - one field containing odd-numbered lines and one, even numbered. The fidelity of the picture reproduced depends upon the number of lines that compose a picture or frame - higher the number higher is the fidelity. In Indian television system, a frame is formed of 625 horizontal lines giving horizontal line frequency of 625 x 25 =15,625. Each field contains 312.5 lines. A half-line in each field ensures the next field lines to lie between the lines of the first field. Thus successive fields are interlaced.

Scanning Sequence:

The scanning spot starts from the upper-left hand corner and travels at a uniform rate from left to right and slanting downward along the line 1 (or ab) fig 5.33(a). When it reaches the end, b, it quickly returns to the left hand end of the line 3, (point c) to start a new line cd. This horizontal return path bc (dotted line) is not required to be seen while reproducing the picture at the receiver. So, the scanning spot is blanked out during this return path by sending a suitable pulse called horizontal blanking pulse. The procedure repeats along odd numbered lines appearing at a constant distance below each other, till it reaches the middle point f at the bottom. The spot then quickly returns to the middle point g at the top, maintaining back and forth motion called vertical retrace as shown in fig 5.33(b). This vertical return path is also, while reproducing the picture, not required to be seen. So, vertical blanking pulses are sent. The spot then scans along line gh and even numbered lines, ij, kl,etc. spaced between odd numbered lines till it reaches the bottom right hand corner point n. The spot then quickly returns to point to start a new frame as in the figure.

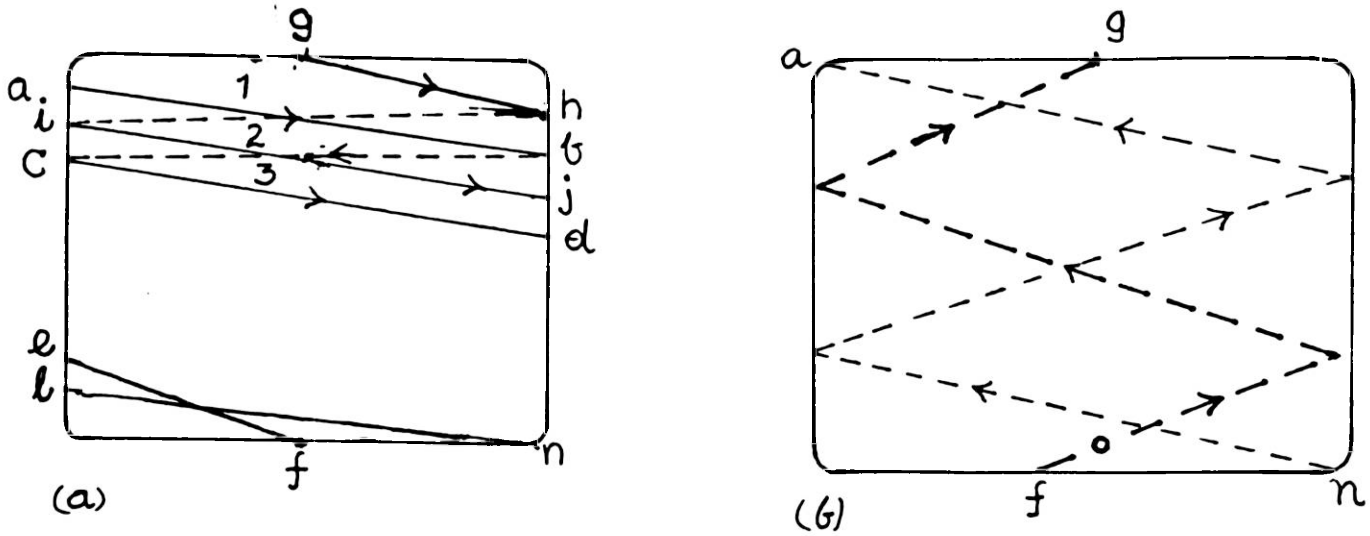


Fig 5.33a Scanning sequence in T.V.
Fig 5.33b Vertical retrace in TV scanning

II. WAVES

2.1 INTRODUCTION

Waves are produced by vibrating system. The vibrating prongs of a tuning fork or the vibrating diaphagram of a loudspeaker produce waves. These waves are mechanical waves. An LC tank circuit in which electric energy is converted into magnetic energy and vice versa at regular intervals of time produce electromagnetic waves. Light waves, X-rays are all electromagnetic waves. In this unit mechanical waves such as ultrasonics, seismic waves, etc. and such interesting topics like lasers, radars, fluorescence etc. which involve electromagnetic waves are discussed. The introductory details on waves are already discussed in Physics Resource Material Vol.II.

Additional Reference Books

The following recent publications are easily available in India.

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2. Introduction to Physics for Scientists and Engineers - Bueche Fredrick J., MacGraw Hill, Kogakusha Ltd.

3. Physics of the Atom - Wehr M.R., Richards Jr. and Adair T.W., Narora Publishing House, New Delhi.

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5. Electricity made simple - Basford L., - Rupe and Co., Calcutta.

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10. Teaching Physical Sciences in Secondary Schools - Sterling Publishers, New Delhi.

Picture Qualities:

The illumination on the picture tube as a result of scanning, in the absence of video signal is known as raster. The quality of picture reproduced should have high brightness, strong contrast, sharp detail and correct aspect ratio. Brightness is the average or overall illumination. In a picture tube, it depends on the amount of high voltage of the picture tube and its d.c. bias in the grid-cathode circuit. The brightness control knob in television receivers varies the picture tube bias. Contrast is the difference in intensity between black and white parts of the picture. The peak-to-peak video signal amplitude determines contrast. Resolution, is a measure of how many picture elements can be reproduced. With many fine details, the picture looks sharp and clear. Resolution depends on the number of scanning lines and band width of transmission channel. The best viewing distance is about four to eight times the picture height. Closer than this,we see all the details, but the speckled grain called 'snow' in the picture is visible and individual scanning lines make the picture coarse. Farther than this, fine picture details may be lost. For proper viewing, the room should have required background illumination. If the background is very bright, the picture appears washed out with little contrast.

T.V Camera Tube:

A T.V. camera has two main requirements: First, it must have photoelectric properties to convert variations of light intensity in the optical image of the picture into electrical image. Second, it must have a scanning arrangement to produce voltage variation for each element of the electrical image, one at a time, in successive order, to televise all the visual information in the complete picture.

The first is accomplished by the phenomenon of either photoemission or photoconduction. There is a class of materials which emit electrons almost instantaneously when light falls on them: the number of electrons emitted is directly proportional to the intensity of light incident. This leaves the surface positively charged in accordance with light intensity. The phenomenon is called photoemission. Various alkali metals sodium, potassium, cesium and lithium exhibit this property. Cesium oxide is often used because its photoemission is more sensitive to incandescent light. There is a second class of materials (such as selenium, antimony, tellurium and lead along with their oxides) whose electrical conductivity varies in accordance with the intensity of light incident on them. The resistance decreases as intensity increases. This phenomenon is termed as photoconduction. The incident photons provide energy for the production of charge carriers, resulting in increased conductivity.

The second function scanning is performed by an electron-gun with its accessories. Its function is to produce a narrow beam of very high velocity electrons. Its construction is shown in fig 5.34. It consists of a cathode (2) and a heater (1) arrangement for emission of electrons. The number of electrons in the beam is controlled by a control grid (3). Accelerating grids (4, accelerate the electrons towards the surface to be scanned. To focus the electrons to a sharp point on the surface to be scanned either electrostatic or electromagnetic focussing technique (5,6) can be used. Electromagnetic focussing is generally used in camera tubes and electrostatic focussing in receiver tubes. The deflection of the scanning beam is accomplished by electromagnetic technique. For this purpose, external deflection coils called yoke are wound round the neck of the glass envelope. Usually the anode is a conductive coating of aquadag 7 on the inside of the evacuated glass envelope. A separate anode connector is used for the high voltage, which is about 20,000 volt. The deceleration of electrons accelerated through such high potentials can produce X-rays, particularly in colour picture tubes which must be properly shielded. Even when the set is shut off a dangerous potential can remain because of capacitive effects. Extra caution should be used when working on a T.V. set. (In most cases, this should be entrusted to an experienced technician).

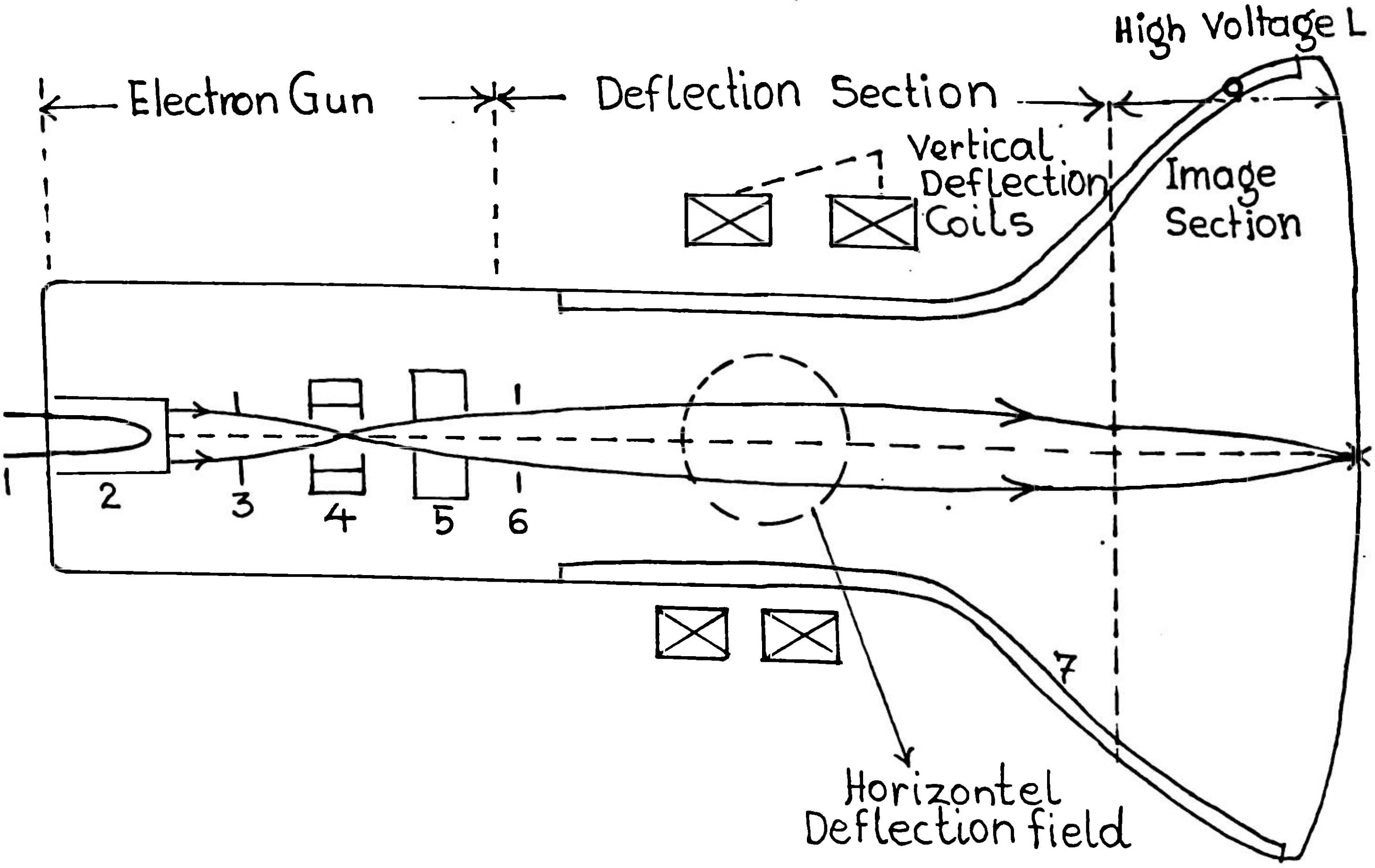

Fig 5.34 Electron gun

Types of Camera Tubes

Vidicon:

The first T.V. camera invented is the iconoscope (in 1928 by V.K.Zworlykin) literally meaning image observer. This was earlier used to televise film but has been replaced by newer camera called the vidicon. It is a modern camera tube of low cost and small size and is simple to operate. The essential parts are a signal or target plate, an electron gun and coils for focussing, deflecting and aligning the electron beam. The signal plate is deposited directly on the flat face glass end of the tube. The signal plate consists of a conducting metallic film so thin that it is transparent to light. It is coated with a thin layer of the photoconducting material, selenium or antimony compound. The image of the scene to be televised is focussed on the signal plate with the help of lenses. Different regions of the selenium film develop different resistances depending upon the intensity of light at those parts. The electron beam from the gun scans the selenium film. Then voltages varying with the degree of brightness of each picture element are developed.

Colour Television:

Any colour can be regarded as a mixture of three basic or primary colours red, green and blue. Therefore, the process in colour television involves the breaking up the light from a scene to be transmitted into the primary colours and of recombining them in the receiver. A receiver should be compatible, that is, a colour receiver should be able to produce a black and white picture and a black and white receiver should show a colour programme in black and white.

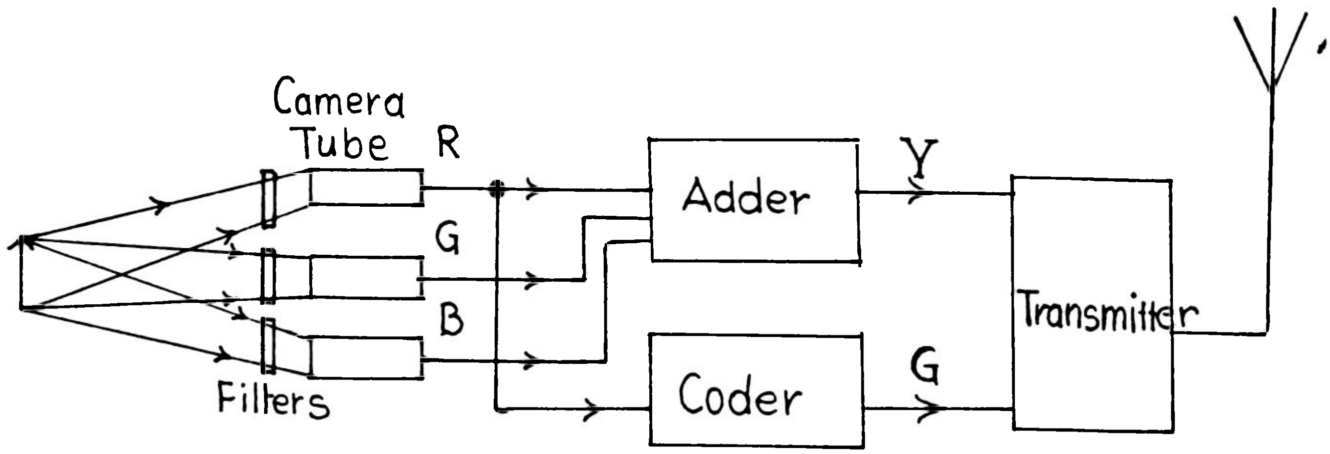

Fig 5.35 Colour Television- Arrangement of cameras

The light from the scene to be telecast is split by a system of mirrors and colour filters into the three primary colour. Each colour component is made to be incident on a camera tube. Hence three cameras are employed (fig 5.35). The output from each camera corresponding to each primary colour is processed electronically to obtain a brightness signal (luminance or Y signal) and a colour information signal (chrominance or C signal). These signals modulate a picture and colour carrier signals respectively. The combined signal is transmitted into space.

T.V. Receiver Tube:

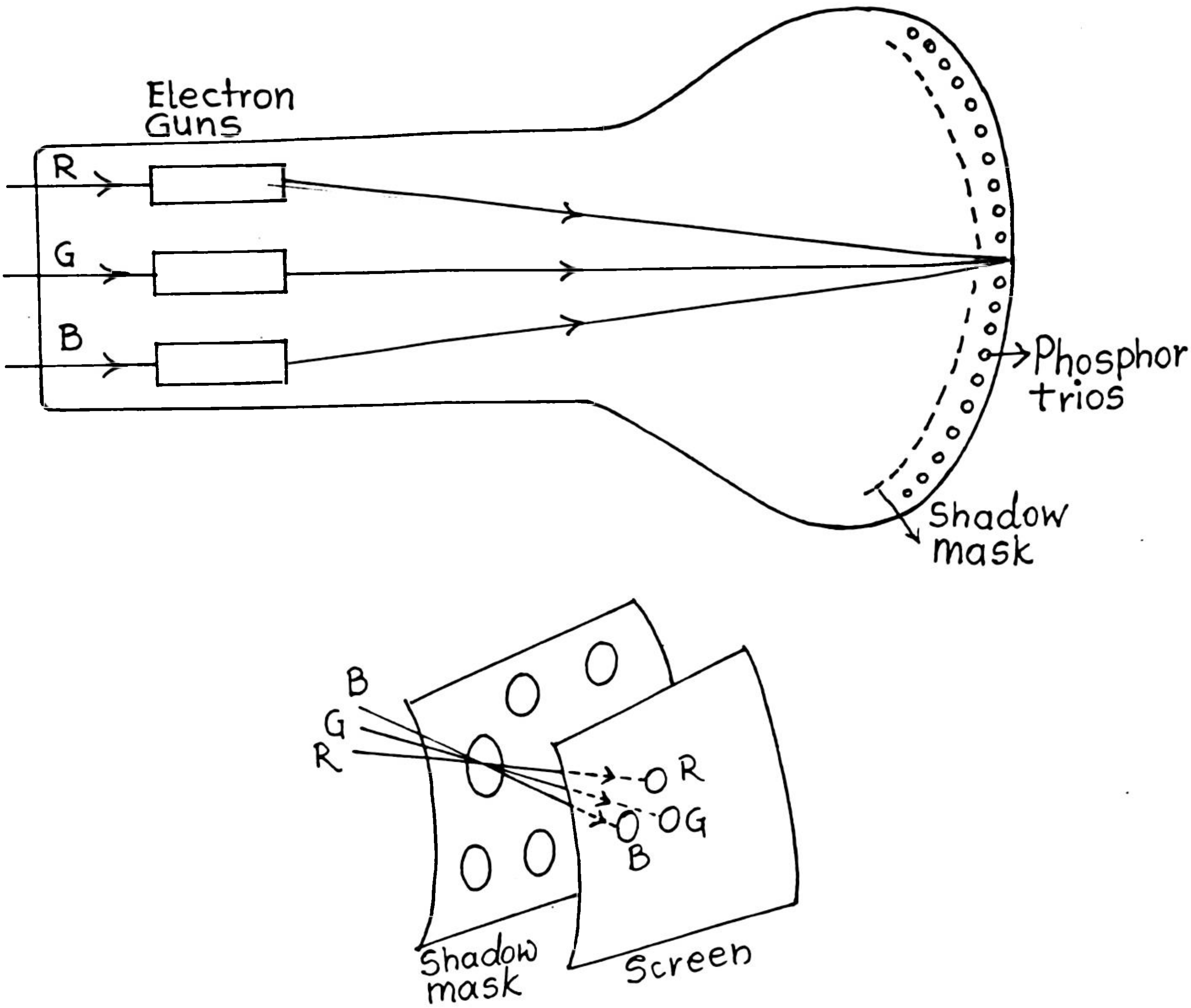

Fig 5.36 Picture tube of a colour T.V.

A colour picture tube should be capable of reproducing any combination of red, green and blue by application of appropriate voltages. In one model of the picture called the trigun tube, there are three electron guns placed at the neck of the picture tube (fig 5.36). They provide three separately controllable beams, one for each primary colour. The viewing surface is coated with large number of trios of red, blue and green phosphor dots. The red dot emits red light when bombarded by an electron beam. Similarly, green and blue dots emit green and blue colours respectively.

A thin metal sheet called shadow mask containing a tiny hole for each trio is carefully positioned between the guns and the viewing surface, but very close to the latter. The electron beams from the three guns are made to cross each other at the holes in the shadow mask and excite the appropriate dots after divergence. The red, green and blue video signals received are applied to the respective guns of the picture tube. They determine the number of electrons produced in the respective electron gun. This, in turn, determines the proportions of red, green and blue light originating from the trio. By deflecting the three beams together, it is possible to scan the surface of tri-phosphor screen and thus reproduce a coloured picture. Viewing distance should be such that the separate dots of the trio are not resolved.

RADAR

RADAR is an abbreviation for Radio Detection and Ranging and is based on the principle of radio echo to detect an object, its distance, direction and velocity. The transmitter sends out a short pulse of ultra high frequency radio waves (microwaves) through a highly directional and rotatable antenna. The outgoing waves, travelling with the speed of light are reflected when incident on an object. A small portion of the returning pulse is picked up, usually by the same antenna and is then fed to an indicator through a receiver circuit. In Radar continuous waves are not used, because there would be overlapping of the transmitted and the reflected waves resulting in a confusion. Because the object to be detected intercepts a very small fraction of the incident pulse and the returning pulse becomes still fainter on account of spreading the transmitted pulse power must be of the order of several megawatts. Remember the power transmitted by a broadcasting station is of the order of kilowatt. Indicators are designed to give continuously the instantaneous distance, direction and relative velocity of the object. Time interval between sending and receiving a pulse is a measure of the distance of the object from the transmitter. The direction is known by the orientation of the rotating antenna. The change in frequency, if any, in the echo gives the relative velocity of the object. If the object moves towards the station then by Doppler Effect, the echo will have higher frequency. If the object is receding from the station, then the frequency of the echo will decrease.

Radars are extensively used for military and civil purposes. Military radars detect enemy planes, ships and submarines located far off even through cloud and fog. They are arranged to, automatically, aim the anti-aircraft guns on the enemy targets and fire them or to automatically steer a guided missile to its target. Airplanes, ships and their control towers are fitted with radars to facilitate navigation and control, especially when the visibility is poor due to fog or cloud. Rain drops and snow reflect very high frequency radio waves. So, radars serve as a means of locating storms, cyclones, etc. and of following their paths. This enables forewarning the people about the likelihood of such disasters. Radars are used in meteorology to trace the flight of weather balloons which transmit weather data from high altitudes back to the ground station.

<u>Circuit:</u>

A radar consists of a pulse modulated transmitter, a highly directional and rotatable antenna with parabolic reflector, a receiver, an indicator, a timer and a duplexer as shown in fig 5.37. Duplexer is an electronic transmit-receiver switch (T-R switch) which enables the use of a single antenna for both functions, sending the pulse and receiving the echo. The timer supplies the synchronizing signal which triggers the transmitter and coordinates the function of the indicator and other associated circuits.

The transmitter is turned on for only a fraction of a second (about one micro second) to send out a burst of microwaves through the antenna. During this interval, the receiver is electronically made insensitive. When the transmitter goes off, the receiver is turned onto full sensitivity to receive the faint echo for a period of the order of 2000 microsecond. Then the receiver goes off enabling the transmitter to send the next burst. The process repeats hundreds of times per second. The output of the receiver is fed to an indicator for analysis. The antenna is capable of rotation so that it scans the horizon or sky. The antenna consists of a dipole (half wave length in length) or a Hertzian doublet (each of quarter wave length) placed at the focus of a parabolic reflector. Coaxial cable is used to connect the antenna to the electronic T-R switch.

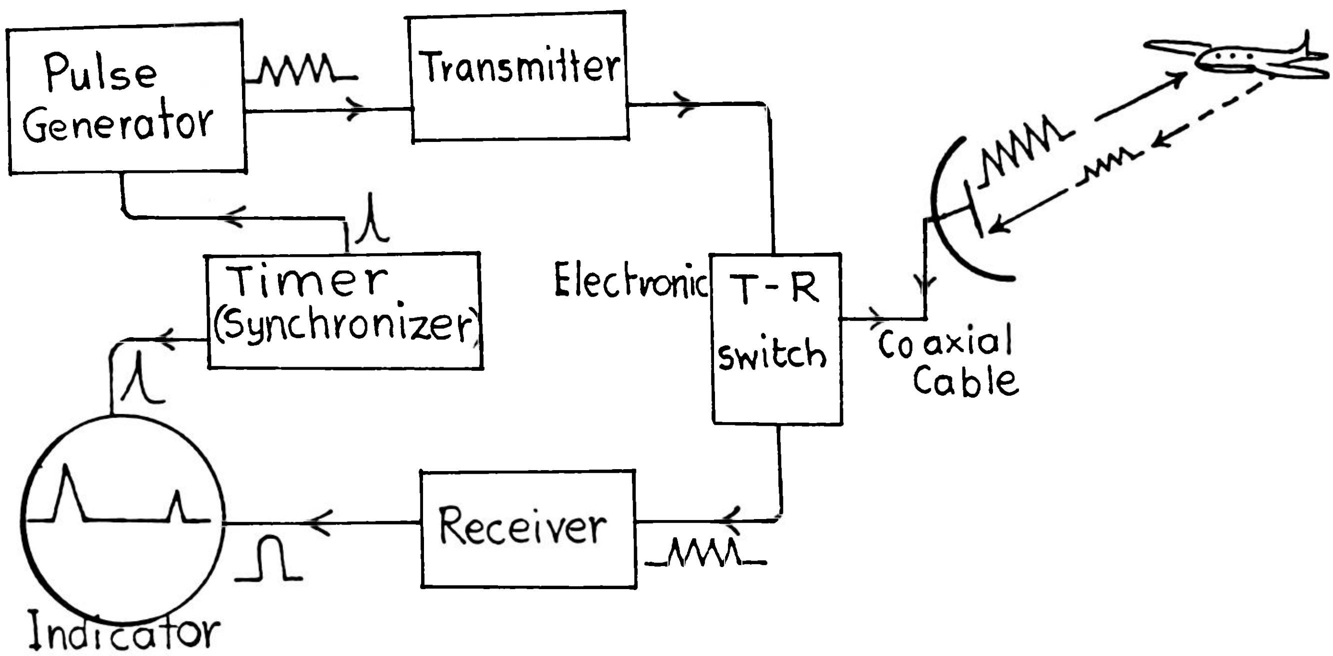

Fig 5.37 A RADAR circuit

<u>Determination of the range:</u>

Fig 5.38 explains the principle of determination of range. The indicator is the fluorescent screen of a suitable cathode-ray oscilloscope. The range can be calculated if the interval between sending of pulse and receiving of reflected pulse is measured. If t is this interval, then the distance between the station and the object is given by $d = 1/2\ c\ t$ where c is the velocity of light. The factor 1/2 comes because t corresponds to a to and fro motion between the station and the object.

Each micro second for example, corresponds to a distance of 0.15 km. between the station and the object detected.

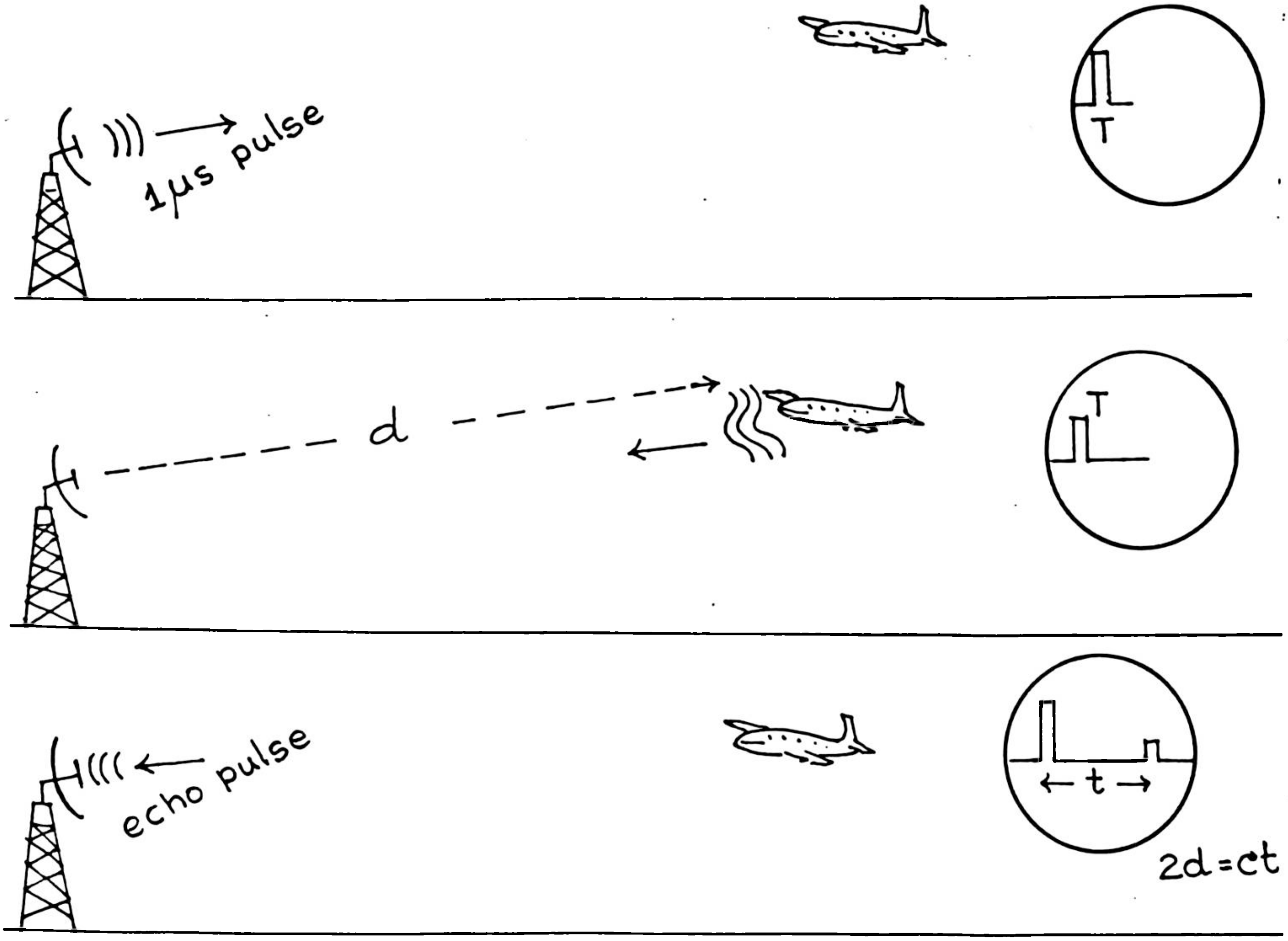

Fig 5.38 Determination of range

One of the most useful indicators is the PPI : plan-position indicator. This plots range and bearing or elevation and bearing on a circular screen (fig 5.39). The cathode ray spot is deflected radially outward from the centre. It is so synchronized with the transmitted pulse that distance outward from the centre is proportional to the distance of the echo producing target from the centre. The angular direction in which the cathode ray spot is deflected at any instant is made to correspond to the direction in which the antenna beam is directed at that moment. Thus, echos are presented to the radar operator as bright spots that give range and azimuth on a map in their true relation in polar coordinates. As different objects such as mountains, rivers, cities, plains, etc. reflect the electromagnet wave to different angles a radar can provide a polar map of the area around the radar on PPI with the radar at the centre. Such a map on the radar screen on the bridge of the ship, in the cockpit of an airplane or at the control tower of an airport makes the navigation safe,especially when the visibility is poor.

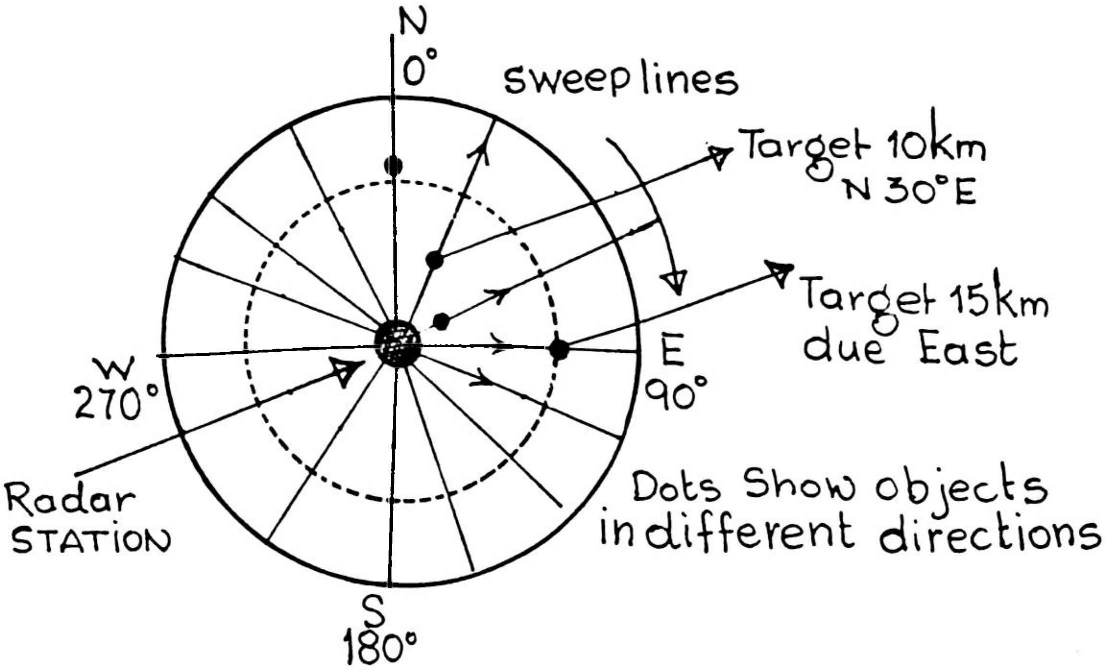

Fig 5.39 Radar - Plan Position Indicator (PPI)

5.4 EVALUATION

1. How is the Edison Effect related to thermionic emission?

2. Comment on the efficiency of carbon (work function = 4.7eV), tungsten (work function = 4.52 eV), and cesium (work function = 1.81 eV) as thermionic emitters.

3. Distinguish between (i) a diode and a triode. ii) temperature saturation and plate saturation and iii) space-charge limited current and temperature limited current.

Draw the wave form of the output from i) a half-wave and ii) a full wave rectifier if the input is of the form as shown in the fig 5.40.

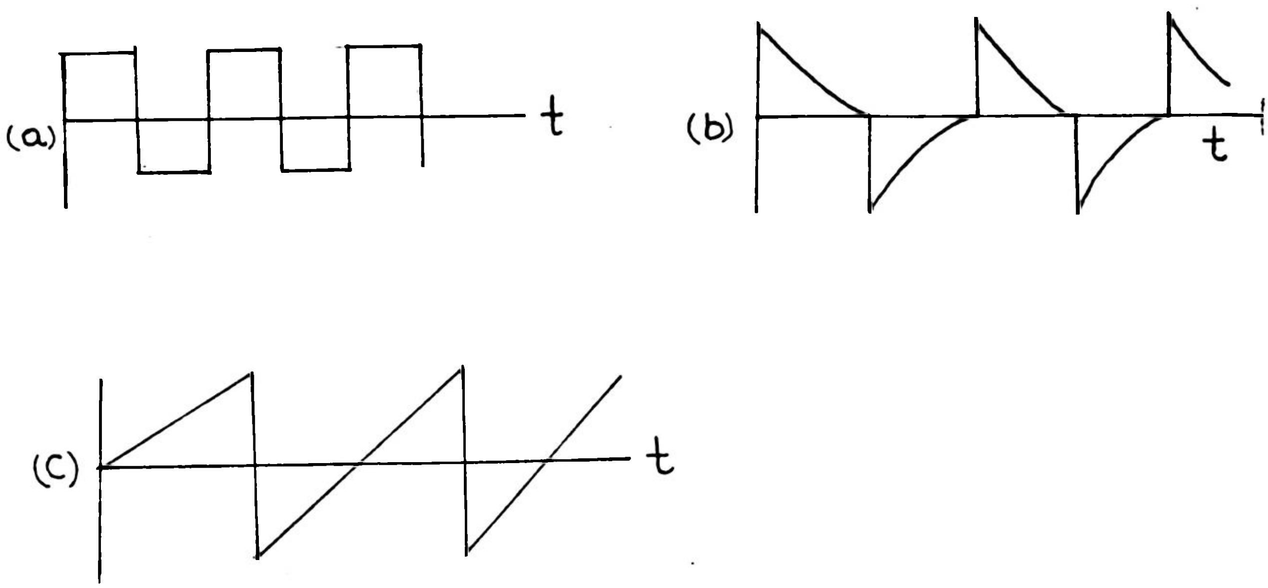

Fig 5.40

Explain why plate resistance of a vacuum tube is considered analogous to the internal resistance of a generator.

6. Can a triode rectify voltage? Explain.

7. A basic diode circuit and current voltage characteristic of that diode are given in the fig 5.41.

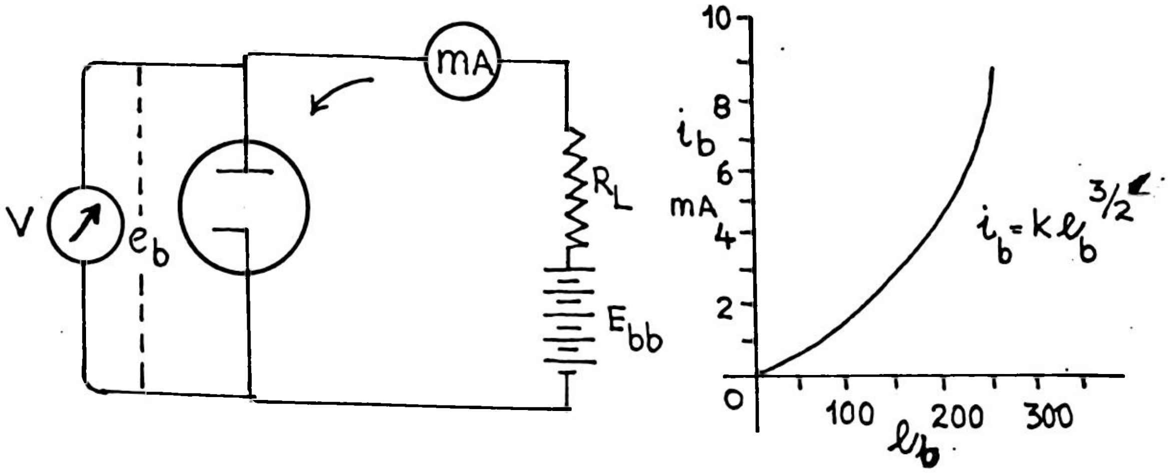

Fig 5.41

What is the potential difference e_b across the diode? Graphically find the values of plate current and plate voltage for a given plate supply voltage E_b and load resistance R_L.

8. How is the plate current effected if a small amount of a gas such as argon or mercury vapour is introduced?

9. How does the plate current in a diode change if the cathode heating power is slowly reduced?

10. The diode is connected in the circuit as shown below. The current-voltage characteristic of the diode is also given, fig 5.42. Predict the nature of the current in the load resistor R_L if $V = V_0$ sin wt.

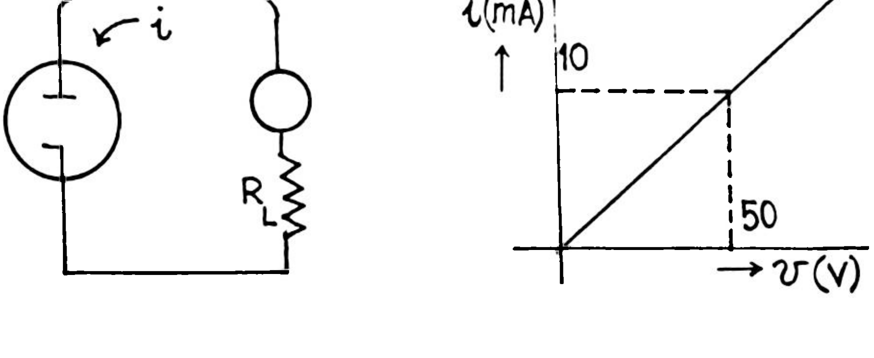

Fig 5.42

11. The number of valence electrons in Ge or Si semiconductors is

a) three b) four c) five d) eight

12. The donor impurity usually used in a semiconductor is

a) indium b) arsenic c) germanium d) aluminium

13. More mobile charge carriers will be created in a semi-conductor when it is

a) heated b) cooled c) cooled to almost absolute zero
d) doped

14. N-type semi conductor will have

a) more positive charge carriers than negative charge carriers

b) more negative charge carriers than positive charge carriers

c) negative charge carriers only

d) positive charge carriers only

15. In a P-type semiconductor, there will be

a) more positive charge carriers than negative charge carriers

b) more negative charge carriers than positive charge carriers

c) negative charge carriers only

d) positive charge carriers only

16. A p-n junction allows current to flow

a) in one direction only

b) in both directions equally

c) in both directions with slight difference

d) both directions with large difference

17. An N-type semiconductor allows current to flow

a) in one direction only

b) equally in either direction

c) in either direction but not with equal magnitude

d) in no direction

18. The direction of flow of current in a triode circuit is

a) from plate to cathode

b) from cathode to plate

c) in both the directions

d) grid to cathode

19. The function of an amplifier in an electronic circuit is
    a) increase the frequency of the A.C. signal
    b) increase the time period of an A.C. signal
    c) increase the amplitude of an A.C. signal
    d) convert the A.C. signal to D.C.

20. In an electrical oscillator, the following energy exchange takes place.
    a) mechanical energy into magnetic energy and vice versa
    b) mechanical energy into electrical energy and vice versa
    c) kinetic energy into potential energy and vice versa
    d) magnetic energy into electric energy and vice versa

21. A damped oscillation system can be made to produce sustained oscillations by
    a) decreasing the resistance of the circuit.
    b) increasing the voltage
    c) supplying energy at regular intervals
    d) starting with a large amplitude

22. The function of a feedback circuit in an electronic oscillator circuit is to
    a) produce oscillations of required frequency
    b) act as an energy source to boost up the oscillations
    c) supply the energy required to the oscillation system in phase
    d) allow undirectional flow of current

23. The function of an L-C circuit in an oscillator is to
    a) produce oscillations of the required frequency
    b) work as an energy source to boost up the oscillations
    c) supply the energy required to the oscillating system in the required phase
    d) allow undirectional flow of current

24. The function of an electronic oscillator is to
    a) amplify the input signal
    b) convert D.C. to A.C.
    c) convert A.C. to D.C.
    d) change the frequency of an input A.C. signal

25. What advantage will there be if the scanning spot is made smaller and the number of scanned lines larger?

26. Why is television system of transmitting and receiving the picture called a sequential method?

27. A T.V. transmitter telecasts on a frequency of 108 MHz. What is the wave length?

28. Why is vertical scanning necessary in addition to the horizontal line scanning?

29. How would the reproduced picture look on a kinescope if its screen is of square shape? Assume the scanning at the transmitter is normal. How would people in the picture appear?

30. How would the picture appear if there is no i) vertical synchronization and ii) horizontal synchronization?

31. Explain the conversion of electrical image into varying voltages at a picture element in a vidicon camera.

32. What would be the result if all of the dots in a colour trios in a T.V. set were equally excited?

33. What are the similarities between a radar and a television? How do they differ?

34. Explain how it is possible to see a radar (map) of the surrounding territory on a radar scope.

35. A certain radar has a 'blind' period of 3 microseconds between emission of a pulse and reception of its echo. Hence there is a sphere surrounding the set within which it cannot detect obstacles. What is the radius of that sphere?

36. Why are stations from all over the world heard by a short-wave receiver but not by an FM or TV receiver?

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