UNIT-1
Michelson Interferometer

Structure of the Unit

1.1 Aim

To determine:

(1) Wavelength (λ) of sodium light,

(2) Difference between the two D-lines of sodium,

(3) Refractive index (μ) of mica sheet.

1.2 Apparatus

Michelson Interferometer, Sodium lamp, White light lamp, Mica sheet and Spectrometer

1.3 Diagram

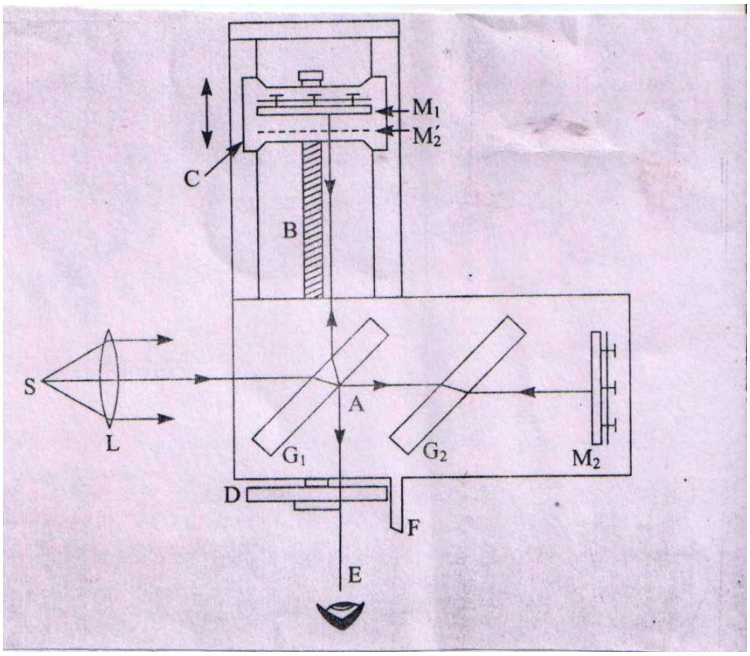


Fig1: Ray diagram of Michelson Interferometer

1.4 Formula

Wavelength (λ) of sodium lamp is given by –

$$\lambda = 2(x_2-x_1)/N$$

Where

x_1= Initial position of mirror M_1 of Michelson interferometer

x_2= Final position of mirror M_2 of Michelson interferometer

N= No. of fringes appeare or disappears at the centre of field corresponding to the distance (x_2-x_1)

(1) The difference of two lines of sodium light (λ_2-λ_1) is given by

$$\lambda_2 - \lambda_1 = \lambda^2_{av}/2x$$

Where

λ_{av}= Average value of wavelength of sodium light (mean of λ_1 and λ_2)

x = distance between the two indistinctness position of mirror M_1.

(2) Refractive index of mica sheet is given by –

$$\mu = (d/t) + 1$$

Where,

d = fringe shift after insertion of a mica sheet

t = thickness of mica sheet

1.5 Theory and description

This is an instrument designed by Michelson in which light from an extended source is divided into two parts partial reflection. These beams are sent in quite different direction against plane mirrors, when they are brought together again to form interference fringes. The arrangement is shown schematically in Fig. 1. The main optical parts consist of two highly polished plane mirrors M_1 and M_2 and two plane – parallel plates of glass G_1 and G_2. Sometimes the rear side of the plate G_1 is lightly silvered (shown by the heavy line in the figure) so that the light coming from the source S is divided

into (1) a reflected and (2) a transmitted beam of equal intensity. The light reflected normally from mirror M_1 passes through G_1 a third time and reaches the eye as shown. The light reflected from the mirror M_2 passes back through G_2 for the second time, is reflected from the surface of G_1 and into the eye. The purpose of the plate G_2 called the compensating plate, is to render the path in glass of the two rays equal. This is not essential for producing fringes in monochromatic light but it is indispensable when white light is used. The mirror M_1 is mounted on a carriage C and can be moved along the well-machined ways or tracks T. This slow and accurately controlled motion is accomplished by means of the screw V which is calibrated to show the exact distance the mirror has been moved. To obtain fringes the mirror M_1 and M_2 are made exactly perpendicular to each other by means of screw shown on mirror M_2.

Michelson Interferometer

Even when the above adjustments have been made, fringes will not be seen unless two important requirements are fulfilled. First, the light must originate from an extended source. A point source or a slit source, as used in the methods previously described, will not produce the desired system of fringes in this case. The reason for this will appear when we consider the origin of the fringes. Second, the light must in general be monochromatic, or nearly so. Especially is this true if the distance of M_1 and M_2 from G_1 are appreciably different. An extended source suitable for use with a Michelson interferometer may be obtained in any one several ways. A sodium flame or a mercury arc if large enough may be used without the screen L shown in Fig. 1. If the source is small a ground glass screen or a lens L will extend the field of view. Looking at the mirror M_1 through thye plate G_1 one then sees the whole mirror filled with light . In order to obtain the fringes, the next step is to measure the distances of M_1 and M_2 to the back surface of G_1 roughly with a millimetre scale, and to move M_1 until they are the same to within a few millimetres. The mirror M2 is now adjusted to be perpendicular to M_1 by observing the images of a common pin, or any sharp point, placed between source andG_1. Two pairs of images will be seen, one coming from reflection at its back surface. When the tilting screws on M_2 are now turned until one pair of images falls exactly on the other, the interference fringes should appear. They will only appear sharp if the eye is focused on the back mirror. M_1, as the observer should look constantly at this mirror while searching for the fringe.

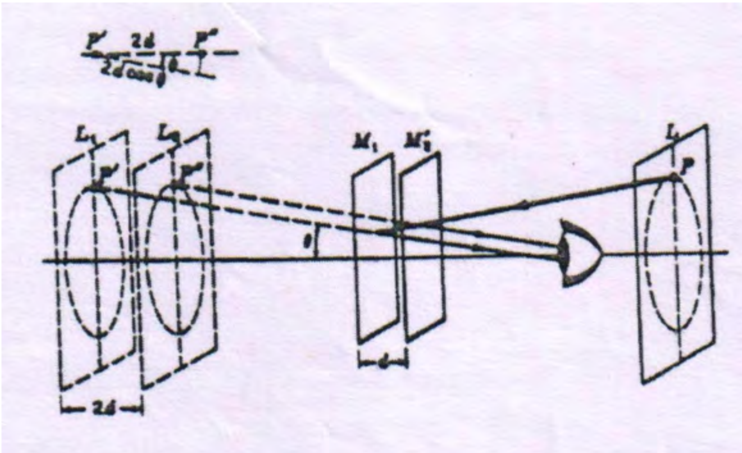


Fig 2: Formation of circular fringes

When the fringes have been found, the adjusting screws are turned in such a way as to continually increase the width of the fringes, and finally a set of concentric circular fringes will be obtained. M_2 is then exactly perpendicular toM_1.

Circular Fringes:

These are produced with monochromatic light when the mirrors are in exact adjustment, and are undoubtedly the most important type of fringes obtained with the Michelson interferometer. Their origin may be understood by reference to the diagram of Fig.2. Here the real mirror M_2 has been replaced by its virtual image M_2 formed by reflection in G_1 and M_2 is then parallel to M_1. Owing to the several reflections in the real interferometer, we may now think of the extended source as being in back of the observer at in and to form two virtual images L_1 and L_2 in M_1 and M_2. These virtual sources are coherent in that the phases of corresponding points in the two are exactly the same at all instances. If d is separationM_1, M_2 then virtual sources will be separated by 2d. When d is exactly an integral number of half wavelengths, i.e., the path difference 2d equal to an integral number of whole wavelengths all rays of light reflected at an mirrors will be in phase. Rays of light reflected at an angle however will in general not be in phase. The path difference between the two rays coming to the eye from corresponding points P_1 and P_2 is $2d\ Cos\theta$ as shown in the figure (2). The angle θ is necessarily the same for the two rays when M_1 is parallel to M_2, so that the rays are parallel. Hence when the eye is focused to receive parallel rays (a small telescope is more satisfactory here, especially for the large values of d) the rays will rainforce each other to produce maxima for those angles θ satisfying the relation

$$2d\ \mathrm{Cos}\ \theta = n\lambda \qquad \text{...................(1.5.1.1)}$$

Since for a given n , λ and d the angle is constant, the maxima will lie in the form of circle about the foot of the perpendicular from the eye to the mirrors. It can easily be shown from Eq. 1 that the radii of the rings are proportional to the square roots of integers, as in Newton's rings. The intensity distribution across the rings follows Eq. 3 in which the phase difference δ is given by

$$\delta = 2\pi/\lambda\ 2d\ cos\ \theta \qquad \text{.............(1.5.1.2)}$$

With monochromatic light the circular fringes are visible for very large path difference the limit being set only by the fact that no actual source gives perfectly monochromic light. If there is even a small range of wavelengths present in the light from the source, the fringes formed by the different components will be differently spaced and will mask all interference at sufficiently large values of d. Using the very nearly monochromic light of the red cadmium line, the fringes remain visible up to path difference of about 50 cm, or d=25 cm. A study of the change of clearness or "visibility" of the fringes with increasing path difference gives information about the sharpness of a spectral line used for the source of light. The larger the path difference over which the fringes remain clear, the more monochromatic the light, or the sharper the line. This was one of the first uses to which Michelson put his interferometer. Maxima and minima in the visibility curve indicate that the line has a fine structure of two or more components. Thus, it is found that with light of the sodium D lines the fringes will become alternately sharp and diffuse, as the fringes formed by the two positions of maximum sharpness is about 1000, indicating that the wavelength of the D lines differ by about one part in a thousand. Since Michelson's method of interfering the structure of lines has been superseded by a more direct method it will not be described in detail here.

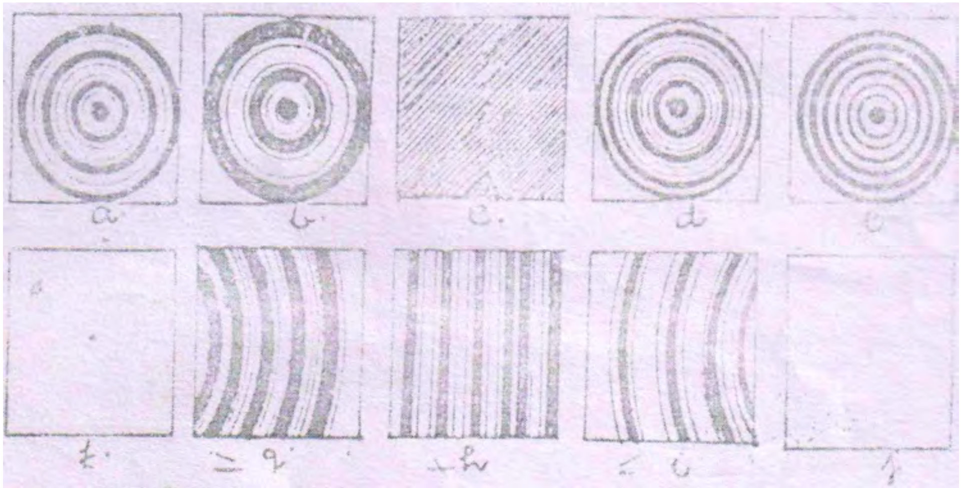


Fig3: Formation of various types of fringes

Starting with M_1 a few centimetres beyond M_2, the fringes system will have the general appearance shown (a) of fig3 with the rings very closely spaced. If M_1 is now moved slowly towards M_2 so that d is decreased, Eq. (1) shows that a given ring, characterized by given value of the order n, must decrease the its radius because the product $2d\ Cos\theta$ must remain constant. The rings therefore shrink and vanish at the centre, a ring disappearing each time 2d decrease by λ or d by λ or d by $\lambda/2$. This follows from the fact that at the centre $cos\ \theta = 1$ so that Eq. (1) becomes

$$2d = n\lambda \tag{3}$$

To change by unity, d must change by $\lambda/2$. Now as M_1 approaches M_2 the rings become more widely spaced, as indicated in Fig.3 (b), until finally we reach a critical position where the central fringe has spread out, to cover the whole field of view , as shown in 3 (c). This happens when M_1 and M_2 are exactly coincident, for it is clear that under these conditions the path difference is zero for all angles of incidence. If the mirror is moved still farther it effectively passes through M_2 and now widely spaced fringes appear, growing out from the centre. These will gradually become more closely spaced as the path difference increase as indicated in 3 (d) and 3(e) of the figure.

Localized Fringes:

If the mirrors M_2 and M_2 are not exactly parallel, fringes will still be seen with monochromatic light for path difference not exceeding a few millimetres . In this case the space between the mirrors is wedge- shaped, as indicated in Fig. 4. The two rays reaching the eye from a point on the source are now no longer parallel, but appear to diverge from a point P near the mirrors. Thus to see these fringes clearly, the eye must be focused on the back mirror M_1.

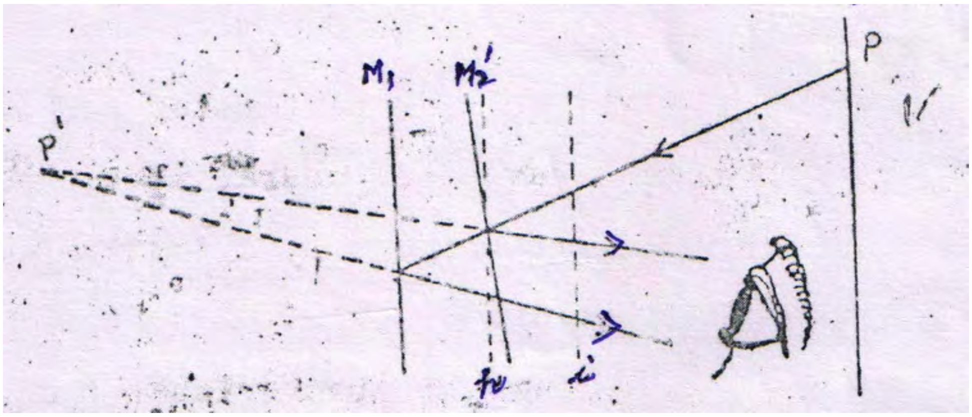


Fig 4: Inclined mirrors

The localized fringes are practically straight, because the variation of the path difference across the field of view is new due primarily to the variation of the thickness of the "air film" between the mirrors. With a wedge – shaped film the locus of points of equal thickness is a straight line parallel to the edge of the wedge. The fringes are not exactly straight , however, if d has an appreciable value, because there is also some variation of the path difference with angle. They are in general curved and are always curved towards the thin edge of the wedge. Thus, with a certain value of d, we might observe fringes shaped like those of Fig. exactly straight , however , if d has an appreciable value, because there is also some variation of the path difference with angle. They are in general curved and are always curved towards the thin edge of the wedge. Thus, with a certain value of d, we might observe fringes shaped like those of Fig. 3(g). Decreasing d, they, move to the left across the field, a new fringing the centre of the field each time d change by $\lambda/2$. As we approach zero path difference, the fringes become straighter, until the point is reached where M_1 actually intersects M_2, when they are perfectly straight, as in 3(h). Beyond this point, they begin to curve in the opposite direction $3(i)$. The blank fields Fig 3(f) and Fig 3(j) indicate that this type of fringes cannot be observed for large path differences.

White Light Fringes

If a source of while light is used , no fringes will be seen at all except for a path difference so small that it does not exceed a few wavelengths. In observing these fringes, the mirrors are tilted slightly as for localized fringes, and the position of M_1 is found where it intersects M2. *With white light there will then be observed a central dark fringe,* bordered on either side by 8 or 10 coloured fringes. This position is often rather troublesome to find using white light only. It is best located approximately beforehand by finding the place where the localized fringes in monochromatic light become straight. Then a very slow motion of M1 through this region using white light will bring these fringes into view.

The fact that only a few fringes are observed with white light is easily accounted for when we remember that such light contains all wavelengths between 4000 and 7500Å. The fringes for a given colour are more widely spaced the greater the wavelength. Thus the fringes in different colour will only coincide for d=0, as indicated in Fig. 4. The solid curve represents the intensity distribution in the fringes for green light, and the broken curve that for red light. Clearly only the central fringe will be uncoloured.

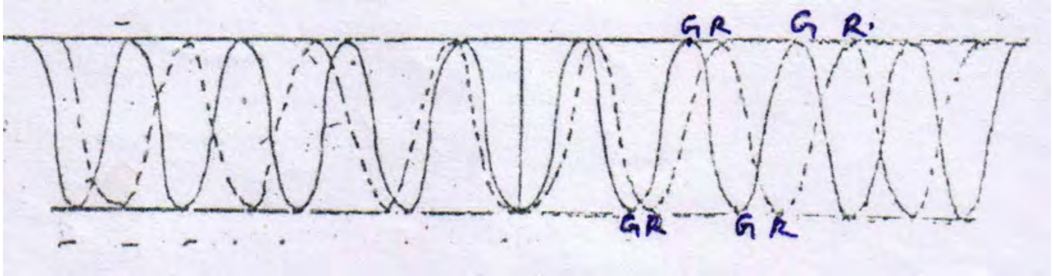


Fig4: Origin of white light fringes

The fringes of different colours will begin to separate at once on either side, producing various impure colours which are not the saturated spectral colours. After 8 or 10 fringes, so many colours are present at a given point that the resultant colour is essentially white. Interference is still occurring in this region, however, because a spectroscope will show a continuous spectrum with dark bands at those wavelengths for which the condition for destructive interference is fulfilled. White light fringes are also observed in all of the other methods of producing interference described above, if white light is substituted for monochromatic light. They are particularly important in the Michelson interferometer, where they may be used to locate the position of zero difference.

Application of the Michelson Interferometer:

The principal advantage of this form of interferometer over the earlier arrangements for producing interference lies in the fact that the two beams are here widely separated, and the path difference between them can be varied at will by moving the mirror M_1 or by introducing a refracting material in the path of one of the beams. Corresponding to these two ways of varying the path difference, there are two types of measurement which can be made with this interferometer. The first is the accurate measurement of distance in terms of the wavelength of light, which we shall discuss in this section. The second is the determination of indices of refraction, which will be briefly referred to at the beginning of the following section.

When the mirror M_1 is moved slowly from one position to another, counting the number of fringes in monochromatic light which cross the centre of the field of view will give a measure of the distance the mirror has moved in terms of λ, since by Eq. (3) we have, for the position d_1 corresponding to the bright fringe of order n_1

$$2d_1 = n_1 \lambda \tag{4}$$

And for d_2, giving a bright fringe of order n_2

$$2d_2 = n_2 \lambda \tag{5}$$

Subtracting these two equations, we find

$$d_1 - d_2 = (n_1 - n_2)\,\lambda/2 \tag{6}$$

Hence, the distance moved equals the number of fringes counted multiplied by a half wavelength. Of course, the distance measured need not correspond to an integral number of half wavelengths. Fractional parts of a whole fringe displacement can easily be estimated to 1/10 of a fringe, and, with care, to1/50. The latter figure then gives the distance to an accuracy of 1/100, or 5 x 10^7cm for green light.

A small Michelson interferometer in which a microscope is attached to the moving carriage carrying M_1 is frequently used in the laboratory for measuring the wavelength of light. The microscope is focused in a fine glass scale, and the number of fringes, n_1-n_2, crossing the mirror between two readings d_1 and d_2 on the scale gives by Eq. 6. The bending of a beam, or even of a brick wall, under pressure from the hand can be made visible and measured by attaching M_1 directly to the beam or wall.

Determination of index of Refraction by Interference Methods:

If a thickness t of a substance having an index of refraction μ is introduced into the path of one of the interfering beams in the $interferometer$, the optical path in this beam is increased because of the fact that light travels more slowly in the substance, and consequently has a shorter wavelength. The optical path is now μt through the medium where it was practically t through the corresponding thickness of air (μ-1) t/λ. Thus the increase in optical path due to insertion of the substance is $(\mu - 1)$. This will introduce $(\mu - 1)\ t/\lambda$ extra wave in the path of one beam, so if we call Δn the number of fringes by which the fringe system is displaced then substance is placed in the beam, we have

$$(\mu-1)\ t = (\Delta n)\ \lambda \qquad (7)$$

In principal a measurement of Δn, t, and λ thus gives a determination of μ. .

In practice, the insertion of a plate of glass in the one of the beams produces a discontinuous shift of the fringes so that the number Δn cannot be counted. With monochromatic fringes it is impossible to tell which fringe in the displaced set corresponds to one in the original set. With white light, the displacement in the fringes of different colours is very different because of the variation of with wavelength, and the fringes disappear entirely. This illustrates the necessity of the compensating plate G_2 in Michelson's interferometer if white light fringes are to be observed. If the plate of glass is very thin, these fringes may still be *visible*, and this affords a method *of measuring* for very thin films. For thicker *pieces*, a practicable method is to use two plates of identical thickness, one in each beam , and to turn once gradually about a vertical axis, counting the number of monochromatic fringes for a given angle of rotation . This angle then corresponds to a certain known increase in thickness T. This slow and accurately controlled motion is accomplished by means of the screw V which is calibrated to show they exact distance the mirror has been moved. To obtain fringes the mirror M_1 and M_2 are made exactly perpendicular to each other by means of screw shown on mirror M_2.

Even when the above adjustments have been made, fringes will not be seen unless two important requirements are fulfilled. First, the light must originate from an extended source. A point source or a slit source, as used in the methods previously described, will not produce the desired system of fringes in this case. The reason for this will appear when we consider the origin of the fringes. Second, the light must in general be monochromatic, or nearly so. Especially is this true if the distance of M_1 and M_2 from G_1 are appreciably different.

An extended source suitable for use with a Michelson interferometer may be obtained in any one of several ways. A sodium flame or mercury is if large enough may be used without the screen L shown in Fig. 1. If the source is small a ground glass screen or a lens at L will extend the field of view. Looking at the mirror M_1 through the plate G_1 one then sees the whole mirror filled with light. In order to obtain the fringes, the next step is to distances of M_1 and M_2 to the back.

Where

d = fringes shift after insertion of a mica sheet

t= thickness of mica sheet.

1.6 Self Learning Exercise-I

Q.1: What is the interference of light? With suitable diagram. What is superposition of waves?

Q.2: Define type of interference phenomenon and also give its condition.

1.7 Procedure

(A) For the wavelength of monochromatic Light

(1) The position of mirror M_1 is adjusted by turning the drumhead so that the bright spot of circular fringes appears at the centre of field of view. The micrometer reading is noted.

(2) The mirror M_1 is moved away, so that the good number of fringes (say 25 or 50) appears at the centre of the field. The micrometer reading is again noted.

(3) The process (2) is repeated to take the other readings.

(B)For the Wavelength of difference of two D-lines

(1) The interferometer is adjusted for circular fringes. The mirror M_1 is moved till there is maximum indistinctness of the fringe pattern, the micrometer screw reading is noted.

(2) By further movement of mirror M_1, the fringe pattern becomes clear. Again the mirror is moved until position of maximum indistinctness is reached again. Note the micrometer reading.

(3) The procedure is repeated for a number of consecutive positions of maximum indistinctness.

(C) For Refractive Index of the mica Sheet

(1) The white light fringes are first obtained and cross wire is fixed on the central dark fringe and reading is noted.

(2) Now a mica sheet of thickness'
t' and refractive index μ is introduced in the path of light from mirror M_2 to plate G_2 normally at the time, the actual path covered by the beam which is reflected from M_2 becomes $2(M_2) + 2(n-1)t$ and the white light fringe shift.

(3) Now the mirror M_1 is displaced through a distance 'd' to bring the central fringe again on the crosswire. The distance is calculated.

(4) The thickness of mica sheet is measured by the spherometer.

1.8 Observation

(A) For the wavelength of monochromatic Light

The least count of the rough micrometer screw (R.M.S.)=........

The least count of the fine micrometer screw (F.M.S.)=........

S.No.	No. of fringes appeared	Position of mirror M_1 (in cm)				Difference x for 100 fringes (cm) 100x	Mean Difference CE(x) (cm)
		Main Scale Reading	RMS reading	FMS reading	Total		
1.							
2.							
3.							
4.							
5.							

(B)For the Wavelength of difference of two D-lines

S.No.	Position of mirror M_1 for max. indistinctness(in cm)				Difference between 3 consecutive position 3x fringes (cm)	Mean Difference CE(x) (cm)	Mean x (cm)
	Main Scale Reading	RMS reading	FMS reading	Total			
1.							
2.							
3.							
4.							
5.							

(c) For Refractive Index of Mica Sheet

S.No.	Position of M_1 before introducing mica sheet (cm)	Position of M_1 after introducing mica sheet (cm)	Distance travelled by M1 is($x-x_1$)	Mean Difference (x_2-x_1)(cm)
1.				
2.				
3.				
4.				
5.				
6.				

1.9 Calculations

1.10 Result

(1) Wavelength of sodium lamp =

(2) Difference between two D lines =

(3) Refractive index of the mica sheet =

$$\%error = \frac{Experimental\ value - Standard\ value}{standard\ value} \times 100$$

1.11 Discussion

1.12 Precautions and Sources of error

1. No mirror and glass plate should be touched by hands.
2. In order to bring white light fingers the rough screen should be rotated slowly and carefully.
3. Before using the white light first bring the straight lines fringes by sodium light.
4. The screw behind mirror M_2 should be rotated through a very small angle.
5. There should not be linear or lateral displacement of circular fringes when viewed by eyes.
6. In the position of max. Indistinctness, the fringes should almost disappear.
7. There should be no disturbance near the experiment.

1.13 Self Learning Exercise-II

Q.1: Give the conditions of interference. Define dark and bright fringes.

Q.2: How can be obtaining the interference phenomenon.

1.14 Glossary

Monochromatic light: A light having one wavelength is known as Monochromatic light.

Circular fringes: Concentric circular fringes are produced with monochromatic light when the interferometer is in normal position i.e. the image M_2' of M_2 in G_1

is exactly parallel to M_1.

Localised fringes: When the mirror M_1 and the virtual mirror M_2' are not exactly parallel but reflected waves are intersecting near M_1, a wedge shaped air film is formed between them. These are called as Localised fringes.

White-light fringes: When the surfaces M_1 and M_2' are intersect then with a white light source along the line of intersection we shall get central achromatic bright fringe, known as White-light fringes.

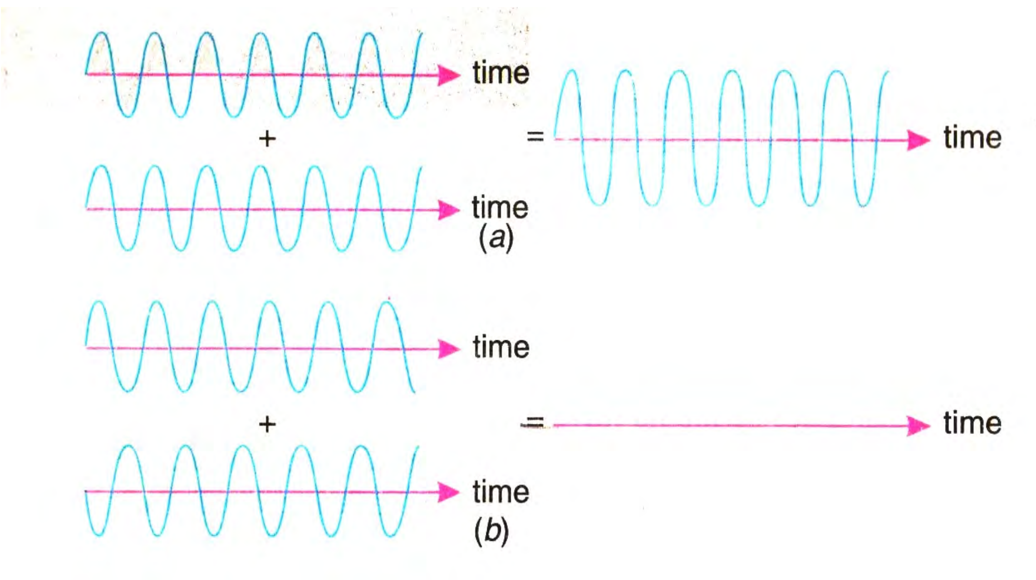
Interferometer: It is primarily employed to determine the wavelength of light in terms of some standard of length and vice-versa utilising the phenomenon of $Interference\ of\ Light$.

1.15 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans1: If two or more light waves of the same frequency overlap at a point, the resultant effect depends on the phase of the waves as well as their amplitudes. The resultant wave at any point at any instant of time is governed by the principle of superposition. The combined effect at each point of the region of superposition is obtained by adding algebraically the amplitudes of the individual waves.

Here the component waves are of the same amplitude.



In other words, **the phenomenon of redistribution of light energy due to the superposition of light waves from two or more coherent sources is known as interference.**

Superposition of waves:

According to the principle of superposition-

When two or more waves overlap, the resultant displacement at any point and at any instant may be found by adding the instantaneous displacements that would be produced at the point by the individual waves if each were present alone.

It means that the resultant is simply the sum of the disturbances. The principle of superposition applies to electromagnetic waves also and is the most important principle in wave optics. In case of electromagnetic waves, the term displacement refers to the amplitude of the electric field vector.

Interference is an important consequence of superposition of coherent waves.

Ans.2:

There are two types of interference:

(1) Constructive interference,

(2) Destructive interference.

(1) Constructive interference: At certain points, the two waves may be in phase. The amplitude of the resultant wave will then equal to the sum of the amplitudes of the two waves. Thus, the amplitude of the resultant wave

$$\boldsymbol{A_R = A + A = 2A} \qquad ....(1)$$

Hence, the intensity of the resultant wave is

$$\boldsymbol{I_R \propto A_R^2 = 2^2A^2 = 2^2I} \qquad ....(2)$$

It is obvious that the resultant intensity is greater than the sum of the intensities due to individual waves.

$$\boldsymbol{I_R} > I + I = 2\boldsymbol{I} \qquad ....(3)$$

Therefore, the interference produced at these points is known as **Constructive interference.**

A **stationary bright band** of light is observed at points if constructive interference.

In other words we can say that the points where maxima are obtained, interference at that point known as constructive interference.

(2) Destructive interference: At certain other points, the two waves may be opposite in phase. The amplitude of the resultant wave will then be equal to the sum of the amplitudes of the two waves. Thus, the amplitude of the resultant wave

$$\boldsymbol{A_R = A + A = 2A} \qquad \text{...........(4)}$$

Hence, the intensity of the resultant wave is

$$\boldsymbol{I_R \propto 0 = 0} \qquad \text{...........(5)}$$

It is obvious that the resultant intensity is less than the sum of the intensities due to individual waves.

$$\boldsymbol{I_R} < I + I = 2I \qquad \text{...........(6)}$$

Therefore, the interference produced at these points is known as Destructive interference.

A stationary dark band of light is observed at points of destructive interference.

In other words we can say that the points where minima is obtained, interference at that points known as Destructive interference.

Let us assume two sources of light S_1 and S_2, as shown in figure 5 Which are identical and produce harmonic waves of same wavelength and that the waves are in the same phase S_1 and S_2 . Light from these sources travel along different paths, S_1P and S_2P and meet at a point P. Now let $S_1P=r_1$ and $S_2P=r_2$, which are different in length. Also, the medium in which waves are travelled, may be different. As a result, the optical path lengths are different. If μ_1 is the refractive index of the medium in which first wave travelled, so the corresponding optical path length is $\mu_1 r_1$. Similarly for second wave corresponding wave length is $\mu_2 r_2$.

Now the optical path difference is ($\mu_1 r_1$ - $\mu_2 r_2$).

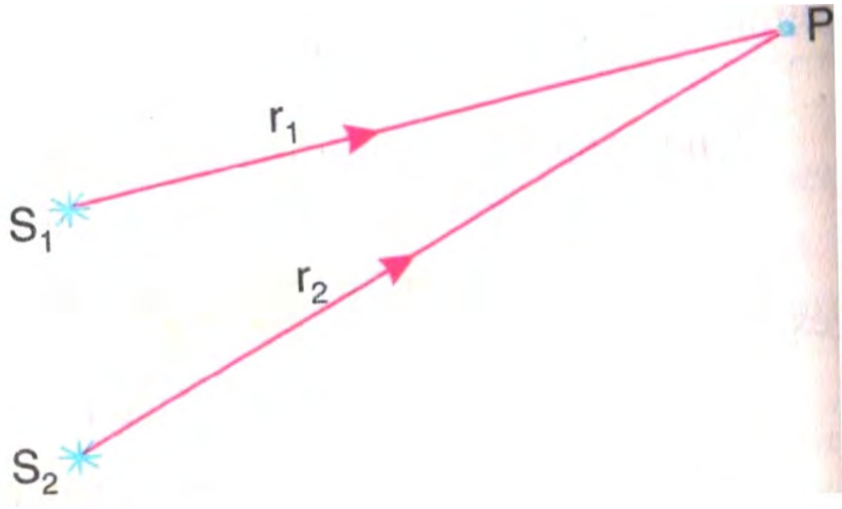


Figure 5

If the optical path difference $\Delta = (\mu_1 r_1 - \mu_2 r_2)$ is equal to zero or a multiple of wavelength λ, then the waves arrive in phase at P

$$\Delta = m\lambda \qquad \text{............(7)}$$

Where m is an integer and takes values, m=0, 1, 2, 3, 4, ..., then the waves are in phase and their overlapping at P produces **constructive interference or brightness.**

If the optical path difference $\Delta = (\mu_1 r_1 - \mu_2 r_2)$ is equal to an odd integral multiple of half-wavelength, $\frac{\lambda}{2}$, then the waves arrive out of phase at P.

$$\Delta = (2m+1)\frac{\lambda}{2} \qquad \text{............(8)}$$

Where m is an integer and takes values, m=0, 1, 2, 3, 4, ..., then the waves are inverted with respect to each other and their overlapping at P produces destructive interference or darkness.

Answers to Self Learning Exercise-II

Ans. 1: Conditions of interference:

(1) The waves from the two sources must be of the same frequency.

If the light waves differ in frequency, the phase difference fluctuates irregularly with time. Consequently, the intensity at any point fluctuates with time and we will not observe steady interference.

(2) The two light waves must be coherent.

If the light waves are coherent, then they maintain a fixed phase difference over a time and space. Hence, a stationary interference pattern will be observed.

(3) The path difference between the overlapping waves must be less than the coherence length of the waves.

(4) If the two sets of waves are plane polarized, their planes of polarization must be the same.

(5) The two coherent sources must lie close to each other in order to discern the fringe pattern.

(6) The distance of the screen from the two sources must be large.

(7) The vector sum of the overlapping electric field vectors should be zero in the dark regions.

Dark and Bright fringes: when the two or more waves of light are superposed, the resultant effect is brightness in certain regions and darkness in certain regions. The regions of brightness and darkness alternate and may take the form of straight bands, or circular rings or any other complex shape. The alternate bright and dark bands are called interference fringes.

The fringes which appear in bright regions are called as **Bright fringes** and which appears in dark regions are called as **Dark fringes.**

Ans.2: The phase relation between the waves emitted by two independent light sources rapidly changes with time and therefore they can never be coherent. If the two sources are derived from a single source by some device, then any phase change occurring in one source is simultaneously accompanied by the same phase difference between the waves emerging from the two sources remains constant and the sources are coherent. The methods used for crating coherent sources of light can be divided into the following two classes:

(a) Wavefront splitting: one of the methods consists in dividing a light wavefront, emerging from a narrow slit, by passing it through two slits closely spaced side by side. The two parts of the same wavefront travel through different paths and reunite on a screen to produce fringe pattern. This is known as **interference due to**

division of amplitude. This method is useful only with narrow sources, Young' s double slit, Fresnel' s double mirror, Fresnel' s biprism etc.

(b) Amplitude splitting: Alternately, the amplitude of a light wave is divided into two parts, namely reflected and transmitted components, by partial reflection at a surface. The two parts travel through different paths and reunite to produce interference fringes. This is known as **interference due to division of amplitude.**

1.16 Viva Questions

Q.1 What is the principle of Michelson Interferometer?

Q.2 Explain the role of plate G_1 and G_2?

Q.3 Why plate G_1 is semi silvered?

Q.4 Describe construction and uses of sodium lamp?

Q.5 Define lateral displacement?

Q.6 Mention the various applications of the Michelson Interferometer?

1.17 Answers to Viva Questions

Ans.1: In Michelson interferometer, a beam of light from an extended source is divided into two parts of equal intensities by partial reflection and refraction. These beams travel in two mutually perpendicular directions and come together after reflection from plane mirrors. The beams overlap on each other and produce interference fringes.

Ans.2: In Michelson interferometer, G_1 plate is working as beam splitting plate and G_2 plate is working as compensating plate.

Ans.3: G_1 is semi silvered beam splitter plate because when beam incident on it then it partly reflected a beam and partially transmitted a beam after splitting. Then, both waves superimposed and giving the phenomenon of interference.

Ans.4: Sodium light is a source of monochromatic light. The wavelength of the sodium light is 5893Å, which is the mean of two wave length 5890Å and 5896Å. The use of sodium light is very much prominent. It is used in Michelson interferometer, to produce Newton's ring and in other phenomenon.

Ans.6: Michelson interferometer can be used to determine:

(1) The wavelength of a given monochromatic source of light,

(2) The difference between the two neighbouring wavelengths or resolution of the spectral lines,

(3) Refractive index and thickness of various thin transparent materials,

(4) For measurement of the standard metre in terms of the wavelength of light.

References and Suggested Readings

1. Optics by A.K. Ghatak.

2. Optics by T.P. Pandya and B.K. Mathur.

3. Fundamental of optics by Jenkins and White.

UNIT-02
Fabry-Perot Interferometer

Structure of the Unit

2.1 Aim

Using Fabry-Perot Interferometer, determine

(i)Wavelength (λ) of sodium light,

(ii)Difference between the two D-lines of sodium light.

2.2 Apparatus

Fabry Perot interferometer, a convex lens, two optically semi silvered plane glass plates, a source of monochromatic light and a screen, Micrometer.

2.3 Diagram

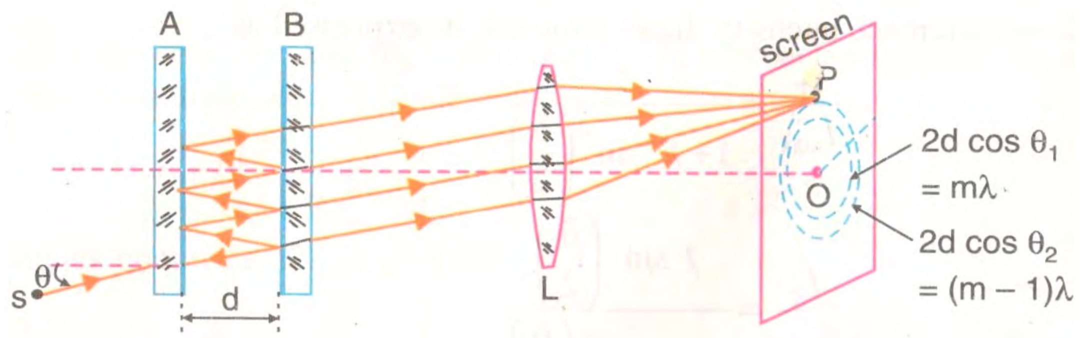


Figure: 2.1

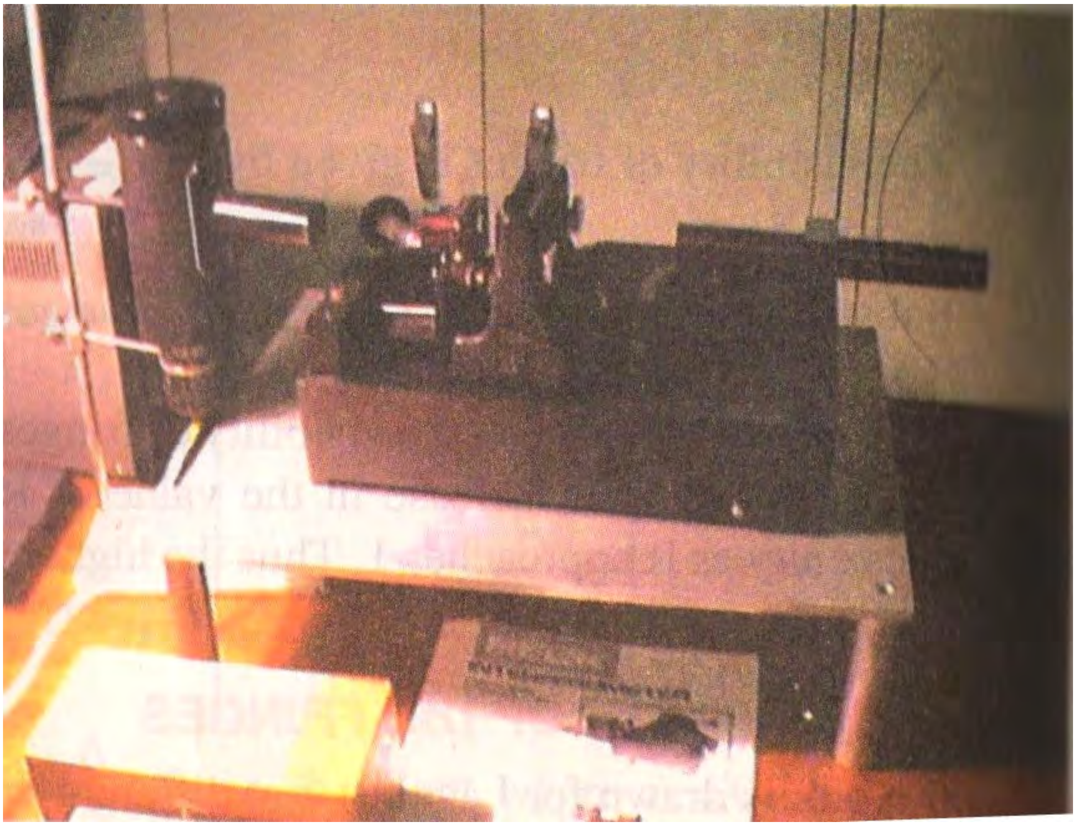


Figure: 2.2 Fabry-Perot Interferometer

2.4 Formula

In this experiment we use two formulas (1) for determining the wavelength of sodium light is given by,

$$\lambda = \frac{2(x_2 - x_1)}{N}$$

Where

x_1= Initial position of the plate of Fabry-Perot interferometer,

x_2= Final position of the plate of Fabry-Perot interferometer,

N= No. of fringes appeare or disappears at the centre of field corresponding to the distance $(x_2 - x_1)$.

(2) (a) The difference of two lines of sodium light (λ_2-λ_1) is given by

$$\lambda_2 - \lambda_1 = \frac{{\lambda_{mean}}^2}{4t_1}$$

Where

λ_{mean}= Average value of wavelength of sodium light (mean of λ_1 andλ_2)

t_1 = separation between the plates when maximum discordance occur.

(b) When the separation between the plates is further increased, then thickness became t_2 now,

Hence

$$\lambda_1 - \lambda_2 = \frac{{\lambda_{mean}}^2}{2(t_2 - t_1)}$$

2.5 Theory and description

The Fabry-Perot interferometer is a high resolving power instrument, which makes use of the 'fringes of equal inclination', produced by the transmitted light after multiple reflections in an air film between two parallel highly reflecting glass plates.

The interferometer consists of two optically plane glass plates A and B with their inner surfaces silvered, and placed accurately parallel to each other. Screws are provided to secure parallelism if disturbed. This system is difficult to manufacture and is no more in use. Instead an etalon which is much more easily manufactured is used. The etalon consists of two semi-silvered plates rigidly held parallel at a fixed distance apart. The reflectance of the two surfaces can be as high as 90 to 99.9%. Although both reflected and transmitted beams interfere with each other, the Fabry-Perot interferometer is usually used in the transmissive mode.

S is a broad source of monochromatic light and L_1 is a convex lens (not shown in figure 1.1) which makes the rays parallel. An incident ray suffers number of internal reflections successively at the two silvered surfaces, as shown in figure 1.1. At each reflection a small fraction of the light is transmitted also. Thus, each incident ray produces a group of coherent and parallel, transmitted rays with a constant path difference between any two successive rays. A second convex lens L brings these rays together to a point in its focal plane where they interfere. Hence the rays from all points of the source produce an interference pattern on a screen placed in the focal plane of L.

(A)Formation of Fringes:

Let d be the separation between the two silvered surfaces and θ be the inclination of a particular ray with the normal to the plates. The path difference between any two successive transmitted rays corresponding to the incident ray is $2dcos\theta$. The condition for these rays to produce maximum intensity is given by

$$2d\ cos\theta = m\lambda$$

Where m is an integer. The locus of points in the source, which gives rays of constant inclination, θ is a circle. Hence, with an extended source, the interference patter consists of a system of bright concentric rings on a dark background, each ring corresponding to a particular value of θ.

(B)Determination of Wavelength of Sodium Light:

When the reflecting surfaces A and B of the interferometer are adjusted exactly parallel, circular fringes are obtained. Let m be the order of the bright fringe at the centre of the fringe system. As at the centre $\theta = 0$, we have

$$2t = m\lambda$$

..............(1.5.2.1)

If the movable plate is moved a distance $\frac{\lambda}{2}$, $2t$ changes by λ and hence a bright fringe of the next order appears at the centre. If the movable plate is moved from the position x_2 and x_1 and the number of fringes appearing at the centre during this movement is N, then

$$N.\frac{\lambda}{2} = (x_2 - x_1)$$

or

$$\lambda = \frac{2(x_2 - x_1)}{N}$$

..............(2.5.2.2)

By the measurement of x_2, x_1 and N, we can determine the value of λ.

(C)Determination of difference in wavelength of Sodium Light:

The light emitted by a source may consist of two or more wavelengths, as D_1 and D_2 lines in case of sodium. Separate fringes patterns corresponding to the two wavelengths are not produced in Michelson interferometer. Hence, Michelson Interferometer is not suitable to study the fine structure of spectral lines. On the other hand, in Fabry-Perot interferometer, each wavelength produces its own ring patterns are separated from each other. Therefore, Fabry-Perot Interferometer is suitable to study the fine structure of spectral lines.

Difference in wavelengths can be found using coincidence method. Let λ_1 and λ_2 be two very close wavelengths in the incident light. Let us assume that $\lambda_1 > \lambda_2$. Initially , the two plates of the interferometer are brought into contact. Then the rings due to λ_1 and λ_2 coincide partially. Then the movable plate is slowly moved away such that the ring systems separate and maximum discordance occurs. Then the rings due to λ_2 are half way between those due to λ_1. Let t_1 be the separation between the plates when maximum discordance occurs. At the centre

$$2t_1 = m_1\lambda_1 = \left(m_1 + \frac{1}{2}\lambda_2\right)$$

...............(2.5.3.1)

$$m_1(\lambda_1 - \lambda_2) = \frac{1}{2}\lambda_2$$

$$m_1 = \frac{\lambda_2}{2(\lambda_1 - \lambda_2)}$$

...............(2.5.3.2)

Using the value of m_1 in equation (1.5.3.1), we get

$$2t_1 = \frac{\lambda_1\lambda_2}{2(\lambda_1 - \lambda_2)}$$

Or

$$(\lambda_1 - \lambda_2) = \frac{\lambda_1\lambda_2}{4t_1} \cong \frac{{\lambda_{mean}}^2}{4t_1}$$

...............(2.5.3.3)

Now when separation between the plates is further increased, the ring systems coincide again and then separate out and maximum discordance occurs once again. If t_2 is the thickness now,

$$2t_2 = m_2\lambda_1 = \left(m_2 + \frac{3}{2}\lambda_2\right)$$

...............(2.5.3.4)

Form equation (1.5.3.4) and (1.5.3.1), we get

$$2(t_2 - t_1) = 2(m_2 - m_1)\lambda_1 = (m_2 - m_1)\lambda_2 + \lambda_2$$

...............(2.5.3.5)

Or $$(m_2 - m_1) = \frac{\lambda_2}{(\lambda_1 - \lambda_2)}$$

Using the above expression into (1.5.3.5), we obtain

$$2(t_2 - t_1) = \frac{\lambda_1\lambda_2}{(\lambda_1 - \lambda_2)}$$

$$2(\lambda_1 - \lambda_2) = \frac{\lambda_1 \lambda_2}{(t_2 - t_1)} = \frac{\lambda_{mean}{}^2}{(t_2 - t_1)}$$

..............(2.5.3.6)

2.6 Self learning exercise-I

Q.1: How can you obtain coherent sources due to interference.

Q.2: What is the plane parallel film? Give suitable figure.

2.7 Procedure

(A) For the Wavelength of Sodium Light:

(1) Set the cross-wires of the telescope on the centre of the fringe system.

(2) Record the least count and allied reading of micrometer screw. Now work the micrometer screw, count the fringes sinking or rising say up to 100 each time.

(3) Again record the reading on micrometer scale. Calculate *d* cm as the difference of two readings.

(4) The above processes are repeated to take the other readings.

(B)For the wavelength of difference of two D lines of the Sodium Light

(1) Now adjust the micrometer screw and set the view of interference pattern.

(2) Stop the telescope when system shows maximum intensity, record this reading on micrometer scale.

(3) Now gradually continue to work the micrometer screw and note and record its readings for minimum, then maximum intensities and so on.

(4) The procedure is repeated for a number of consecutive positions of maximum intensities.

2.8 Observation

(A) For the Wavelength of the Monochromatic Light

The least count of the micrometer =........(in cm)

S.No.	Number of fringes shifiting(say 100)each time	Initial micrometer reading (A) (in cm)			Final micrometer reading (B) (in cm)			Difference (B-A) (in cm)
		MSR	CSR	TR	MSR	CSR	TR	
1.								
2.								
3.								
4.								
5.								

(B) For difference of D lines of Sodium Light

Alternate position of consonance or dissonance	Micrometer readings (in cm)			Distance moved by screw between two successive		$\Delta\lambda$(in cm)
	MSR	**CSR**	**TR**	**CON.**	**DIS.**	

Here MSR- Main scale reading CON.- Consonance

CSR- Circular scale reading DIS. – Dissonance

TR- Total reading

2.9 Calculations

By putting all above given readings in the equations:

$$\lambda = \frac{2(x_2 - x_1)}{N}$$

$$\lambda_2 - \lambda_1 = \frac{\lambda_{mean}{}^2}{4t_1}$$

$$\lambda_1 - \lambda_2 = \frac{\lambda_{mean}{}^2}{2(t_2 - t_1)}$$

We get the wavelength of sodium light and difference between D- lines of sodium light.

2.10 Result

(1) Wavelength of sodium lamp =..........Å

(2) Difference between two D lines =.........Å

$$\%error = \frac{Experimental\ value - Standard\ value}{standard\ value} \times 100$$

2.11 Discussion

2.12 Precautions and Sources of error

1. No glass plate should be touched by hands.

2. There should not be linear or lateral displacement of circular fringes when viewed by eyes.

3. In the position of max. Indistinctness, the fringes should almost disappear.

4. Too great a force should not be applied while adjusting the screws of glass plates.

5. There should be no disturbance near the experiment.

6. It is necessary that the both mirrors should be accurately parallel.

2.13 Self Learning Exercise-II

Q.1: Give a brief description on Interference Filter.

Q.2: A shift of 200 fringes is observed when movable mirror of Fabry-Perot interferometer is shifted by 0.0295 mm. Calculate the wavelength used.

2.14 Glossary

Interference: The phenomenon of redistribution of light energy due to the superposition of light waves from two or more coherent sources is known as Interference.

Etalon: An etalon is a substandard for length. It consists of two mirrors, which are plane-parallel and semi silvered on their front faces. The mirrors can be made perfectly parallel by means of screws attached to them.

Haidinger fringes: When the fringes are produced in this case due to the superposition of rays, which are equally inclined to the normal. These fringes are called fringes of equal inclination. The fringes of equal inclination are known as Haidinger fringes.

Coherence: It means the coordinated motion of several waves in a medium maintaining a fixed and predictable phase relationship over a length of time.

Interference filters: An interference filter is an optical system that will transmit a very narrow range of wavelengths and thus provides a monochromatic beam of light.

2.15 Answers to Self Learning Exercises

Anwsers to Self Learning Exercise-I

Ans.1: The two sources are derived from a single source by some device, then any phase change occurring in one source is simultaneously accompanied by the same phase difference between the waves emerging from the two sources remains constant and the sources are coherent. The phase relation between the waves emitted by two independent light sources rapidly changes with time and therefore they can never be coherent. The methods used for creating coherent sources of light can be divided into the following two classes:

(a) By the method of splitting of wavefront: This method consists in dividing a light wave front, emerging from a narrow slit, by passing it through two slits closely spaced side by side. The two parts of the same wave front travel through different paths and reunite on a screen to produce fringe pattern. This is known as interference due to division of amplitude. This method is useful only with narrow sources, Young's double slit, Fresnel's double mirror, Fresnel's Biprism etc.

(b) By the splitting of amplitude of light wave: Alternately, the amplitude of a light wave is divided into two parts, namely reflected and transmitted components, by partial reflection at a surface. The two parts travel through different paths and reunite to produce interference fringes. This is known as interference due to division of amplitude.

Ans.2: A transparent thin film of uniform thickness bounded by two parallel surfaces is known as a $plane\ parallel\ thin\ film$.

When light is incident on a parallel thin film, a small portion of it gets reflected from the top surface and a major portion is transmitted into the film. Again, a small part of the transmitted component is reflected back into the film by the bottom surface and the rest of it is transmitted from the lower surface of the film. Thin films transmit incident light strongly and reflect only weakly. After two reflections, the intensities of reflected rays drop to a negligible strength. Therefore, we consider the first two reflected rays only (fig. 2.1). These two rays are derived from the same incident ray but appear to come from two sources located below the film. The sources are virtual coherent sources. The reflected waves 1 and 2 travel along parallel paths and interfere at infinity, this is a case of $two - beam\ interference$.

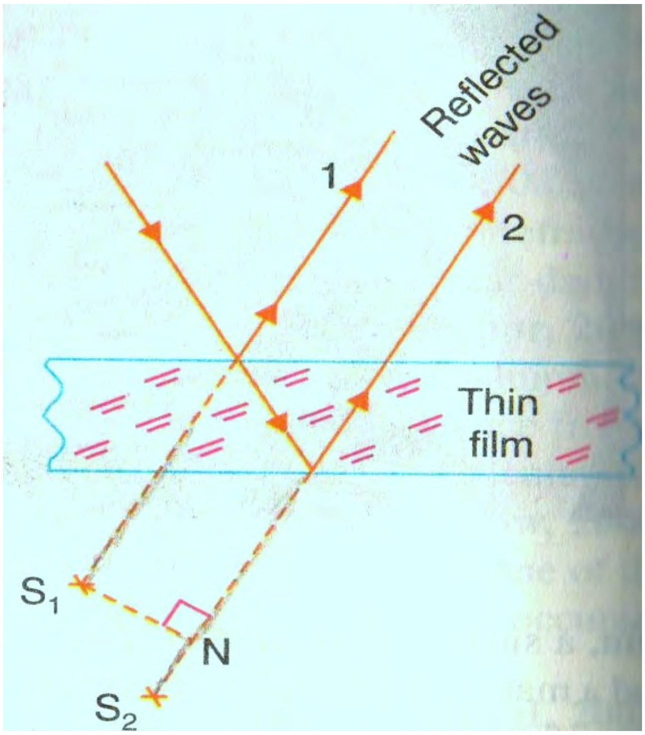


Fig: 2.1

The condition for maxima and minima can be deduced once we have calculated the optical path difference between the two rays at the point their meeting.

Anwsers to Self Learning Exercise-II

Ans.1: An interference filter is an optical system that will transmit a very narrow range of wavelengths and thus provides a monochromatic beam of light.

Interference filters are fabricated earlier as follows. A thin metallic film, usually of aluminium or silver, is deposited on a glass substrate by vacuum deposition technique. Then a thin layer of cryolite is deposited over this. The structure is again covered by another metallic film. Another plate is placed over it to protect the thin film structure. The filter is shown in figure 2.2. By varying the thickness of the dielectric film, any particular wavelength can be filtered out. However, the filtered light will have a narrow spectrum centred on the chosen wavelength. By increasing the reflectivity of the surfaces, the transmitted spectrum can be made narrow. But it is not possible to increase the thickness of metallic films indefinitely, as they start absorbing the light.

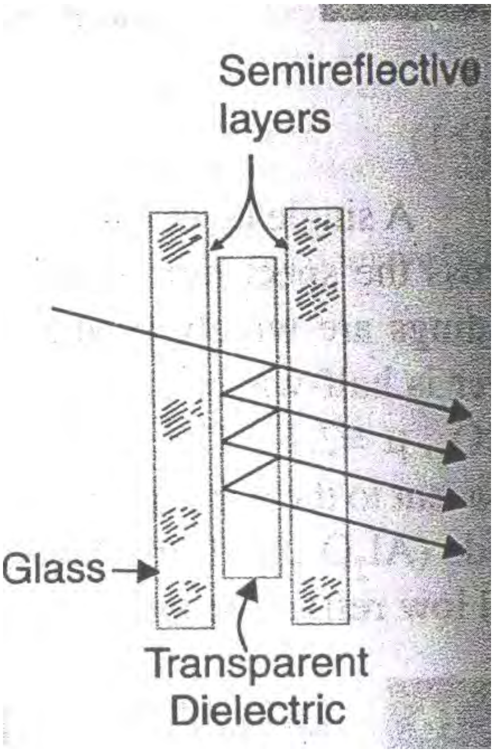


Figure: 2.2

In modern versions metallic films are not used; instead dielectric films are used. In all dielectric interference filter, layers of dielectric materials of appropriate refractive indices are deposited. To obtain an interference filter, a $\frac{\lambda}{4}$ thick film of titanium oxide is deposited and then over it a film of dielectric material with lower refractive index, such as magnesium fluoride is deposited, on this again a $\frac{\lambda}{4}$ thick film of titanium oxide is deposited. In this way alternately high and low refractive index materials are deposited to obtain an interference filter.

Ans.2: Given that

Shift let $\Delta x = 0.0295mm$, and

No. of fringes N=200

We know that from the Fabry-Parot interferometer, we have

$$\lambda = \frac{2\Delta x}{N}$$

Now

$$\lambda = \frac{2 \times 0.0295}{200}$$

Or

$$\lambda = 2950\text{Å}$$

2.16 Viva Questions

Q.1 What is the principle of Fabry-Parot Interferometer?

Q.2 What is the difference between the Fabry-Parot Interferometer and Etalon?

Q.3 Given mirrors are silvered on the inner surfaces, why?

Q.4 Mention the various type of application of Fabry-Parot Interferometer.

Q.5 What are the bright and dark fringes?

Q.6. Give the conditions of interference.

Q.7 What are the applications of thin film interference?

Q.8 What is etalon?

2.17 Answers to Viva Questions

Ans.1: The Fabry-Parot Interferometer is a highly resolving power instrument, which makes use of the 'fringes of equal inclination', produce d by the transmitted light after multiple reflections in an air film between two parallel highly reflecting glass plates.

Ans.2: The interferometer consists of two optically plane glass plates M and N with inner surfaces silvered but the etalon consists of two semi silvered plates. The manufacture of interferometer is hard compare to the Etalon.

Ans.3: An incident ray suffers a large number of internal reflections, successively at the two. At each reflection a small fraction of light is transmitted also. Thus each incident ray produces a group of coherent and parallel, transmitted rays with constant path difference between any two successive rays. So it use two silvered glass plate.

Ans.4: There is some type of use of Fabry-Parot Interferometer, which is given below:

(a) To determine the wavelength of monochromatic sodium light,

(b) To determine the difference between the wavelengths of sodium light.

Ans.5: When the two or more waves of light are superposed, the resultant effect is brightness in certain regions and darkness in certain regions. The regions of brightness and darkness alternate and may take the form of straight bands, or circular rings or any other complex shape. The alternate bright and dark bands are called interference fringes.

The fringes which appear in bright regions are called as **Bright fringes** and which appears in dark regions are called as **Dark fringes.**

Ans.6: The conditions of interference are given as:

(1) The waves from the two sources must be of the same frequency.

(2) The two light waves must be coherent.

(3) The path difference between the overlapping waves must be less than the coherence length of the waves.

(4) If the two sets of waves are plane polarized, their planes of polarization must be the same.

(5) The two coherent sources must lie close to each other in order to discern the fringe pattern.

(6) The distance of the screen from the two sources must be large.

(7) The vector sum of the overlapping electric field vectors should be zero in the dark regions.

Ans.7: There is various type of application of thin film interference, which are:

(1) Measurement of small displacement,

(2) Testing of surface finish,

(3) Testing of a lens surface,

(4) Thickness of a thin film coating.

Ans.8: An etalon is a substandard for length. It consists of two mirrors, which are plane-parallel and semi silvered on their front faces. The mirrors can be made perfectly parallel by means of screws attached to them.

References and Suggested Readings

1. Optics by A.K. Ghatak.
2. Optics by T.P. Pandya and B.K. Mathur.
3. Fundamental of optics by Jenkins and White.

UNIT- 03
Fresnel's Biprism Experiment

Structure of the Unit

3.1 Aim

To determine the wavelength of a sodium light using Biprism method and to determine the thickness of thin mica sheet using Biprism arrangement.

3.2 Apparatus

Optical bench, sodium lamp, uprights Slit, Bi-Prism, convex lens, micrometer eyepiece.

3.3 Diagram

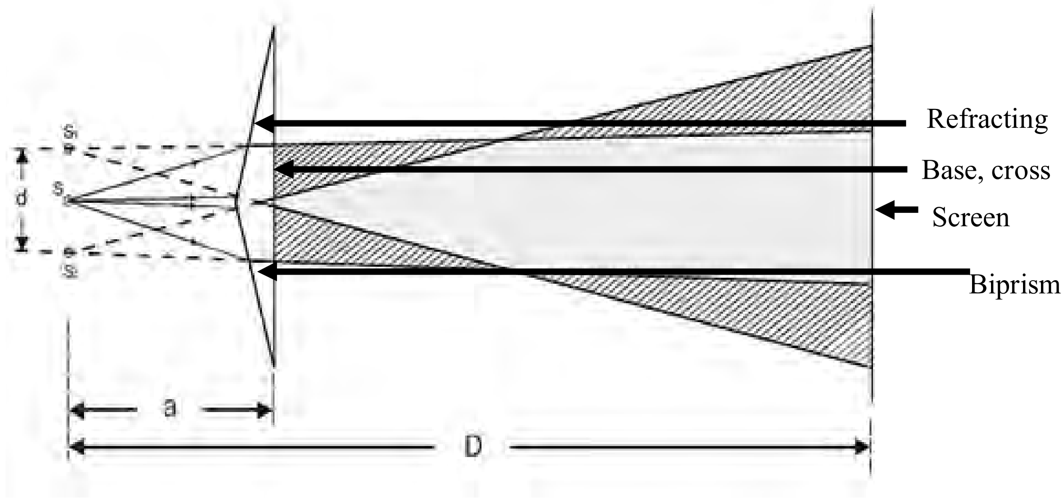


Figure 1*: Schematic sketch for fringes formation in Fresnel's Biprism experiment.*

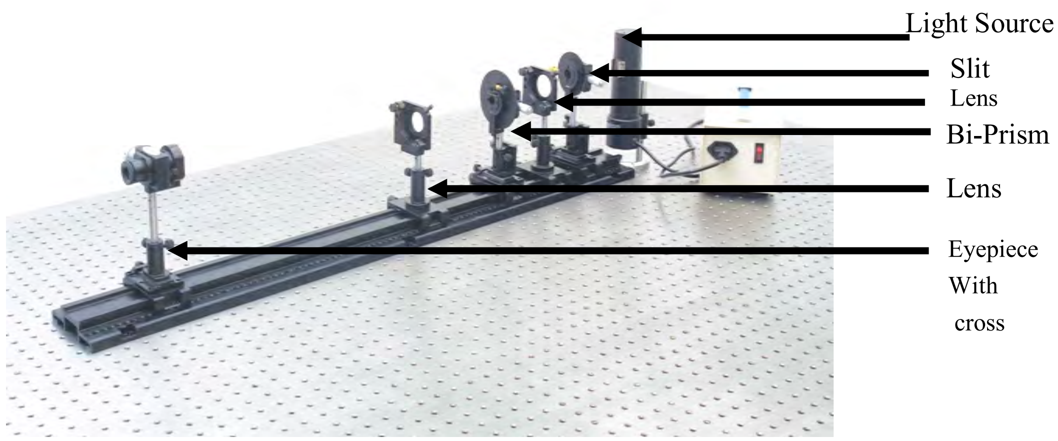


Figure 2*: Experimental arrangement of Fresnel's Biprism Experiment.*

3.4 Formula

(a) To determine the wavelength of given monochromatic light source:

The wavelength λ of the given monochromatic light source is given by the formula in case of Biprism experiment.

$$\lambda = \beta \frac{d}{D}$$

Here:

β = fringe width,

d = distance between the two virtual sources,

D = distance between the slit and screen.

Also $d = \sqrt{d_1 d_2}$

Here:

d_1 = distance between the two images formed by the convex lens in one position.

d_2 = distance between the two images formed by the convex lens in the second position.

(b) To determine the thickness of Mica sheet:

$$t = \left(\frac{S}{D}\right)\frac{d}{\mu - 1}$$

Here:

S = Shift in white fringe.

μ = refractive index of given mica sheet.

3.5 Theory and Description

(i)Interference of light waves: When two light waves from different coherent sources travelling in same medium meet, then the distribution of energy due to one wave is disturbed by the other in results on screen some points are much illuminated and some are less. This modification in the distribution of light energy due to super position of two light waves is called "Interference of light".

(ii)Condition for interference: Interference is not possible in any two light sources. Interference in the light waves occurs whenever two or more waves overlap at a given point

Practically, to observe the interference pattern it is required that:

1) The sources should be coherent.
2) The sources should have identical wave lengths.
3) Both light sources should possess same or almost same amplitude.

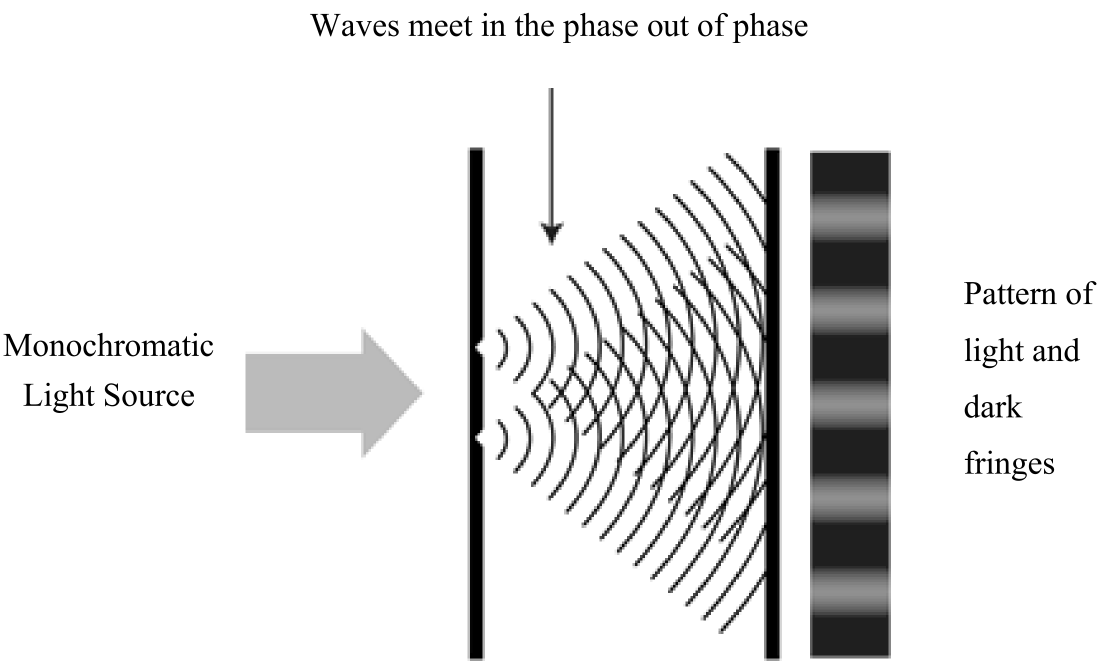


Figure 3: *Interference in light through two slits*

(iii)Coherent Sources: Two sources will be coherent if the phase difference between the lights coming from these sources is constant with time.

(iv)Methods to achieve Coherent sources: Two different light sources even having same manufacture details, same power, and having same wavelength still cannot be coherent, since in the most of cases light from the sources is in actual molecular or electronic spectra. The molecules and electrons are randomly excited and generate the photons. It is the reason that those all cannot be in same phase or phase cannot be constant with time.

Practically the coherent sources are achieved by dividing the light from single light source in two parts. There are two methods to archive the coherent sources on the basis of this division of light:

a. *By the division of amplitude:* If the system designing in such a way that two virtual coherent sources are achieved by division of the amplitude of single monochromatic light source e.g. Interference through thin films, soap bubble, Newton ring experiment, Michelson Interferometer etc.

b. *By the division of wavefront:* In such designing the wavefront actually divided in two parts and single source split into two coherent sources e.g. Young's double slit experiment, Fresnel's Biprism experiment etc.

i. Requirement of coherent sources for interference: The interference in light waves occurs due to superposition of two waves, and when the two maxima or two minima superimposed; we get bright fringes known as constructive interference. The points where the maxima of one wave superimposed with minima of other wave, we get dark bands or fringes on such points, it is known as destructive interference.

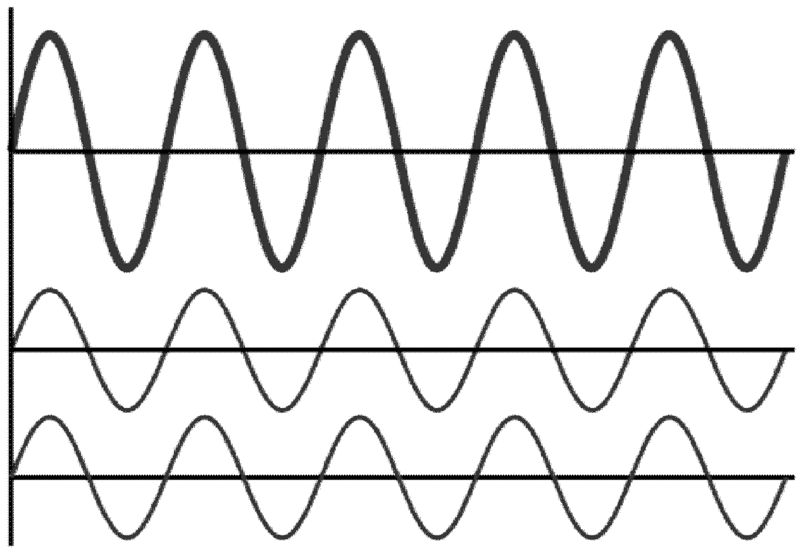


Figure 4*: Constructive Interference; waves meet in the phase.*

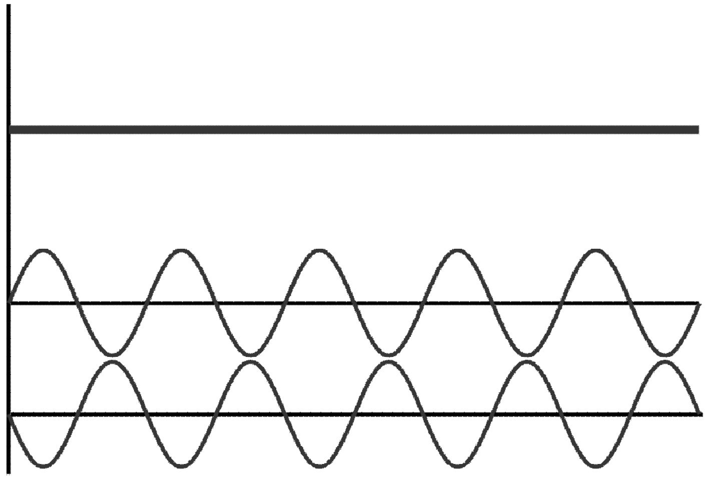


Figure 5: *Destructive Interference; waves meet out of phase.*

(i)If the phase difference will not constant with time, on any point of the screen the waves will meet in and out of phase in results the constructive and destructive inference will happen on the same point and pattern will change with the time. This change will so fast that the dark and bright fringes cannot be able to differentiate, hence no pattern at all.
(ii)The amplitude of both waves must be same or almost same since otherwise there will either bright or less bright fringes not dark fringes. The contrast will be very poor in such case if the amplitude will not be same.

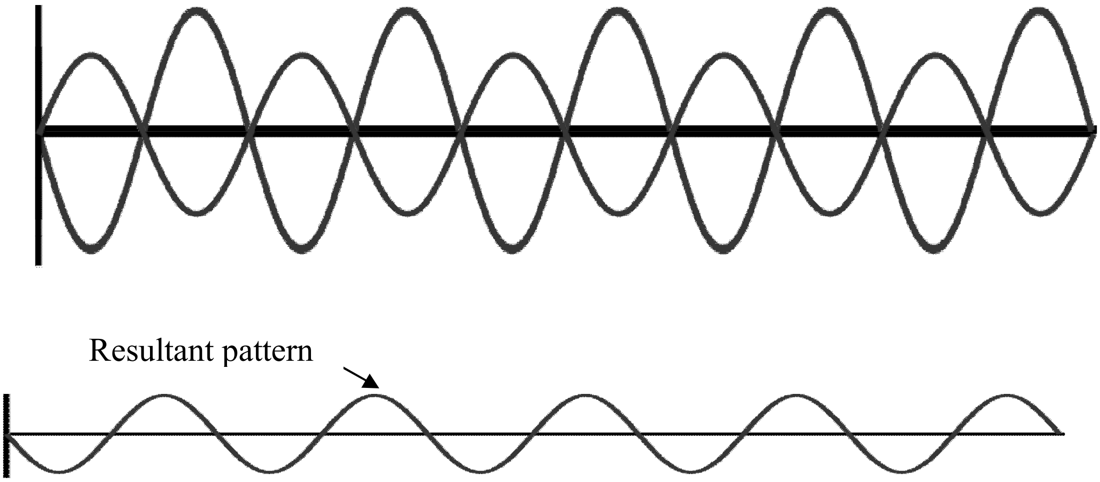


Figure 6: *Destructive Interference if amplitudes of both waves are not same*

(iii)Wave length should be identical of both of the waves for interference, this condition is required because of the waves can be meet in same phase or out of phase and constructive and destructive inference can be occur.

ii. Interference experiments to determine the wavelength of unknown monochromatic light source: Various experiments based on the principles of achieving coherent sources have been designed. These experiments are used to observe this phenomenon. These experiments have several significant applications in science and engineering such as measurement of wavelength of a light source, the wavelength difference between two closely separated waves, the optical flatness of surfaces, thickness of the thin film, refractive index of material etc. various efficient systems are described as below:

a. Young's Double slits experiment
b. Fresnel's Biprism experiment
c. Michleson Interferometer
d. Fabri-Perot interferometer.

iii. Fresnel's Biprism Experiment: Fresnel's Biprism experiment is an elegant method for studying the interference of a light. The Fresnel Biprism is a variation on that theme which is Young's Slits. The Fresnel Biprism overcomes the difficulty associated with the extended secondary slits in young's double slit experiment by replacing them with "virtual slits". In this experiment the coherent sources are achieved by the division of wavefront of a single monochromatic light source with the help of a Biprism.

iv. Biprism: A biprism essentially consist of two prisms, each of very small refracting angle (0.5º to 1º) placed base to base.

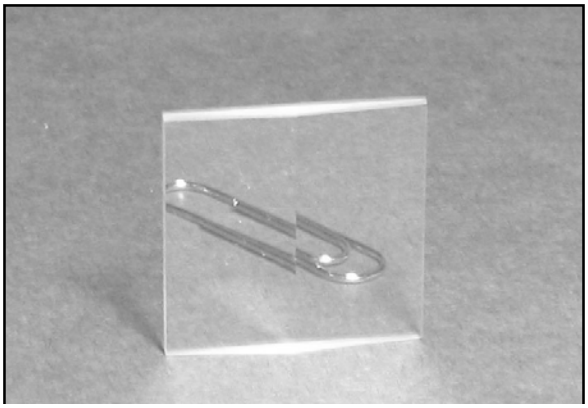


Figure 7: *Picture of Fresnel's Biprism.*

Fresnel constructed this structure by adding two prisms base to base but now a days it constructed by shaping of a single rectangular glass slab.

Monochromatic light passing through a narrow slit, adjusted parallel to the refracting edge, is allowed to fall symmetrically on the biprism. The division of the incident wave front into two parts by the refracting edge B takes place as shown in Fig. 1. The two emergent wave fronts appear to originate from virtual sources S_1 and S_2, which being derived from the same source S act as coherent sources. As a result, interference fringes are observed in the overlapping region of the screen.

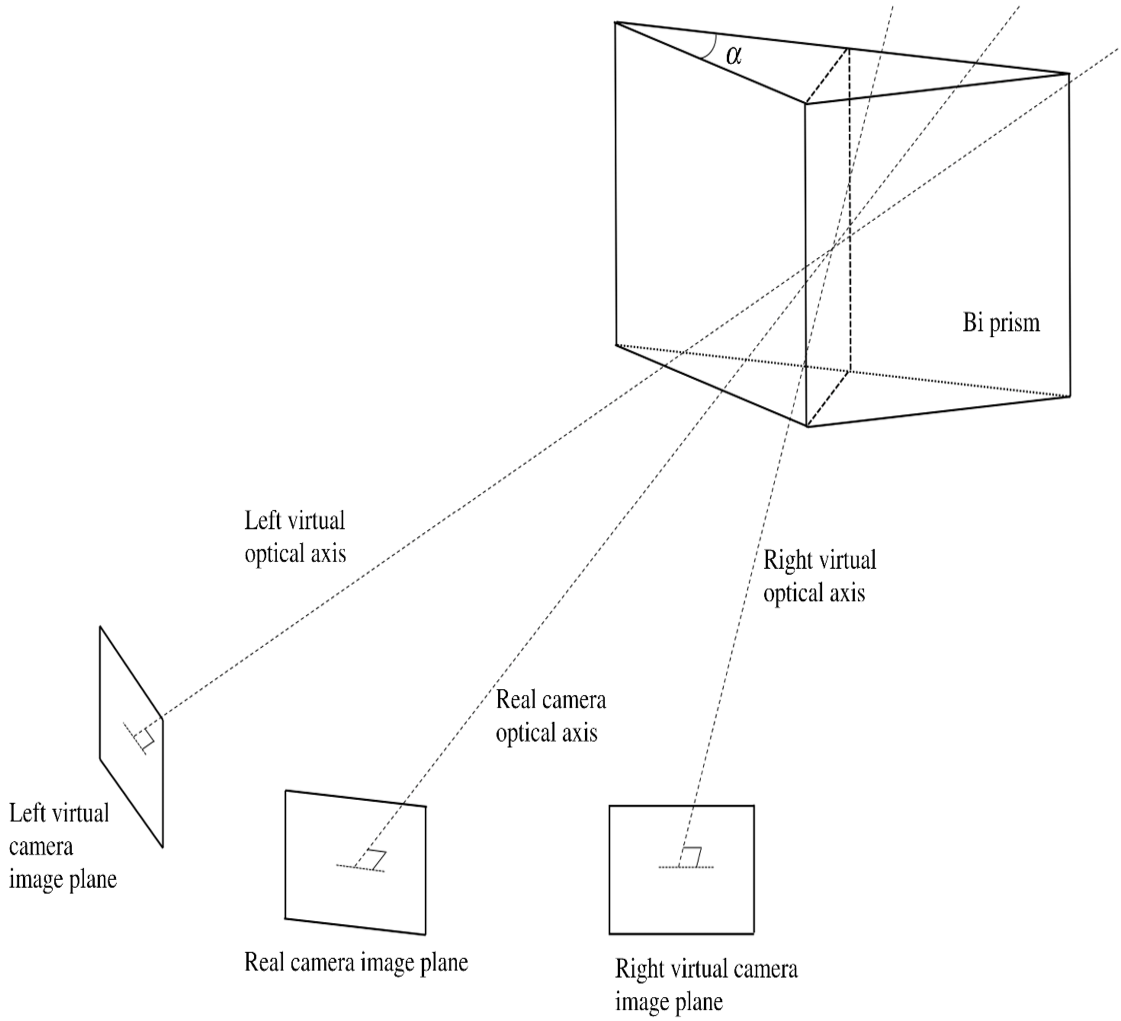


Figure 8: *The formation of virtual sources by Fresnel's Biprims [4].*

3.6 Self Learning Exercise-I

Q.1 What is Interference?

Q.2 What are the conditions to achieve interference?

Q.3 What are the coherent sources?

Q.4 Why the phase difference between two light source is require being constant with time for interference?

Q.5 What do you understand by a fringe?

3.7 Procedure

Experimental set up:

(i) The height of the slit, Biprism and the eyepiece is adjusted at the same level.

(ii) The Biprism upright is placed near the slit.

(iii) The slit is adjusted narrow and vertical.

(iv) Slit is illuminated with given monochromatic light source.

(v) If refracting edge of the Biprism is parallel to the slit then looking through the Biprism two clear images of the slit can be observed by moving the eyes sideways. Otherwise if there is some fault in the adjustment, the images will not appear as a whole to cross the edge. The Biprism is adjusted by rotating it in its own plane to effect the sudden transition of the full image.

(vi) The eyepiece is placed near the Biprism. The Biprism is adjusted using screws attached with its stand in such a way that fringes of light are clearly visible in eyepiece. If the fringes are not seen then the Biprism is rotated in its cross plane with the help of tangential screw till fringes are obtained.

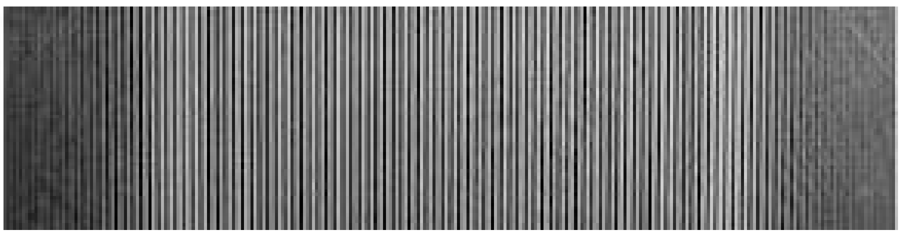


Figure 9: *Fringe pattern in Fresnel's Biprism experiment.*

(vii) The vertical cross wire is adjusted on one of the bright fringe at the center of the fringe system and the eyepiece is moved away from the Biprism. In doing so, if fringes give a lateral shift, it must be removed in the following way: From any position, the eyepiece is moved away from the Biprism and at the same time lateral shift is given to the Biprism with its base screw so that the vertical crosswire remains on the same fringe on which it was adjusted. The eyepiece is now moved towards the Biprism and this procedure is repeated for few times till the lateral shift is removed.

Measurement of fringe width (β):

(i) The eyepiece is fixed around 100 cm away from the slit.

(ii)The vertical cross wire is set on middle (or corner left/right) of one of the bright fringes and reading on eyepiece scale is noted.

(iii)The cross wire is moved on the mid (same selected corner left/right) of next bright

fringe and the reading is noted. In this way observations are noted for about 20 fringes.

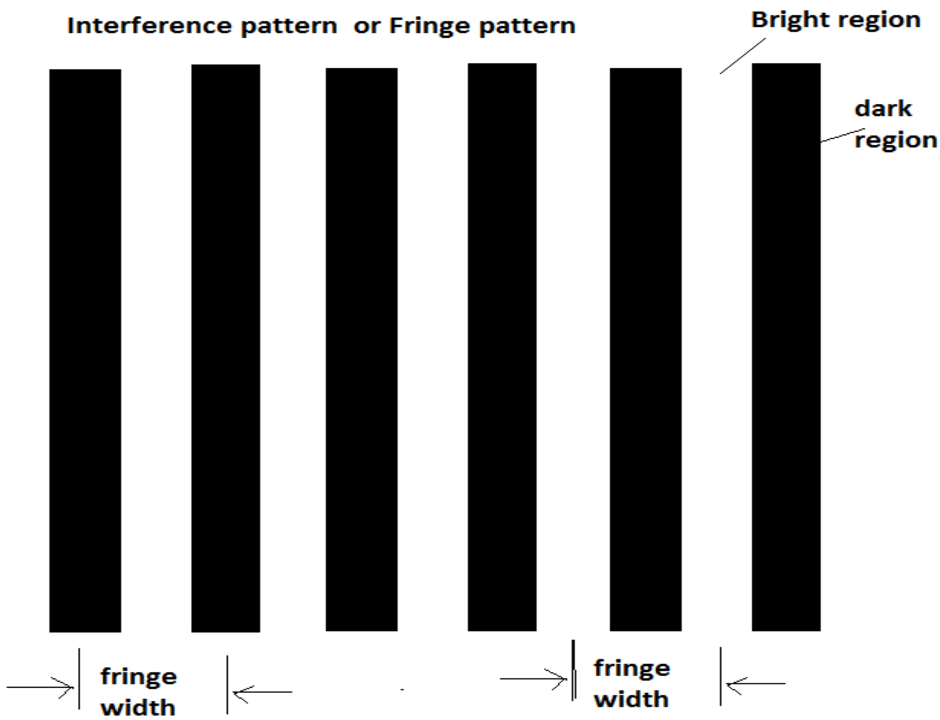


Figure 10: *Measurement of fringe width (β).*

Measurement of D:

(i) The distance between the slit and the eyepiece.

(ii) It is measured with the help of a meter scale on bench.

(iii)However, this value of D may not be the same as the actual distance between the slit and the plane of the crosswire. The difference [D_{actual}–$D_{measured}$] is called the bench error (Δ). Use the given value of Δ to obtain the actual value of D.

Measurement of d:

(i) For the measurement of d, the convex lens is placed between the Biprism and eyepiece and ensured that it is sited near to the eyepiece.

(ii)The distance between the eyepiece and slit should be kept slightly more than four times of the focal length of the lens. Meanwhile, the position of the slit and the Biprism should not be changed.

(iii)The lens is moved towards the Biprism till two sharp images of the slit can be observed through the eyepiece.

(iv)The distance between these two images is measured with help of the micrometer attached with eyepiece. It is in actual d_1.

(v)The lens is moved towards the Biprism till two images are again appeared. The distance between these two images is d_2.

(vi)At least two sets of observations for d_1 and d_2 are taken.

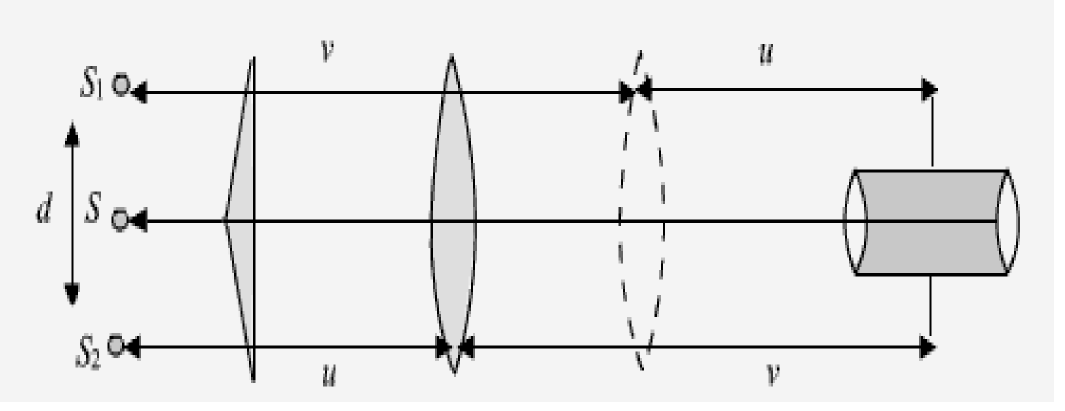


Figure 11*: Measurement of d using a convex lens (www.mywbut.com).*

Measurement of thickness of Mica sheet (t):

(i) To determine the thickness of transparent thin sheet (mica), the monochromatic source is replaced by white light source.

(ii) In this case the fringe pattern consists of various colorful fringe patterns corresponding to all wave length and the resultant of this is a central white fringe surrounded by dark region.

(iii) The position of this central white fringe is recorded with help of micrometer by focusing the cross wire of eye piece on it

(iv) Now mica sheet is introduced in the path of one wave in such a way that it blocks the one half of biprism.

(v) The central white fringe is now shifted to another position of cross wire.

(vi) This 'S_1' is measured by the help of micrometer in the cross wire.

(vii)This experiment is repeated again by covering the other half part of biprism. We can have the value of shift S_2.

(viii)The mean value of shift 'S' can be determined accurately.

3.8 Observation

(I)Measurement of fringe width (β):

Least count of the vernier scale = ……………………………

No. of Fringe (n)	Micrometer reading			
	Main Scale Reading 1 (cm)	Micrometer Circular Scale Divisions 2	Vernier Scale Reading 3 = 2 × L.C. (cm)	Total x_n 1+3 (cm)
1				
2				
3				
4				
5				

6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Slope of plot between n and x_n = ………………………… cm
Mean Separation of fringe width β = …………………… meter

(II) Measurement of (D):

D = ……………………… meter

(III) Measurement of (d):

S. No.	**Micrometer Reading in I position of Lens**			d_1 (cm) (I2-I1)	Mean d_1 (cm)
	M.S. (cm)	V.S. (cm)	Total (cm)		
Image 1.					
Image 2.					
Image 1.					
Image 2.					

S. No.	Micrometer Reading in II position of Lens			d_2 (cm) (I2-I1)	Mean d_2 (cm)
	M.S. (cm)	V.S. (cm)	Total (cm)		
Image 1.					
Image 2.					
Image 1.					
Image 2.					

Mean d_1 = …………………. Meter
Mean d_2 = …………………. Meter

(IV)Measurement of shift (S):

	Micrometer Reading			Shift in white fringe (cm)	Mean shift S (cm)
	M.S. (cm)	V.S. (cm)	Total (cm)		
1. Position of White fringe without Mica sheet					
2. Position of white fringe while mica sheet in one half part of biprism				S_1 (2-1) =	
3. Position of white fringe while mica sheet in other half part of biprism				S_2 (2-1) =	

Shift due to Mica sheet S = …………………………… Meter

3.9 Graph

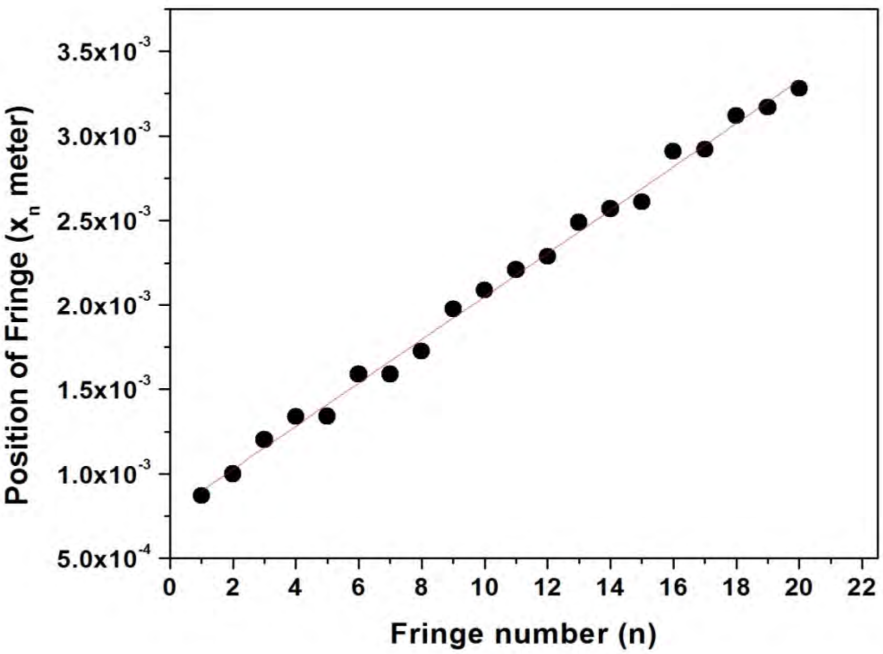


Figure: graph between fringe number and position of corresponding fringe to calculate the fringe width. (e.g. here Slope (β) = 1.28 × 10^{-4} meter).

3.10 Calculations

Sample calculations

Measurements **are**

1. D = 0.845 meter
2. d_1 = 0.007 meter
3. d_2 = 0.002 meter
4. $\beta = 1.28 \times 10^{-4}$ meter
5. $S = 22.77 \times 10^{-3}$ meter
6. Given $\mu = 1.56$

Distance between two virtual sources

$$d = \sqrt{d_1 d_2}$$
$$d = \sqrt{0.007 \times 0.002}$$

$d = \sqrt{14 \times 10^{-6}}$
$d = 3.74 \times 10^{-3}$meter
Wavelength of given unknown monochromatic source

$$\lambda = \beta \frac{d}{D}$$

$$\lambda = 1.28 \times 10^{-4} \times \frac{3.74 \times 10^{-3}}{0.845}$$

$\lambda = 5.6653 \times 10^{-7}$ meter $= 5665.3$ Å

Thickness of mica sheet

$$t = \left(\frac{S}{D}\right)\frac{d}{\mu - 1}$$

$$t = \left(\frac{22.77 \times 10^{-3}}{0.845}\right)\frac{3.74 \times 10^{-3}}{1.56 - 1}$$

$t = 0.18$ mm

3.11 Result

(i) Wavelength of Sodium light = ……………………………………………..Å

Standard value of wavelength of given source = 5893 Å

(ii) % Error = …………………………………………………………………

(iii) Thickness of Mica sheet = ……………………………………………. meter

3.12 Discussion

3.13 Precautions and Sources of Error

1. Distance between the slit and the Biprism must be kept constant throughout the experiment. After the initial adjustment to get sharp fringes with good contrast, does not change the silt width, rotates the Bi-Prism.

2.Move the eyepiece only backward to observe the lateral shift. For removing lateral shift, there is no other adjustment required except the lateral movement of the birprsim. Occasionally, the eyepiece may have to be also moved laterally (using the base screw) only to ensure that the fringe system is in its field of view.

3.During measurement of d_1 and d_2, do not keep the eyepiece at a very large distance (>> 4f) from the slit, which results in a large difference in d_1 and d_2 leading to enhanced error in their product.

4.While measuring the fringe width, align the cross wire at the centre of a bright fringe.

5.While measuring fringe width the cross wire must be moved only in one direction to avoid error due to backlash.

3.14 Self Learning Exercise-II

Q.1 Why do you use Biprism in Fresnel Biprism experiment?

Q.2 Why it made so thin?

Q.3 How the two coherent sources are achieved by Biprsim?

Q.4 What is shape of Interference fringes in Fresnel's experiment?

Q.5 If the eyepiece is made far away from birpsim what will be effect on the fringe pattern?

3.15 Glossary

Monochromatic: the light with single frequency.

Eyepiece: The lens or group of lenses that is closest to the eye in a microscope, telescope, or other optical instrument. Sometime attach with micrometer having a cross wire for desired measurements.

Fringe: A bright or dark band caused by beams of light that are in phase or out of phase with one another.

Mica: a shiny silicate mineral with a layered structure, found as minute scales in granite and other rocks, or as crystals. It is used as a thermal or electrical insulator.

3.16 Answers to Self Learning Exercises

Answers to Self Learning Exercise -I

Ans.1: If two waves from coherent sources having same wavelength meet, the resultant pattern having higher intensity on some points and on points it is less, this event is known as interference in optics.

Ans.2: The wavelength of both waves should be same, amplitude should be same or almost same, and phase difference should be constant with time.

Ans.3: If Phase difference in waves coming from both sources is constant with time called coherent sources.

Ans.4: If the phase difference will not be constant with time then the fringes will

follow the condition for bright and dark at the same position, and it will change so fast

that pattern would not be observed.

Ans.5: Dark and bright bands on screen or eyepiece due to constructive and destructive interference.

Answers to Self Learning Exercise -II

Ans.1: To achieve virtual coherent sources.

Ans.2: It is thin because d should be small.

Ans.3: By the division of wave-front

Ans.4: Hyperbolic

Ans.5: Fringe width will be reduced.

3.17 Viva Questions

Q.1 What do you mean by interference of light?

Q.2 What are the conditions to get interference pattern?

Q.3 How it will affect the interference pattern if there is large difference in amplitude of two waves?

Q.4 Is there any loss of energy in the interference phenomenon?

Q.5 Why the wavelength should be same of both waves for interference?

Q.6 What are the different types of interference?

Q.7 Is interference possible in sound waves too?

Q.8 What are the coherent sources?

Q.9 Why the coherent sources are essential to get interference?

Q.10 How many methods to achieve coherent sources?

Q.11 What do you understand by interference fringes?

Q.12 What is a Bi-prism?

Q.13 Why it named so?

Q.14 Why are the refracting angles of the two prisms made so small?

Q.15 What is the purpose of the Bi-prism, in Fresnel's Biprism experiment?

Q.16 What is the effect of changing the distance between the slit and Biprism on the fringe –width?

Q.17 How do you measure d?

Q.18 How will you locate zero order fringes in Biprism experiment?

Q.19 How can you measure the thickness of mica sheet?

Q.20 Are the Biprism fringes perfectly straight?

3.18 Answers to Viva Questions

Ans.1: If two waves from coherent sources having same wavelength meet, the resultant pattern will have higher intensity on some points and on some less, this event is known as interference in optics.

Ans.2: Wavelength should be identical of both sources, amplitude should be same or almost same, and both light sources should be coherent.

Ans.3: The contrast of pattern will be poor.

Ans.4: No, there is only redistribution of energy.

Ans.5: It is necessary to meet the waves in the phase and out of phase.

Ans.6: Constructive and destructive.

Ans.7: Yes, it is possible.

Ans.8: If two light sources having phase difference which is constant with time.

Ans.9: See theory (requirement of coherent sources)

Ans.10: Two, by division of wavefront, and by division of amplitude.

Ans.11: Dark and bright bands on screen or eyepiece due to constructive and destructive interference.

Ans.12: Biprism is some kind of prism which is used to split one real source into two virtual light sources by division of wavefront of the light.

Ans.13: It was constructed by Fresnel by adding two prisms base to base.

Ans.14: It is thin because d should be small.

Ans.15: To achieve virtual coherent sources.

Ans.16: If it will increase (D = a+ b) the fringe width will decrease.

Ans.17: By introducing a convex lens (see procedure)

Ans.18: By replacing monochromatic light source by white light source.

Ans.19: See procedure.

Ans.20: No , actually they are they are hyperbolic in shape.

References and Suggested Readings

1. B. K. Mathur, Introduction to Geometrical and Physical Optics. Kanpur : Gopal Printing Press, 1959

2. S. Brij Lal, M N Avadhanulu & N Subrahmanyam, A text book of optics,S. Chand,23rd revised Edition,2006

3. Russell Celyn Jones, An Interference of Light

4. W.L. Kee, K.B. Lim, Z.L. Tun, B. Yading, J. Electronic Imaging, Vol. 23, page033005(2014)

UNIT-4
Fresnel's Law

Structure of the Unit

4.1 Aim

Verification of Fresnel's law of refraction and reflection

4.2 Apparatus

Light source, glass plate, Convex lens, Rotating stage, Polarizer, Photocell, and Ammeter.

4.3 Diagram

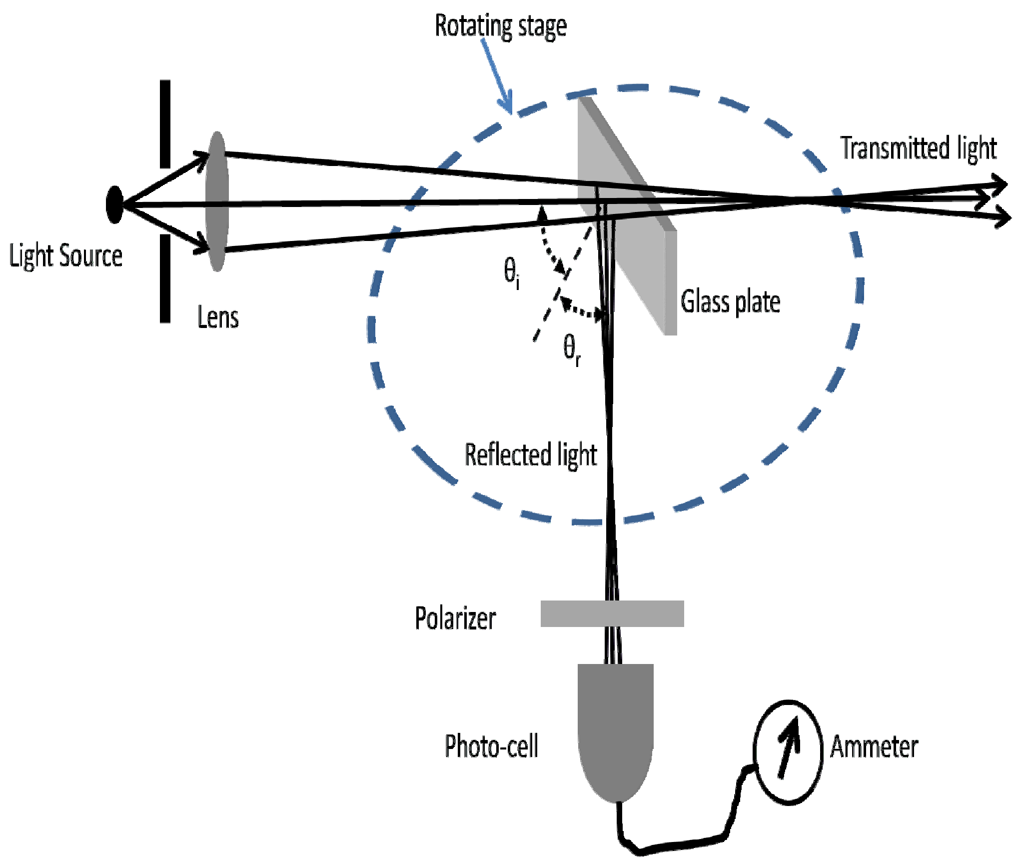


Fig. 1: *The arrangement of Fresnel`s experiment.*

4.4 Formula

Reflectance :

When electric fields **E** is parallel to the plane-of-incidence, than Fresnel`s Equations for reflection and transmission coefficients:

$$r_{\parallel} = \frac{n_i \cos(\theta_i) - n_t \cos(\theta_t)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}$$

$$t_{\parallel} = \frac{2n_i \cos(\theta_i)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}$$

$$R_{\parallel} = {r_{\parallel}}^2, \quad R_{\perp} = {r_{\perp}}^2$$

Brewster''s law: The angle of incidence for maximum polarization depends only on the refractive index.

$$\tan(\theta_p) = \frac{n_t}{n_i} = n_{ti}$$

Degree of polarization (P) :

$$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

Where: n_i = Refractive index of incident medium (air, n=1)

n_t = Refractive index of refractive medium (glass, n=1.5)

θ_i = Angle of incidence

θ_t = Angle of refraction

θ_p = Brewster's angle or polarization angle

I_{max} = Maximum intensity

I_{min} = Minimum intensity

4.5 Model Graph

Reflectance:

$$R_{\parallel} = \left[\frac{n_i \cos(\theta_i) - n_t \cos(\theta_t)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}\right]^2,$$

$$R_{\perp} = \left[\frac{n_t \cos(\theta_i) - n_i \cos(\theta_t)}{n_t \cos(\theta_i) + n_i \cos(\theta_t)}\right]^2$$

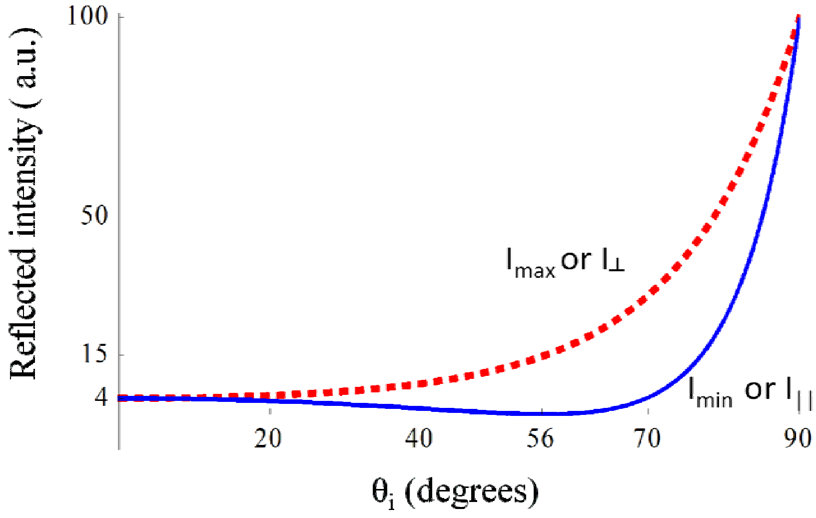


Fig. 2: *Reflectance and transmittance. as a function of incident angle for air-glass interface (n_i =1, n_t = 1.5).*

<u>Degree of polarization (P)</u>

$$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

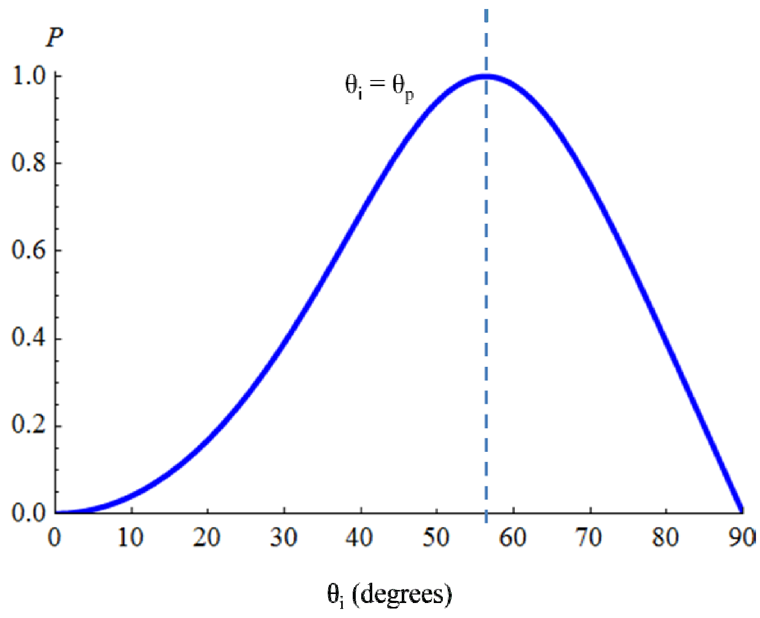


Fig. 3: *Degree of polarization as a function of incident angle.*

4.6 Theory and Description

Light is an electromagnetic wave whose electric and magnetic fields oscillate sinusoidally in space and time, perpendicular to each other, and to the direction of propagation of the electromagnetic wave. In figure 4, the electric field E_x is along the x-axis, and varies sinusoidally with z, at a given time. The magnetic field B_y is along the y-axis, and again varies sinusoidally with z. Here the electric and magnetic fields E_x and B_y are perpendicular to each other, and to the direction z of propagation.

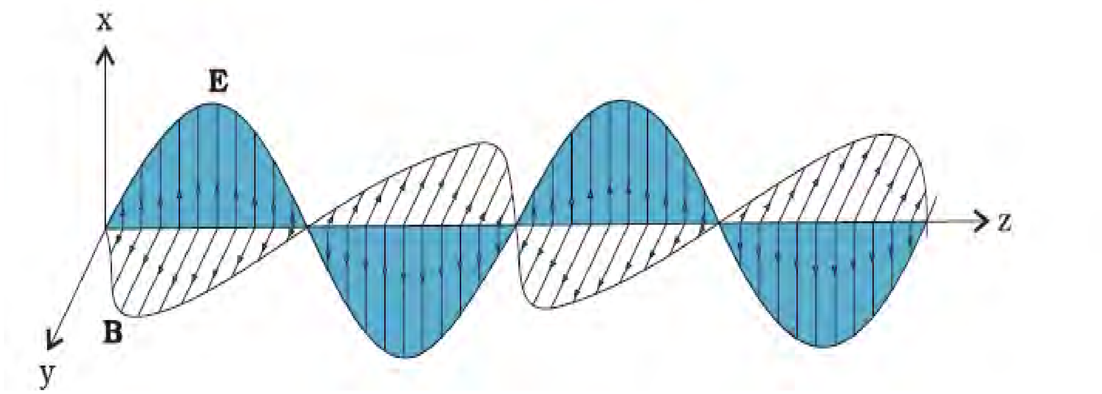


Fig.4: *A linearly polarised electromagnetic wave, propagating in the z-direction with the oscillating electric field* ***E*** *along the x-direction and the oscillating magnetic field* ***B*** *along the y-direction.*

The speed c of electromagnetic wave in vacuum is related to ε_0 and μ_0 (the free space permeability and permittivity constants) as follows: $c = 1/(\varepsilon_0\mu_0)^{1/2}$. The speed of light, or of electromagnetic waves in a medium is given by $c = 1/(\varepsilon\mu)^{1/2} = c/n$. Where ε is the permeability of the medium and μ its permittivity and $n = (\varepsilon \backslash \varepsilon_0)^{1/2}$ is the refractive index of medium for nonmagnetic medium.

Table 1: Approximate value of refractive index (at wavelength of 589 nm) for various Substances*

S. No.	Material	Refractive Index
1.	Vacuum	1

2	Air	1.0003
3.	**Glass**	**~1.5**
4.	Water	1.33
5	Diamond	2.42

*Values vary with physical conditions--purity, pressure, temperature etc.

Polarized and unpolarized light

The direction of polarization of an electromagnetic wave is represented by oscillations of its electric field. Figure 5 shows a common way of representing of these vibrations. Figure 5(a) and (b) representing the two plane-polarized components. Dots represent the end-on view of linear vibrations, and double-pointed arrows represent vibrations confined to the plane of the paper.

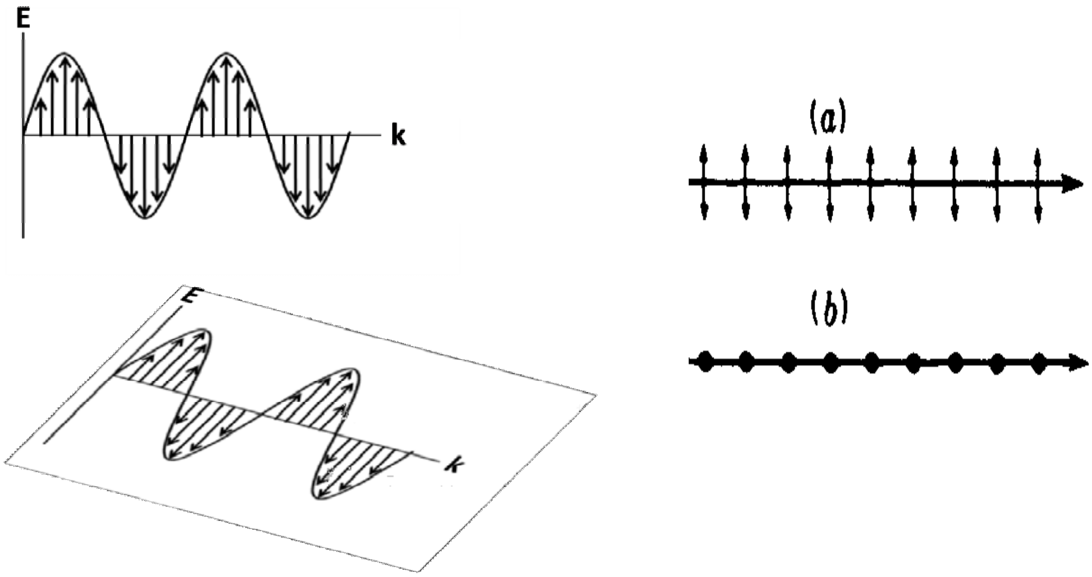


***Fig.5**: Pictorial representations of side and end views of plane-polarized light beams.*

If the incoming light is unpolarized (sun, light bulb), one may imagine that there are sudden, random changes in **E** occurring in time intervals of the order of 10^{-8}s. Every orientation of **E** is to be regarded as equally probable, in plane normal to the direction of propagation (see fig. 6(a)). Because electric field is a vector quantity, hence it can represent by two orthogonal components (E_x=E cos(θ), E_y=E sin(θ))

along two mutualy perpendicular directions(x, and y -axis) (fig 6(b)). So finally the unpolarized light can be represented as two vibrations at right angles with equal amplitudes but no coherence of phase (fig. 6(c)).

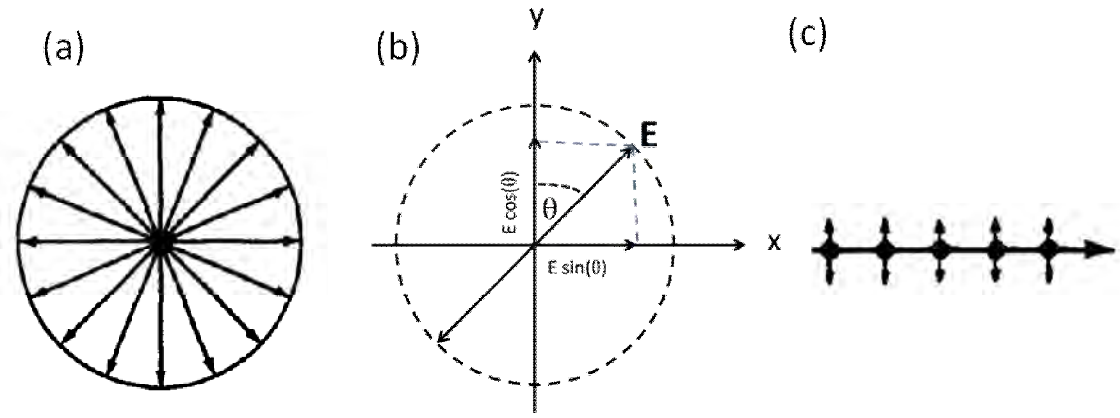


***Fig.6**: Pictorial representations of unpolarized light beams Each vibration can be resolved in two components in the x and y directions.(c) Pictorial representations of side views of an ordinary light*

The Law of Reflection and Refraction

Suppose a light ray initially traveling within the lower-index medium n_i (air) and the ray entering a higher-index medium n_t (glass) as shown in figure 7. (or reverse of it also true). So according to law of reflection "*The incident ray, the perpendicular to the surface, and the reflected ray all lie in a plane called the plane-of-incidence; the angle-of-incidence equals the angle-of-reflection or* $\theta i = \theta r$" [1].

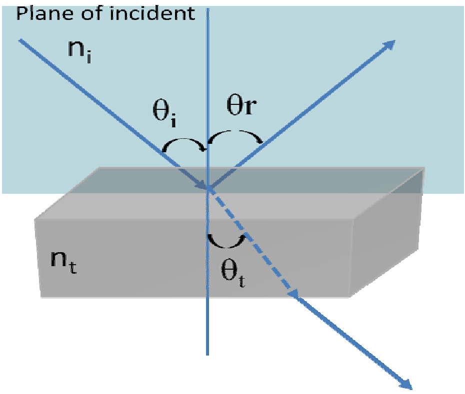


***Fig.7:** The incident, reflected, and refracted rays all lie in the same plane.*

Here all the angles are measured from the perpendicular. Further we can see that the ray entering into a higher-index medium, bends toward the normal (The reverse is also true), called refracted ray that follows the Snell's Law.

$$\frac{\sin(\theta_i)}{\sin(\theta_t)} = \frac{n_t}{n_i} = n_{ti}$$

Here θi and θt are the angle of incidence and refraction respectively.

Here we did not consider the polarization state of incident light and we can't get any information about the incident, reflected, and transmitted intensities by simply using Snell`s law. To answer these questions we need detailed study on reflection and refraction and how these are related with vector nature of light (Polarization).

Polarization by reflection

When an unpolarized light is incident on a dielectric (like glass, water) at an angle, then at interface of two medium (air and glass) there will always be a reflected ray and a refracted ray. We can infer from figure 8(a) that the reflected ray from glass surface is partially plane-polarized but for a certain definite angle, about 57° (Fig .8 (b)) it is plane-polarized and this angle called polarizing angle where the reflected and refracted rays are just 90° apart.

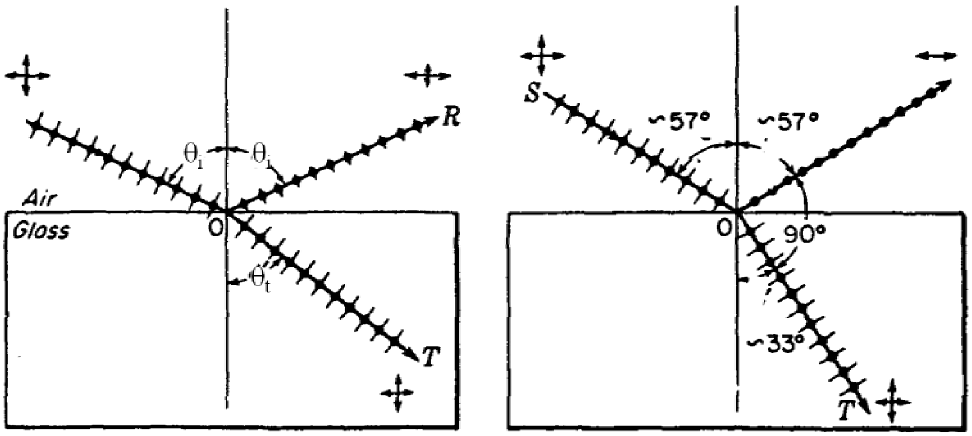


Fig.8 ***(a)*** *Polarization by reflection and refraction,* ***(b)*** *Brewster's law for the polarizing angle.*

According to Brewster's law, the angle of incidence ($\theta_i = \theta_p$) where maximum polarization occur depends only on the refractive index or

$$\tan(\theta_p) = \frac{n_t}{n_i} = n_{ti}$$

We know from dispersion relation, that the refractive index generally depends on the wavelength, and Brewster`s angle depend on refractive index, hence Brewster`s angle depends on wavelength of the incident light. But for ordinary glass the refractive index does not change so much in whole visible spectrum, therefore the polarizing angle does not change much for glass in visible spectrum.

The Fresnel Equations

The Fresnel equations describe the effects of the polarization direction of an incoming electromagnetic plane wave on the reflection and transmission intensities (or amplitudes) at interface between two different dielectric media. The reflected and transmitted field amplitudes are related to the incident amplitude via the angles of θ_t transmission and reflection θ_r. The amplitude reflection (or transition (t)) coefficient (r) defined as the ratio of the reflected (or transmitted) to incident electric-field amplitudes. $r = [E_{0r}/E_{0i}]$ or $t = [E_{0t}/E_{0i}]$.

In this section we will assume that our dielectric mediums are linear, isotropic, homogeneous, with $\mu \sim \mu_o$ (like air, glass). So that we can use the simple form of Fresnel`s equations.

Let **E** is perpendicular to the plane-of-incidence than Fresnel`s Equations for reflection and transmission amplitude coefficients are:

$$r_{\perp} = \frac{n_i \cos(\theta_i) - n_t \cos(\theta_t)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}$$

$$t_{\perp} = \frac{2n_i \cos(\theta_i)}{n_i \cos(\theta_t) + n_t \cos(\theta_i)}$$

And when E is parallel to the plane-of-incidence than Fresnel`s equations for reflection and transmission amplitude coefficients are:

$$r_{\parallel} = \frac{n_i \cos(\theta_i) - n_t \cos(\theta_t)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}$$

$$t_{\parallel} = \frac{2n_i \cos(\theta_i)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}$$

Figure 9 shows the amplitude coefficients of reflection , when E is parallel or perpendicular to the plane-of-incidence as a function of incident angle for air- glass interface (n_i =1, n_t= 1.5).

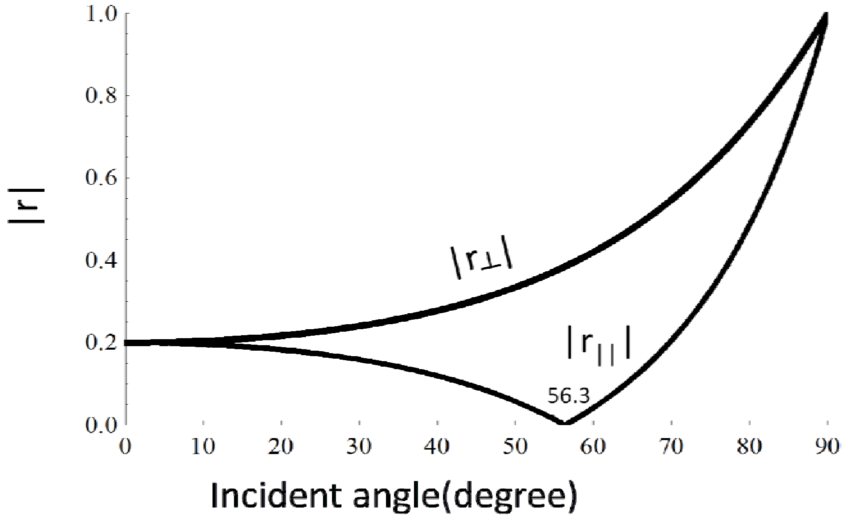


Fig.9: *The amplitude coefficients of reflection as a function of incident angle for air- glass interface (n_i =1, n_t= 1.5).*

But the experimentally measurable quantity is the light intensities not amplitude. Hence in particular, we are interested to determining the intensities of light that are reflected and refracted. The reflectance R is the ratio of the reflected intensity to the incident intensity which is equal to square of the amplitude coefficients of reflection.

$$R = r^2$$

So reflectance gives information about how much light of incident will be reflect for a given incident angle and material. When E is parallel to the plane-of-incidence than reflectance is

$$R_{\parallel} = r_{\parallel}{}^2 = \left[\frac{n_i \cos(\theta_i) - n_t \cos(\theta_t)}{n_i \cos(\theta_i) + n_t \cos(\theta_t)}\right]^2 \dots\dots\dots\dots\dots (1)$$

When E is perpendicular to the plane-of-incidence than reflectance is

$$R_{\perp} = r_{\perp}{}^{2} = \left[\frac{n_t \cos(\theta_i) - n_i \cos(\theta_t)}{n_t \cos(\theta_i) + n_i \cos(\theta_t)}\right]^2 \text{ ………… (2)}$$

When there is no absorption than the total incident intensity is the sum of reflected and transmitted intensities or

$$R + T = 1 \Rightarrow T = 1 - R \text{ ……………….. (3)}$$

So if we know the reflectance then we can calculate the transmittance. In figure 10 we can see the behaviour the reflectance and transmittance. as a function of incident angle for air- glass interface (n_i =1, n_t = 1.5). The essential features of reflectance curve are briefly described as follows. At normal incidence (θ_i=0) about 4 % of the intensity of a beam of for both the polarizations is reflected. At a particular angle of incidence (θ_p =56.3°) call Brewster`s angle , the reflected light is completely plane-polarized (in electric vector perpendicular to the plane incidence($R_{\perp} = 15\%,\ R_{||} = 0\ \%$)).

In our experiment we will use a glass plate kept in front of unpolarized light source (light bulb, see fig. 1 and 11). We know that if, the incoming light is unpolarized, and in that case we can represent it by two orthogonal, equal-amplitude and incoherent in polarized sates (see fig. 6). One polarization state is parallel to plane of incident and other one is perpendicular to plane of incident. Here equal in amplitude means that the incident intensity (I_i =Square of amplitude)) is equally share by these two polarization states (parallel and perpendicular to plane of incident) is

$$I_{i\parallel} = I_{i\perp} = I_i/2$$

After incident on glass plate these to polarization states are reflected according to equations (1) and (2). The amount of these reflected intensity can written as:

$$I_{r\parallel} = R_{\parallel} I_{\parallel i}/= R_{\parallel} I_i/2$$

$$I_{r\perp} = R_{\perp} I_{i\perp}/= R_{\perp} I_i/2$$

Further the reflected light passes through a polarizer and detected with a photocell. Photocell converted the light intensity in electrical current and it is measured by an ammeter. The measured current is proportional to the intensity falling on the photocell. We can see in figure 10, that the reflectance $R_{\perp}$generally greater than or equal to $R_{\parallel}$. Hence

$$I_{r\perp} = R_{\perp} I_i/2 \geq I_{r\parallel} = R_{\parallel} I_i/2$$

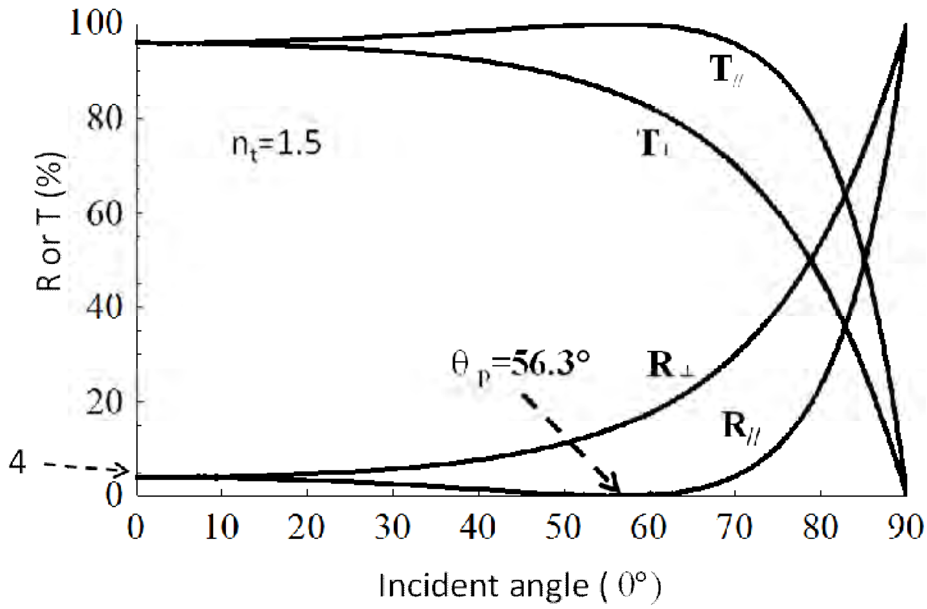


Fig.10: *Reflectance and transmittance. as a function of incident angle for air-glass interface (n_i =1, n_t = 1.5).*

To verify Fresnel`s law we will rotate the glass plate by means changing of incident angle (10 20....80 degree) and corresponding to each incident angle we have record the maximum (I_{max}) and minimum (I_{min})value of current by rotating the polarizer. We know that current will be maximum when reflected intensity $I_{r\perp}$ is parallel to polarizer axis. Similarly current will be minimum when reflected intensity $I_{r\parallel}$ is parallel to polarizer axis.

$$I_{max} \propto I_{r\perp} \; and \; I_{min} \propto I_{r\parallel}$$

Plotting the I_{max} and I_{min} as a function of incident angle (θ_i) we can verify the Fresnel`s law for a given glass plate.

Further we can see that the difference between the I_{max} and I_{min} is amount of polarization of the reflected light. The degree of polarization P of the reflected light can be calculated by using the I_{max} and I_{min} (intensities of the parallel and perpendicular components).

$$P\ (\theta_i) = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

The photocell current I_{max} and I_{min} depends on angle of incident, hence P also depndet on incident angle of the light. At a particular angle of incidence (θ_p =56.3°**)** call Brewster`s angle, the reflected light is completely plane-polarized having electric vector perpendicular to the plane incidence ( $R_\perp = 15\%$, $R_{||} = 0\ \%$)). Since $R_{||} = 0$ , then $I_{min}$= 0 and P=1, this is the maximum value of P. All other incident angles, expect Brewster`s angle, the P always less than one. If we plot the P as a function of incident angle for glass then the maximum of P versus θ_i curve gives the Brewster angle of the glass (see the figure 3) .

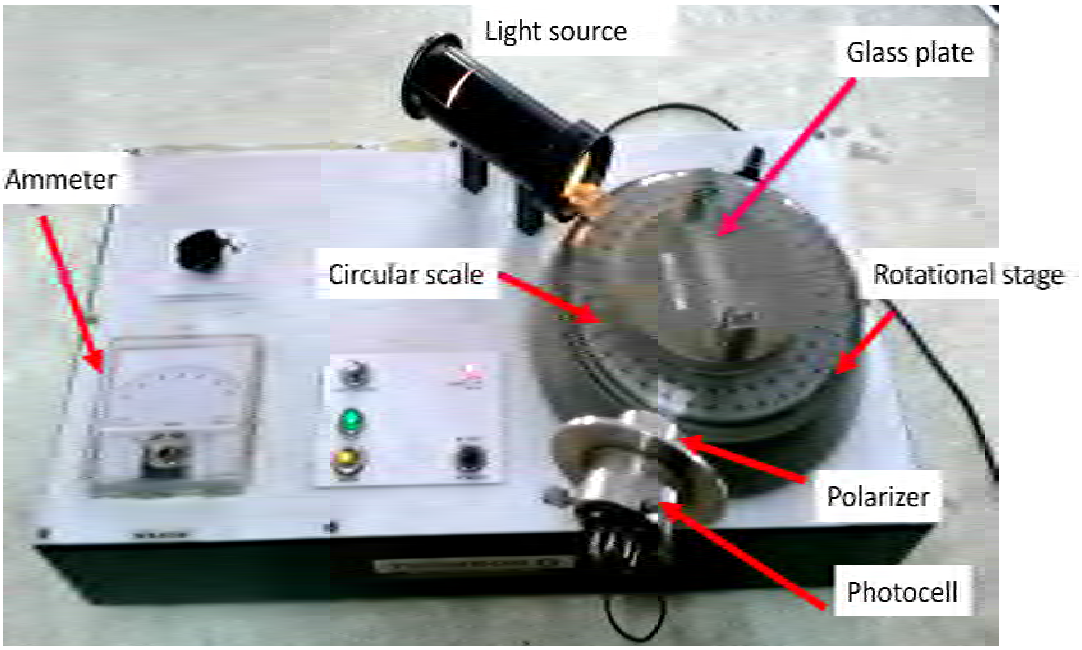


***Fig. 11:** Experimental setup for Verification of Fresnel`s law of refraction and reflection*

4.7 Self Learning Exercise-I

Q.1 What is the dimension of the refractive index?

Q.2 What is the refractive index of glass?

Q.3 What is the speed of light in a medium having a refractive index of ‘n’?

Q.4 Does the refractive index depend on wavelength (frequency) of incident light?

Q.5 Does the refractive index of glass depend on the incident angle of light?

4.8 Procedure

1. Arrange light source, lens, glass plate, polariser and the photocell, according to figure 12.
1. Align the photocell such that the light after polariser falls on its full area (Generally the photocell and polarizer are mounted on same arm).
2. After alignment, rotate the glass plate such that the angle between the incident light rays and the normal of the surface of the glass plate is 10 degree.
3. Now rotate the arm containing photocell and polarizer, so that the light reflected light from glass plate fall on photo cell through polarizer (see figure 1 and 11).

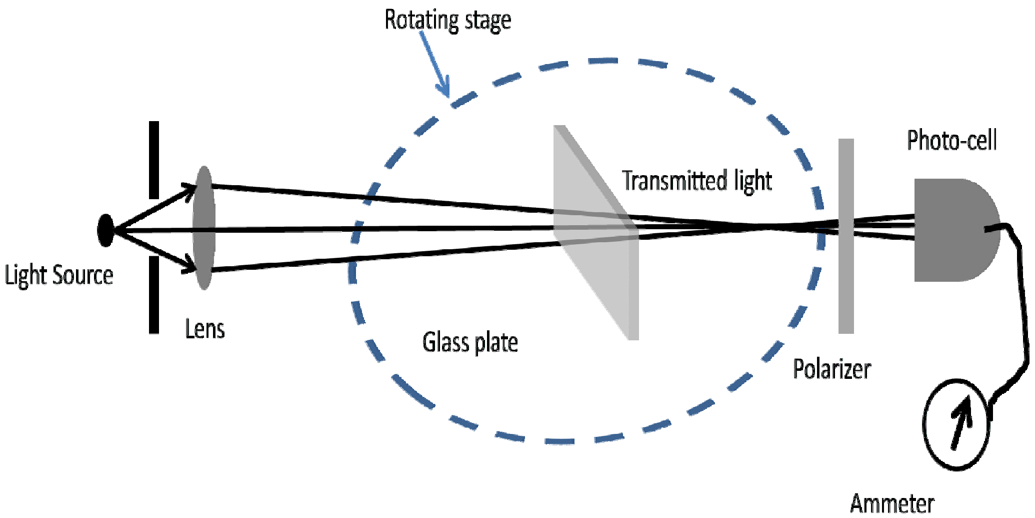


Fig.12*: The arrangement of Fresnel`s experiment.*

4. Now rotate the polarizer about its own axis, and take the reading of maximum current (I_{max}) and minimum current (I_{min}) of ammeter .
5. Now take the reading of maximum current (I_{max}) and minimum current (I_{min}) of ammeter for different incident angles (i.e. 20,30,40,50,60,70, and 80) repeating the steps 3 to 5.

6. Plot the graph between I_{max}, I_{min} and θ_i.
7. Plot the degree of polarization (P) versus different values of θ_i .

$$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

8. Find out the value of incident angle corresponding to the maximum value of P, this angle called as Brewster angle θ_p.
9. Find out the tan (θ_p) and compare it with refractive index of the glass plate.

4.9 Observation

Least count of rotating stage = …………… (Degree)

Refractive index of glass plate=.................... (Given).

Table 2: For Fresnel's relations and degree of polarization

S. No.	**Incident angle (degrees)**	**Photo cell Current (μA)**		$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$
		I_{max}	**I_{min}**	
1.	**10**			
2.	**20**			
3.	**30**			
4.	**40**			
5.	**50**			
6.	**60**			
7.	**70**			
8.	**80**			

4.10 Graph

Plot the graphs on graph paper.

4.11 Calculations

Model Calculations:

Suppose the maxima of P versus θ_i curve occur at $\theta_i = 56^0$

Hence Brewster angle is $(\theta_p) = 56^0$

So tan (θ_p) = refractive index of glass plate = tan (56) = 1. 48

4.12 Result

(i) The reflected intensities plots from glass plate are shown figure (...........) .These curves are consistence with Fresnel's law of reflections.

(ii) The degree of polarization for reflected light from glass plate is shown in figure (.........) gives the Brewste angle θ_P=...degree.

(iii) The refractive index for glass plate is = tan (θ_P) =......

4.13 Discussion

4.14 Precautions and Sources of error

1. Glass plate should be cleaned.
2. Do not touch the glass plate and polarizer otherwise the finger print affect the reflection efficiency.
3. The intensity of light source should be constant.
4. Take more reading near polarization angle.
5. The reflected light from glass plate should be fall on photocell properly.

4.15 Self Learning Exercise-II

Q.1 Does the refractive index of glass depend on the polarization of incident light?

Q.2 A medium having refractive index 'n' always changes the frequency (in vacuum) 'f_0' of the light when it travel into the medium.

Q.3 A medium having refractive index 'n' always changes the wavelength (in vacuum) 'λ_0' of the light when it passing through the medium.

Q.4 Does the refractive index depends on temperature and pressure?

Q.5 How much percentage of light is reflected by glass upon normal incident?

4.16 Glossary

Photocell: A transducer used to detect and measure light and other radiations.

Dispersion: Separate (light) into spectral rays.

Quasi: Partly similar

4.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: The refractive index is a dimensionless quantity.

Ans.2: n_g~1.5

Ans.3: v=c/n

Ans.4: Generally refractive index depends on wavelength called dispersion of light.

Ans.5: No

Answers to Self Learning Exercise-II

Ans.1: No

Ans.2: No, frequency remain same

Ans.3: Wavelength and velocity changes.

Ans.4: Yes.

Ans.5: 4%

4.18 Viva Questions

Q.1 What is the nature of the light wave?

Q.2 Which event of light of light support that light is a transverse wave?

Q.3 What is the Snell's Law?

Q.4 What do you mean by unpolarized light?

Q.5 What do you mean by plane-of-incidence?

Q.6 Do electromagnetic waves carry energy like other waves?

Q.7 What do you mean by plane of polarization of EM wave?

Q.8 What are coherence light sources?

Q.9 What do you mean amplitude reflection coefficient?

Q.10 What is the Brewster`s law?

Q.11 Does the Brewster`s angle depends on the wavelength of incident light?

Q.12 What percentage of incident light is reflected from glass plate, when $\theta i = \theta_B$?

Q.13 What is the value of polarization angle for glass?

Q.14 What are the parallel and perpendicular components of reflectance for normal incidence of light?

Q.15 What is the relation between reflected, incident intensity and reflectance?

Q.16 What is the percentage of transmitted light from air-glass interface upon normal incident?

Q.17 What is the angle between reflected and refracted rays when $\theta i = \theta B$,?

Q.18 Is it true that the incident unpolarized light is reflected at 90^0 is partially polarized?

Q.19 What do you mean by degree of polarization?

Q.20 What is the value of the degree of polarization (**P**) at $\theta_i = \theta_B$.

4.19 Answers to Viva Questions

Ans.1: Light is a transverse electromagnetic (EM) wave

Ans.2: Polarization of light.

Ans.3: $\frac{\sin(\theta_i)}{\sin(\theta_t)} = \frac{n_t}{n_i} = n_{ti}$

Ans.4: For unpolarized light, every orientation of **E** is to be regarded as equally probable, in plane normal to the direction of propagation.

Ans.5: Law of Reflection maintains that the incident ray, the perpendicular to the surface, and the reflected ray all lie in a plane called the plane-of-incidence.

Ans.6: Yes

Ans.7: The direction of polarization of an electromagnetic wave is represented by oscillations of its electric field.

Ans.8: The light sources having same frequency (monochromatic) and their relatively phase difference should be zero or remain constant with time.

Ans.9: The amplitude reflection coefficient (r) defined as the ratio of the reflected to incident electric-field amplitudes. $r = [E_{0r}/E_{0i}]$

Ans.10: Brewster`s law correlate the polarization angle with the refractive index of the medium or

$$\tan(\theta_p) = n_t/n_i = n_{ti}$$

Ans.11: Yes, As the refractive index is a function of the wavelength, and Brewster`s angle depend on refractive index, hence Brewster`s angle depends on wavelength of the incident light.

Ans.12: 15 %

Ans.13: 56.3^0

Ans.14: $R_{\parallel} = R_{\perp} = \left(\frac{n_t - n_i}{n_t + n_i}\right)^2$

Ans.15: $I_{Reflected} = R\, I_{incident}$

Ans.16: 96%

Ans.17: 90^0

Ans.18: No, because at $\theta = 0$ and 90^0, the reflectance $R_{\parallel} = R_{\perp}$, hence reflected light at 0^0 and 90^0 is always unpolarized.

Ans.19: $P = (I_{max} - I_{min})/(I_{max} + I_{min})$

Ans.20: **P**=1

References and Suggested Readings

1. F. A. Jenkins and H. E. White, "*Fundamentals of Optics"* 4th Ed., The Mcgraw-Hill Companies, Inc., USA (2001).
2. Eugene Hecht, "*Optics*" 4th Ed., Addison Wesley, San Francisco, CA (2002).

UNIT-5
Hartman's Formula

Structure of the Unit

5.1 Aim

Determine the wavelength of Neon light taking Hg source as a standard source applying Hartman's formula.

5.2 Apparatus

Constant deviation prism, spectrometer, condensing lens, travelling microscope, mercury lamp, camera, photographic plate, developer film folder and finer.

5.3 Diagram

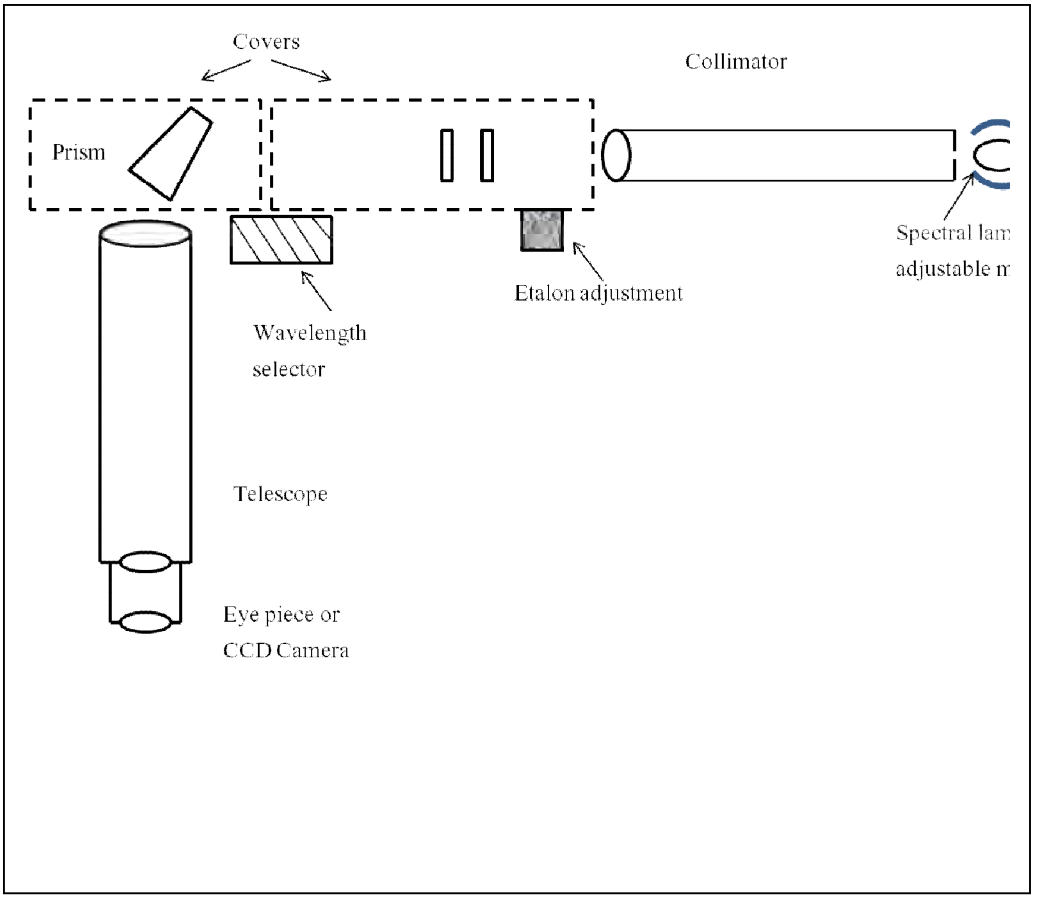


Figure 1: Block diagram of the experimental setup

5.4 Formula

The Hartmann dispersion formula, which is valid over a restricted wavelength interval, is given by:

$$n(\lambda) = A + \frac{B}{\lambda - C}$$

The Hartmann constants are defined as below:

$$C = \frac{\frac{n_1 - n_2}{n_2 - n_3}\ \lambda_1(\lambda_2 - \lambda_3) - \lambda_3(\lambda_1 - \lambda_2)}{\frac{n_1 - n_2}{n_2 - n_3}(\lambda_2 - \lambda_3) - (\lambda_1 - \lambda_2)}$$

$$B = \frac{n_1 - n_2}{\frac{1}{\lambda_1 - C} - \frac{1}{\lambda_2 - C}}$$

$$A = n_1 - \frac{B}{\lambda_1 - C}$$

5.5 Theory and Description

Refraction:

The bending of a wave when it enters a medium with different speed is known as refraction. When a light ray passes from a fast medium to a slow medium, it bends towards the normal to the boundary between the two medium. The amount, by which the light ray bends, depends upon the index of refraction of the two medium and can be described by Snell's law.

Snell's law

The law of refraction states that the sine of the angle of incidence (i) and the sine of the angle of refraction are in constant ratio to each other.

$$\boxed{\frac{Sin\ i}{Sin\ r} = \frac{n_2}{n_1}}$$

The refracted ray lies on the opposite side of the normal from the incident ray. The incident ray, surface normal and the refracted ray all lie in the same plane.The law of refraction is also known as Snell's law. The constant in the Snell's law is the ratio of the refractive indices of the two materials.

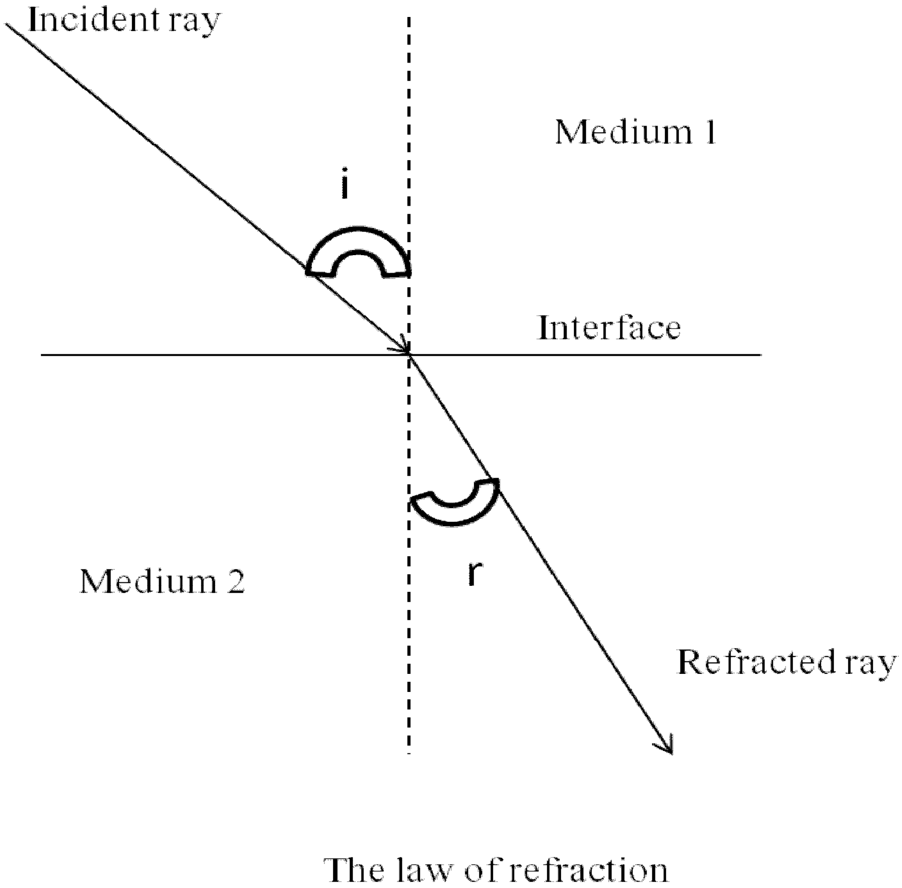


Figure 2: The law of refraction

Dispersion: Variation of n with λ

The index of refraction can be easily measured and this is closely related to the speed, the study of the variation of speed with wavelength (or frequency) can be studied by the index of refraction as a function of the wavelength (or frequency). With visible light, we call it normal dispersion when the medium's index of refraction decreases gradually as the wavelength increases. The graphical display of n vs. λ is called a dispersion curve.

Cauchy's equation

In 1836, Cauchy explained the curve of normal dispersion by an equation.

Cauchy's equation is an analytical form for the dependence of the refractive index on the wavelength λ.

$$n(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \cdots$$

where *n* is the refractive index, λ is the wavelength, *B*, *C*, *D*, etc., are coefficients that can be determined for a material by fitting the equation to measured refractive indices at known wavelengths. This equation represents the curve in visible region with considerable accuracy.

With th knowledge of values of refractive index n for three different wavelengths, the three constants can be found out.

It is also quite accurate and sufficient to include only two constants. The two term form of the above equation is:

$$n(\lambda) = B + \frac{C}{\lambda^2}$$

On differentiating above equation with respect to λ,

$$\frac{dn}{d\lambda} = -\frac{2C}{\lambda^3}$$

The above equation shows that the dispersion varies with the inverse cube of the wavelength. The negative sign in the equation is due to the negative slope of the dispersion curve.

Constant deviation spectrometer

A constant deviation prism is used in the constant deviation spectrometer. A prism, when is used in a spectrometer, is always used in minimum deviation position. The construction of a constant deviation prism is shown below:

This prism, which is a single piece, can be seen as composed of three different pieces. Two 30^0 prism PQR and QST and a reflecting prism PRS. If a light ray AB incidents at an angle i, for certain i, BC is perpendicular to PR, it gets totally reflected at PS and undergoes deviation of 90^0. By using geometry, it can be shown that the emergent ray is perpendicular to the incident ray.

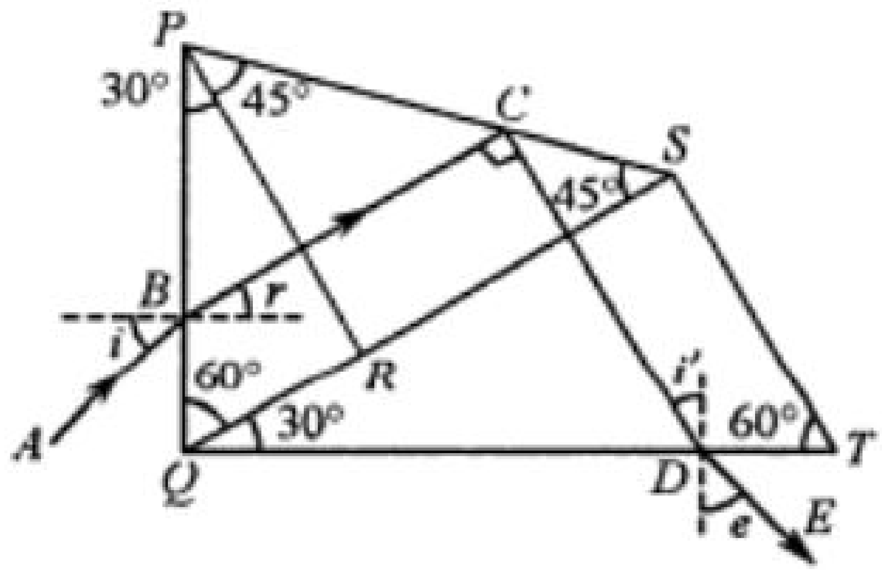


Figure 3: Constant deviation prism.

The two 30^0 prisms can also be thought as a 60^0 prism. Minimum deviation occurs when the angle of incidence is equal to the angle of emergence.

A light ray deviated through 90^0 by constant deviation prism passes through a position of minimum deviation. This principle is used in constant deviation spectrometer.

The Hilger Wavelength Spectrometer (Constant Deviation Type)

The Hilger wavelength spectrometr is a constant deviation type spectrometer. It uses a "constant deviation prism" (described in the section above) in place of a normal prism. In this, both the telescope and collimator are rigidly fixed. The spectrum can be obtained only by rotating the prism. As a result of this, the construction of this type of spectrometer is extremely convenient and mechanically sound.

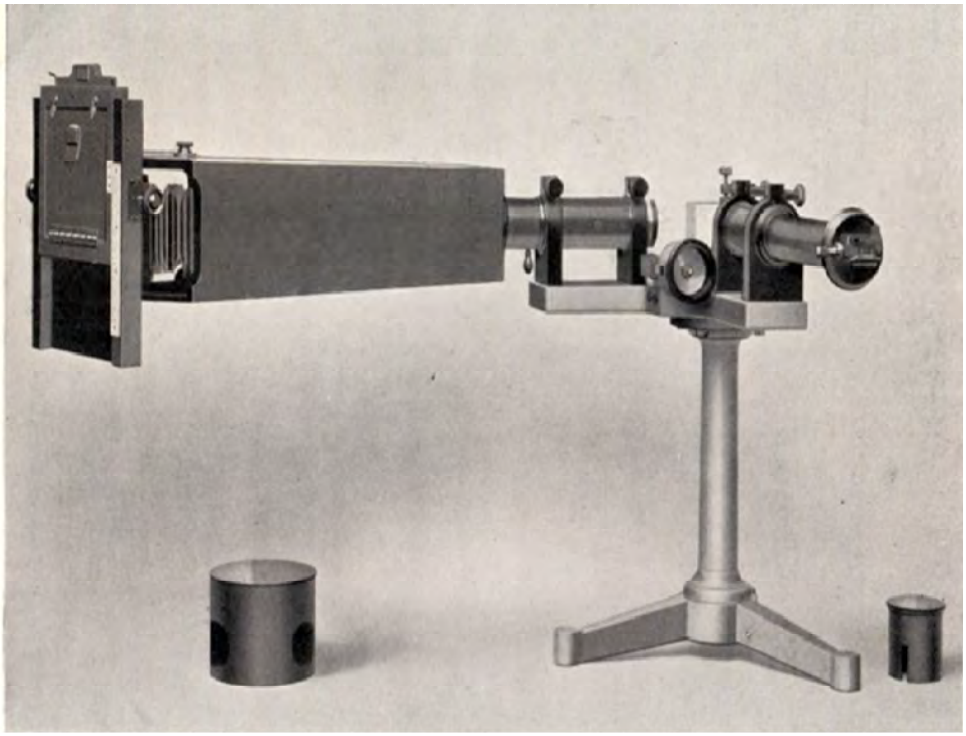


Figure 4: Hilger Wavelength Spectrometer.

[REF: The Hilger wavelength spectrometer manual]

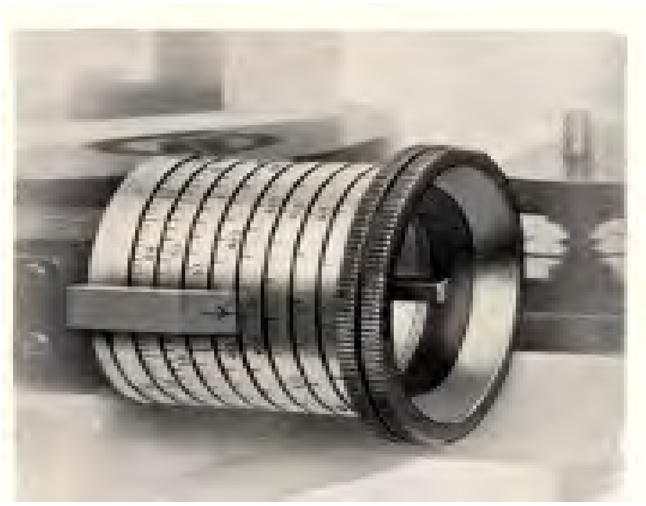


Figure 5: Drum

The prism table on which the prism stands is rotated with the help of fine steel screws. A drum is fixed to these screws [Figure5]. With the help of this drum, the wavelength of the lines in the spectrum can be read directly. The index is indicated in the helical slot. The drum is in the side of the eyes in the most recent instruments so that the wavelengths of the lines can be read off without quitting the eyepiece. The point of the micrometer screw is of hardened steel, and is permanently fixed before the screw thread is cut.

The telescope and collimator both are rigidly fixed to the cast iron base, and the whole is screwed to a strong cast iron tripod. The design is extremely strong and simple; and the accuracy is as great as that obtained by the use of very high class of divided circle spectrometer.

Sources:

In this experiment, Mercury and Copper sources are used. A brief description of these sources is given below:

Mercury Vapour Lamp

A high pressure mercury-vapor lamp is a gas discharge lamp, which consists of a quartz discharge tube enclosed in a glass bulb. The tube contains a few milligrams of mercury and around 25-50 torr of pure argon as a buffer gas to carry the discharge while the lamp warms up. It uses an electric arc which produces light through vaporized mercury. The glass bulb is internally coated with fluorescent phosphor which converts the UV radiation emitted by the tube into visible light.

The internal pressure in these bulbs, while in operation, is around one atmosphere. Their operation requires special assembly. They also require electrical ballast. The warm period for these bulbs to reach at their full output is around 4 – 7 minutes.

At room temperatures, Mercury in the glass tube is in the liquid form. For the arc to start and the electricity to conduct, the mercury in the tube needs to be vaporized and ionized. This lamp like other lamps also needs a starter. This starter is also contained in the lamp.

In addition to the mercury, the lamp is also filled with the argon gas at the low pressure. When the lamp is switched on, full voltage is applied on the two electrodes and a discharge passes between two. This leads to the ionization of the gas. As the lamp warms up, the mercury in the lamp gradually vaporizes and the pressure insides increases.

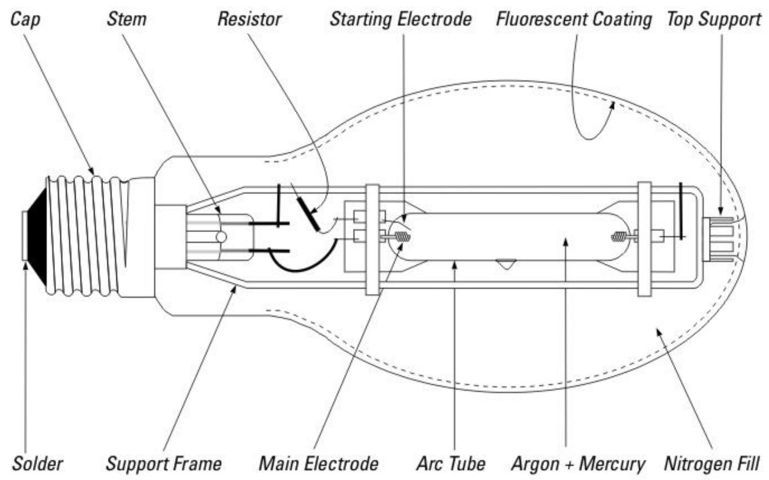


Figure 6: A Typical High Pressure Mercury Lamp

[REF:http://www.lamptech.co.uk/Documents/M1%20Introduction.htm]

The resistance of Mercury vapor lamp decreases as the current through the tube increases. If the lamp is directly connected to the power lines, the current through it will start increasing and the lamp will be destroyed. Hence it needs an electrical ballast to limit the operating current through it.

Copper arc lamp

In a copper arc lamp, two copper rods are used to produce the arc. They are separated in the beginning. Once they are connected to the dc supply, and the electrodes are brought together, the tips touch each other and then they are removed away.

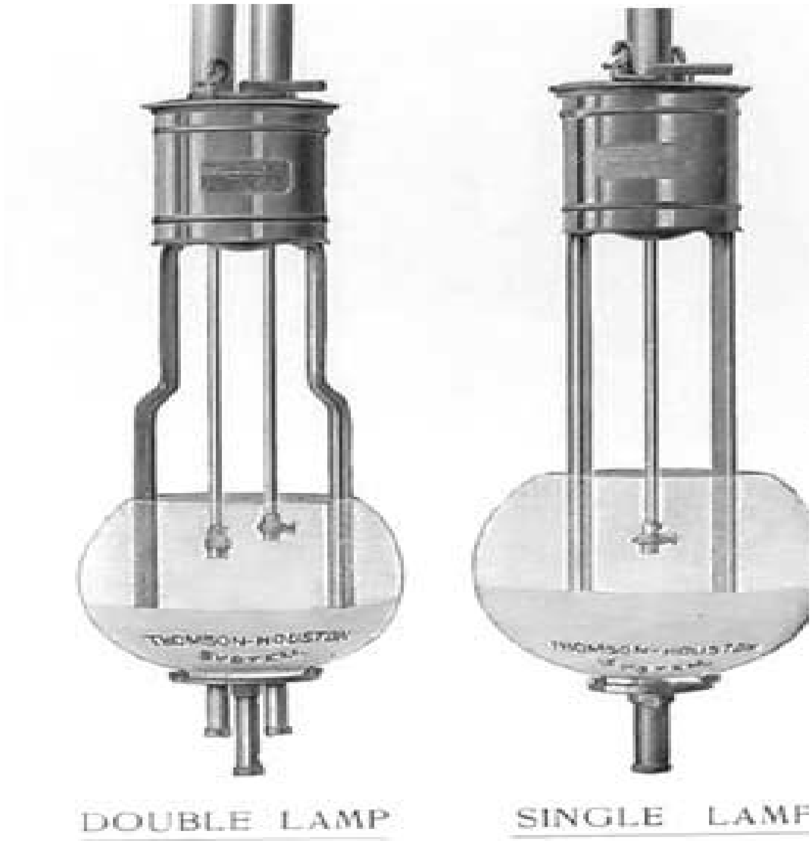


Figure 7: Carbon Arc Lamp

[REF: http://www.edisontechcenter.org/ArcLamps.html]

An electric discharge passes through air having copper atoms in excited states between two electrodes. This gives the characteristic spectrum of copper.

5.6 Self Learning Exercise-I

Q.1 What is the definition of refraction?

Q.2 How do you define the refractive index?

Q.3 What is the unit of refractive index?

Q.4 List out the factors on which the refractive index of a medium depends.

Q.5 The bending of a beam of light when it passes obliquely from one medium to another is known as _______.

a. Reflection
b. Refraction
c. Dispersion
d. Deviation

5.7 Procedure

1. All the instruments must be aligned at the same level so that the light which emerges out of the source passes through the condensing lens and focuses completely on the slit. For the spectrums of mercury and copper, the settings of the whole apparatus should remain the same.
2. Put the copper source on and change the position of condensing lens so that a sharp focus on the slit is obtained. There are two screws in the collimator: one is to put the slit on or off and the other is to change the width of the spectral lines. Another system is provided to vary the length of the line.
3. By doing these settings and using the drum, a very neat and sharp spectrum of copper may be obtained.
4. The position of condensing lens has been made in such a way that when the mercury source is put on, a sharp focus is obtained on the slit similar to that of the copper source.
5. After this, use the photographic film to obtain the photograph of our spectrum. The copper arc spectrum is obtained in roughly 30 seconds and the mercury spectrum is obtained in around 5 seconds. By developing and fixing the film, the spectrum pattern can be seen on the film.
6. Use the comparator to compare copper with respect to the mercury. By using any three wavelengths of mercury spectrum and with the help of Hartman's dispersion formula, all the wavelengths of copper can be obtained.
7. Error should be calculated for the copper wavelengths between the values obtained and the standard values.

5.8 Observation

Least count of comparator =

S.No.	Symbol of spectrum	Comparator reading (cm)	Observed wavelength (A^0)	Corresponding wavelength (A^0)	Error (A^0)
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					

5.9 Graph

Plot the graph on graph paper

5.10 Calculations

5.11 Result

Model Result:A good agreement has been found between the calculated and corresponding standard copper wavelengths. Thus Hartman's dispersion formula is verified. A curve is also drawn between error and standard between wavelengths.

5.12 Discussion

----

*Model discussion:*In this experiment we have proved the validity of Hartmann's formula. The lines from Mercury source has been used as the standard. The observed wavelength of Copper spectrum lines are very close to the literature values. A wide range of wavelengths from 2300 A^0 to 6000 A^0 have been observed using the photograph arrangement.

5.13 Precautions and Sources of Error

1. The source (mercury lamp or copper arc lamp) should be placed at axis of the collimator so that best resolution and best intensity is obtained.
2. The width of the slit should be adjusted to the minimum.
3. The exposure time for the mercury spectrum should be around 5 seconds and for copper spectrum should be around 30 seconds.
4. The slit should be clean.

5.14 Self Learning Exercise-II

Q.1 How does dispersion of light take place?

Q.2 Why does the dispersion take place only in prism and not in a glass slab?

Q.3 What is the difference between wave refraction and dispersion?

Q.4 What is difference between normal and anomalous dispersion?

Q.5 What is the angle of minimum deviation?

5.15 Glossary

Normal dispersion : It occurs where shorter wavelengths travel slower than longer wavelengths.

Anomalous dispersion : occurs when shorter wavelengths travel faster than longer wavelengths.

5.16 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: When the light passes from one medium to another medium of different density, it deviates from its original path. This is known as refraction.

Ans.2: Refractive index of a medium is the ratio of the speed of light in vacuum to the speed of light in a medium.

Ans.3: Refractive index is the ratio of velocity of light in two media and hence it is a mere number without any unit.

Ans.4: The refractive index of a medium depends on

a. the nature of the medium

b. the colour or wavelength of the incident light

Ans.5: (b) refraction

Answers to Self Learning Exercise-II

Ans.1: In Physics, 'dispersion' is the property by which light is spread out according to its color as it passes through an object. For example, when you shine a white light into a prism, all of the different colors of light are bent different amounts, so they spread out and make a rainbow. This works because of the fact that different colors of light actually have different wavelengths. (The wavelength is the distance between the peaks in the wave.) Light interacts with the molecular structure of the prism differently depending on its wavelength. So different wavelengths of light are bent different amounts.

Ans.2: When a beam of light travelling in one material enters a new material, and when it is perpendicular to the common surface, it goes straight into the new material without bending. When the beam enters at an angle it is bent. The amount of bending is related to the relative indices of refraction. Now it turns out that the index of refraction of most materials is dependent on the wavelength of light. Hence different wavelengths are bent by different amounts; hence dispersion.

In a slab of glass the effects on the beam due to the entrance and exit angles cancel out. In a prism these effects do not cancel out due to the different entrance and exit angles

Ans.3: Refraction refers to any bending of waves due to a change in speed. When water waves move through different depths, the wave is said to be refracted.

Dispersion is the frequency dependence of refraction. In the case of light being refracted by a prism, dispersion means that the higher frequency light bends more. In short, refraction is the bending of light, and dispersion is the frequency dependence of this behavior.

Ans.4: Normal dispersion occurs where shorter wavelengths travel slower than longer wavelengths. Anomalous dispersion occurs when shorter wavelengths travel faster than longer wavelengths

Ans.5: When a light ray enters into a transparent material, it gets deflected. This deflection depends on both the refractive index of the material and the incident angle. When a light ray passes through a prism, it gets deflected twice: first at the entrance and then at the exit. The total of these two deflections is called as the deviation angle. The angle of deviation depends upon the refractive index of the prism, angle of prism and the angle of incidence. There is an angle of incidence at which the sum of the two deflections is a minimum. The deviation angle at this point is is called the "minimum deviation" angle, or "angle of minimum deviation.

5.17 Viva Questions

Q.1 Define wavelength.

Q.2 What is the law of reflection?

Q.3 What is index of refraction?

Q.4 What is Snell's law?

Q.5 What do you understand by dispersion?

Q.6 What is Hartmann dispersion formula?

Q.7 What is a dispersion curve?

Q.8 What is normal dispersion?

Q.9 What is anomalous dispersion?

Q.10 What is a spectrometer?

Q.12 How does refractive index change with wave length?

Q.12 How does the deviation depend on the angle of the prism?

Q.13 What is a dispersion relation?

Q.14 What is a constant deviation prism?

Q.15 What are the examples of the constant deviation prism?

Q.16 Why Mercury vapor lamp is called a line source?

Q.17 What are the wavelengths present in a Mercury source?

Q.18 What are the advantages of a Mercury source?

Q.19 What is the use of the drumhead in the constant deviation spectrometer?

Q.20 Which spectrometer is better: an ordinary prism spectrometer or a constant deviation prism spectrometer?

5.18 Answers to Viva Questions

Ans.1: The distance between two points or particles in the same phase—i.e., points that have completed identical fractions of their periodic motion is known as wavelength.

Ans.2: According to the law of reflection, the angle of incidence equals the angle of reflection.

Ans.3: The speed of light in vacuum divided by the speed of light in a medium is known as the index of refraction for that medium.

Ans.4: When a wave passes between two given medium, the ration of Sine of angle of incidence to the sine of angle of refraction is constant. This law is known as Snell's law.

Ans.5: Dispersion is the phenomenon which gives the separation of colors in a prism.

Ans.6: Hartmann dispersion formula is a semi empirical formula which relates the refractive index n and the wavelength by the relation:

$$n(\lambda) = A + \frac{B}{\lambda - C}$$

Where, A, B, and C are empirical constants.

Ans.7: A graph showing the dependence of the frequency on the wavenumber for dispersive waves is known as dispersion curve.

Ans.8: In the case of normal dispersion, $dn/d\omega > 0$ and $dn/d\lambda < 0$

Ans.9: In the case of anomalous dispersion, $dn/d\omega < 0$ and $dn/d\lambda > 0$.

Ans.10: A spectrometer is an instrument used to analyze the spectrum of a source of light.

Ans.11: Higher the wave length, smaller is the refractive index.

Ans.12: Greater the angle of the prism, more the deviation is.

Ans.13: A dispersion relation relates the wavelength or wave number of a wave to its frequency.

Ans.14: A constant deviation prism is a prism which has the property that the minimum deviation is always at the same angle.

Ans.15: Pellin-Broca prism and Abbe prism are the examples of constant deviation prism.

Ans.16: The Mercury vapor lamp is called as a line source as it emits radiation only at well-defined wavelengths.

Ans.17: The wavelengths present in a Mercury source are: 257.7 nm, 313.0 nm, 365.0 nm, 404.7 nm, 407.8 nm, 435.8 nm, 546.1 nm, 577.0 nm, and 579.1 nm.

Ans.18: The advantages of a Mercury source are its intensity and stability. Also it provides a monochromatic beam at each wavelength.

Ans.19: In a constant deviation spectrometer, the prism table can be rotated using a drum. This drum is attached to the table. The head of this drum is calibrated for the known wavelengths. Hence with the help of it, wavelengths can be measured directly.

Ans.20: A constant deviation prism spectrometer.

References and Suggested Readings

1. B. L. Worsnop and H. T. Flint, Advanced Practical Physics for Students (1951)

2. The Hilger wavelength spectrometer manual

3. A Simple ation Formula for the Prismatic Spectrum, Hartmann, J. Astrophysical Journal, vol. 8, p.218, 11/1898.

4. F. A. Jenkins and H. E. White, Fundamentals of Optics, 4th ed. McGraw-Hill, Inc. (1981)

UNIT-6
Babinet Compensator

Structure of the Unit

6.1 Aim

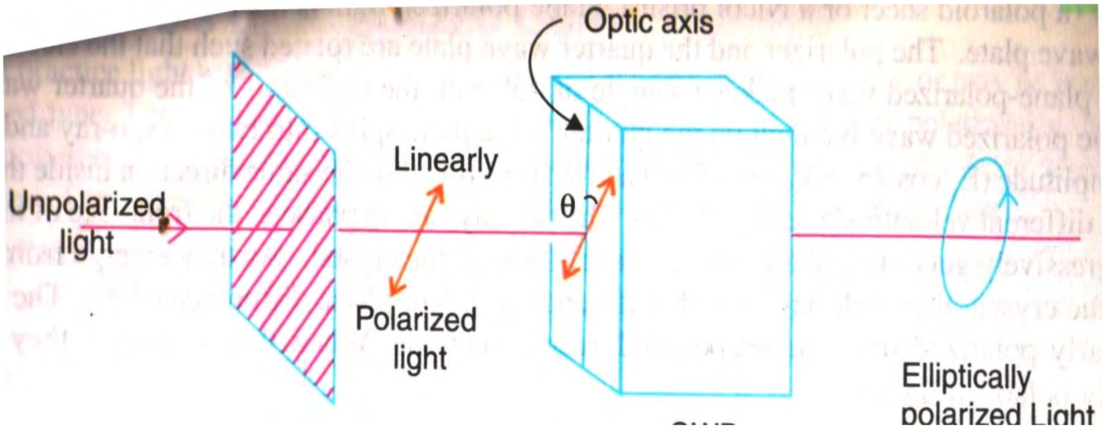
To (i) analyze elliptically polarized light.

(ii) determine the phase difference introduced between ordinary and extraordinary rays.

6.2 Apparatus

Babinet compensator, the source of sodium light, quarter wave plate, polarised, the source of white light .

6.3 Diagram



Polariser Quarter wave plate

Figure1

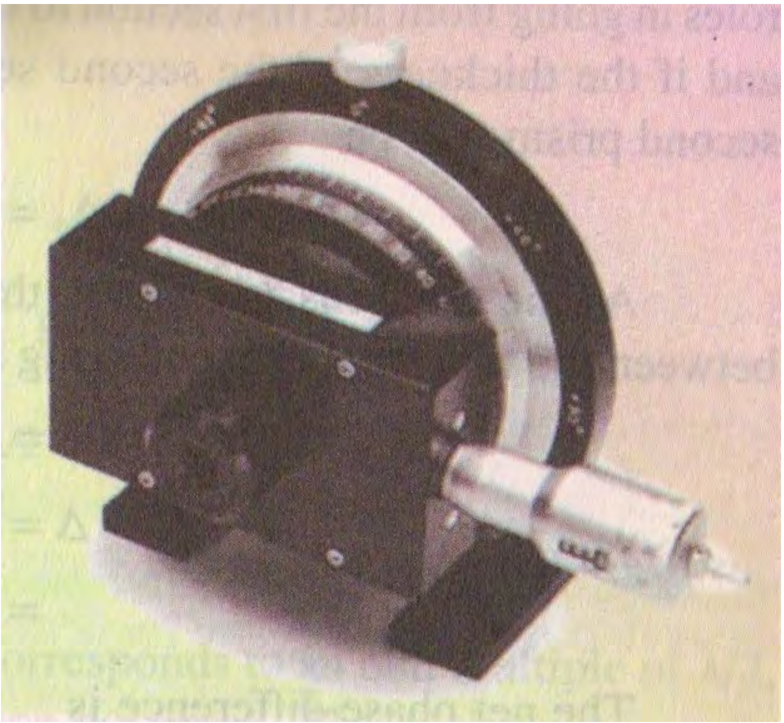


FIGURE 2: BABINET COMPENSATOR

6.4 Formula

(i) The initial phase difference between two components of the elliptic vibration is given by ;

$$(\phi - \alpha) = \pi L/x$$

Where, L is the micrometer reading for the shift with elliptically polarised light

x is the micrometer reading for a phase change π or path change $\lambda/2$

(ii) The ratio of the axis is given by –

$$tan\Theta = a/b$$

Where a & b are the semi major & minor axes .

Θ is the relation of analyses for complete extinction

(iii) **(μ_e-μ_o)** , the value of birefringence may be obtained by the relation ,

$$(\mu_e - \mu_0) = \delta ex\lambda/2\pi t$$

Where, t is the thickness of the doubly refracting plate λ is the wavelength of monochromatic light used.

δex is the extra phase introduced by the doubly refracting plate. (It's value is determined by calibration part)

6.5 Theory and description

Quarter wave plate used for the production or analysis of elliptically or circularly polarised light is suitable only for the particular wavelength for which it is meant, but the Babinet compensator can be used for wide range of frequencies.

It is made of two wedges of quartz of equal acute angles. The wedges are cut that for one of the wedges the optic axes is parallel and for other perpendicular to the rectangular sides of the wedges opposite to the acute angles , Thus optic axes of two wedges are mutually perpendicular to each other as shown in figure3. Two wedges form a rectangular quartz block. A cross wire of a line is fixed in front of the upper wedge & a micrometer screw is attached to the wedge to give it a relative motion the other. The arrangement affords a means to change t or the block.

Consider a point on compensator where the upper & lower edges have thickness t_1 and t_2 respectively. If plane polarised monochromatic light, polarised by placing a Nicol or Polaroid between source & the compensator, is made to fall normally on the compensator. It is broken up into E & O (Extraordinary & ordinary) vibration travelling with different velocities (o faster in the uniaxial crystal) in passing through upper wedge. If the plane of vibration is inclined at an angel of 45 degree to the optic axis & vibrations will be along & over perpendicular to the optic axis . The E & O vibrations suffer a path difference given by –

$$t_1(\mu_e-\mu_o)\text{............where } \mu_o<\mu_e$$

Where μ_e, μo, v_e , v_o are refractive indices and velocities for E&O vibrations respectively .The status of affairs is refused in the lower wedge and the path difference in E & O vibrations is given by –

$$-t_2(\mu_e-\mu_o)\text{ ....where } \mu_e>\mu_o$$

Hence total path difference introduced by the compensator

$$\Delta=(t_1-t_2)(\mu_e-\mu_o)$$

The change in phase can be studied by the means of an analysing Nicol usually provided with the apparatus.

The thickness of the compensator along perpendicular lines to the longer edge of the wedge is the same & corresponding to definite but variable optical thickness for a central ray(t_1-t_2=0);optical path difference between O & E is zero & incident vibrations is transmitted as such . Consequently a carve fringe is observed along the central ray with two crossed Nicols. The condition for fringes is given by –

$$\delta=0, \pm 2\pi, \pm 4\pi \ldots \pm 2m\pi$$

Where m is integers.

The sign represent both sides with respect to t_1=t_2i.e. central ray. Hence a central black fringe is an indication of correct setting. Along other rays, where maximum brightness occurs. The phase difference as given by –

$$\delta=\pm(2m+1)\pi$$

The condition shows that planes of incident and transmitted vibrations are inclined at angle to each other, hence vibrations are transmitted by crossed Nicols. In the intermediate position for the phase difference between $\pm 2m\pi$ and $\pm (2m+1)\pi$ the transmitted light is circularly or elliptically polarised. Hence the state of polarisation along the compensator worries, & the variation gives rise to a series of alternate & bright straight bands. Bands can be seen with the help of low power microscope. If of 45 degree to the optic axes, the band will not be sharp, because above conditions are not fulfilled exactly; correct setting will indicate the correct inclination of incident vibrations to optic axis.

The optical thickness of plate can be varied by working micrometer screw which gives relative displacement to two wedges. The bands shift laterally. Thus any desired band can be brought under crosswire.

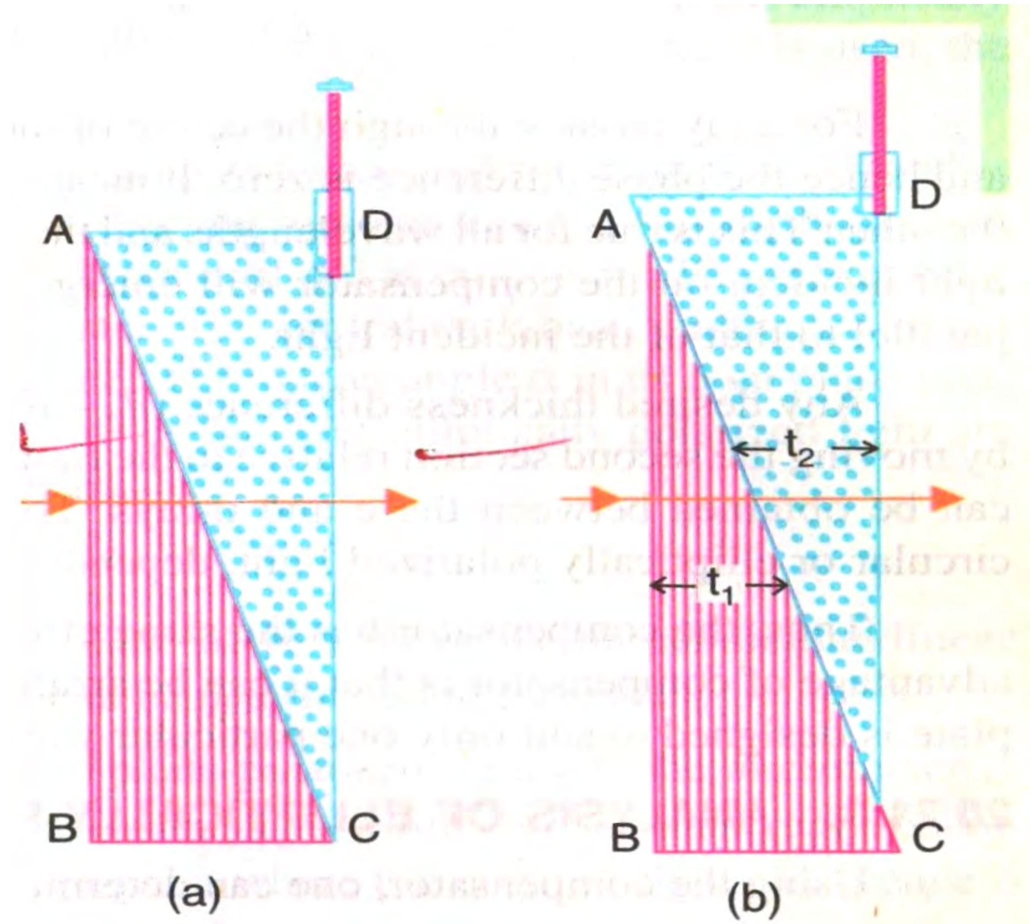


FIGURE 3

A Babinet compensator placed between crossed polariser and analyser.

Let the angels motion of the screw be o to replace a dark band and x the corresponding linear motion of the wedge. The phase change or path change will be respectively. In this way the micrometer can be calibrated in terms of phase difference.

Central black band can be easily rotated by using while light. It is because for δ=0, t_1=t_2, the central band is dark fringed by coloured bands on either sides.

The fig (3) shows the production of bright & dark bands by a Babinet compensator placed between crossed polarised & analyser.

6.6 Self learning exercise-I

Q.1: What are retarders? Give suitable diagram of wave plates.

Q.2: Give the classification of the wave plates.

6.7 Procedure

(A) Caliberation of micrometer in terms of phase difference:

(1) Place a polarised between the monochromatic source of light and the compensator view the series of bright and dark bands through the low power microscope provided with the instrument. Rotate – the compensator & analyser to get a fine pattern of bright and dark bands.

(2) Now work the micrometer screw and bring one of two dark bands under the indicator line. Take the reading of the micrometer. Again work the screw to bring the next dark band under the indicator line. Note the reading of micrometer. Find the difference of two readings.

(3) Repeat it for other consecutive bands & find the average displacement. This gives the value of linear displacement of the wedge for radians phase or path.

(B)To determine the initial phase difference (ϕ-α)between the components f elllipitical vibrations:

(1) Insert a Polaroid between the white light source and compensator obtained a system of crowded band with central dark band. Rotate the compensator and analyser to get a fine system of coloured bands. Bring the central dark band under the indicator line by working the screw. Note the reading of micrometer.

(2) Insert a quarter wave plate between the compensator and Polaroid to get elliptically polarised light. The central band shifts from the indicator line. Now, the micrometer is worked again to bring the central band under the indicator line. Note the reading find out the difference of two readings.

(3) Knowing the past (A), find the phase difference corresponding to the above difference.

(C)To determine the ratio of axes:

(1) Get a pattern of fine bright and dark bands with monochromatic light by inserting a Polaroid between the compensator and the source. Being a dark band under the indicator line by working the micrometer.

(2) Let be the distance through which the micrometer screw is shield to replace one dark band by other. Now, shift the micrometer through. The indicator line shifts a little from the dark band.

(3) Insert the quarter wave plate between the compensator and Polaroid to get elliptically polarised light.

(4) Now, rotate the compensator so that indicator returns to the same dark band and clamp it. Note its reading on micrometer.

(5) Next, rotate the analyser keeping the compensator in the same position to make the dark band under the indicator line as black as possible. Note this reading of the analyser by means of the pointer provided with it. If the analyser now rotated through the angle θ, the bands will disappear. The tangent of θ will be the ratio of the axes of the elliptical polarisation.

Repeat experiment with different orientation of $\frac{\lambda}{4}$ plate.

See figure to understand the basis of determination.

(D) **To determine the value of the birefringes ,the difference between the refractive indices of crystal for ordinary and extraordinary:**

(1) Insert a Polaroid between the between the source of monochromatic light and the compensator and obtain fine system of bright and dark bands.

(2) Work the screw to bring a dark band under the indicator line. Note the reading

, Insert a doubly refractive plate, with its optic axis parallel to its faces, between the compensator and polariser. The fringe system shifts, i.e. the dark band is no more under the indicator.

(3) Work the micrometer to bring dark band under the indicator. Note rotation of the micrometer, Reduce the rotation of the screw to the phase. It gives the value of, the extra phase introduced by the change. Use relation (3) to find. Note the thickness of the plate.

Use a quarter or half wave plate.

6.8 Observation

(1) Calibration of micrometer in terms of phase or path difference: (Monochromatic light used, white light used to detect central band)

Least count of the screw =........

Thickness 't' =.........

S.NO.	Micrometer reading for central band (cm)	Difference of 3 bands (cm)	Mean of 3 bands (cm)	Linear displacement wedge of 2x (cm)	Value of x (cm)
1.					
2.					
3.					
4.					
5.					

(2) For initial phase difference (ϕ-α) of elliptic vibration

S.NO.	Micrometer reading without plate (cm)	Micrometer reading with plate (cm)	Difference L=(x-x')cm	Mean (cm)	Phase difference (ϕ-α) $=\pi L/x$
1.					
2.					
3.					
4.					
5.					

(3) Ratio of axes a/b and direction of axes:

S.NO	Reading of bright band of analyser (cm)	Reading of dark band of analyser(cm)	Difference	Mean
1.				
2.				
3.				
4.				

(4) Difference $(\mu_e - \mu_0)$:-

S.NO.	Micrometer reading with dark band under crosswire without plate (cm)	Micrometer reading with same dark band with plate (cm)	Difference	Phase diff. Mean
1.				
2.				
3.				
4.				
5.				

6.9 Calculations

6.10 Result

1. Phase difference $(\phi-\alpha)$ =
2. Birefringes =
3. Ratio of the axes a/b =

Standard values –

μ_e=1.55336

μ_o=1.54425

μ_e-μ_o=0.00911

$$\%error = \frac{Experimental\ value - Standard\ value}{standard\ value} \times 100$$

6.11 Discussion

6.12 Precautions and Sources of error

1.Calibration of micrometer in terms of wavelength should be made.

2.Analyser should be rotated only in one direction in clockwise or anticlockwise.

3.Take the measurements accurately.

4.Polariser, analyser and quarter wave plate should not be touched by hands.

6.13 Self Learning Exercise-II

Q.1: How can you produce elliptically polarized light using quarter wave plate?

Q.2: Give the analysis of elliptically polarized light using Babinet compensator.

6.14 Glossary

Retarders: Retarders are a class of optical elements that serve to change the state of polarization of an incident wave.

Quarter wave plate: A quarter wave plate is thin plate of irefringent crystal having the optic axis parallel to its refracting faces

Half wave plate: A half wave plate is a thin plate, having the optic axis parallel to its refracting faces

Polarizer: These are the optical devices necessary to produce polarized light from unpolarized light.

Polarisation: A process in which we get the light which has acquired the property of one sideness is called a polarised light, and the process is known as Polarisation.

Optic axis: A line passing through any one of the blunt corners and making equal angles with three faces which meet there is the direction of optic axis.

Uniaxial Crystals: The crystals having one direction along which the two refracted rays travel with the same velocity are called as uniaxial crystal.

Biaxial crystals: In these types of crystals, there are two optic axes along which the refracted rays travel.

Double refraction: A ray of light is incident on the face of the crystal and it travels along the principal section or perpendicular to optic axis then the ray split into two rays, named as e-ray and o-rays. This phenomenon is called as Double refraction.

6.15 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Retarders are a class of optical elements that serve to change the state of polarization of an incident wave. The operation of a retarder is very simple. When plane polarized light is incident on a retarder, it splits the light into two plane polarized light waves and one of the wave's lags behind the other by a known amount. Upon emerging from the retarder, the two waves superpose on each other to produce a wave, which is of a different state of polarization.

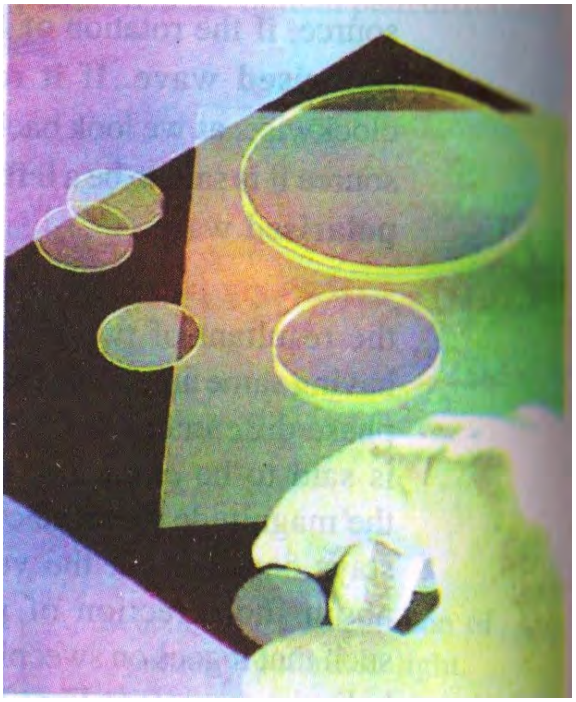


Figure 4: Retarders

A quarter wave plate and a half wave plate are two important retarders. As calcite is brittle and difficult to handle in the form of thin slices, it is not generally used to make retarding plates. Retarders are frequently made from quartz but more often they are made using the biaxial crystal mica.

Ans.2: Mainly there are two types of retardation plates or wave plates which are given below:

(1) quarter wave plate:

A quarter wave plate is thin plate of irefringent crystal having the optic axis parallel to its refracting faces and its thickness adjusted such that it introduce a quarter wave $\left(\frac{\lambda}{4}\right)$ path difference $\left\{or\ a\ phase\ difference\ of\ \left(\frac{\pi}{2}\right)\right\}$ between the e-ray and o-ray propagating through it.

When a plane polarized light wave is incident on a birefringent crystal having the optic axis parallel to its refracting face, the wave splits into e-wave and o-wave. The two waves travel along the same direction but with different velocities. As a result, when they emerge from the rear face of the crystal, an optical path difference would be developed between them. Thus, for a quartz wave plate

$$(\mu_e - \mu_0)d = \frac{\lambda}{4} \qquad \text{................(1)}$$

$$d = \frac{\lambda}{4(\mu_e - \mu_0)} \qquad \text{................(2)}$$

A quarter wave plates introduces between e-ray and o-ray a phase difference δ given by

$$\delta = \frac{2\pi}{\lambda}\Delta = \frac{\pi}{2} = 90°$$

A quarter-wave plate is used to produce elliptically and circularly polarised light**.** It converts plane polarized light into elliptically or circularly polarised light depending upon the angle that the incident light vector makes with optic axis of the quarter wave plate.

(2) half wave plate:

A half wave plate is a thin plate, having the optic axis parallel to its refracting faces and its thickness chosen such that a half-wave$\left(\frac{\lambda}{2}\right)$ path difference $(or\ a\ phase\ difference\ of\ 180°)$ between e-ray and o-ray.

When a plane polarized light wave is incident on quartz crystal having the optic axis parallel to its refracting faces, it splits into two waves: ordinary wave and extra ordinary wave. The two waves travel along the same direction inside the crystal but with different velocities. As a result, when these waves emerge from the rear face of the crystal, an optical path difference would be developed between them

$$(\mu_e - \mu_0)d = \frac{\lambda}{2} \qquad \text{................(3)}$$

$$d = \frac{\lambda}{2(\mu_e - \mu_0)} \qquad \text{................(4)}$$

A half wave introduces a phase difference between ordinary ray and extra ordinary ray, which is given below

$$\delta = \frac{2\pi}{\lambda}\Delta = \pi = 180°$$

Answers to Self Learning Exercise-II

Ans.1: ***Production of Elliptically Polarized Light:***

A quarter wave plate and a polarizer are the optical devices necessary to produce elliptically polarized light from unpolarized light. Unpolarized light is first converted to plane polarized light by allowing it to pass through a polarizer (a Polaroid sheet or a Nicol prism). The plane polarized light is then made incident on a quarter wave plate (see figure 1). The quarter wave plate or the polarizer is rotated such that the electric vector E of plane polarized light wave makes an angle θ ($\neq$45°) with the optic axis of the quarter wave plate. The incident ray divides into o-ray and e-ray of amplitudes$E sin\theta\ and\ E\cos\theta$. The rays travel along the same direction in the crystal with different velocities. The two rays are polarized in orthogonal planes. They are in phase at the front face but progressively get out of phase as they travel through the crystal. When they emerge out of the crystal they will have a path difference of $\frac{\lambda}{4}$ or a phase difference of 90°. When they combine, they produce elliptically polarized light.

Ans.2: ***Analysis of Elliptically Polarizer light:***

Using the compensator, we can determine the characteristics of elliptically polarized light.

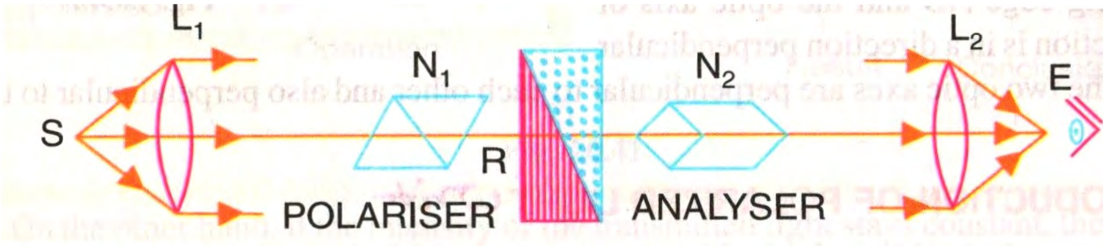
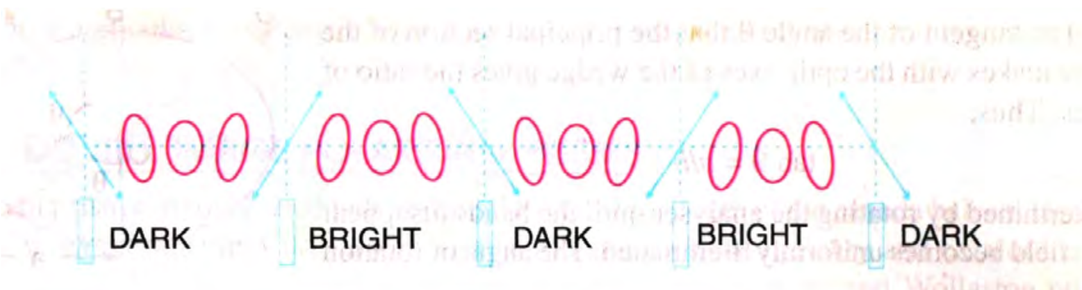


Figure5

Let the compensator be placed between crossed polarizer N_1 and analyser N_2, as shown in figure5. Let the transmission axis of polarizer be oriented at 45° with respect to the optic axis of wedge ABC of the compensator. At midpoint R the light emergent from the compensator is plane polarized in the same plane transmitted by N_1 and therefore it will be extinguished by the analyser N_2. Similarly, at distances from the midpoint for which the retardation is 1λ, 2λ, 3λ, ...$m\lambda$, and the emergent light is plane polarized in the same plane as transmitted by N_1 and hence will be extinguished by the analyser. So the field of view is crossed by a series of equidistant parallel dark bands.



$-\lambda$ $\quad$ $-\lambda/2$ $\quad$ 0 $\quad$ $\lambda/2$ $\quad$ λ

centre

At positions between them, where the path difference corresponds to an odd multiple of $\lambda/2$,that means $\lambda/2$, $3\lambda/2$, $5\lambda/2$, ...$(2m+1)\lambda/2$, the transmitted light is plane polarized. The analyser transmits the light completely and those regions will be dark while others will be coloured.

When we use white light source, the compensator is adjusted at that position in which the central dark band under a cross wire and the micrometer reading is noted. The micrometer screw is turned through an angle at which the compensator introduces a phase difference of $\pi/2$ at cross wire. Then elliptically polarized light is made to be incident on the compensator. The central dark band is shifted with respect to the cross wire. The compensator is rotated through an angle α in its own plane until the central dark band is on the cross wire. The axes of the incident elliptically polarized light are parallel to the optic axes of the wedge of the compensator.

6.16 Viva Questions

Q.1: Define the polarisation of light.

Q.2: How the polarisation phenomenon connected to light waves?

Q.3: What is difference between polarized and unpolarized light?

Q.4: Define longitudinal waves.

Q.5: Give the definition of plane of vibration.

Q.6: Give the definition of double refraction.

Q.7: What is the optic axis?

Q.8: Give the definition of uniaxial and biaxial crystals.

Q.9: Differentiate between o-ray and e-ray.

Q.10: Give the principle of Babinet compensator.

6.17 Answers to Viva Questions

Ans.1: A process in which we get the light which has acquired the property of one sideness is called a polarised light, and the process is known as Polarisation.

Ans.2: When we study the polarisation phenomenon, we get that light waves are transverse waves.

Ans.3: The unpolarised light is symmetrical about its mean position or the direction of propagation while in case of plane polarised light, there is lack of symmetry about the direction of propagation.

Ans.4: A wave in which particles of medium oscillate to and fro along the direction of wave propagation is called a longitudinal wave**.**

Ans.5: A plane, which contains the optical vector E and the direction of propagation, called as plane of vibration.

Ans.6: A ray of light is incident on the face of the crystal and it travels along the principal section or perpendicular to optic axis then the ray split into two rays, named as e-ray and o-rays. This phenomenon is called as Double refraction.

Ans.7: A line passing through any one of the blunt corners and making equal angles with three faces which meet there is the direction of optic axis.

Ans.8: The crystals having one direction along which the two refracted rays travel with the same velocity are called as uniaxial crystal. In biaxial crystals, there are two optic axes along which the refracted rays travel.

Ans.9: (1) Ordinary ray obeys the conventional laws of refraction, whereas the e-ray does not confirm to them.

(2) Both o-ray and e-ray is plane polarized.

(3) O-ray travels with same speed in all directions within the crystal while E-ray travels with different speed within the crystal.

(4) The refractive index corresponding o-ray has a constant value while the refractive index corresponding e-ray varies from direction to direction.

Ans.10: A compensator is an optical device whose function is to compensate a path difference(δ). It is used in conjunction with a polarizer and analyzer combination to investigate elliptically polarized light.

References and Suggested Readings

1. Optics by A.K. Ghatak.
2. Optics by T.P. Pandya and B.K. Mathur.
3. Fundamental of optics by Jenkins and White.

UNIT-7
Verification of Malus Law

Structure of the Unit

7.1 Aim

To verify the Malus law (cosine square law) for a plane polarized light with the help of photovoltaic cell: The dependence of the intensity of light when passed through a set of polarizer's as a function of their relative orientation.

7.2 Apparatus

The experimental set-up consists of the following:

(i) Optical Bench.

(ii) Incandescent Lamp with box.

(iii) Double convex lens (50 mm diameter & Focal length 10 cm)

(iv) Polarizer and Analyzer with tube.

(v) Photovoltaic cell with collimated house: is used to measure light intensity.

(vi) Microammeter (0-50 μA).

All the components can be mounted on an optical bench with proper alignment.

7.3 Diagram

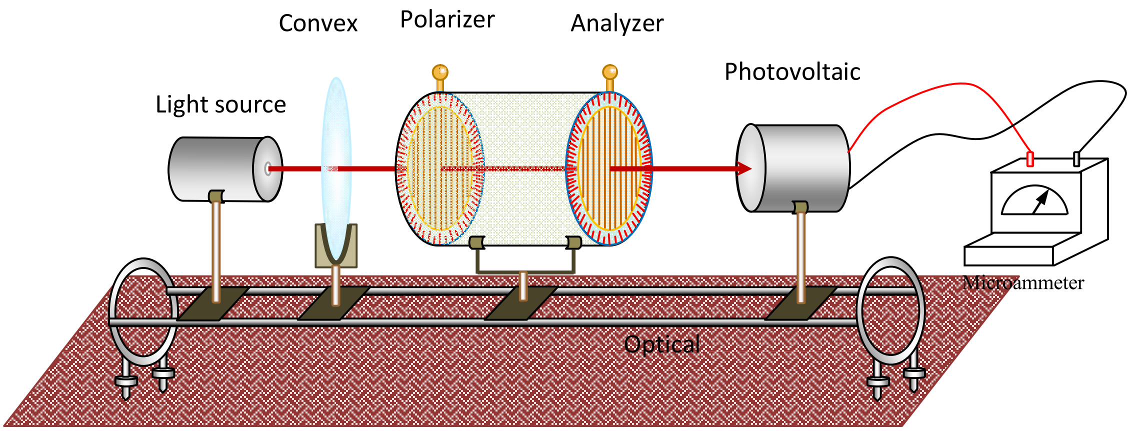


Fig.1. Diagram of optical Bench Arrangement for the Malus Law

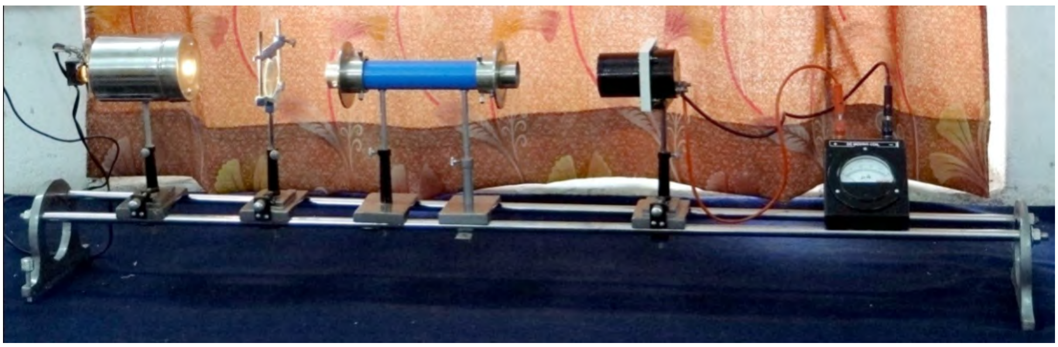


Fig.2. Experimental Arrangement of OMEGA TYPE ES-266

7.4 Formula

According to Malus Law, When light beam passes through a set of polarizers (the first one is called the polarizer and the second the analyzer), the intensity of transmitted light is a function of the angle θ between the polarizing directions of the polarizer and the analyzer. This statement is known as Malus Law.

If unpolarized light beam of intensity I_0 is incident on a polarizer then plane polarized light beam of intensity $I_0/2$ is transmitted by it. Let us now denote $I_0/2$ by I_{max}. After that plane polarized light pass through an analyzer, the output intensity is proportional to $\cos^2\theta$. Thus the output intensity of light beam transmitted through the analyzer given by

$$I_{output} = I_{max}\cos^2\theta = \frac{I_0}{2}\cos^2\theta$$

Where θ is the angle between the planes of the polarizer and the analyzer

We consider two special cases;

Case (i)	If $\theta = 0°$	axes are parallel	$I_{output} = I_{max} = I_0/2$
Case (ii)	If $\theta = 90°$	axes are perpendicular	$I_{output} = I_{min} = 0$
Case (iii)	If $\theta = 180°$	axes are parallel	$I_{output} = I_{max} = I_0/2$
Case (iv)	If $\theta = 270°$	axes are perpendicular	$I_{output} = I_{min} = 0$

Thus, we observe two position of maximum intensity and two position of minimum intensity when we rotate the analyzer with respect to the polarizer.

To verify Malus law, the light from analyzer is made to enter in photovoltaic cell which is connected to a microammeter. The photovoltaic cell is connected to microammeter. The reading of current deflection (Φ) in microammeter is directly proportional to the intensity falling on photovoltaic cell. According to cosine law

$$\Phi \propto \cos^2\theta$$

and the deflection of microammeter Φ is calculated as

since 50 μA corresponds to Φ = 90°, therefore

$$1\mu A = \frac{90°}{50}$$

For Example, if reading of current deflection in microammeter is 25 μA then

$$25\mu A = \frac{90°}{50} \times 25 = 45°$$

7.5 Model Graph

Using Malus Law

$$I_{output} = I_{max} \cos^2\theta$$

and the trigonometric identity,

$$\cos^2\theta = \frac{\cos 2\theta}{2} + \frac{1}{2}$$

so that we can rewrite the first equation in the linear form

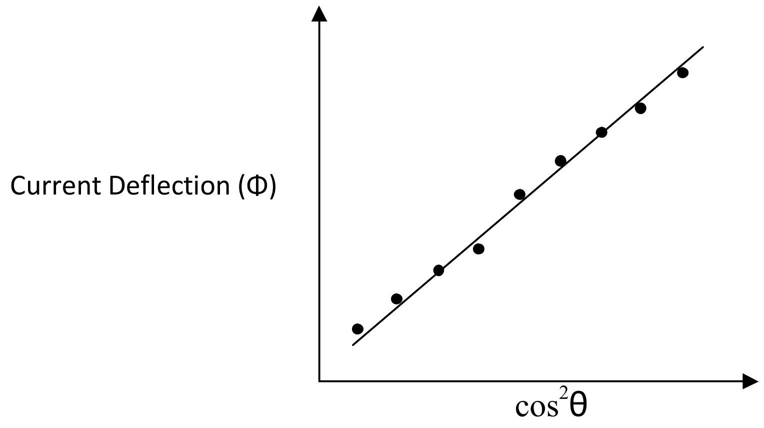


Fig.9. Verification of Malus Law

$$I_{output} = \frac{I_0}{2}\cos 2\theta + \frac{I_0}{2}$$

which is similar to the equation straight line y = mx+c. Hence, we plot a graph between Φ (current deflection in microammeter) and $\cos^2\theta$ (θ is the angle between transmission axis of polarizer and analyzer) it comes out to be a straight line, thus verifying cosine law.

7.6 Theory and description

Light is a transverse electromagnetic wave (EM), in which electric field and a magnetic field oscillating in phase and perpendicular to one another. Both fields also oscillate perpendicularly to the direction of motion, and therefore, the light is a transverse wave.

As we know that light is produced (e.g. incandescent light from a candle or a light bulb) by Transition of excited (hot) electrons and atoms from high energy level to low energy level. Hot electrons and atoms which are oriented in random directions, so that the light is unpolarized. This means that the electric field associated with the wave oscillates in random directions (though always at right angles to the direction of the propagation of the light). So there is no particular direction for polarization.

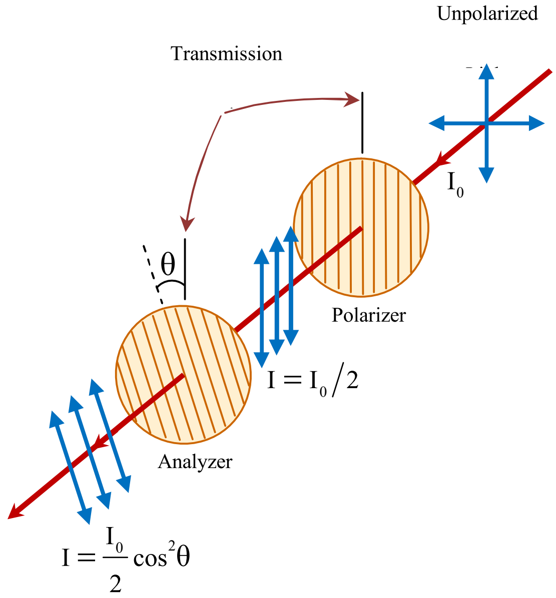


Fig.3. Polarization of Light

When the electric field of a light wave is oriented in a particular direction, that is to say, not in random directions, we say the light wave is *polarized*. The just means of Polarization is 'orientation'. Polarization is the property of light waves that describes the orientation of their oscillation. Polarization occurs only in transverse waves.

A polarizer is a filter device which transmits light in a particular direction. This direction is called as the "axis" of polarization. If unpolarized light is incident upon an "ideal" polarizer, only half will be transmitted through the polarizer. Since, in reality no polarizer is "ideal", so less than half the light will be transmitted. The transmitted light is polarized in one plane.

If this polarized light is incident upon an analyzer, the axis of which is oriented such that it is perpendicular ($\theta = 90°$) to the plane of polarization of the incident light, no light will be transmitted by the analyzer.

However, if the analyzer is oriented at some angle, there will be present some component of the electric field of the polarized light that lies in the same direction as the axis of the analyzer, thus some light will be transmitted through the analyzer (see the bottom figure).

Case (i): If θ is zero, the analyzer is aligned with the polarizer, and the value of $\cos^2 0$ is one. Thus the intensity transmitted by the analyzer is equal to the light intensity that passes through the polarizer. In this case maximum intensity will pass through the analyzer.

Case (ii)

If θ is 90º, the analyzer is oriented perpendicular to the plane of polarizer, and the $\cos^2$ (90º) gives zero. Thus, no light is transmitted through the analyzer. In this case minimum intensity will pass through the analyzer.

Polarization can be obtained by following ways:

(a) By selective absorption

When light passes through certain materials, then light waves whose polarization (E-field) is parallel to polarizing axis, are transmitted without absorption but light wave whose polarization is perpendicular to the polarizing axis are completely absorbed (i.e., light waves transmit along a certain transmission axis) and this process is called polarization by absorption.

Polarizing materials are made of long chain molecules/atoms that are aligned parallel to each other.

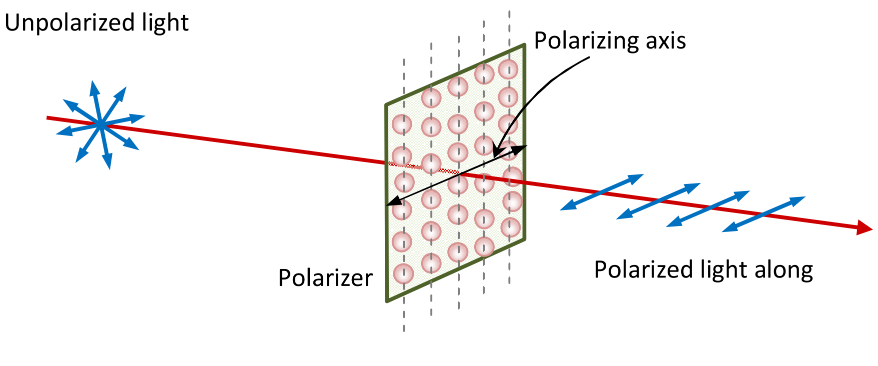


Fig.4. Polarization by absorption

The long chain molecular structure of a polarizer causes the component of electric field perpendicular to the polarizing axis to be absorbed and polarized (transmitted) along the polarizing axis. For an ideal polarizer intensity of emerging light from polarizer is reduced by half.

$$I_{Polarized} = I_{Unpolarized} < \cos^2\theta > = \frac{1}{2} I_{Unpolarized}$$

In general, the input is unpolarized light wave and the output is polarized light (linear, circular, elliptical states). This process is done by absorption (dichroism), birefringence, reflection, or scattering.

(b) By reflection

When ordinary light (Sunlight) incident on reflecting surface such as glass, plastic, mica etc will be reflected back and gets partially or completely polarized. As a result the reflectance varies with the direction of polarization.

At a particular angle of incidence is such that the angle between the reflected ray and refracted ray is 90°, in this condition reflected light will be completely polarized (only the component with its *E* field parallel to the surface is reflected).It is called the polarizing angle or *Brewster's* angle and is given by

$$\tan\theta_B = \frac{n_2}{n_1}$$

where n_1 and n_2 are the refractive indices of the two mediums. If the first medium is air (n_1=1), the Brewster angle is equal to $\theta_B = \tan^{-1} n_2$.

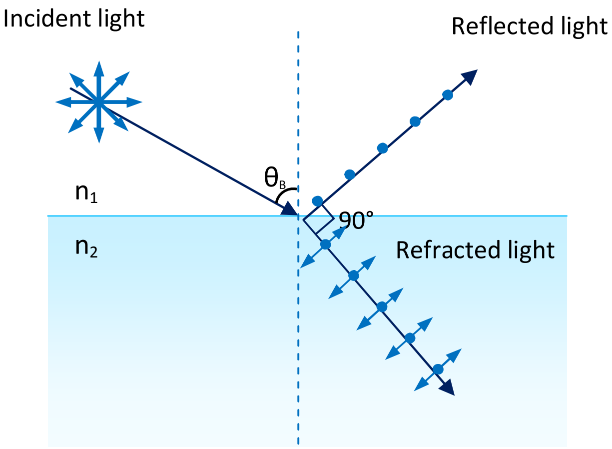


Fig.5. Polarization by reflection

(c) By Scattering

When unpolarized sunlight falls on air molecules (O_2, N_2), the light wave is absorbed and then quickly re-emitted in all directions. This process is called scattering. After scattering of sunlight from small particles of air molecules, the scattered light will be completely plane polarized if it is scattered by 90° (i.e., perpendicular to the plane of scattering) from incident light.

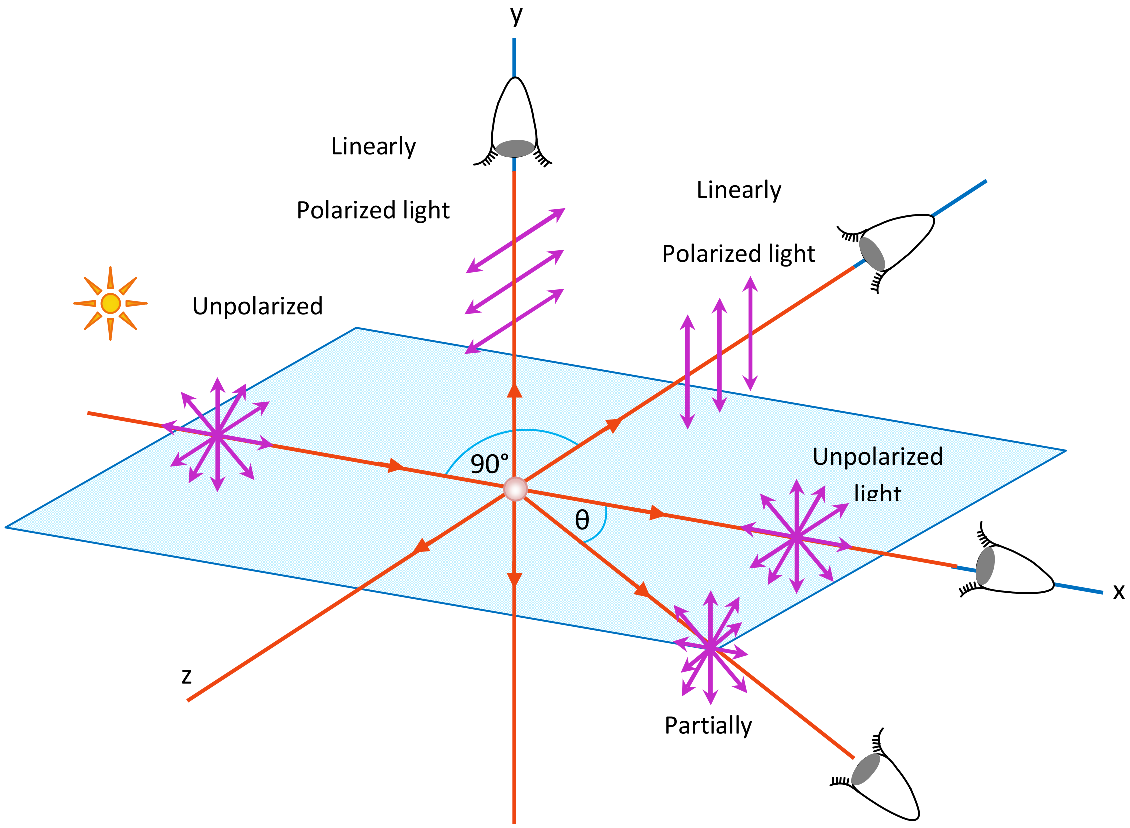


Fig.6. Polarization by scattering

For example Light wave is propagating in the z-direction has polarization occurs in the x-y plane.

(d) By Double refraction

Certain transparent crystalline materials such as calcite (Calcium Carbonate $CaCO_3$), mica, quartz (Silicon Dioxide, SiO_2) etc. which produces two images of an object are caused by double refraction. The phenomenon of refraction in which incident ray splits into two refracted rays (ordinary and extraordinary) is called as birefringence and materials showing this phenomenon are called birefringent. The two refracted rays of light are plane polarized in mutual perpendicular planes and travels at different speeds in the material, i.e., the speed of light depend both on the polarization and direction of travel of the light.

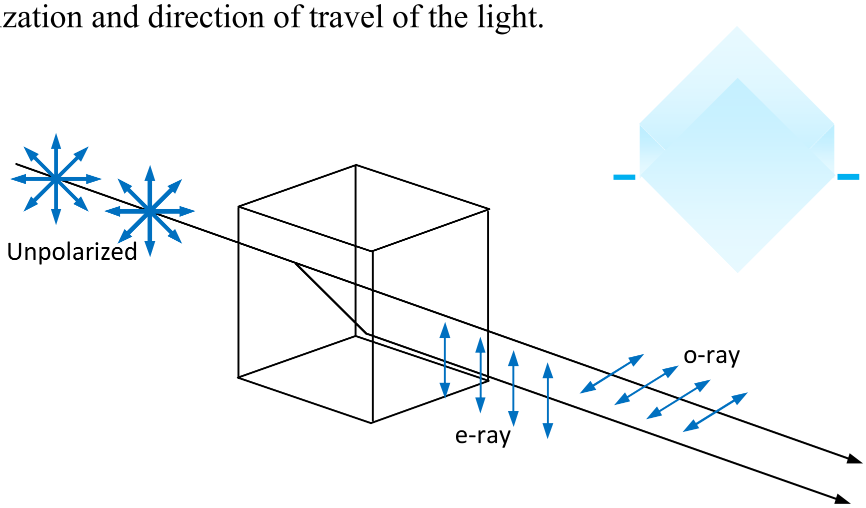


Fig.7. Birefraction in crystal

There are some particular direction in which the ordinary (O) and the extra ordinary (E) rays travel with same velocities. This direction is called as *optic axis*. The crystals having one optic axis are called as uniaxial crystals meanwhile, the biaxial crystals having two. Quartz and calcite are uniaxial axial crystals while mica, feldspar, borex and topaz are biaxial crystals.

In some birefringent, the extra-ordinary ray move faster than ordinary ray are called negative crystal, conversely is the case for positive crystal quartz is the positive crystal while calcite is the negative crystal.

4.1 Photovoltaic (Solar) Cell

A photovoltaic cell is the basic device which generates electricity when it is subjected to optical irradiation. The basic building block of this device is called as the solar cell. In general a solar cell that includes both solar and non-solar sources of light (such as photons from incandescent bulb) is termed as photovoltaic cell. The photovoltaic cell is based on the principles of photovoltaic effect.

Light is composed of *photons* (bundles of radiant energy).when photons strike on a PV cell, the energy of the photons is absorbed by a semiconducting material of cell. This absorption of photon energy creates charge carriers (electron-hole pairs) generating electrical power.

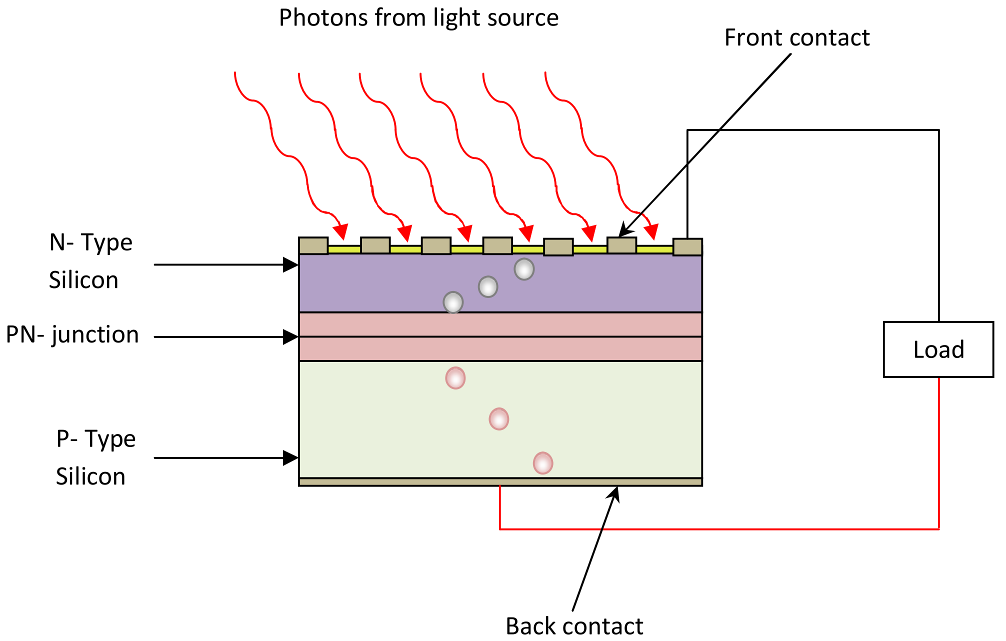


Fig.8. A photovoltaic cell

7.7 Self Learning Exercise-I

Q.1 What is polarization?

Q.2 Is candle light polarized?

Q.3 What is "Malus' Law"?

Q.4 Explain how a polarizer and an analyzer can be arranged so that no light exits the analyzer.

Q.5 When unpolrized light is incident on the polarizer, what is the intensity of transmitted light?

7.8 Procedure

Preliminary Setup:

The experimental arrangement is shown in fig. Polarizer and analyzer are fitted with ends of metallic tube and mounted with the optical bench. Both are capable to rotate around the common axis indecently. The angle of rotation can be read by the circular scale provided with each of them. The light detector used here is a semiconductor solar cell. When light falls on the solar cell it produce a current and it depends on the amount of light falling on detector. i.e., the measured current deflection is as an estimation of the light intensity

Procedure:

1. The experimental setup is arranged as shown in the figure.1. In this arrangement, the light source S, convex lens, Polarizer P, Analyzer A and the window of Photovoltaic cell must be at the same height (common axis).
2. Now switch on the incandescent bulb. Light from the bulb S rendered parallel with the help of convex lens L is allowed to fall on polarizer P and then on analyzer.
3. For any orientation of the polarizer P, the polarized light passes through analyzer A. The analyzer A is rotated till there is maximum deflection recorded in the micro-ammeter i.e., Adjust the analyzers for *maximum* transmission of light. The position of analyzer is noted on the circular scale. The corresponding micro-ammeter current deflection is also recorded. The position of analyzer corresponds to $\theta = 0$ (here θ is the angle between Planes of transmission of polarizer and analyzer.)
4. The analyzer A is rotated through a small angle, say 10^o and then the steady micro-ammeter deflection is noted.
5. The experiment is repeated by rotating the analyzer through 10^o degree each time and noting down the corresponding micro-ammeter deflection till it become practically zero.

7.9 Observation

S.No.	Angle of rotation (Analyzer) θ	Microammeter Current deflection		$\cos\theta$	$\cos^2\theta$	$\frac{\Phi}{\cos^2\theta}$
		μA	Φ			
1						

2						
3						
4						
5						
6						
7						
8						
…						
…						

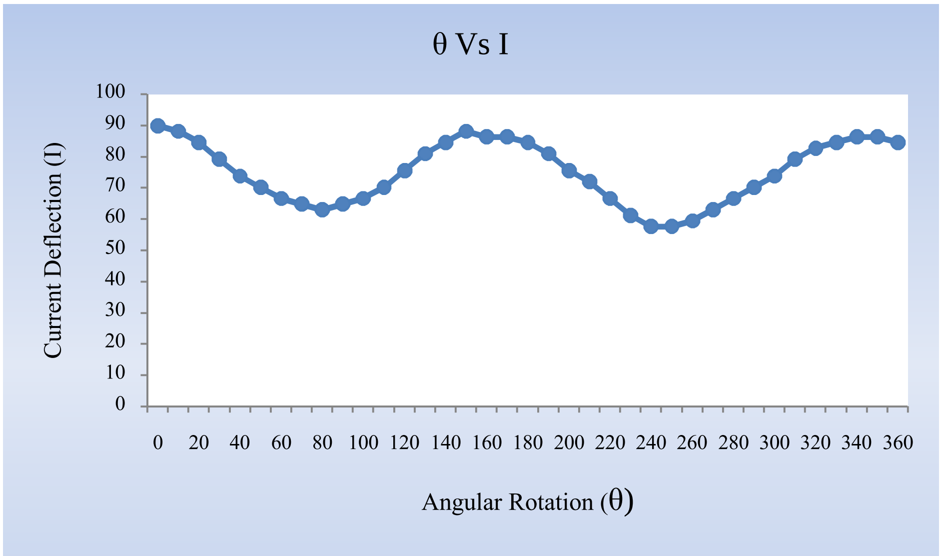
7.10 Calculations

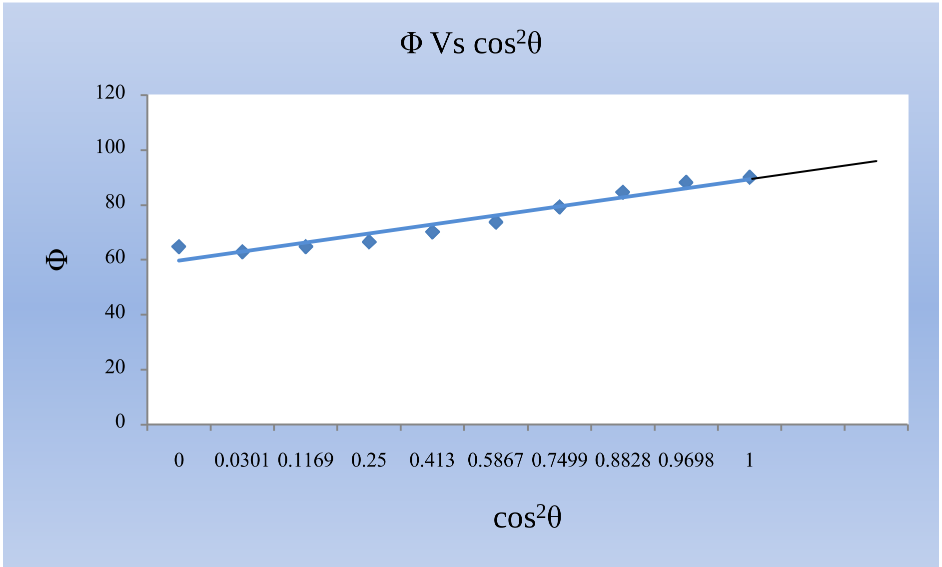
Model calculations

S.No.	Angle of rotation (Analyzer) θ	Microammeter Current deflection		$\cos^2\theta$
		μA	Φ	
1	0	50	90	1.0000
2	10	49	88.2	0.9698
3	20	47	84.6	0.8828
4	30	44	79.2	0.7499
5	40	41	73.8	0.5867
6	50	39	70.2	0.4130
7	60	37	66.6	0.2500

8	70	36	64.8	0.1169
9	80	35	63.0	0.0301
10	90	36	64.8	0.0000
11	100	37	66.6	0.0301
12	110	39	70.2	0.1169
13	120	42	75.6	0.2500
14	130	45	81.0	0.4130
15	140	47	84.6	0.5867
16	150	49	88.2	0.7499
17	160	48	86.4	0.8828
18	170	48	86.4	0.9698
19	180	47	84.6	1.0000
20	190	45	81.0	0.9698
21	200	42	75.6	0.8828
22	210	40	72.0	0.7499
23	220	37	66.6	0.5867
24	230	34	61.2	0.4130
25	240	32	57.6	0.2500
26	250	32	57.6	0.1169
27	260	33	59.4	0.0301
28	270	35	63.0	0.0000
29	280	37	66.6	0.0301
30	290	39	70.2	0.1169
31	300	41	73.8	0.2500
32	310	44	79.2	0.4130
33	320	46	82.8	0.5867
34	330	47	84.6	0.7499
35	340	48	86.4	0.8828
36	350	48	86.4	0.9698
37	360	47	84.6	1.0000

7.11 Graph





7.12 Result

The graph between current deflection in microammeter (Φ) and $\cos^2\theta$ comes a straight line. This graph verifies the Malus law (the cosine square law).

7.13 Discussion

7.14 Precautions and Sources of error

(1) Experiment must be performed in the dark room to avoiding interfere of extra light.

(2) Alignment of all mounted objects should not be disturbed during experiment.

(3) Intensity of light source should not change throughout the experiment.

(4) Light bulb, polarizer, analyzer, convex lens and solar cell must be at the same height.

7.15 Self Learning Exercise-II

Q.1 Mention the name of methods of producing plane polarized light.

Q.2 Write the name of devices for producing polarized light.

Q.3 What is the shape of the plot of light intensity versus $\cos^2\theta$?

Q.4 An unpolarized light beam with an intensity of $I_0 = 20\ W/m^2$ is incident on a pair of polarizers. The polarizer has its transmission axis aligned at 60° from the vertical. The analyzer has its transmission axis aligned at 30° from the vertical.

(a) What is the intensity of the light when it emerges from the polarizer?

(b) What is the intensity of the light when it emerges from the analyzer?

Q.5 Is the sound wave polarized? Explain.

7.16 Glossary

Polarizer: A polarizer is a filter device which transmits light in a particular direction.

Birefringence: The phenomenon of refraction in which incident ray splits into two refracted rays (ordinary and extraordinary) is called as birefringence and materials showing this phenomenon are called birefringent.

7.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: *Polarization* is the property of light waves that describes the definite direction of vibration of the electric vector relative to the direction of propagation of the wave.

Ans.2: No

Ans.4: The angle between polarizer and analyzer must be 90°.

Ans.5: Half intensity of the unpolarized light.

Answers to Self Learning Exercise-II

Ans.1: by reflection, by refraction, by double refraction and by selective absorption.

Ans.2: Glass slide, Nichol Prism, Tourmaline plate etc.

Ans.3: Straight line.

Ans.4: (a) 10 W/m^2 (b) 2.5 W/m^2

Ans.5: No. Because the sound wave is a longitudinal wave and it cannot be polarized. In longitudinal wave, the oscillations are parallel to the direction of the propagation of the traveling wave. On the hand, the transverse wave vibrations are perpendicular to the direction of the propagation of the wave.

7.18 Viva Questions

Q.1 The phenomenon of polarization proves that light is a:

(A) monochromatic (B) longitudinal

(C) transverse (D) particle nature

Q.2 Can human eyes distinguish between unpolarized and polarized light?

Q.3 Define the unpolarized light.

Q.4 Draw the pictorial diagrams of polarized light.

Q.5 A light wave is passing through a polarizer. Which component of electric field will be absorbed?

Q.6 Define transmission axis.

Q.7 Define the polarization states. Give its name.

Q.8 What is the polarization state of a light wave whose E- vector is described as

$$E_x = E_0 \sin(kz - \omega t)$$
$$E_y = E_0 \cos(kz - \omega t)$$

Q.9 Define polarizer.

Q.10 Give the example of polarized light.

Q.11 When plane polarized light is passed through an analyzer, it emerges out with minimum intensity. if the analyzer is rotated through 90° then intensity of emerging light will be?

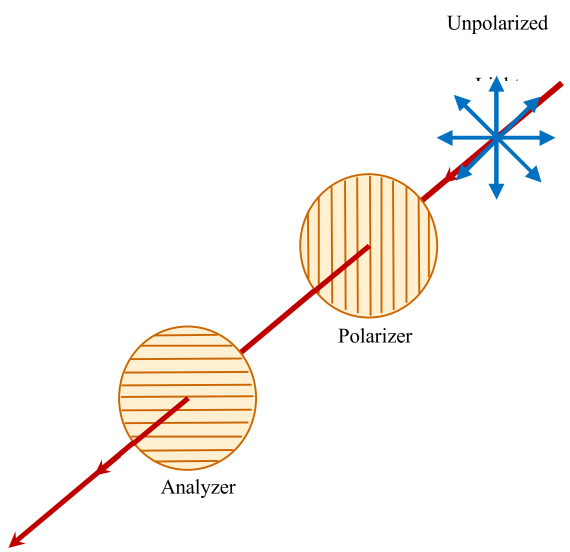
Q.12 A sunlight ray is reflected by air-water interface. At what angle the sunlight would be completely polarized. (n_{water}=1.333)

Q.13 Does the Brewster angle depend on the wavelength of light wave?

Q.14 Does a monochromatic light is essential for the completely polarized reflected wave (polarization by reflection) at a time? Explain.

Q.15 If a light ray incident perpendicular on the glass sheet. Will it polarize?

Q.16 An unpolarized light wave incident on two orthogonal polarizers. What will be output intensity through the both polarizers?



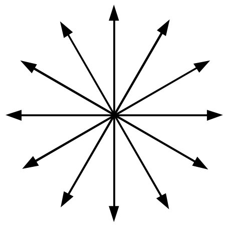
Q.17 Write a short note on Nicol Prism.

7.19 Answers to Viva Questions

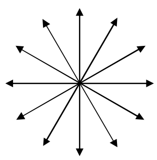
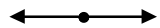
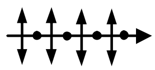
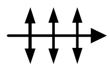
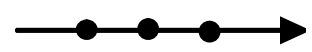
Ans.1: transverse

Ans.2: No

Ans.3: An ordinary light in which electric vector oscillates in many planes i.e., vibrations occur in random direction (vibrating up-down, left-right, diagonally back and forth, in each and every direction) is referred to as unpolarized light.



Ans.4:

Viewing	Unpolarized	Vertically polarized	Horizontally polarized
Viewed head on (when wave coming toward			
Viewed from side			

Ans.5: Perpendicular to the polarizing axis

Ans.6: The transmission axis is a fixed direction on the Polarizer where light wave is transmitted through the Polarizer if its electric vector is parallel to the transmission axis and light is absorbed if its electric vector is perpendicular (along the molecular chain direction) to the transmission axis.

Ans.7: The trajectory of the tip of the electric vector at a specific point composes a certain pattern, termed as polarization pattern or polarization state.

(a) Linearly polarization: A plane light wave is said to be linearly polarized.

(b) Circular polarization: A result of superposition of two waves of same amplitude with orthogonal linear polarizations, and 90° difference in phase.

(c) Elliptically polarization: A result of superposition of two waves of different amplitude with orthogonal linear polarizations, and 90° difference in phase.

Ans.8: taking square of the above equations, we get

$$E_x^2 = E_0^2 \sin^2(kz - \omega t)$$
$$E_y^2 = E_0^2 \cos^2(kz - \omega t)$$

Now adding the above equations, we get

$$E_x^2 + E_y^2 = E_0^2\left[\sin^2(kz - \omega t) + \cos^2(kz - \omega t)\right]$$
$$E_x^2 + E_y^2 = E_0^2$$

This equation represents a circle; therefore, light wave will be circularly polarized.

Ans.9: polarizer is an optical element is used to change an ordinary light (unpolarized) to polarized light. Polarizing materials are made of long chain molecules that are aligned parallel to each other.

Ans.10: Laser light

Ans.11: Maximum

Ans.12: A reflected ray is fully reflected at Brewster angle.

$$\tan\theta_B = \frac{n_2}{n_1} = \frac{1.333}{1} = 53°$$

Ans.13: Yes, because refractive index depends on the wavelength of light.

Ans.14: Yes, monochromatic light is essential for the completely polarized reflected wave in polarization by reflection because refractive index of material varies with the wavelength of incident light.

Ans.15: No, it will be completely unpolarized.

Ans.16: According Malus law

$$I_{output} = \frac{I_0}{2}\cos^2\theta = \frac{I_0}{2}\cos^2 90° = 0$$

Ans.17: Nicol prism is an optical device used to produce and analyze the plane polarized light. It is made from very pure calcite whose length is nearly three times its breadth or thickness. It works on a principle of double refraction.

A calcite crystal is carefully shaped and cut along the proper direction in two parts.

After that two parts policed and rejoined using a thin layer of transparent glue (Canada balsam) whose refractive index lies between the refractive index of o-ray and e-ray of calcite.

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UNIT-8

Determination of Wavelength of Laser using (I)Diffraction Grating (II)Ruler

Structure of the Unit

Part-(I) Wavelength of Laser using Diffraction grating

Part-(II) Wavelength of Laser using Ruler

Part-(I) Wavelength of Laser using Diffraction grating

8.1A Aim

To determine the wavelength of He-Ne laser by studying the different pattern due to a diffraction grating and to find out its angular spread.

8.2A Apparatus

He-Ne laser, diffraction grating, stands, a screen with a graph paper pasted on it, metre-scale and a travelling microscope.

8.3A Diagram

Diffraction pattern is shown in the diagram.

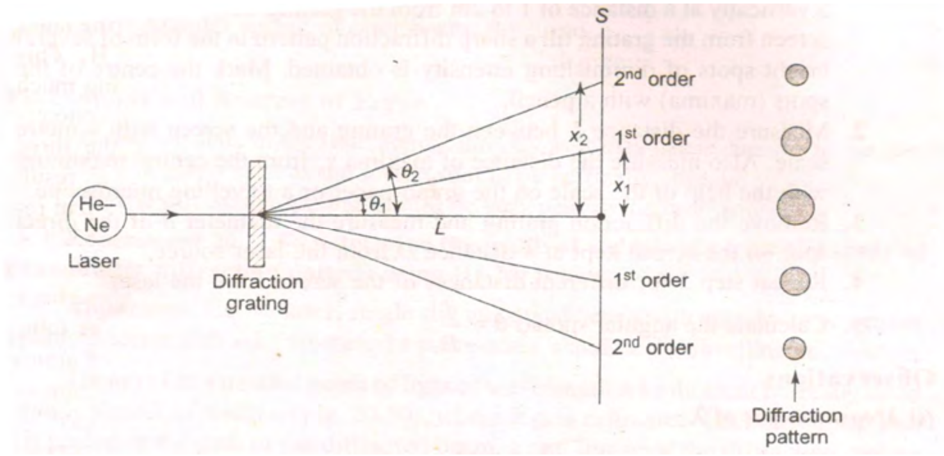


FIGURE: 8.1

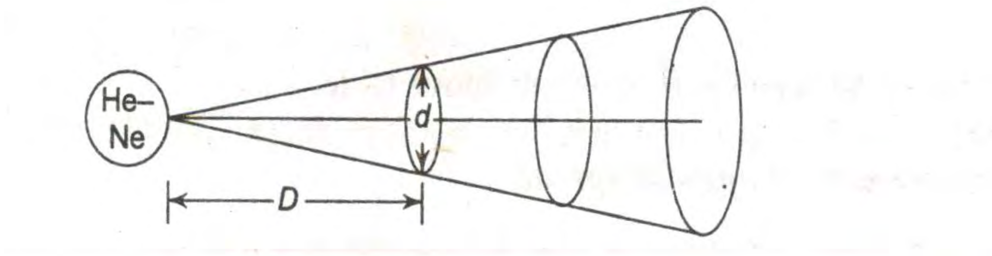


FIGURE: 8.2

8.4A Formula

For determining the wavelength of monochromatic beam

$$\lambda = \frac{(a+b)sin\theta_n}{n}$$

where λ = wavelength of monochromatic beam,

θ_n= angle where principal maxima is formed,

$(a+b)$ = the grating constant,

n = order of principal maxima.

8.5A Theory and description

When a monochromatic beam of wavelength λ is diffracted by a diffraction grating, the nth order principal maxima is formed at an angle Θ_n given by

$$(a+b)sin\theta_n = n\lambda$$

Where (a+ b) is the grating constant.

$$\lambda = \frac{(a+b)\ sin\theta_n}{n} \qquad \text{..........(8.5.1)}$$

When laser light is incident on the diffraction grating and diffraction pattern is obtained on the screen formed by a graph paper, $\sin\theta_n$ can be obtained for different order maximas as shown in Fig.1.

From the figure 1, we have

$$\sin\theta_n = \frac{x_n}{\sqrt{L^2 + {x_n}^2}}$$

$$= \frac{x_n}{L} \qquad if\ L \gg x_n$$

Substituting $\sin\theta_n$ for different orders in the above equation, λ can be obtained.

Angular Spread :

When laser light is directly incident on a screen kept at a distance D, it shows a circular spread of diameter d (Fig.2). The angular spread of the laser beam is given by

$$\theta = \frac{d}{D} \qquad \text{..........(8.5.2)}$$

θ is expected to be very small.

Special Features of Laser Beams:

Intensity:

The energy of the laser beam is concentrated in a small region. This concentration of energy accounts for the high laser beam intensity. Thus, even an ordinary laser of nearly a few watts would have more intensity than a 100 W ordinary lamp. The intensity of the ordinary beam may be compared with the laser beam with the following example.

In the case of laser, the output power varies between $10^{-3}W\ and\ 10^{9}W.$ since one photon of visible light represents nearly $10^{-19}J$ of energy, thus

Photon output per second = $\frac{P}{10^{-19}} \approx 10^{16}\ to\ 10^{28}$ ....(1)

According to black body radiation, emissive power for the frequency ω and $(\omega + d\omega)$ for a non-laser source is given by

Emissive power = $\frac{\omega^2}{4\pi^2 c^2} \times \frac{1}{e^{\frac{\hbar\omega}{kT}} - 1} d\omega$ ....(2)

If the width of the line emitted in visible range (wave length λ= 6000Å) be 1000Å at temperature 1000K, here we consider $c\ as\ velocity\ of\ light.$

$$\omega = 2\pi \frac{c}{\lambda} = \frac{2 \times 3.14 \times 3 \times 10^8}{6000 \times 10^{-10}}$$

$$=3.14 \times 10^{15}$$

and $$d\omega = 18.84 \times 10^{15}$$

Substituting the values in equation (2), we get

Number of photons emitted per square centimetre per second=10^{12} .....(3)

Thus, from equations (1) and (2), it may be concluded that it takes a fairly large and hot body to generate as much visible light as is produced by even the smallest laser.

Monochromaticity:

The light emitted by laser source is much more monochromatic than that of a conventional monochromatic source. The monochromaticity of the conventional light source and that of the laser may be understood in terms of bandwidth with prism experiment.

The bandwidth of white light is as wide as the whole visible spectrum of about 300 nm, after dispersing from prism [figure 1a] . If a conventional monochromatic light is incident on the prism, the bandwidth of the component of red light reduces to nearly 10 to 20 nm [figure 1b]. But the prism will have no discernible effect on the red light emitted from the laser because the bandwidth is vanishingly smaller compared with that of the conventional monochromatic light [figure 1c]. The bandwidth of He-Ne laser is in the range of nearly 1nm.

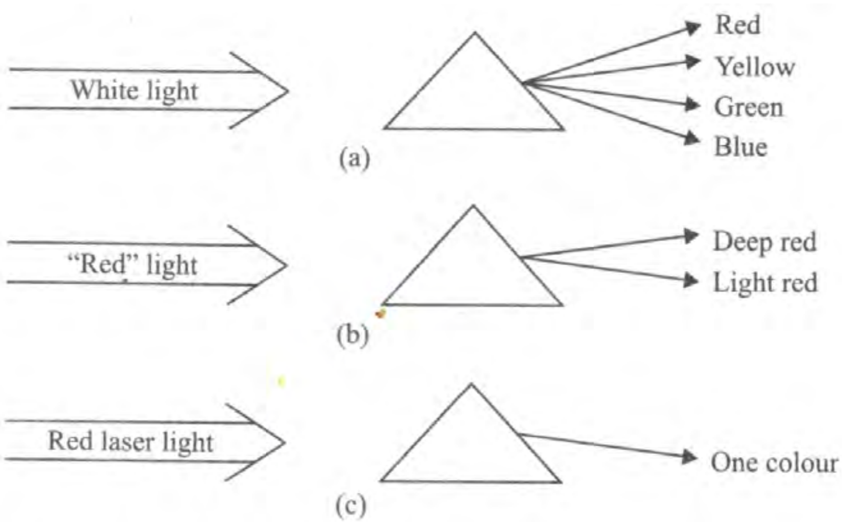


Figure 1: *Comparative monochromaticity of laser beam.*

A comparative bandwidth diagram of the conventional source and laser source has been shown in figure 2. it may be noted, however, that even a laser cannot be perfectly monochromatic, because optical source will violate the uncertainty principle. Quantitatively, the degree of monochromaticity of light is characterized by the spread in frequency of a line-by-line widthdv. The degree of non-monochromaticity of a wave may be defined as its relative bandwidth given by

$$\text{Bandwidth} = \frac{\Delta v}{v_0} \qquad \text{............(1)}$$

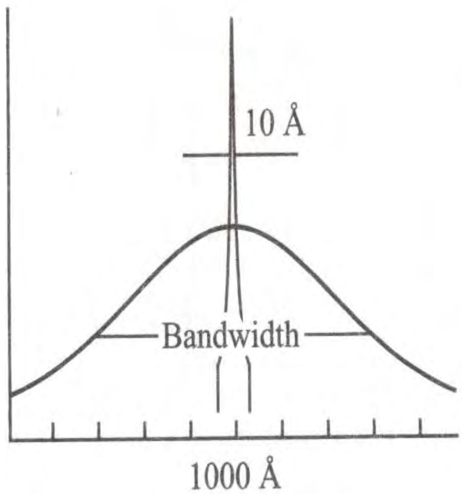


Figure2:*Comparative bandwidth of laser source and Conventional source.*

Where v_0 is the central frequency of light beam. According to the uncertainty principle, dV cannot be zero. Thus, we can conclude that the laser beam has a higher degree of monochromaticity and has a smaller bandwidth compared to the ordinary monochromatic source.

8.6A Self learning exercise-I

Q.1: How is a four-level laser better than a three-level laser? Give examples of each.

Q.2: What is the wavelength of laser light from?

(i)Ruby laser and (ii)He-Ne laser?

How are the two lasers different?

Q.3: Which of the two lasers is better? Why?

Q.4: What is population inversion? How is it achieved?

Q.5: Why is population inversion necessary for laser action?

8.7A Procedure

1. Mount a diffraction gratingon a stand and illuminate it with the laser beam coming from the He-Ne laser source. Place a graph paper pasted on a screen S vertically at a distance of 1 to 2m from the grating. Adjust the distance of screen from the grating till a sharp diffraction pattern in the form of several bright spots (maxima) with a pencil.
2. Measure the distance L between the grating and the screen with a metre scale. Also measure the distance of maxima x from the central maximum with the help of the scale on the graph-paper or a travelling microscope.
3. Remove the diffraction grating and measure the diameter d of the direct spot on the screen kept at a distance D from the laser source.
4. Repeat step 3 for different distances of the screen from the laser .
5. Calculate the angular spread θ=d/D.

8.8A Observation

(I)Measurement of Wavelength

Number of lines per inch on the grating, N=......

Grating constant (a+ b) = 2.54/N=.....cm

Distance of screen from the grating , L=.....cm

S.No.	Order of diffraction n	Distance of maxima from central spot, x_n (cm)	$\sin\theta_n = \frac{x_n}{\sqrt{L^2 + x_n{}^2}}$	$\lambda = \frac{(a+b)sin\theta_n}{n}$
1. 2. 3. 4.				

Mean λ=.........cm

=..........Å

Note: If L>>x , take $sin\theta_n = \frac{x_n}{L}$ in above table.

(II) Measurement of Angular Spread

S. No.	Distance D (cm)	Diameter d (cm)	Angular spread θ=d/D
1. 2. 3.			

8.9A Calculations

8.10A Result

(i) Wavelength of He-Ne laser light=..........Å

Actual value =6328Å

% Error=.........%

(ii) Angular spread of laser beam, θ=......rad.

=.......degree

8.11A Discussion

8.12A Precautions and Sources of error

1. Do not stare at the laser source directly as it may cause damage to the eye.
2. The graph used as the screen should be vertically straight.
3. The diffraction grating should be very near to the laser source.

8.13A Self Learning Exercise-II

Q.1: In He-Ne laser, lasing is through neon gas. What is then the role of helium ?

Q.2: What is coherence?

Q.3: What is temporal coherence?

Q.4: What is spatial coherence?

8.14A Answers to Self Learning Exercises I&II

Answers to Self Learning Exercise-I

Ans.1: Three – level= Ruby laser

Four - level= He-Ne laser

Ans.2: (i) 6943 Å (ii) 6328 Å

Ruby laser is a three-level solid state laser whereas He-Ne is a four- level gas laser. Ruby laser has a pulsed output whereas He-Ne laser has a continuous output.

Ans.3: He-Ne laser. The output of ruby laser is in the form of pulses. He-Ne laser is better than ruby laser as (i) it has continuous output. (ii) Being a four-level laser, laser action is fast in it and (iii) its active material is relatively cheaper.

Ans.4: Population inversion is the non-equilibrium condition of a materials where the number of atoms in the upper energy level exceeds the number of atoms in the lower energy level. Population inversion is achieved by pumping energy from some external sources.

Ans.5: When light propagates through the laser material, a photon may get absorbed by hitting an atom in the lower level or may stimulate an excited atom in the upper level. Laser light is produced by the latter process which will dominate only when the number of atoms in the upper level is more than that in the lower level or when population inversion is there . If population inversion is not there , the material will absorb light rather than emitting light.

Answers to Self Learning Exercise-II

Ans. 1: In He-Ne laser, helium serves as a buffer gas and helps in the excitation of neon atoms. Since He-atoms are much lighter than Ne-atoms, electrons transfer energy more readily to He-atoms. The excited He-atoms in turn transfer their energy to Ne- atoms.

Ans.2: A wave which is appears to be a pure sine wave for an infinitely large period of time or in an infinitely extended space is said to be a perfectly coherent wave. In such a wave, there is a definite relationship between phase of the wave at a given time and at a certain time later or at a given point and at a certain distance away. No actual light source, however, emits a perfectly coherent wave. Light waves which are pure sine waves only for a limited period of time or in a limited space are partially coherent waves.

Ans. 3: The oscillating electric field 'E' of a perfectly coherent light wave would have a constant amplitude of vibration at any point, while its phase would vary linearly with time. As a function of time, the field would appear as shown in figure (1). It is an ideal sinusoidal function of time.

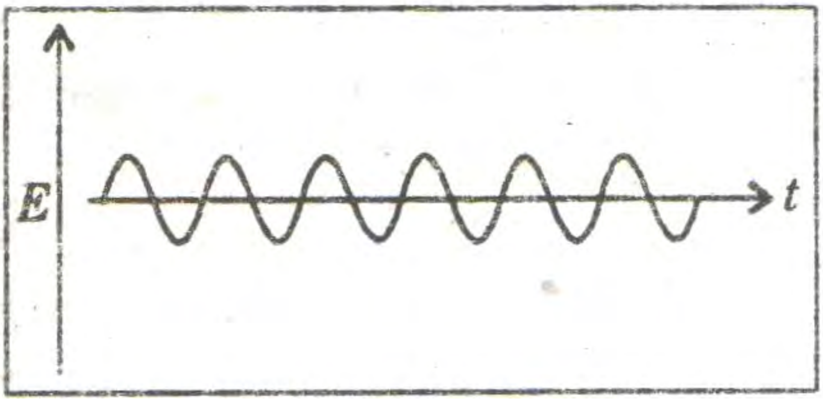


FIGURE 1

However, no light emitted by an actual source produces an ideal sinusoidal field for all values of time. This is because when an excited atom returns to the initial state, it emits light pulse of short duration such as of the order of 10^{-10} second for sodium atom. Thus, the field remains sinusoidal for time intervals of the order of 10^{-10} second after which the phase changes abruptly. Hence, the field due to an actual light source will be as shown in figure 2.

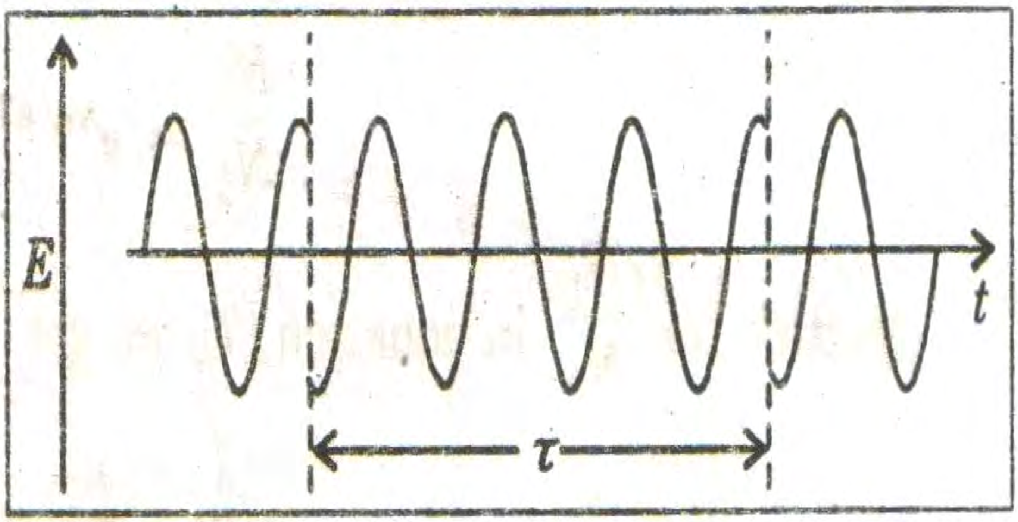


FIGURE 2

The average time-interval for which the field remains sinusoidal (i.e., definite phase relationship exists) is known as “coherence time” or “temporal coherence” of the light beam and is denoted by. The distance L for which the field is sinusoidal is given by

$$L = \tau c$$

Where c is the velocity of light in vacuum. L is called the “coherence length” of the light beam.

Ans.4: The spatial coherence is the phase relationship between the radiation fields at different points in space. Let us consider light waves emitting from a source S(figure 1). Let A and B be two points lying on a line joining them with S.

The phase relationship between A and B depends on the distance AB and on the temporal coherence of the beam. If AB<<L (coherence length), there will be a definite phase relationship between A and B, i.e. there will be high coherence between A and B. On the other hand, if AB>>L, there will be no coherence between A and B.

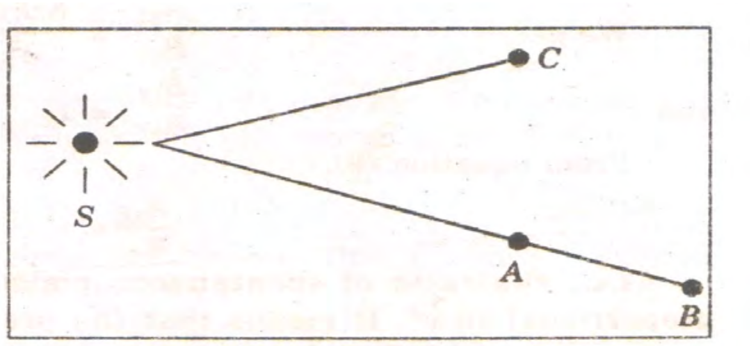


FIGURE 1

8.15A Viva Questions

Q.1: What is diffraction of light?

Q.2: Give the classification of diffraction of light.

Q.2: What is the population inversion?

Q.3: What is the pumping?

Q.4: How many types are producing population inversion?

Q.5: What is optical pumping?

Q.6: What is direct conversion?

Q.7: What is semiconductor Laser?

8.16A Answers to Viva Questions

Ans.1: For diffraction phenomenon we assumes that light travels in the form of waves and bends round the corners of an obstacle. This phenomenon of deviation of light from rectilinear propagation and bending round the cornered of an obstacle is known as Diffraction of light.

Ans.2: Depending upon the position of source the phenomenon of diffraction of light is divided into the following two classes, which is given below:

(1) Fresnel's class of diffraction**,**

(2) Fraunhoffer class of diffraction.

Ans. 3: Under ordinary conditions of thermal equilibrium, the number of atoms in the higher energy state is considerably smaller than the number in the number in the lower energy state. Reverse of this is known as population inversion.

Ans.4: The method of producing population inversion is called pumping. The population inversion can be achieved by exciting the medium with suitable form of energy.

Ans. 5: There are five types of producing population inversion or pumping, which is given below:

(1) Optical pumping,

(2) Electric discharge,

(3) Inelastic atom-atom collision,

(4) Direct conversion,

(5) Chemical reactions.

Ans.6: If we supply luminous energy to the medium for causing population inversion, then the pumping is called the optical pumping.

Ans.7: It is a method of producing population inversion. A direct conversion of electrical energy into radiant energy occurs in light emitting diodes (LEDs). This method of pumping occurs in SEMICONDUCTOR LASERS.

Part-(II) Wavelength of Laser using Ruler

8.1B Aim

To determine the wavelength of He-Ne laser source with a mm. Ruler acting as a reflection grating.

8.2B Apparatus

A He-Ne laser, a steel or plastic ruler with mm markings, an upright stand, a screen and a metre scale.

8.3B Diagram

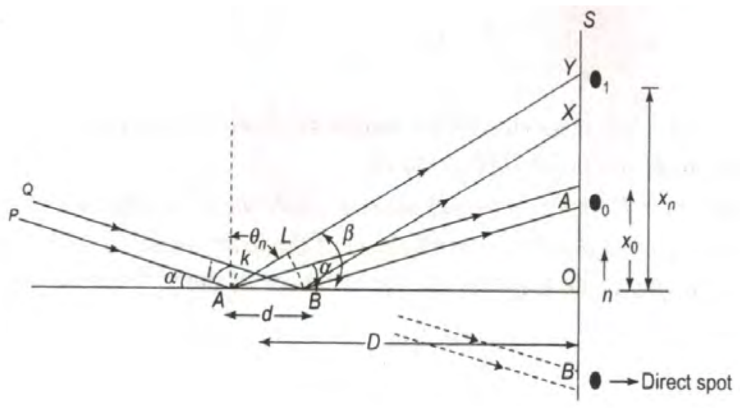


FIGURE 8.1

8.4B Formula

$$\lambda = \frac{d}{2D^2} \times slope$$

Since d and D are known, λ can be easily determined.

8.5B Theory and description

If a laser beam is incident on a ruled scale at a large angle of incidence, the beam covers a large number of engravings. The ruler acts a reflections grating with a grating element equal to the spacing between the two successive engravings, if a screen is kept at a large distance (2 m) from the point at which the laser beam strikes the ruler, a diffraction fringe pattern is observed on it consisting of a number of bright spots (maxima) with dark spaces (minima) between them. The first spot marked as n=0 is due to pure reflection while the other spots with n=1,2,3,......are due to different from the grating.(Fig.8.1.).

Path difference between the rays from Q and P, reaching at XY on the screen S is

$$\Delta = (QB + BX) - (PA + AY)$$
$$= (QK + KB + BX) - (PA + AL + LY)$$

In fig. 8.1, BL perpendicular to AY and AK perpendicular to QB so that QK = PA and BX = LY. So

$$\Delta = KB - AL \qquad \text{.............(1)}$$

In $\Delta ABL, \angle LBA = \theta_n, so\ that\ AL = ABsin\theta_n$

Also in $\Delta KAB, \angle KAB = i, so\ that\ KB = ABsin\ i.$

So equation (1) becomes

$$\Delta = AB(\sin i - \sin\theta_n) \qquad \text{.............(2)}$$

But $\sin i = \sin\left(\frac{\pi}{2} - \alpha\right) = cos\alpha$

And $\sin\theta_n = \sin\left(\frac{\pi}{2} - \beta_n\right) = cos\beta_n$

So equation (2) becomes,

$$\Delta = d(cos\alpha - cos\beta_n) \qquad \text{.............(3)}$$

Now, since angles α and β_n are small, $sin\alpha \simeq \frac{x_0}{D}\ and\ sin\beta_n \simeq \frac{x_n}{D}$

So $$cos\alpha = \sqrt{1 - \left(\frac{x_0}{D}\right)^2} = 1 - \frac{x_0^2}{2D^2}$$

And $$cos\beta_n = \sqrt{1 - \left(\frac{x_n}{D}\right)^2} = 1 - \frac{x_n^2}{2D^2}$$

So $$\Delta = d(cos\alpha - cos\beta_n)$$

$$\Delta = d\{1 - \frac{x_0^2}{2D^2} - 1 + \frac{x_n^2}{2D^2}\}$$

$$= d\left(\frac{x_n^2 - x_0^2}{2D^2}\right) \qquad \text{.............(4)}$$

For XY to be a bright fringes,

$$d\left(\frac{x_n^2 - x_0^2}{2D^2}\right) = n\lambda, \qquad n = 0, 1, 2, \ldots\ldots\ldots\ldots$$

Or $\lambda = d\left(\frac{x_n^2 - x_0^2}{2nD^2}\right)$ ....(5)

Where x_n^2 and x_0^2 are respectively the distances of the first and the (n+ 1)^th spots on the screen from the point O(Fig.8.1).

Note: *(n+ 1)^th spot on the screen is actually the n^th maximum due to diffraction and the first spot is due to pure reflection of the laser beam.*

Let x_{n_1} *and* x_{n_2} be respectively the distances of the n_1^{th} and n_2^{th} maxima, then

$$x_{n_1}^2 - x_0^2 = \frac{2n_1D^2}{d}\lambda \qquad \text{..............(6)}$$

$$x_{n_2}^2 - x_0^2 = \frac{2n_2D^2}{d}\lambda \qquad \text{..............(7)}$$

Subtracting $equation\ (6) - (7),$ we get

$$x_{n_2}^2 - x_{n_1}^2 = (n_2 - n_1)\frac{2D^2}{d}\lambda$$

Or

$$\lambda = \frac{d}{2D^2}\,\frac{x_{n_2}^2 - x_{n_1}^2}{(n_2 - n_1)}$$

Hence of a graph is plotted between the order of maxima n-along x-axis and square of their distances x_n^2 along y-axis, we get a straight line with a slope $\frac{x_{n_2}^2 - x_{n_1}^2}{(n_2 - n_1)}$.

$$\lambda = \frac{d}{2D^2} \times slope$$

Since d *and* D are known, λ can be easily determined.

8.6B Self Learning Exercise-III

Q.1: What is gaseous laser? Define with suitable diagram.

Q.2: Give the construction of the He-Ne laser.

8.7B Procedure

1. Keep a steel ruler horizontally on an upright.
2. Fix the He-Ne laser close to it so that the laser beam is incident on the ruler at a large angle of incidence (angle between the laser beam and normal to the ruler). Switch on the laser.
3. Fix a screen vertically on a stand and place it at a large distance $(2\ m)$ from the point where the laser beam hits the ruler.

4. Adjust the angle of tilt of the laser and the distance of the screen till you get a sharp and well defined diffraction pattern in the form of bright diffraction spots on the screen.
5. Mark the centre of the bright spots with a soft pencil. First spot (lowest) is due to reflection, 2nd spot is due to diffraction of order n=1, 3rd spot due to diffraction of order n=2 and so on.
6. Measure the distance D between the screen and the region where the laser strikes the ruler.
7. Remove the scale without disturbing the laser and the screen and mark the position of the direct spot of the laser beam.
8. Choose the mid-point of the first spot (point A in Fig.8.1) and the direct spot (point B in Fig.8.1). This mid-point is the point O in Fig.8.1.
9. Measure the distances x of all the spots from the point O with the help of metre scale.
10. Plot a graph between the order of maxima, n ,along $x - axis$ and x_n^2 along $y - axis$.

8.8B Observation

Distance between the adjacent engravings on the ruler, d=....mm.=...cm.

Distance between the screen and the point where the laser beam strikes the ruler, D=....cm.

S.No.	Order of maxima *n*	Distance of nth maximum (cm)	$x_n^2 (cm^2)$
1.			
2.			
3.			
4.			
5.			

Note: *Remember that the bright spot with n=1 is the second spot above the direct spot and the spot above it correspond to n =2,3,...*

8.9B Graph

Model Graph

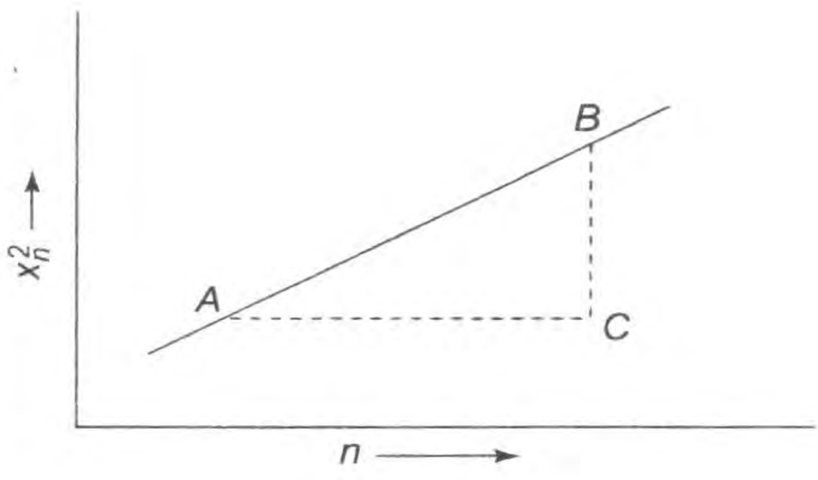


FIGURE 8.2

8.10B Calculations

The graph between n and x_n^2 is shown in Fig.8.2.

$$\text{Slope} = \frac{BC}{AC} = \ldots\ldots(cm^2)$$

$$\lambda = \frac{d}{2D^2} \times slope$$

$$= \ldots\ldots\ldots \text{cm}$$

$$= \ldots\ldots\ldots \text{Å}$$

8.11B Result

The wavelength of the He-Ne laser =......Å

Actual value=......Å

% Error = ...%

8.12B Discussion

8.13B Precautions and Sources of error

1. Laser beam should be tilted to strike the ruler at a large angle of incidence.
2. Care should be taken to distinguish between the spot due to reflection and the spots due to diffraction.
3. Laser beam should be horizontal and not tilted.
4. The slit should be vertical.
5. The laser beam should be kept normal to the incident beam.
6. The distance of minima should be measured accurately.

8.14B Self Learning Exercise-IV

Q.1: Describe the working of He-Ne laser.

Q.2: Why is it necessary to use a narrow tube in a He-Ne laser?

8.15B Answers to Self Learning Exercises

Answers to Self Learning Exercise-III

Ans.1: He-Ne laser is also known as gaseous laser. Ruby laser does not generate a continuous laser beam. To overcome this difficulty, Javan, Bennett and Harriot reported a gas laser, which emits continuous laser beam rather than in pulses. It uses a mixture of helium (He) and neon (Ne) gases. Its operation involves four energy levels-three in neon and one in helium. The excitation of helium and neon atoms to higher energy states is performed by means of radio (high) frequency electromagnetic field.

Ans.2: It consists of following parts:

(1) A working substance in the form of a mixture of helium and neon gases in the ration 7:1 at total pressure of 1nm of Hg.

(2) A resonant cavity of quartz tube of about 0.5m length and 5mm diameter. There are two windows W_1 and W_2 made optically flat and cemented at Brewster's angle to the tube axis for specific wavelengthλ. The ends of the cavity are enclosed by two concave mirrors, M_1 and M_2, one perfectly reflecting and other partially reflecting.

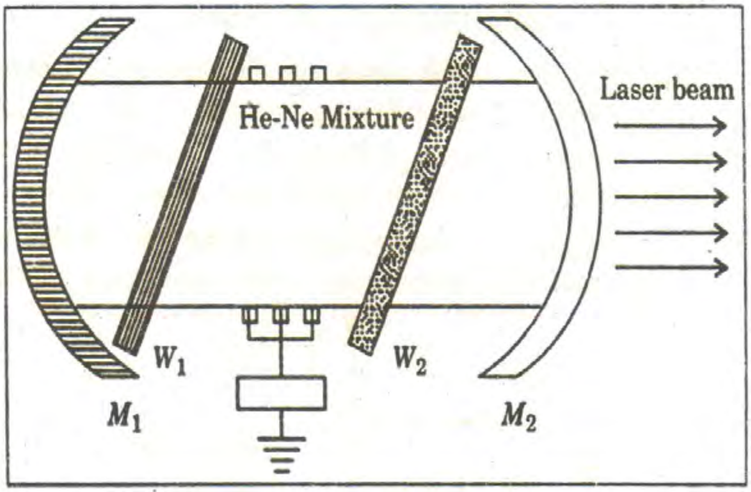


FIGURE 1: He-Ne LASER

(3) An exciting source for creating a discharge in the tube. It is generally a radio frequency high voltage source such as a Tesla coil and is applied by means of metal bands around the outside of the tube.

Answers to Self Learning Exercise-IV

Ans.1: The working of the He-Ne laser is based on the fact that the neon has energy levels very close to metastable energy levels of helium. He-Ne gas lasers can operate into three distinct spectral regions in the red 6328Å, in the near infrared around 1.15μm and in the infrared at 3.39μm. the partial energy level diagram of He-Ne is shown in figure 1, which explains the origin of these lines. When electromagnetic energy is injected into the tube through metal bands by means of a radio frequency high voltage source, helium atoms get excited to metastable state. The excited helium atoms collide with unexcited neon atoms and resonant energy transfer takes place so that neon atoms get excited to a specific energy level. Helium atoms after transferring energy return to the ground state

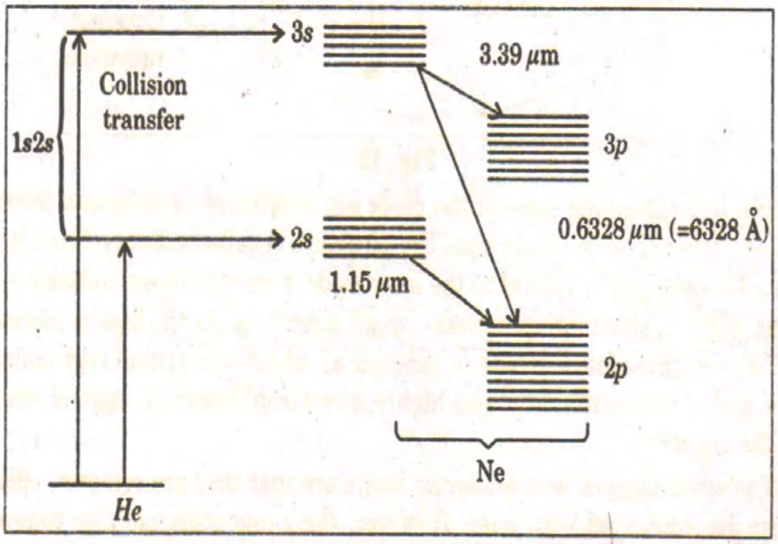


FIGURE 2: *Partial energy level of He-Ne gas LASER along With transitions.*

The laser action takes place only in neon-atoms while helium in the mixture serves the only purpose to enhance to excitation process.

When population inversion has occurred in Ne- atoms, they return to lower energy states emitting the photons. The photons emitted parallel to the axis of tube bounce back and forth between polished mirrors and stimulate emission of the same wavelength from other excited Ne-atoms. Thus, the photons get multiplied and a powerful, coherent, parallel laser beam emerges from the partially reflecting end of the tube.

Ans.2: A narrow discharge tube is necessary for the rapid dexcitation of atoms by collision with the walls. With a tube of large diameter, the probability of collisions of atoms with the walls decreased and less atoms are available at the ground level for further excitation. This can cease the laser action in due course.

8.16B Viva Questions

Q.1: In optical pumping, what is the source of energy?

Q.2: How can you produce population inversion by chemical reactions?

Q.3: What is LASER?

Q.4: Give two applications of laser.

Q.5: What is the use of laser in medical field?

8.17B Answers to Viva Questions

Ans.1: In optical pumping, the light is luminous nature. It is usually comes form of *short flashes of light.*

Ans.2: In chemical conversion, energy comes from a chemical reaction without any need for other energy sources. From chemical energy we produce the population inversion.

Ans.3: It is a device by which an intense, monochromatic, collimated and highly-coherent light beam can be obtained.

Ans.4: (1) Laser is used for three-dimensional photography or holography.

(2) Lasers can be extremely useful tool in controlled fusion research (Laser-fusion).

Ans.5: The laser beam is used in delicate surgery as cornea grafting. With laser beam, the surgery is completed in much shorter time. The laser beam is also used in the treatment of kidney, stone, cancer and tumour and in depositing and cutting the blood cells in brain operations.

Glossary

Laser**:** It is a device by which an intense, monochromatic, collimated and highly-coherent light beam can be obtained.

Population Inversion**:** Population inversion is the non-equilibrium condition of a materials where the number of atoms in the upper energy level exceeds the number of atoms in the lower energy level.

Spatial Coherence**:** The spatial coherence is the phase relationship between the radiation fields at different points in space.

Pumping**:** The method of producing population inversion is called pumping. The population inversion can be achieved by exciting the medium with suitable form of energy.

***Optical Pumping*:** If we supply luminous energy to the medium for causing population inversion, then the pumping is called the optical pumping.

References and Suggested Readings

1. Laser and Non-linear Optics by B.B. Laud.
2. Atomic and Molecular Spectra: Laser by Raj Kumar.
3. Laser Physics by Peter W. Milonni and Joseph H. Eberly.
4. Laser physics and its application by L.V. Tarasov.

UNIT-9
LED Characteristics and Determination of Planck's Constant

Structure of the Unit

9.1 Aim

Study of LED characteristics and determination of Planck's constant.

9.2 Apparatus

The experimental set-up consists of the following:

(i) Light Emitting Diodes (LED) with different colours.

(ii) Digital multimeter (used as an ammeter)

(iii) Voltmeter (with 0.1 V increments)

(iv) Resistors (100 - 200 Ω)

(v)Variable Power supply (Low voltage)

(vi) Bread board

(vii) Banana plug

(viii) Connecting wire (jumper wire)

All the components can be mounted on an optical bench with proper alignment.

9.3 Diagram

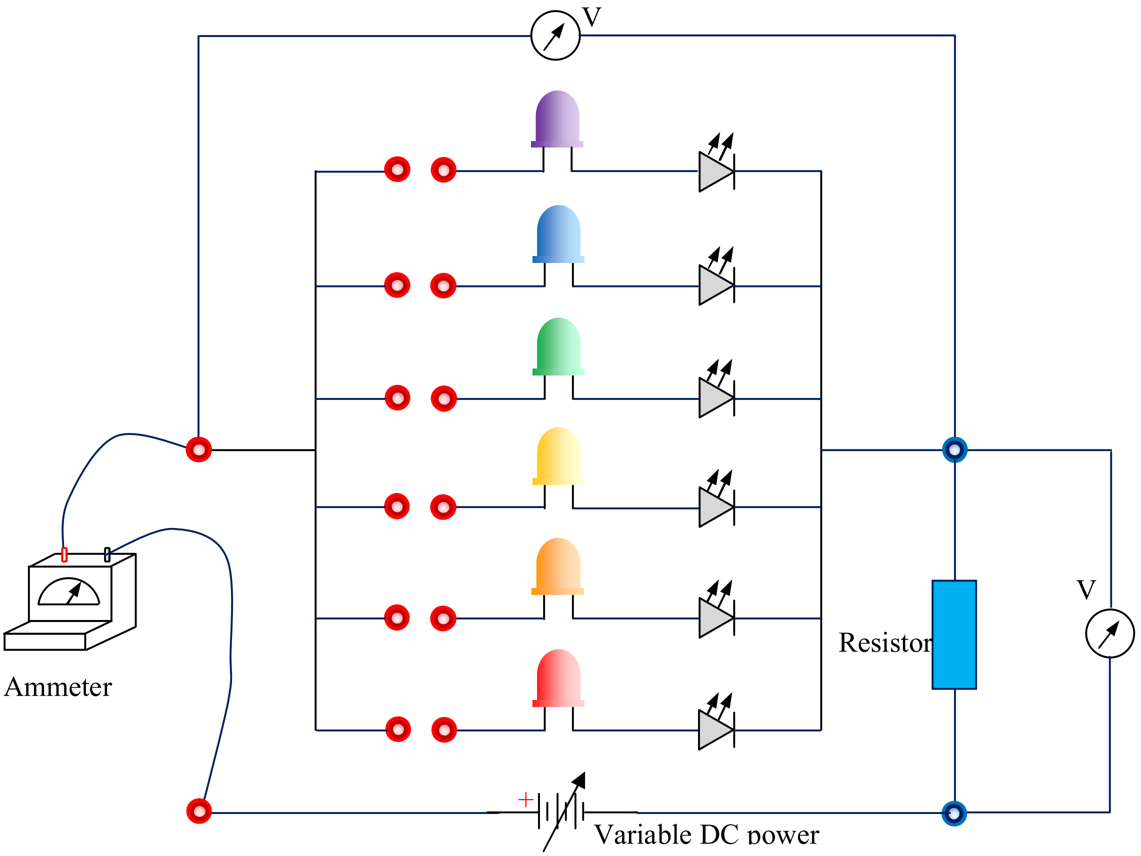
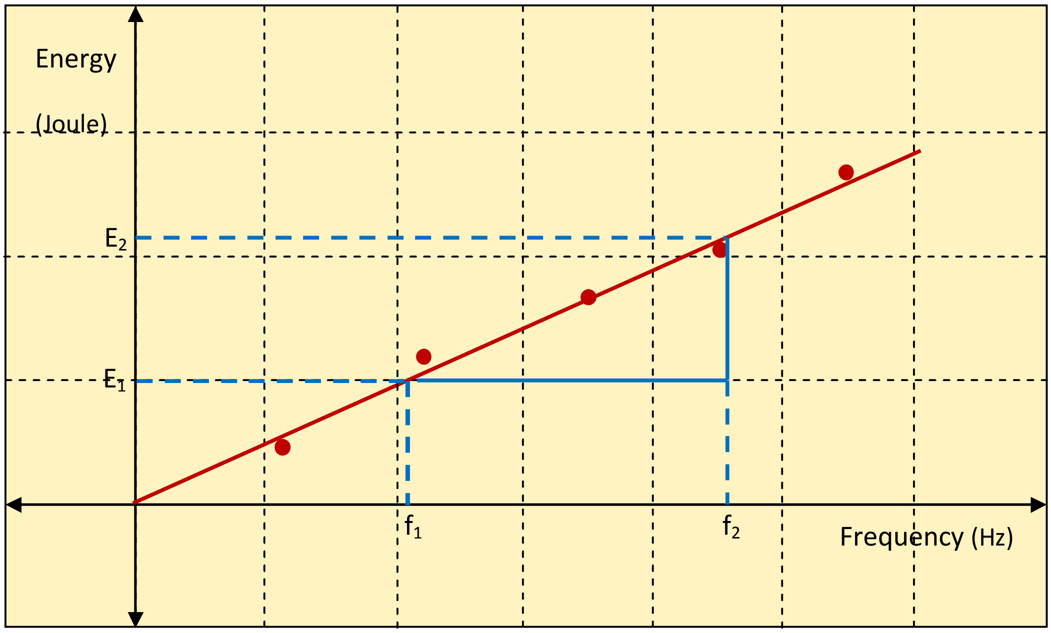


Figure 1

9.4 Formula

$$\text{Slope of Curve (h)} = \frac{e[V_{th}(2) - V_{th}(2)]}{(f_2 - f_1)}$$

9.5 Model Graph



9.6 Theory and description

Quantum mechanics born by Planck's law and Planck's constant (symbolized by 'h') is its seed. It is a fundamental physical constant which is used to describe the energy of photon (quanta).It also exhibits the connection between the particle like nature and wavelike nature of the radiation.

The energy of photon is given by relationship

$$E_n = nh\nu,$$

where n is an integer, ν is the frequency, and h is called Planck's constant.

$$h = 6.6261 \times 10^{-34} \text{ J - S}$$

There are several methods used to determine the Planck's constant. Light emitting diode (LED) is one of the best electronic devices to measure the Planck's constant in lab. The current – voltage (I-V) characteristics of LED are to be used to determine the Planck's constant in last few years.

Light Emitting Diode (LED):

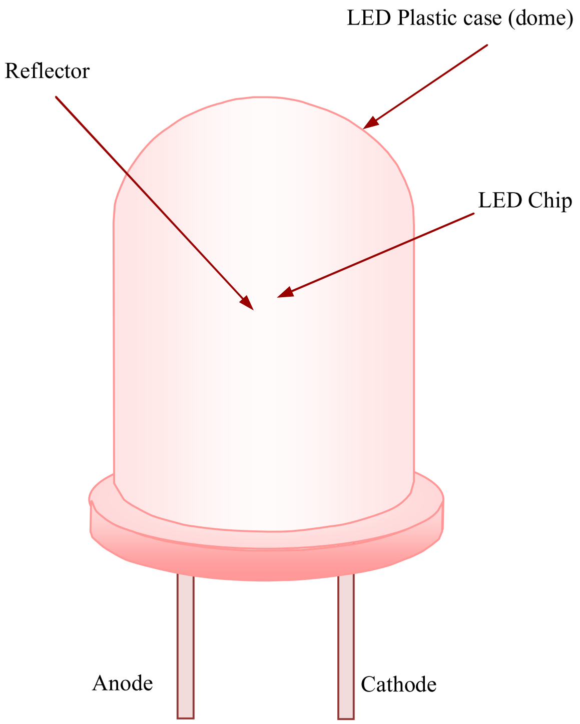


Fig.2 LED construction

A semiconductor chip is encapsulated by special type of transparent plastic (called as epoxy lens of LED) material inside light emitting diode. In LED, the semiconductor chip is mounted in a reflected cup in order to improve the light output. The transparent plastic case encloses the LED frame which provides high resistance against moisture (environmental effect) and mechanical strength.

A Light Emitting Diode (LED) is a simple pn junction semiconductor diode that converts electrical energy into light energy of a certain wavelength (color). The phenomenon of spontaneous emission of light takes place when it is connected in a circuit and operated in a forward biased direction.

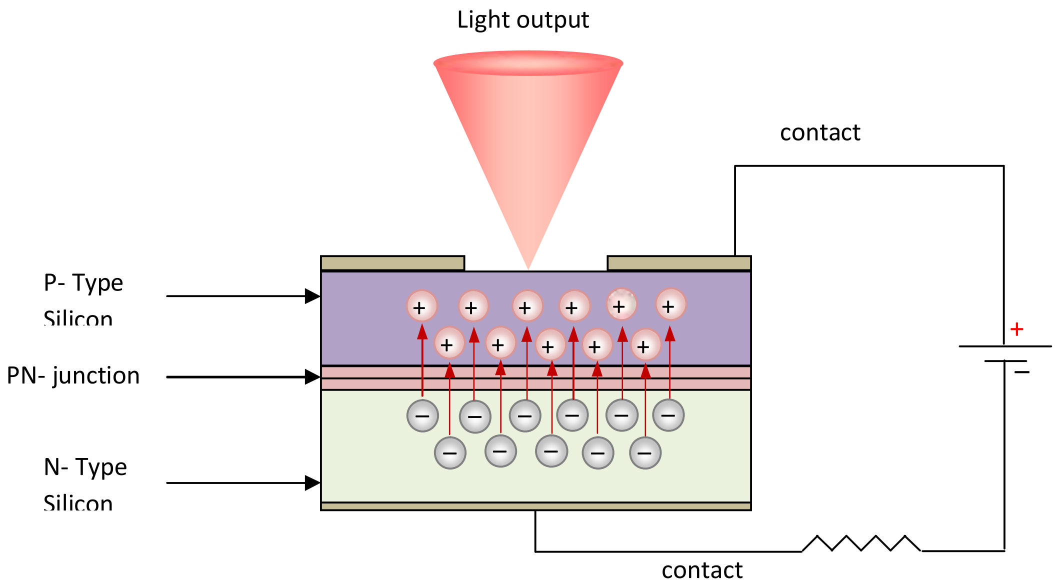


Fig.3 Light output form LED junction

When sufficient electrical energy (threshold voltage) supplied to the LED and current starts to flow (i.e, p- side of the junction is connected to the positive terminal of a battery and the n side to the negative terminal), electrons gain enough energy to cross over the junction and enter into the p region (i.e., electrons are attracted by positive charge due to columbic forces). Afterward they recombine with holes within the device and lose their energy by emitting photons of light. As the p region is lightly doped, only few numbers of holes cross over to the n region than the more numbers of electrons diffuse to the n region. Such process is termed as radiative recombination. *Recombination* takes place in the depletion region (active region) and photons are emitted in random direction.

This effect is called *electroluminescence* (emission of light when the device is supplied with some electrical energy).

Energy diagram:

(A) Zero bias (no bias) condition:

Energy diagram for zero bias is shown below.

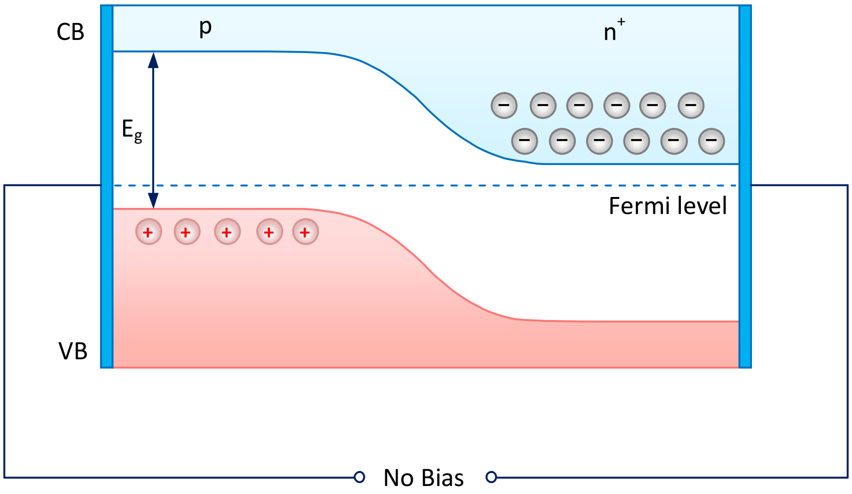


Figure:4

(B) Forward bias condition

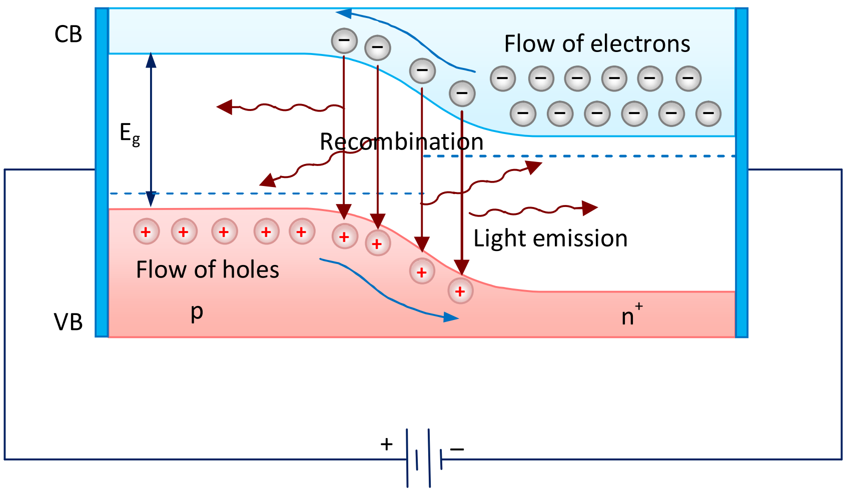


Figure5

When apply the certain voltage across the device (Under forward condition), the majority carriers from both sides (electrons in n-type and holes) cross the depletion region and entering the other side.

Upon entering, the majority carriers become minority carriers (for example, the electrons as minority carries in the p- region and holes as minority carries in n-region) and they recombine with that side of majority carries. The recombination process causes light to be emitted.

The wavelength of emitted photons is decided by the bandgap energy of the semiconductor materials.

$$E = hf = \frac{hc}{\lambda} = eV_{th}$$

where

h = Planck's constant

λ = wavelength of emitted photons

V_{th} = Threshold voltage

c = velocity of light

e = electron charge

Above the threshold voltage, the excess electrical energy create more photons- the LED gets brighter. Given this, by measuring both the threshold voltage V_{th} and the wavelength of emitted photons of light, we will able to determine the Planck's constant h.

$$h = \frac{eV_{th}\lambda}{c}$$

Table.1. Approximate threshold voltages of LED of different wavelength

LED colour	V_{th} (volt)
Red	2.2
Yellow	2.2
green	3.5
Blue	3.6
Purple	3.6
White	3.6

LED characteristics:

I-V characteristic of Light emitting diode is same as an ordinary diode in which current flows only in one direction. When low bias voltage is applied across the LED, then current starts to flow through it and LED starts to glow with emission of little light. As further increasing the bias voltage the current becomes larger and LED gets bright and bright. The graph between current and voltage can be plotted as shown below.

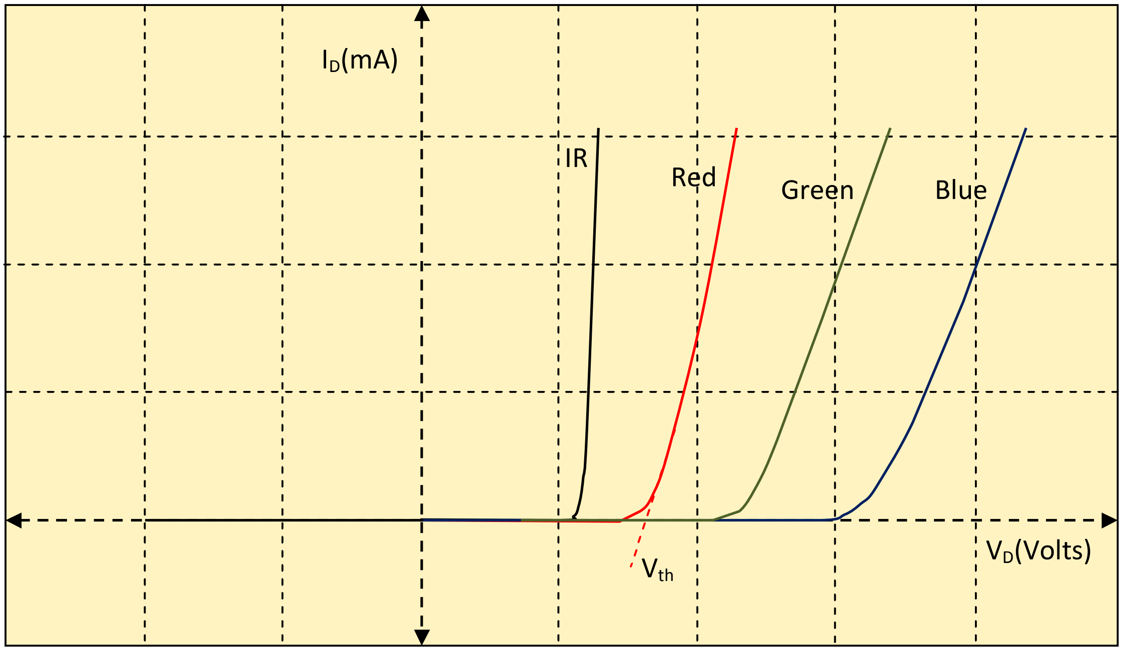


Figure:6

I-V characteristics of LEDs

9.7 Self Learning Exercise-I

Q.1 What is the standard value of Planck's constant?

Q.2 LED stands for what?

Q.3 Define threshold voltage.

Q.4 Is LED voltage operated device?

Q.5 The threshold voltage for a light emitting diode is 2.2 volts. What is the wavelength of the LED? What is its color?

9.8 Procedure

The basic experimental circuit for the determination of Planck's constant is shown below as. This circuit consists of a power supply (6 volt DC), a limiting resistor and blue, green, red, IR LEDs.

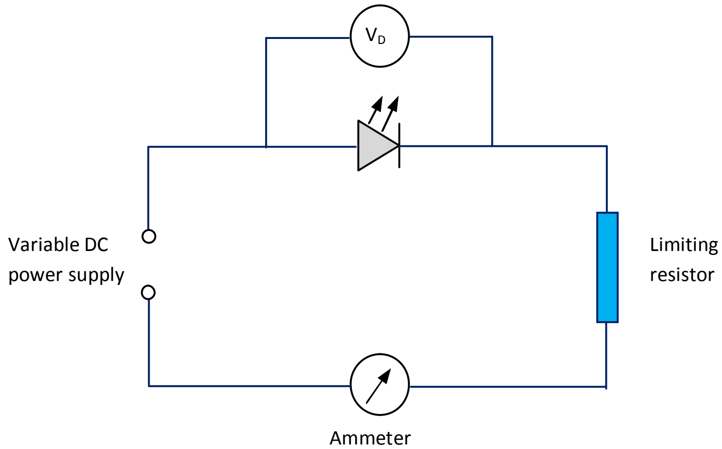
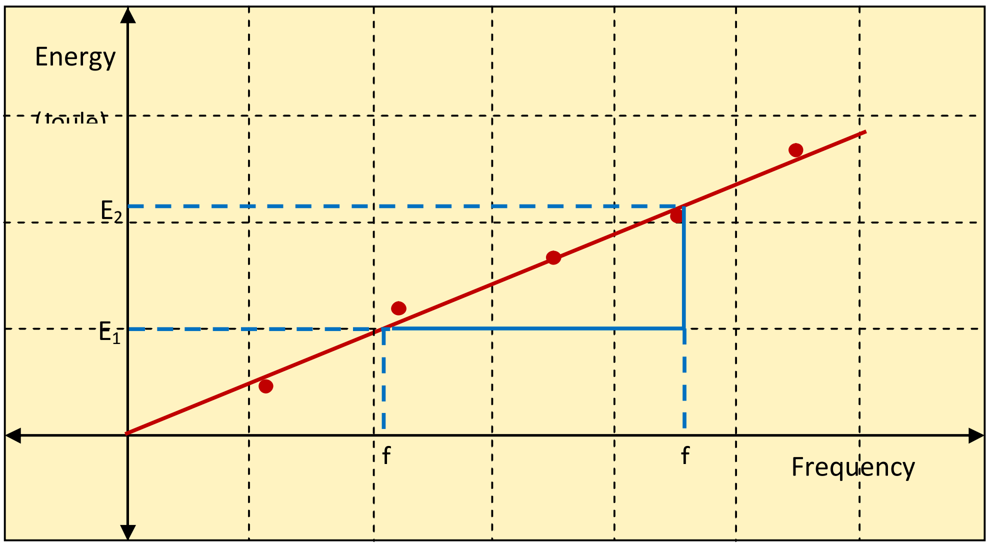


Figure 7 :Circuit for IV characteristics

The IV characteristics are used to determine Planck's constant. The value of threshold voltages can be obtained from IV characteristic of different LEDs (From the extrapolation at I = 0 of the linear portion of the IV characteristic curve of the LED). When plotting the curve between energy ($E = eV_{th}$) verses frequency (f) of the emitted light, we get a straight line whose slope is equal to Planck's constant (h), see fig below.



$$\text{Slope of Curve (h)} = \frac{e[V_{th}(2) - V_{th}(2)]}{(f_2 - f_1)}$$

9.9 Observation

LEDs Colour	Wavelength	Frequency	Threshold voltage	Energy
Blue				
Green				
Orange				
Red				
IR				

Determination of wavelength

The wavelength of the LED can be determined by LED diffraction by grating method.

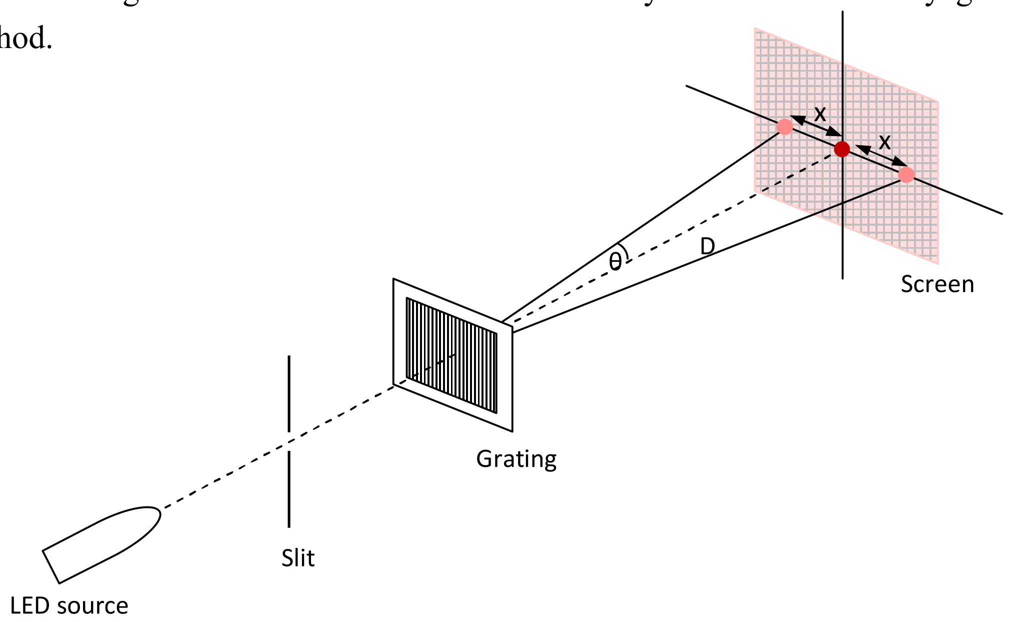


Figure 8: Experimental setup for determining wavelength of light from LED.

The experimental arrangement is shown in fig. The LEDs light is allowed to fall on grating via slit and the diffraction pattern (in form of dots) is obtained on the screen. Now using the spacing of the diffraction grating, we can calculate the wavelength of LEDs light. formula used

$$m\lambda = d \sin\theta$$

where m = order of diffraction

d= spacing

and

$$\theta = \tan^{-1}\left(\frac{x}{D}\right)$$

x= distance between pattern and central spot

D= distance screen and grating

Repeat the procedure for all LEDs.

LEDs	**x**	**D**	$\theta = \tan^{-1}\left(\frac{x}{D}\right)$	$\boldsymbol{\lambda}$
Blue				
Green				
Orange				
Red				
IR				

Mean value of Planck's constant (h_{mean})

$$h = \frac{h(blue) + h(green) + h(orange) + h(red) + h(IR)}{5} = \ldots\ldots \text{ J - sec}$$

Average value of Planck's constant (h) =………………… J-sec

9.10 Graph

Plot the required graph on graph paper and obtain the slope.

9.11 Calculations

9.12 Result

The measured value of Planck's constant h =

The standard value of Planck's constant h $=6.62\times10^{-34}$ J-s

% error in the experiment $= \dfrac{h_{Standard} - h_{exp}}{h_{Standard}} \times 100$

9.13 Discussion

9.14 Precautions and Sources of error

(1) Experiment must be performed in the dark room to avoiding interfere of extra light.

(2) Alignment of all mounted objects should not be disturbed during experiment.

(3) Threshold voltage must be observed carefully.

(4) The reading of ammeter and voltmeter must be stable while measuring.

(5) Do not connect LED directly without limiting resistor.

9.15 Self Learning Exercise-II

Q.1 What is the function of slit ?

Q.2 What do you understand by the order of diffraction?

Q.3 What is grating ?

Q.4 The threshold voltage of LEDs is 2 volt. What is its color of light?

Q.5 If the diffraction grating has 800 lines per mm, x = 5 cm, and D = 0.5 m, what is the wavelength of the light source?

9.16 Glossary

LED: Light Emitting Diode

Electroluminescence: emission of light when the device is supplied with some electrical energy is called *electroluminescence*.

Threshold voltage: Minimum voltage applied to the device(LED) and current starts to flow.

9.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Planck's constant $h = 6.6261 \times 10^{-34}$ J - S

Ans.2: Light Emitting Diode (LED)

Ans.3: When sufficient electrical energy (threshold voltage) supplied to the LED and current starts to flow (i.e, p- side of the junction is connected to the positive terminal of a battery and the n side to the negative terminal), electrons gain enough energy to cross over the junction and enter into the p region (i.e., electrons are attracted by positive charge due to columbic forces).

Answers to Self Learning Exercise-II

Ans.1: It acts as narrow vertical light source.

Ans.2: wavelength of LEDs light λ then formula used

$$m\lambda = d \sin\theta$$

where m = order of diffraction

Ans.2: Diffraction grating is an arrangement that is equivalent in its action to number of parallel slits of the same width. Laboratory grating normally has 15000 lines per inch. Gratings are constructed by ruling fine grooves with a diamond point on a plane glass surface to make a transmission grating.

Ans.4: Wavelength of the light

$$\lambda = \frac{hc}{E} = \frac{12420}{2} A^0$$

$= 6210A^0$ Red

9.18 Viva Questions

Q.1 What is LED?

Q.2 What are the some major sources of error in the experiments?

Q.3 What is the standard value of Planck's constant?

9.19 Answers to Viva Questions

Ans.1: A Light Emitting Diode (LED) is a simple pn junction semiconductor diode that converts electrical energy into light energy of a certain wavelength (color). The phenomenon of spontaneous emission of light takes place when it is connected in a circuit and operated in a forward biased direction.

Ans.2: Refer section 9.14

References and Suggested Readings

1. H.S.Palsania, Sardar singh, “Practical Physics”. College Book House, Jaipur (2014).
2. Gupta & Kumar, “Practical Physics”.
3. Omega electronics manual, “Determination of Planck’s constant by solar cell”. OMEGA TYPE ES – 214.
4. Omega electronics manual, “LASER Diffraction experiment”. OMEGA TYPE ES – 361.

UNIT-10
Stefan's Constant

Structure of the Unit

10.1 Aim

To determine the value of Stefan's constant.

10.2 Apparatus

A metallic hemisphere , blackened silver disc, steam chamber, thermometers, low resistance or ballistic galvanometer, heater, rheostat, stop watch, connection wires.

10.3 Diagram

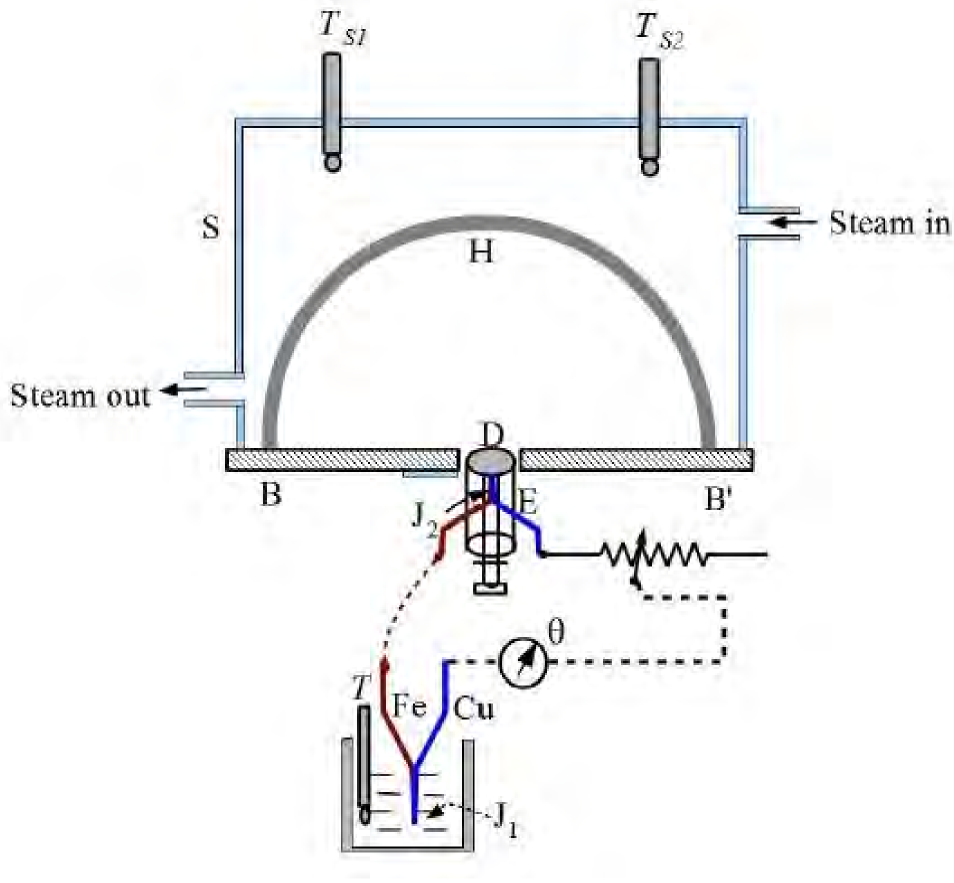


Figure 1. A schematic view of the experimental set up used for the determination of Stefan's constant.

10.4 Formula

The rate of emission of radiant energy per unit area from a blackbody is:

$$\mathbf{R = \sigma(T_1^4 - T_2^4) \quad W/m^2}$$

Where σ is Stefan's constant,

T_1 (K) is the temperature of blackbody and

T_2 (K) is the temperature of the surrounding.

The rate of rise of temperature of blackened silver disc due to the radiation received by it from a hemispherical enclosure is equal to Stefan's constant.

$$\boxed{\sigma = \frac{mS}{A(T_1^4 - T_2^4)} \frac{dT}{dt}} \qquad W/m^2K^4$$

Where,

m is the mass of the disc in *kg*,

S is the specific heat of the material of the disc in *J/kg.K*,

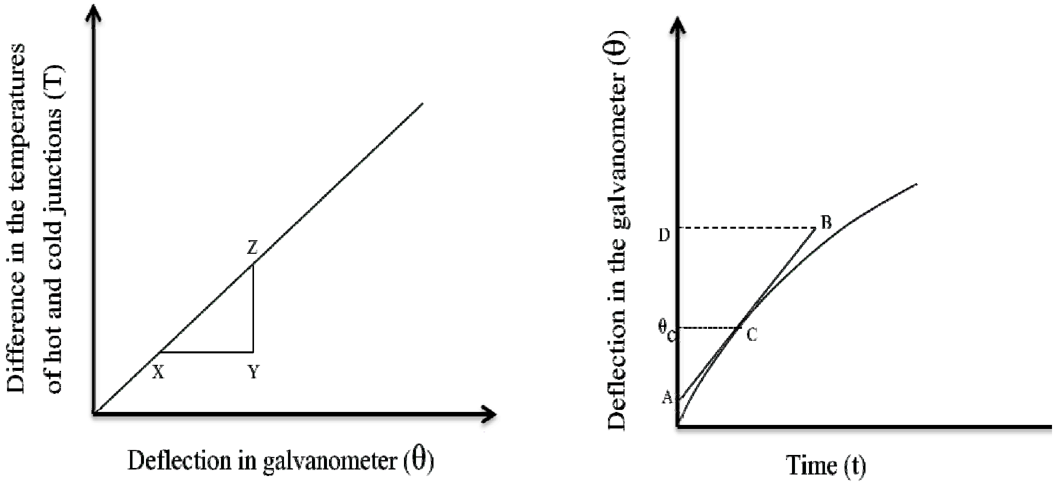
A is the area of the disc in m^2,

T_1 is the temperature of steam chamber (blackbody) in *K*,

T_2 is the temperature of disc in *K*,

$\frac{dT}{dt}$ is the rate of rise of temperature of disc at steady temperature T_2 in *K/sec.*

10.5 Model Graph



10.6 Theory and description

Stefan-Boltzmann Law

This law states that the rate at which a perfectly black body emits the radiant energy is directly proportional to the fourth power of its absolute temperature.

Thus,

$$E=\sigma T^4$$

where, σ is a constant known as Stefan's constant.

A body which emits or absorbs all types of electromagnetic radiation is called a black body. The term 'black body' was first coined by the German physicist Kirchhoff during 1860's. At constant temperature, the electromagnetic radiation emitted by a Black body is called Black body radiation. The intensity of this electromagnetic spectrum depends only on the temperature of the Black body.

According to Stefan- Boltzmann law, the energy radiated per unit area per unit time by a body is given by,

$$R = \varepsilon\sigma T^4 \tag{1}$$

Where R = energy radiated per area per time,

ε = emissivity of the material of the body,

σ = Stefan's constant = 5.67x10-8 $Wm^{-2}K^{-4}$,

and T is the temperature in Kelvin.

For an ideal black body, emissivity ϵ=1, and hence equation (1) becomes,

$$R = \sigma T^4 \tag{2}$$

The experimental set up used in the present experiment uses a blackened silver disc which absorbs radiation from the metallic hemisphere as shown in the figure 1. If T_1 and T_2 are the temperatures of the disc and the hemisphere in the steady state, the net heat transfer to the disc per unit time is given by,

$$\frac{\Delta Q}{\Delta t} = \sigma A(T_1^4 - T_2^4) \tag{3}$$

where A is the area of the disc and $\Delta Q = (Q_1 - Q_2)$.

Now, we have another equation from thermodynamics for heat transfer as,

$$\frac{\Delta Q}{\Delta t} = mS\frac{dT}{dt} \qquad (4)$$

Where 'm' mass of the disc, S specific heat of the copper, dT/dt is the change in temperature per unit time.

Equating equations (3) and (4),

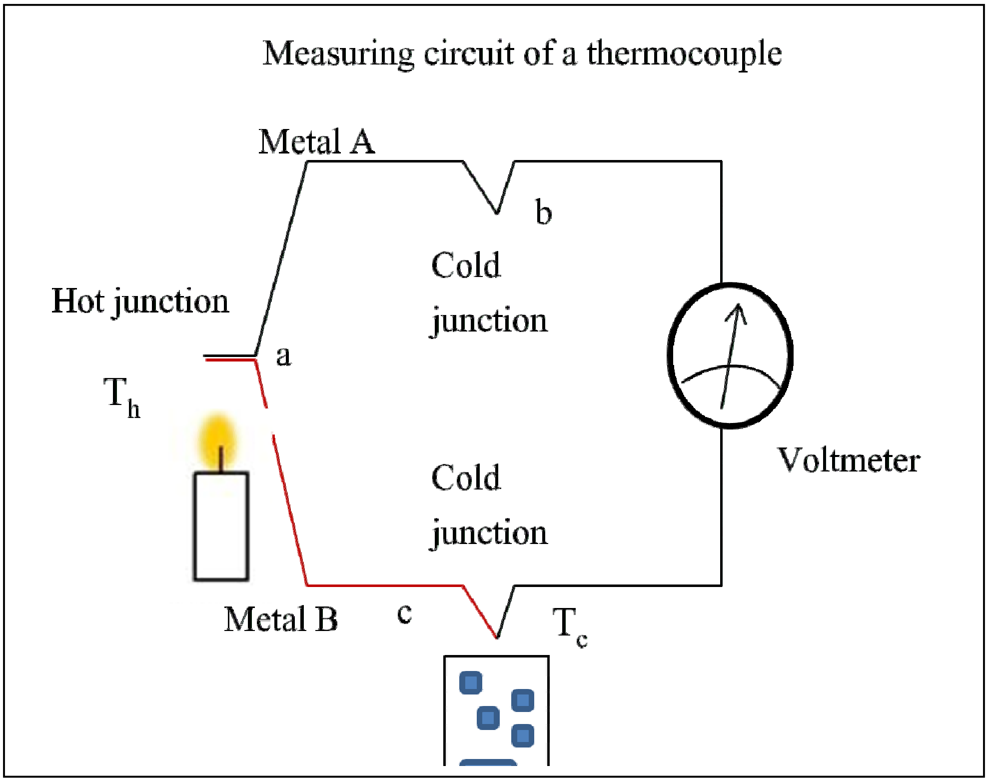
$$\sigma A(T_1^4 - T_2^4) = mS\frac{dT}{dt}\ldots \qquad (5)$$

Hence,

$$\sigma = \frac{mS}{A(T_1^4 - T_2^4)}\frac{dT}{dt} \qquad (6)$$

Thermocouple

A thermocouple is a device which is used to measure temperature. It consists of two dissimilar metals which are joined to form two junctions. Both the junctions are kept at different temperatures.



The hot or measuring junction is connected to the body whose temperature has to be measured and the other junction, which is colder, is connected to a body of known temperature.

Seebeck Effect

When two different metals or semiconductors are joined to form two junctions and they are kept at different temperatures (One junction hot and other junction cold), heat flows from the hot junction to the cooler one and a voltage difference is produced between the two substances. The e.m.f. thus produced is called thermo e.m.f. and the resulting current is known as thermoelectric current .This effect is known as Seebeck Effect.

Prevost's Heatexchange principle

Unless a body is at absolute zero temperature, it emits thermal radiation. If a body is placed in a surrounding where the temperature of surrounding is lower than that of the body, it emits radiation at a faster rate than the rate it absorbs the radiations. As a result of this the temperature of the body starts decreasing until a stage of equilibrium is reached. This is known as Prevost's theory of heat exchange.

Absorptivity, Reflectivity and Transmittivity

If Q is the total amount of energy incident on the surface of a body, it will be partly absorbed (Q_A), partly reflected (Q_R) and partly transmitted (Q_{TR}).

$$Q_A + Q_R + Q_{TR} = Q$$

$$\frac{Q_A}{Q} + \frac{Q_R}{Q} + \frac{Q_{TR}}{Q} = 1$$

$$\alpha + \rho + \tau = 1$$

α is called absorptivity, which is the fraction of incident radiation which is absorbed,

ρ is known as reflectivity and is the fraction which is reflected and

τ, the fraction which has been transmitted is known as transmissivity or transmittance.

A perfectly black body is one which absorbs all the incident radiations. Thus for a perfectly black body $\alpha = 1$ and $\rho = \tau = 0$.

10.7 Self Learning Exercise-I

Q.1 What do you mean by Stefan's constant?

Q.2 What is Prevost's theory of heat exchange?

Q.3 State Stefan's law?

Q.4 Why the upper face of the disc is blackened?

Q.5 Explain the principle and working of a thermocouple?

10.8 Procedure

1. Measure the diameter ***d*** and the mass ***m*** of the blackened silver disc ***D*** and the room temperature T_0.

2. Put the one junction (J_1) into a beaker containing cold water. Use a thermometer to read the temperature of the water. Solder the other junction (J_2) of the thermocouple to the lower surface of the disc.

3. As shown in the figure 1, attach a low resistance galvanometer in series with a variable resistance in the thermocouple circuit.

Calibration of the galvanometer:

4. The chamber S has to be kept at room temperature T_0. No steam should be passed into it. Open the shutter and put the disc at the centre of the hemisphere H. The temperature of the junction J_2, which is attached to the disc is now T_0.

5. Adjust the galvanometer so that the spot reads zero on the scale.

6. Pour some hot water in the beaker which has junction J_1 in it. This will heat the junction J_1. Measure its temperature and corresponding deflection in the galvanometer θ.

7. Increase the temperature of water by repeating the step 6. Take a number of observations for different temperatures T of junction J_1 and the corresponding deflection in the galvanometer θ. Do this step until the temperature of water rises 20-25 ^{o}C above the room temperature i.e. $(T-T_0)$ ~20-25 ^{o}C.

8. Plot a graph between $(T-T_0)$ and θ. This is the calibration curve of the galvanometer. It will be a straight line (Figure 2).

Measurements of the temperature of the silver disc D:

9. Lower the disc and close the hole of the shutter. Pass the steam in the steam chamber. Fill the beaker with the junction J_1 with cold water (at T_0).

10. When the chamber attains the steady state (i.e. the readings of T_1 and T_2 becomes steady), remove the shutter and insert the disc in the hole. Simultaneously start the stop watch. With the rise in the temperature of the disc, the deflection in the galvanometer will also be increased. Note down the reading of the galvanometer every 10 seconds. In this case junction J_2 gets heated. Reverse the connections of galvanometer if the zero of the scale is not at the centre of the scale.

11. Plot a graph between θ and t. The shape of the curve should be as shown in the figure3.

12. Choose a point C in the beginning of the graph in figure3. In this case

$$\frac{d\theta}{dt} = \frac{DA}{DB}$$

The deflection corresponding to the point C is denoted by θ_c.

13. From the figure 2, determine the difference in the temperature $(T-T_0)$ corresponding to the deflection θ_c.

14. From the plot of between $(T-T_0)$ and θ we can determine

$$\frac{d(T-T_0)}{d\theta} = \frac{dT}{d\theta} = \frac{YZ}{XY}$$

15. The rate of rise of the temperature of the disc can be determined from the following relation:

$$\frac{dT}{dt} = \frac{dT}{d\theta} X \frac{d\theta}{dt}$$

16. T is given by $T = (T_1 + T_2)/2$

17. Thus the Stefan's constant can be determined by substituting all the values in the formula

$$\boxed{\sigma = \frac{mS}{A(T_1^4 - T_2^4)} \frac{dT}{dt}}$$

10.9 Observation

1. Diameter of the disc (d) = …….cm = ……..m
2. Mass of the disc (m) = …….kg
3. Specific heat of the material of the disc(S) = ……..$Jkg^{-1}K^{-1}$
4. Room temperature T_0 =…..^oC = …..K
5. Joule's mechanical equivalent J =
6. Thermometers reading

   T_1 = …^oC = ….K, T_2 = …^oC = ….K

   Temperature of blackened metal hemisphere T = $(T_1+T_2)/2$ ^oC = ….K

Table for the relation between ($T-T_0$) and θ

S. No.	Temperature (T) of hot junction (J_1) (in K)	Difference in the temperatures ($T – T_0$) (in K)	Deflection of galvanometer (θ) (in divisions)
1.			
2.			
3.			
4.			
5.			
6.			
7.			

Galvanometer deflection (θ) versus time (t)

S.No.	Time(t) (in seconds)	Deflection of the galvanometer (θ) (in divisions)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

10.10 Graph

(i) Plot the difference in the temperature (of hot and cold junctions)with deflection in galvanometer

(ii) Plot the deflection in the galvanometer with time

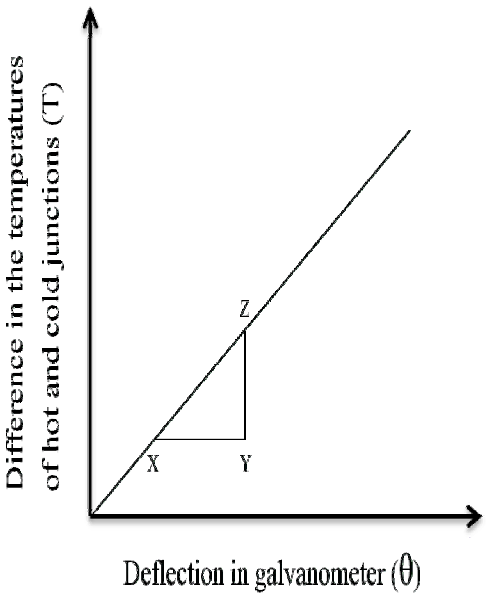


Figure 2: Plot of the difference in temperatures vs. the deflection in the galvanometer.

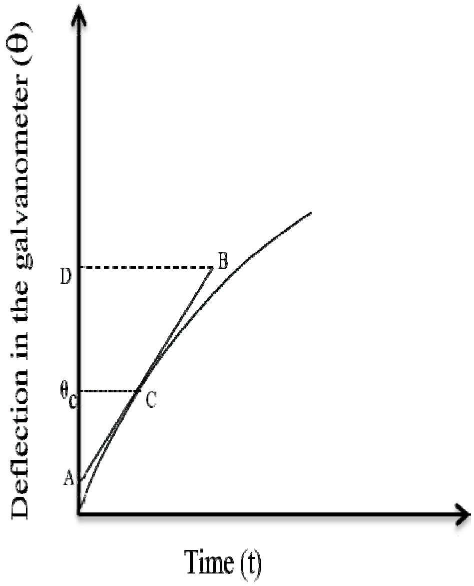


Figure 3: Plot of the deflection in the galvanometer vs. time.

10.11 Calculations

From the graph between T and θ,

$$\frac{dT}{d\theta} = \frac{YZ}{XY} = \cdots \quad (1)$$

From the graph between θ and t

$$\frac{d\theta}{dt} = \frac{DA}{DB} = \cdots \quad (2)$$

From equations (1) and (2),

$$\frac{dT}{dt} = \frac{dT}{d\theta} \times \frac{d\theta}{dt} = \cdots K/sec$$

Stefan's constant can then be calculated by the equation

$$\boxed{\sigma = \frac{mS}{A(T_1^4 - T_2^4)} \frac{dT}{dt}}$$

10.12 Result

The value of Stefan's constant determined from this experiment is

σ = ……………$Wm^{-2}K^{-4}$

10.13 Discussion

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- -

- -

10.14 Precautions and Sources of error

1. Insert the disc in the chamber only when it has acquired the steady state.
2. The measurements of all quantities should be expressed in SI units.
3. In the second part of the experiment junction J_2 gets heated. The connections to the galvanometer should be reversed if the zero of the scale is not at the centre.
4. To avoid the reflections of the radiations, the top of the disc D should be blackened.
5. In the graph of θ vs. t, point C should be chosen closer to the origin to avoid the errors which starts arising due to the conduction from disc D.
6. The reading of the timer and the galvanometer should be started as soon as the disc is uncovered. Their reading should be taken simultaneously at regular intervals.

10.15 Self Learning Exercise-II

Q.1 What is a black body?

Q.2 What is the value of *Stefan's constant* in S.I units?

Q.3 State Wien's displacement law?

Q.4 Define emissive power of a body?

Q.5 Define absorptive power of a body.

10.16 Glossary

Black Body : A body is said to be black if it absorbs all the incident radiations.

Emissive power : Emissive power of a body at a temperature is defined as the energy radiated by the body per unit time per unit area.

10.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: According to Stefan's law, the relationship between emitted power per unit area (in Watt per square meter, denoted M) and the absolute temperature temperature (in Kelvin) T is:

$E = \sigma T^4$

That is, the power per unit area is directly proportional to the fourth power of the thermodynamic temperature. σ is known as Stefan's constant. Its value is approximately 5.67 x 10^{-8} watt per meter squared per Kelvin to the fourth ($W \cdot m^{-2} \cdot K^{-4}$)

Ans.2: See the section theory and description.

Ans.3: See the section theory and description.

Ans.4: The upper face of the disc is blackened so that it absorbs all the radiations i.e. the reflection becomes negligible.

Ans.5: See the section, theory and description.

Answers to Self Learning Exercise-II

Ans.1: A body is said to be black if it absorbs all the incident radiations.

Ans.2: The value of Stefan's constant in SI units is $\sigma=5.67X10^{-8}$ Wm^{-2} K^{-4}.

Ans.3: The relation between energy and wave length emitted from a black body is given by

$\lambda_m T$ = constant

Ans.4: Emissive power of a body at a temperature is defined as the energy radiated by the body per unit time per unit area.

Ans.5: The ability of absorbing radiation falling on a body is known as its absorptive power.

10.18 Viva Questions

Q.1 What is the value of Stefan's constant?

Q.2 What is Kirchhoff's law of thermal radiation?

Q.3 What is the importance of Stefan's constant?

Q.4 State the difference between a perfectly black body and a non-perfect black body?

Q.5 Why $d\theta/dt$ is determined at the origin of the curve?

Q.6 What is radiation?

Q.7 How do you define emissivity?

Q.8 How do you define absorptivity?

10.19 Answers to Viva Questions

Ans.1: The value of Stefan's constant in SI units is σ=5.67X10^{-8} Wm^{-2} K^{-4}.

Ans.2: For an arbitrary body radiating and emitting thermal radiation, the ratio E / A between the emissive spectral radiance, E, and the dimensionless absorptive ratio, A, is one and the same for all bodies at a given temperature. That ratio E / A is equal to the emissive spectral radiance I of a perfect black body, a universal function only of wavelength and temperature.[Wikipedia]

Ans.3: With the help of the Stefan's constant, the temperature of the heavenly bodies like sun can be easily determined.

Ans.4: For a perfectly black body, the emissivity is one. For non perfectly black bodies its value is less than one.

Ans.5: So that the assumption that the disc has been inserted in a radiator at constant temperature holds good.

Ans.6: Radiation is the process by which heat is transferred from one place to another.

Ans.7: Emissivity is defined as the ratio of the emissive power of the body to that of black body at the same temperature

Ans.8: Absorptivity is the ratio of energy flux absorbed in certain time to the total energy flux incident on the body in the same time

References and Suggested Readings

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UNIT-11
L-C-R Series and Parallel Resonance

Structure of the Unit

11.1 Aim

(i) To study the series and parallel response circuits

(ii) To plot the frequency response curve characteristics of a series circuit.

(iii)To plot the frequency response of a parallel tuned circuit.

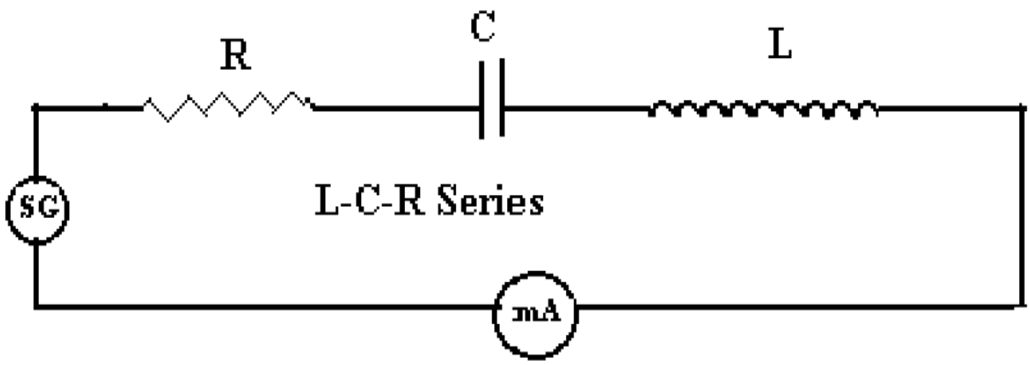
11.2 Apparatus

A variable resistor, a variable capacitor, a variable inductor, a signal generator, an a.c. milli- ammeter and connecting wires.

11.3 Diagram

I. Series L-C-R circuit

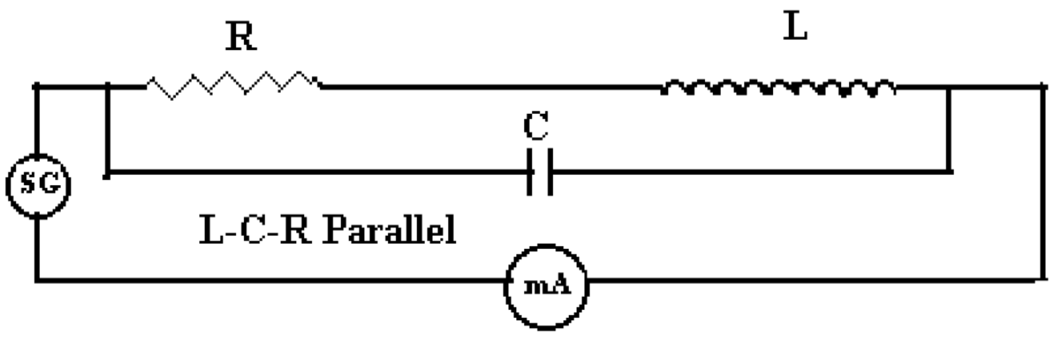
When resistor R, inductor L and capacitor C are connected in series with a source, the circuit is called as the series resonant circuit. This is an acceptor circuit, that means it allows maximum current to flow through it at a particular frequency which is known as resonant frequency and at all other frequencies it allows less current.



II. Parallel L-C-R circuit:

Parallel resonant circuit is one in which one branch consists of an inductor L with associated resistor R and the other branch consists of a capacitor C.

This is a rejecter circuit that means it rejects the current or allows minimum current to flow through it, at a particular frequency which is known as anti resonant frequency and it allows more current at all other frequencies.



11.4 Formula

The resonance frequency

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Where L=self inductance (mH)

C=Capacity of the capacitor (μF)

Band width

$$B = (f_2 - f_1) \text{ Hz}$$

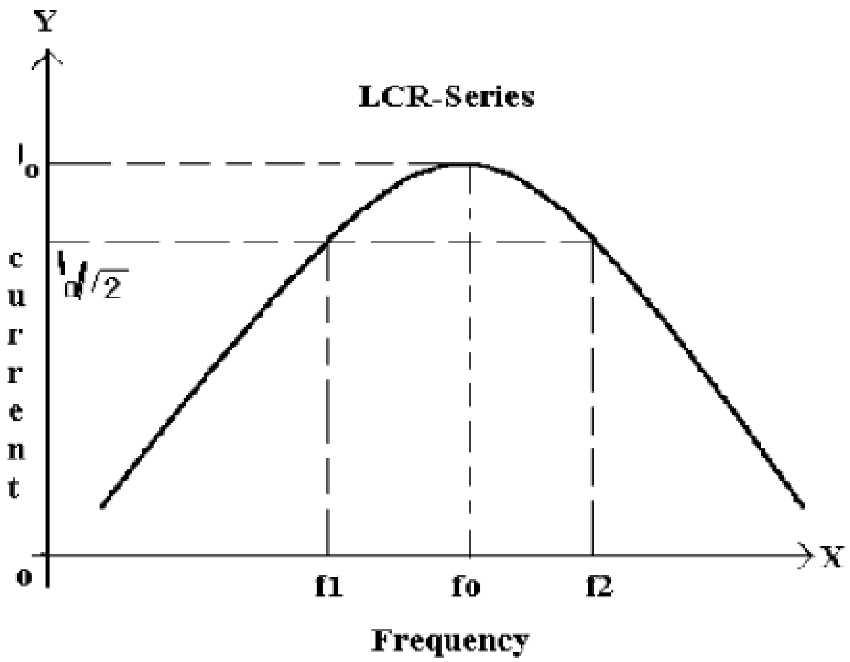
Quality factor

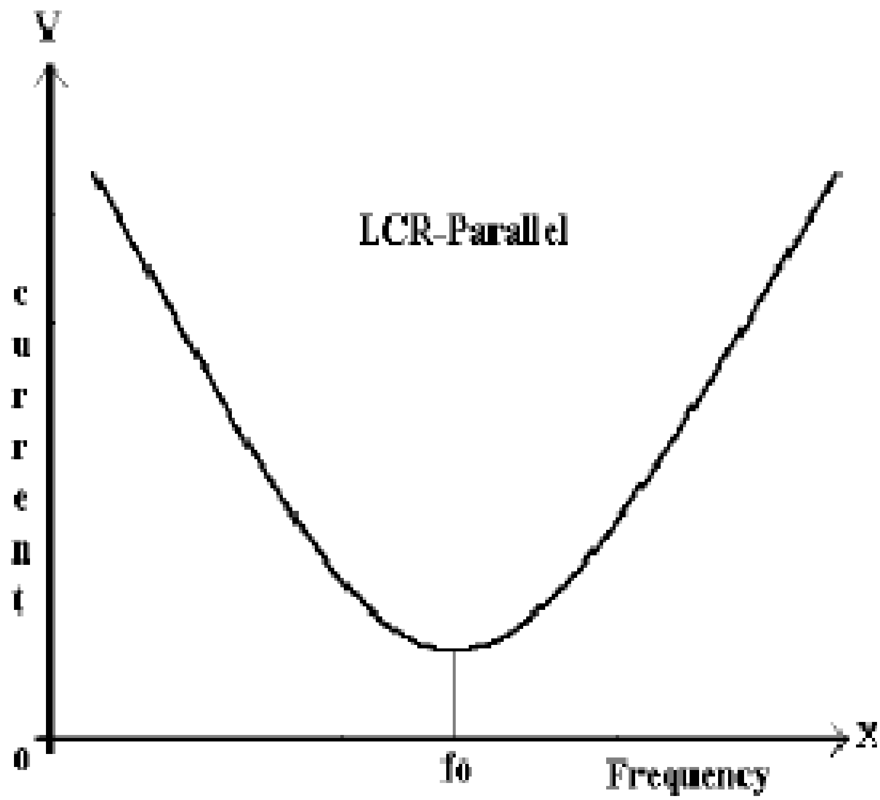
$$Q = \frac{2\pi f_0 L}{R} = \frac{f_0}{(f_2 - f_1)}$$

Where R is resistance in Ω, f_2, f_1 are frequencies at the half power point.

11.5 Model Graph

For L-C-R series, graph is drawn for current against frequency. The frequency corresponding to maximum current is noted and it is the resonant frequency f_0. The frequencies f_1 and f_2 corresponding to half power points is noted and from it the bandwidth, $(f_1 - f_2)$ is noted. From the values of f_0, f_1 and f_2, the quality factor Q is calculated.


Y
LCR-Series
I_o
$I_o/\sqrt{2}$
current
o
f1
fo
f2
X
Frequency


Y
LCR-Parallel
current
0
fo
X
Frequency

For L-C-R parallel, the circuit is connected as shown in the figure. The frequency of the signal generator is changed in steps and corresponding current values are noted from a.c. milli- ammeter. Here, the current values decrease with the increase of frequency up to the anti- resonant frequency, further increase of frequency causes the increase of current. The anti- resonant frequency f_0 is noted corresponding to the minimum current in the circuit.

11.6 Theory and description

LCR CIRCUITS

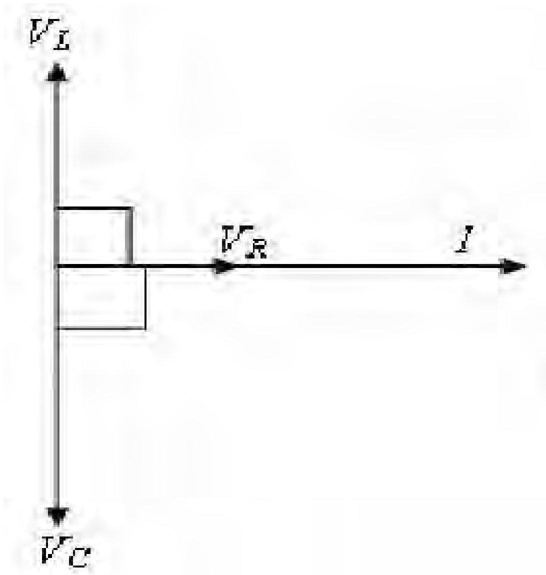
Circuits containing an inductor L, a capacitor *C*, and a resistor *R*, have special characteristics useful in many applications. Their frequency characteristics (impedance, voltage, or current vs. frequency) have a sharp maximum or minimum at certain frequencies. These circuits can hence be used for selecting or rejecting specific frequencies and are also called tuning circuits. These circuits are therefore very important in the operation of television receivers, radio receivers, and transmitters. In this section, we will present two types of LCR circuits, viz., series and parallel, and also discuss the formulae applicable for typical resonant circuits.

A series LCR circuit includes a series combination of an inductor, resistor and capacitor whereas; a parallel LCR circuit contains a parallel combination of inductor and capacitor with the **resistance** placed in series with the inductor. Both series and parallel resonant circuits may be found in radio receivers and transmitters.

The **selectivity** of a tuned circuit is its ability to select a signal at the resonant frequency and reject other signals that are close to this frequency. A measure of the selectivity is Q, or the **quality factor.**

The study of these circuits is basically an application of alternating current circuit analysis. We make use of the complex number notation with sinusoidal varying quantities like alternating voltage and current. In general, the impedance *Z* is a sum of the real part called resistance *R* and the complex part called the **reactance** *X*, i.e., $Z = R + jX$. The magnitude and phase of the impedance are given by $\sqrt{R^2 + X^2}$ and $\varphi = \tan^{-1}\left(\frac{X}{R}\right)$, respectively.

Since in an inductor, voltage leads the current by π/2, the reactance of is L *is* $j\omega L$, C while in case of a capacitor, voltage lags behind the current by π/2, the reactance of is C $1/j\omega C$. If the current in the circuit is I, the relative voltage drops across the inductor, capacitor and resistor can be represented in the phasor diagram as shown in figure.



We will study the property of **resonance** in context of series as well as parallel configurations of LCR circuit. It is a very useful property of reactive a.c. circuits and is employed in a variety of applications. One of the common applications of resonance effect is in radio and television transmissions, e.g., tuning a radio to a particular station by selecting a desired frequency (or band of frequencies). The series resonant circuit can be used for voltage magnification. A parallel resonant circuit provides current magnification and can be used in induction heating. Another application of resonant circuit is screening certain frequencies out of a mix of different frequencies with the help of circuits called filters.

Series L-C-R

Let us consider the LCR circuit, which consists of an inductor, L, a capacitor, C, and a resistor, R, all connected in series with a source as shown in Figure 1. We will first derive the condition of resonance and then explain the methods of determination of the resonant frequency and hence the Quality factor

Let an **alternating voltage** $V_0 \sin\omega t$ or $V_0 e^{j\omega t}$ be applied to an inductor, a resistor R and a capacitor C all in series as shown in Figure. If I is instantaneous current flowing through the circuit, the applied voltage in phasor form is given by

$$V = V_R + V_L + V_C = RI + j\omega LI + \frac{I}{j\omega C} = \left[R + j\omega L + \frac{1}{j\omega C}\right] I$$
$$= \left[R + j\left(\omega L - \frac{1}{\omega C}\right)\right] I$$

The impedance

$$Z = \frac{V}{I} = \left[R + j\left(\omega L - \frac{1}{\omega C}\right)\right]$$

If we write $Z = Ze^{i\varphi} = Zcos\ \varphi + Zsin\ \varphi$,then

$$Z = \left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^{\frac{1}{2}}$$

And

$$\tan\varphi = \left[\frac{\left(\omega L - \frac{1}{\omega C}\right)}{R}\right]$$

Therefore,current

$$I = \frac{V_0 e^{j\omega t}}{Ze^{j\varphi}} = \frac{V_0 e^{j(\omega t - \varphi)}}{Z}$$

Three cases thus arise:

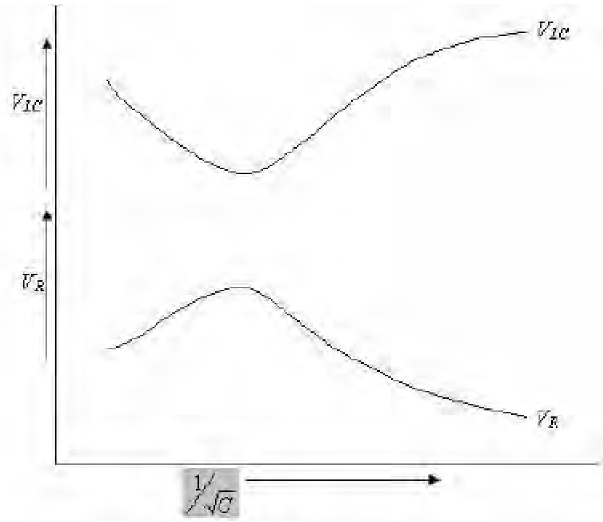
1. $\omega L > \frac{1}{\omega C}$, $tan\varphi$ is positive and applied voltage leads current by phase angle φ.
2. $\omega L < \frac{1}{\omega C}$, $tan\varphi$ is negative and applied voltage lags behind current by φ .
3. $\omega L = \frac{1}{\omega C}$, $tan\varphi$ is zero and applied voltage and current are in phase. This condition is known as resonance and frequency

$$\omega L = \frac{1}{\omega C} \rightarrow \omega^2 = \frac{1}{LC}$$
$$\omega = \omega_0 = \frac{1}{\sqrt{LC}}$$

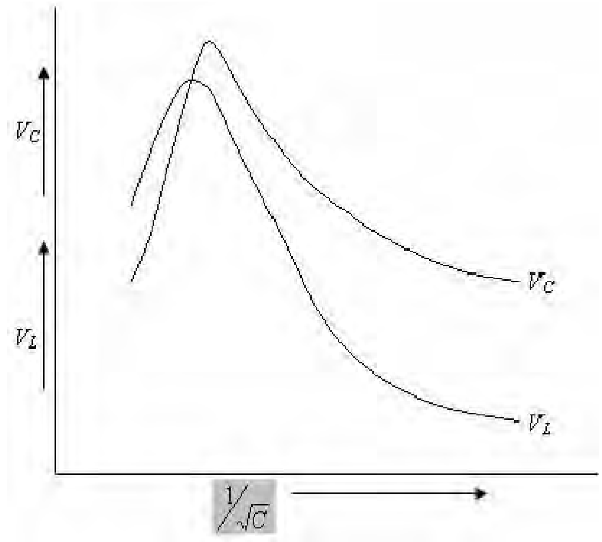
$$f = f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$\omega L - \frac{1}{\omega C} = 0 \text{ and } V_L = V_C$$

If L, R and f (frequency of function generator) are fixed and the **Capacitance** is varied, then for lower values of C, $\omega LI < \frac{I}{\omega C}I$ or $V_c > V_L$. As the capacitance is increased in the circuit, the situation called resonance is achieved when $V_c = V_L$. If C is increased further, V_c will decrease and we have $V_c < V_L$. The point of intersection of V_c and V_L versus $1/\sqrt{C}$ curves will give resonance condition. This is depicted in Figure.



At resonance V_R is a maximum while V_{LC} is minimum as shown in Figure.



Corresponding to maximum value of V_R, C is obtained. Similarly, for minimum value of V_{LC}, C is obtained. This value of C makes the given circuit resonant at the supply frequency with constant values of L and R.

Theoretically at resonance should be zero. This should be so if the inductor is of ne gligible resistance and there are no other losses. The minimum value of V_{LC} is a measure of the effective resistance of inductor coil which is equal to the d.c. resistance plus a.c. resistance corresponding to iron and hysteresis losses.

At resonant frequency f_0, the impedance of circuit is minimum. Hence frequencies near f_0 are passed more readily than the other frequencies by the circuit. Due to this reason LCR-series circuit is called acceptor circuit. The band of frequencies which is allowed to pass readily is called **pass-band**. The band is arbitrarily chosen to be the range of frequencies between which the current is equal to or greater than $I_0/\sqrt{2}$. Let f_1 and f_2 be these limiting values of frequency. Then the width of the band is

$BW = f_2 - f_1$

The Quality factor is defined in the same way as for a mechanical oscillator and is given by

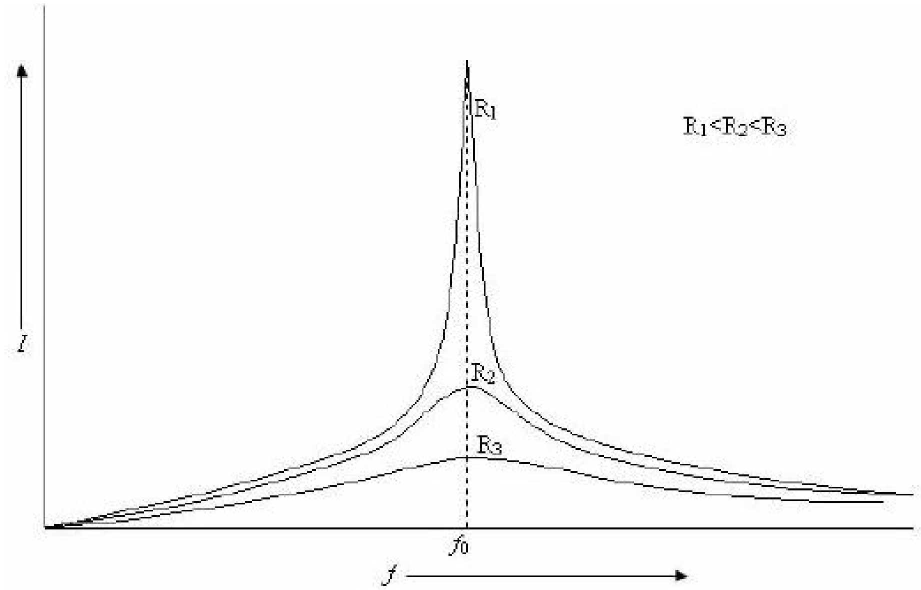
$$Q = \frac{resonant\ frequency}{bandwidth} = \frac{f_0}{f_2 - f_1}$$

Q-factor is also defined in terms of reactance and resistance of the circuit at resonance, i.e.,

$$Q = \frac{X_L}{R} = \frac{\omega_0 L}{R}$$

$$Q = \frac{X_C}{R} = \frac{1}{\omega_0 CR}$$

The resonance condition is also evident from the **resonance curves** or the graphs between $I_R = V_R/R$ and f for different values of R shown in Figure. The **bandwidth** as well as Q-factor can be calculated.



Parallel L-C-R

At resonance the parallel resonant circuit has very high impedance. The resistance at resonance offered by the parallel resonant circuit is very high if the resistance of the inductance is very small, and is known as the dynamic resistance.

We now discuss how a series LCR circuit is different than a parallel LCR circuit. The condition of resonance in this case is known as **anti-resonance**. We will derive the condition of anti-resonance of a parallel LCR circuit. The laboratory method of determination of the anti-resonant frequency and hence the Quality factor is explained.

Consider a circuit containing an inductor L and a capacitor C connected in parallel to an a.c. source (Figure 2). The resistance R is connected in series with the inductor L and includes its resistance.

The total admittance of the LCR combination is given by

$$\frac{1}{Z} = \frac{1}{X_c} + \frac{1}{X_L + R}$$

$$\frac{1}{Z} = \frac{1}{(1/j\omega C)} + \frac{1}{j\omega L + R}$$

$$= j\omega C + \frac{R - j\omega L}{R^2 + \omega^2 L^2}$$

$$= \frac{R}{R^2 + \omega^2 L^2} + j\left(\omega C - \frac{\omega L}{R^2 + \omega^2 L^2}\right)$$

For the condition of resonance, current and voltage are in phase and the coefficient of j, i.e., the reactive term which brings about a phase change is zero, hence

$$\omega_0 C - \frac{\omega_0 L}{R^2 + \omega^2 L^2} = 0$$

$$2\pi f_0 C - \frac{2\pi f_0 L}{R^2 + 4\pi^2 f^2 L^2} = 0$$

Which gives

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

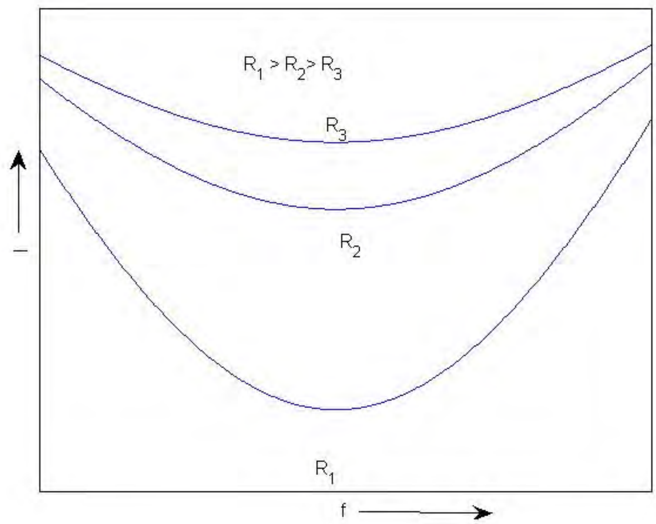
At resonance, the impedance of the circuit is maximum and is given by

$$\frac{1}{Z} = \frac{R}{R^2 + \omega_0^2 L^2}$$

$$Z = R + \frac{L^2}{R}\left(\frac{1}{LC} - \frac{R^2}{L^2}\right)$$

or

$$Z = \frac{L}{RC}$$



The impedance at resonance is called **dynamic resistance.** The current has minimum value (Figure). It is for this reason that the condition of resonance for a parallel LCR circuit is known as anti-resonance and the corresponding frequency as the anti-resonance frequency.

The shape of the impedance versus frequency curve in a parallel LCR circuit is the same as the shape of the current versus frequency curve in a series LCR circuit. In other words, the circuit has very high impedance at the anti-resonant frequency. The parallel tuned circuit is used to select one particular signal frequency from among others. It does this by rejecting the resonant frequency because of its high impedance. This is the reason why this type of circuit is also known as a rejector circuit.

The circuit is more selective if it offers a high impedance at resonance and much lower impedance at other frequencies. The Q-factor is defined in the same way as for a series LCR circuit. As in the series circuit, Q can also be written as

$$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 C\, R} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

11.7 Self Learning Exercise-I

Q.1 Give other names of LCR series circuit.

Q.2 Give any practical application of parallel LC circuit.

Q.3 Define resistance.

Q.4 If keeping same L and C and then we change value of R in a series LCR circuit what would be the effect on its behavior.

Q.5 If in an LCR series circuit resistance is made four times. What would be the effect on resonance frequency which quantity would be affected and how.

11.8 Procedure

A. Series resonance:

1. Connect the circuit as shown in the figure1. The source resistance and the series resistance should be small.

2. Set the output of function generator to sine wave signal of approximately $5V_{AC}$ rms and set the frequency at 100Hz.
3. Increase the frequency in small steps towards 10 kHz and every time note down the observations in table. At a particular frequency current starts decreasing. The frequency at which current starts decreasing is the resonant frequency.
4. Repeat the procedure for different value of R and C.
5. Plot graph between frequency and current by taking frequency X axis and current along Y axis.

B. Parallel resonance

1. Connect the circuit as shown in the figure2.
2. Set the output of function generator to sine wave signal of approximately $3V_{AC}$ rms and set the frequency at 100Hz.
3. Increase the frequency in small steps towards 10 kHz and every time note down the observations in table. At a particular frequency current starts increasing. The frequency at which current starts increasing is the anti-resonant frequency.
4. Repeat the procedure for different value of R and C.
5. Plot graph between frequency and current by taking frequency X axis and current along Y axis.

11.9 Observation

1. L-C-R series

S.No.	Frequency (Hz)	Current (mA)

2. L-C-R parallel

S.No.	Frequency (Hz)	Current (mA)

11.10 Graph

LCR Series: A graph is drawn for current against frequency. The frequency corresponding to maximum current is noted and it is the resonant frequency f_0. The frequencies f_1 and f_2 corresponding to half power points is noted and from it the bandwidth is noted. From the values of f_0, f_1 and f_2, the quality factor Q is calculated.

LCR Parallel: A graph is drawn for current against frequency. The frequency corresponding to minimum current is noted and it is the anti- resonant frequency f_0.

11.11 Calculations

In Series resonant circuit

Resonant frequency f_0 =

Inductance $L=1/4\pi^2 f_0^2 C=$

From graph, f_1 = and f_2 =

Bandwidth $B = f_2 - f_1 =$

Quality factor $Q = f_0/B=$

In Parallel resonant circuit

Resonant frequency f_0 =

Inductance $L=1/4\pi^2 f_0^2 C=$

And from graph, f_1 = and f_2=

Bandwidth $= f_2 - f_1 =$

Quality factor $Q = f_0/B=$

11.12 Result

1. Frequency responses are shown in the graphs.
2. The resonant frequency of L-C-R series circuit is………………
3. The resonant frequency of L-C-R parallel circuit is…………………….
4. The quality factor …………… and band width …………….of L-C-R series circuit.
5. The quality factor …………… and band width …………….of L-C-R parallel circuit.

11.13 Discussion

Model Discussion:

We have verified the behavior near the resonance point of the LCR-circuit. We have done this for circuits connected in the series and in the parallel combinations.

In investigating the theory of the components in series we discovered that the resistance of the inductor was important when analyzing our experimental data. This resistance added a constant factor to our theoretical formula and was important in calculation the quality factor.

In investigating the theory of the components in the parallel combination, we discovered a much greater spread in the amplitude ratio. This was probably caused by the spread in the argument of the sinusoidal input and using a generator with a more narrow peak would improve the fit to the theory.

11.14 Precautions and Sources of error

1. Make the connections according to the given diagram.
2. Connection should be tight.
3. The internal resistance of the source and series resistance should be small.
4. For the complete experiment voltage and frequency of oscillator should remain constant.

11.15 Self Learning Exercise-II

Q.1 Impedance is at maximum in LCR ……… circuit, at resonance

Q.2 At resonance, circuit current is at……in LCR parallel circuit.

Q.3 How the LCR parallel circuit behave at resonance?

11.16 Glossary

***Resistivity* :**Resistance between the terminal of unit and unit length conductor is known as resistivity of that material, its unit is OHM-meter.

Reactance: Resistance offered to the flow of current by any inductive coil or a capacitor is known as reactance. Reactance of a inductor is $X_L=2\pi f L$ where L is coefficients of self induction and f is frequency when L is in Henry and f in cps/Hz the reactance X_L is in OHMS. The reactance of a capacitor is $X_c=1/2\pi fC$. Where C is in farads and f in cps/Hz the reactance X_c is in OHMS.

I*mpedance:* In any circuit the impedance is $Z=\sqrt{R^2+X^2}$ where X is resultant reactance of the circuit $X=X_L \sim X_C$. Unit of this is also OHM.

Admittance: The admittance is defined as reciprocal of impedance i.e. Y. Admittance =1/ Impedance. Its unit is MHO.

Susceptance: Susceptance=1/reactance (MHO)

Conductance: Conductance=1/resistance (MHO)

Conductivity :Conductivity=1/resistivity (MHO-m^{-1})

Anti-resonance: the condition in a parallel LCR circuit when the impedance of the circuit is maximum and the current minimum is termed as anti-resonance.

Anti-Resonant Frequency: For a parallel LCR circuit the frequency at which the current has minimum value, is called anti-resonant frequency.

Bandwidth: The range of frequencies lying within the upper and lower cut-off frequencies which correspond to 0.707 times the voltage value at resonance is called bandwidth. It is also defined as the difference between the two half power frequencies which correspond to the points where the power has been reduced to one half of its value at resonance.

Capacitance: The property of a conductor that describes its ability to store electric charge is called capacitance C and is given by Q/V where Q is the charge stored on the conductor and V is the potential difference between the conductor and earth.

Pass-band **:** certain range, or band, of frequencies allowed to pass, all other frequencies being blocked by the series LCR circuit.

RMS **:**An alternating potential difference has a value of one volt rms (root mean square) if it produces the same heating effect when applied to the ends of a resistance as is done by a steady potential difference of one volt applied to the same resistance in the same time. Numerically, rms value is $1/\sqrt{2}$ times the maximum value. The a.c. ammeters and voltmeters measure the root mean square (rms) value of the current and potential difference respectively.

Quality factor :It is a measure of the selectivity or the sharpness of the resonance curve and is denoted by Q. A low value of resistance in the circuit leads to a high Q. Quality factor is given by the ratio of the voltage across the inductor to the input voltage and is hence a dimensionless quantity. Since Q is ordinarily greater than unity, it is termed as the magnification factor of the circuit.

Resonance: The condition in a series LCR circuit when the impedance is purely resistive and hence minimum and current maximum is called resonance.

Resonance Curve **:**A graph showing the variation of the voltage across a circuit (or a part of it) with frequency in the vicinity of resonance is the response curve or the resonance curve.

Resonant Frequency: For a series LCR circuit the frequency at which the reactance due to the inductor, X_L, is exactly equal and opposite to the reactance due to the capacitor, X_C, resulting in the impedance of the circuit being purely resistive, is called the resonant frequency.

11.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Tuning circuit, resonance circuit, selector circuit.

Ans.2: This circuit is used as oscillator means like alternative current generator. This circuit is also used like a form of component of very high impedance circuit.

Ans.3: Opposition offered by any conductor to flow of current is known as resistance. If in any conductor I ampere current flows for the potential difference of V volts across its terminal then the resistance R=V/I, its unit is OHM.

Ans.4: The resonant frequency in two case would be the same but Q factor would increase with decrease in resistance i.e. the curve would be narrower for lesser R.

Ans.5: There is no difference because resonance frequency does not depend upon the resistance of the circuit. The quality factor Q would change as per $Q=\omega L/R$ it would become one fourth.

Answers to Self Learning Exercise-II

Ans.1: Parallel

Ans.2: Minimum

11.18 Viva Questions

Q.1 Define resonance?

Q.2 What are the impedances of Condenser of 50μF and coil of 50mH in a DC circuit?

Q.3 In series resonance the current is …. …& the impedance is ……

Q.4 In parallel resonance the current is …… & the impedance is ……

Q.5 Define bandwidth.

Q.6 Define selectivity

Q.7 When resistors are connected in series, the total resistance ………the individual resistor values.

Q.8 When resistors are connected in parallel, the total resistance………the individual resistor values.

Q.9 At frequency below resonant frequency, what will be the nature of overall reactance?

Q.10 At frequency above resonant frequency, what will be the nature of overall reactance?

Q.11 Does resonance occurs in dc or ac circuits?

Q.12 What is the effect of resistance on the frequency response curve?

11.19 Answers to Viva Questions

Ans.1: In case of forced oscillation when frequencies of driver and driven become equal, it is called condition of resonance or in any LCR circuit there is a frequency called resonance frequency f_r=1/2π√LC, when applied frequency $f = f_r$ it is called condition of resonance.

Ans.2: Infinite and zero respectively.

Ans.3: Maximum, minimum

Ans.4: Minimum, maximum

Ans.5: The frequency band within the limits of lower & upper half power frequency is called the bandwidth

Ans.6: It is defined as the ratio of resonant frequency f to the bandwidth of the circuit i.e. Selectivity=$f_0 / (f_2-f_1)$

Ans.7: is greater than

Ans.8: is less than

Ans.9: At $f<f_0$, the overall reactance will be capacitive

Ans.10: At $f>f_0$, the overall reactance will be inductive

Ans.11: Resonance occurs in ac circuits only.

Ans.12: The frequency response curve with small resistance rises steeply & has a tall narrow peak while the curve with large resistance rises less steeply & has a low broad.

References and Suggested Readings

1. Electric circuits & Network by Kumar and Kumar.
2. Digital Principles and Applications by Leach and Malvino.
3. Electronics Principles by Malvino.

UNIT-12

Conductance, Resistance and Inductance of a coil at radio frequency and to study the variation of Z with frequency.

Structure of the Unit

12.1 Aim

To determine the value of Conductance, Resistance and Inductance of a coil at radio frequency and to study the variation of Z with frequency.

12.2 Apparatus

Power supply unit, the bridges, the oscillator, switches, fuses, coupling agreements, inductance, resistance and capacitance.

12.3 Diagram

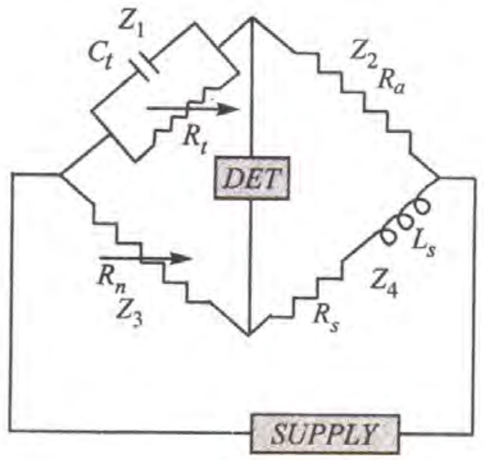


Figure 7.1: Series L Bridge

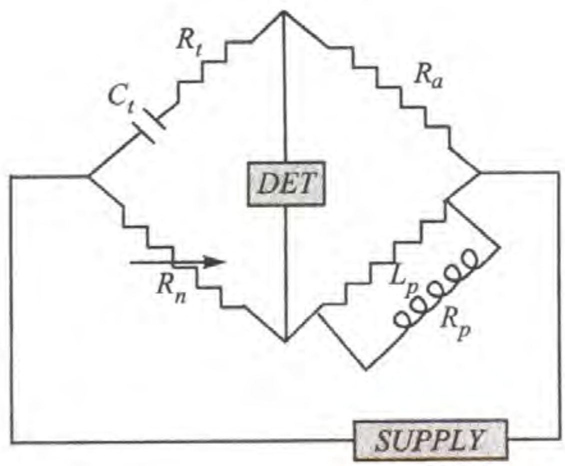


Figure 7.2: Parallel L bridge

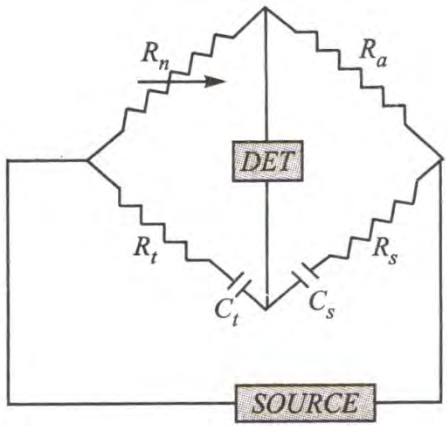


Figure7.3: Series Capacitance Bridge

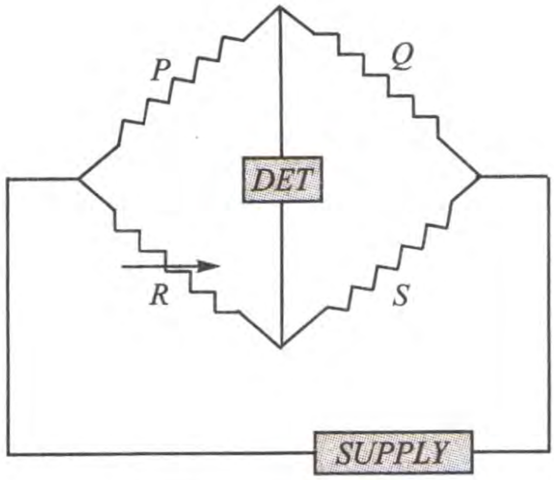


Figure 7.4: Wheatstone bridge

12.4 Formula

Impedance bridges in A.F. range are based on the principle of Wheatstone bridge. A number of suitable bridges may be combined to form an impedance bridge. The selection of the components of the bridges depends upon

(i)The measurements to be made,

(ii)The frequency at which the measurements are to be made,

(iii)The desired accuracy of measurement and other minor considerations,

The selection of the detector is mainly based on the frequency. But, in general, a centre zero micro ammeter or a mA with bridge rectifier serves a very good purpose over a wide range of frequencies.

Impedance bridges are supplied by manufactures. These are made for direct reading by using a number of switches and calibrated dials. These bridges afford direct current as well as alternating current measurements. The usual internal alternating current supply is at 1 KHz. The gap terminals are provided for the test L, C, R parts or combinations, the external supply and detector. Proper coupling and shielding arrangements are made internally.

12.5 Theory and description

For the determination of the value of the inductance resistance and capacitance, we have the following knowledge:

Series and Parallel Inductance Bridge:-

The bridges for the determination of series and parallel inductances are sown in figure 7.1 and 7.2. By applying Wheatstone bridge principle in conjunction with $Kirchoff$'$s\ laws$, the series and parallel inductances L_S, L_P respectively are given by the relations

$$L_s = R_a . R_n . C_t$$

...................(7.1)

$$L_P = R_a . R_n . C_t \qquad ....(7.2)$$

(i) The relations are arrived as by equating imaginary parts of the following relations:

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}; \frac{R_t}{(1 + j\omega C_t R_t) R_a} = \frac{R_n}{R_a + j\omega L_s}$$

From figure 7.1 ....(7.3)

Similarly,

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}; \frac{1/\, j\omega C_t R_t}{R_a} = \frac{R_a (R_P + j\omega L_P)}{j\omega L_P R_P}$$

From figure 7.2 ....(7.4)

On equating real parts, the Wheatstone bridge condition is obtained. R_S, R_P are substituted from these conditions in equations (7.6) and (7.7).

(ii)The relations further show that R_a, R_n, C_t, R_t are selected according to L_S, L_P.

Dissipation Factor:-

It is the reciprocal of the 'Quality'Q, i.e. the dissipation factor is the ratio of the resistance to reactance. Hence

$$D = \frac{1}{Q} = \frac{R}{X} \quad \text{...................(7.5)}$$

Where X is the reactance.

In the above case for R_S and R_P, series and parallel resistances respectively, we get

$$D_S = \frac{R_S}{\omega L_S} = \frac{R_S}{\omega R_a.R_n.C_t} = \frac{1}{\omega R_t.C_t} \quad \text{...................(7.6)}$$

$$D_P = \frac{R_P}{\omega L_P} = \frac{R_P}{\omega R_a.R_n.C_t} = \frac{1}{\omega R_t.C_t} \quad \text{...................(7.7)}$$

Where ω is the angular frequency of the alternating current source and R_S, R_P are the series and parallel direct current resistances.

Series Capacitance Bridge:-

The bridge is shown in the above given figure 7.3. The series capacitance in the fourth arm of the bridge is given by the relation.

$$C_S = \frac{R_n}{R_a} C_t \quad \text{...................(7.8)}$$

The dissipation factor is given by the relation:

$$D = \omega R_t. C_t \quad \text{...................(7.9)}$$

Resistance Bridge:-

The ordinary Wheatstone bridge is shown in figure 7.4. The unknown resistance is given by:

$$S = \frac{Q}{P} R \quad \text{...................(7.10)}$$

Variation of Impedance with Frequency:-

We know that in a coil where inductance, capacitance and resistance all are present, in that circuit for the study of the impedance variation with radio frequency (here no matter while frequency is radio frequency or audio frequency).

We know that in the circuit the total voltage is V (say) given by:

$$V^2 = V_R^2 + V_L^2 + V_C^2 \qquad \text{..................(7.11)}$$

For resistance, we know that $V_R = iR$

For inductance, we know that $V_L = iX_L$

For conductance, we know that $V_C = iX_C$

Now put these all value in equation (7.11), we have

$$V^2 = (iR)^2 + (iX_L)^2 + (iX_C)^2$$

Or

$$\left(\frac{V}{i}\right)^2 = R^2 + {X_L}^2 + {X_C}^2$$

Here $\frac{V}{i}$ is known as a new resistance 'Impedance'. It is denoted by Z. So

$$Z = \sqrt{R^2 + {X_L}^2 + {X_C}^2}$$

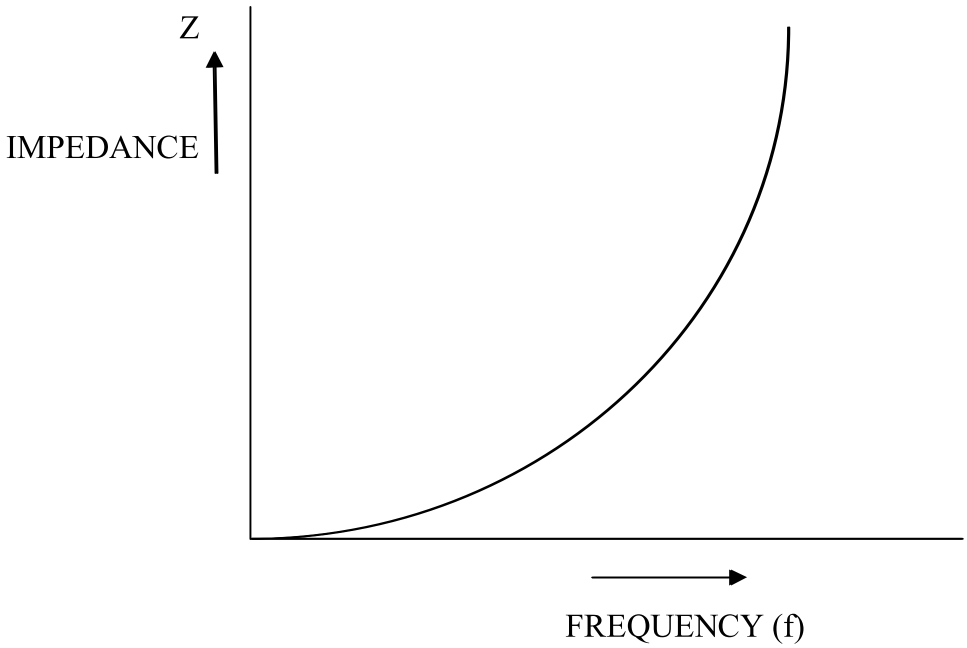
and also we know that $X_L = \omega L$ and $X_C = \frac{1}{\omega C}$

$$Z = \sqrt{R^2 + (\omega L)^2 + \left(\frac{1}{\omega C}\right)^2}$$

Now for the variation with frequency

$$\frac{\partial Z}{\partial \omega} = \frac{1}{2\sqrt{R^2 + (\omega L)^2 + \left(\frac{1}{\omega C}\right)^2}}\left(2\omega L^2 - \frac{2}{\omega^3 C^2}\right) \qquad \text{..................(7.12)}$$

From the above relation we get that as well as we increase the value of frequency, then the value of impedance will also be increase.



12.6 Self learning Exercise-I

Q.1 Give the theory of one Power supply filter.

Q.2 Give the theory of Series Inductance filter.

12.7 Procedure

For using of an impedance bridge, we may follow the procedure which is given below:

1.The mechanical zero of the detector is adjusted to give zero reading.

2.The knob is turned to $L, C\ or\ R,$ whichever is to be measured. The test inductance, capacitance or resistance is connected across the gap provided for it.

3.The supply knob is turned to alternating current or direct current according to the type of the measurement to be made. If internal supply is to be used, the knob is turned to internal(INT). It is turned to external (EXT), if external supply is to be used.

4. In order to protect the detector meter from the damage by heavy current due to unbalanced bridge, the shunting knob is turned to 'shunted', which is turned to

‘unshunted’ after adjusting the detector reading near zero to obtain the final balance.

5.If the external detector is to be used, the corresponding detector knob is turned to external detector $(EXT\ DET)$.

6. The unit is switched on and allowed to warm up for few minutes. The respective knobs L, C and R are worked to get the approximate balance with shunted and accurate balance with unshunted detector. The readings are taken. The values are read either directly in case of a direct reading instrument or calculated by the balanced bridge relations.

(a) A capacitor with losses may be thought to be equivalent to a perfect capacitor with a series or parallel resistance. The principle shows the determination of such capacitance.

(b) Parallel capacitance determination is important at $radio\ frequencies$, where leakage resistance and lead inductance losses are important. The series and parallel capacitances are related through the dissipation factor D and given by the relation:

$$\frac{C_S}{C_P} = 1 + D^2 \qquad \text{..................(7.11)}$$

7.Series and parallel resistance of the capacitor: The series resistance is given by the relation:

$$R_S = \frac{D}{\omega C_S} \qquad \text{..................(7.12)}$$

Where D is the Dissipation factor.

The parallel resistance or the leakage resistance is given by the relation:

$$R_P = \frac{1+D^2}{D^2} R_S = \frac{1+D^2}{D\omega C_S} = \frac{1}{D\omega C_P} \qquad \text{..................(7.13)}$$

8.The capacitance of the bridge, the inductance of the connecting leads may be determined by balancing the bridge without the capacitor and with leads in the gap, respectively as separate experiments.

9. **Measurements of parallel inductance of an inductor:** It is given by the relation:

$$L_P = \frac{1+Q}{Q^2} L_S \qquad \text{..................(7.14)}$$

Where L_S is the series inductance and 'Q' is the quality factor or storage factor.

The factor 'Q' is given as the ratio of reactance to resistance, i.e.

$$\frac{1}{D} = Q = \frac{X}{R} = \frac{\omega L}{R} \qquad \text{..................(7.15)}$$

Series Inductance: The meaning of the series inductance is the effective inductance at a given frequency together with a series residual resistance.

Parallel Inductance: It refers to the effective inductance paralleled by the insulation resistance of the coil.

10. **The series and parallel a.c. resistance of the coil:** The series and parallel a.c. resistance of the coil are given by the relation.

$$R_S = \frac{\omega L}{Q} \qquad \text{..................(7.16)}$$

$$R_P = (1 + Q^2) R_S = \frac{1+Q^2}{Q} \omega L_S = Q\omega L \qquad \text{.................(7.17)}$$

The above given theory is the basis of the determining the L, C, and R.

12.8 Observation

For Inductance:

(A) When inductance connected in series:

S.NO.	CAPACITANCE $C_t\ (\mu F)$	FIXED RESISTANCE $R_n\ (in\ k\Omega)$	VARIABLE RESISTANCE $R_a\ \ (in\ \Omega)$	L_S
1	4.1	0.11		
2	4.1	0.11		
3	4.1	0.11		
4	4.1	0.11		

Here $R_a = 1\Omega\ to\ 100k\Omega, R_n = 0.11k\Omega, C_t = 4.1\mu F, R_t = 160\Omega$

(B) When inductance connected in parallel:

S.NO.	CAPACITANCE C_t (μF)	FIXED RESISTANCE R_n $(in\ k\Omega)$	VARIABLE RESISTANCE R_a $(IN\ \Omega)$	L_P
1	4.1	0.11		
2				
3				
4				
5				

Here $R_a = 1\Omega\ to\ 100k\Omega, R_n = 0.11k\Omega, C_t = 4.1\mu F, R_t = 160\Omega$

$$D_S = \frac{1}{\omega R_t . C_t}, D_P = \frac{1}{\omega R_t . C_t}$$

By putting the value of above parameters, you can successfully calculate the value of Dissipation factor for Parallel and Series.

For Series Capacitance:-

S.NO.	CAPACITANCE C_t (μF)	FIXED RESISTANCE R_n $(in\ k\Omega)$	VARIABLE RESISTANCE R_a $(IN\ \Omega)$	VARIABLE RESISTANCE R_t $(IN\ \Omega)$
1	0.01	0.11		
2				
3				
4				
5				

$$R_a = 1\Omega\ and\ M\Omega, R_n = 0.11k\Omega\ , C_t = 0.01\ \mu f, R_t = 1.5\ to\ 16\ k\Omega$$

For Resistance:-

S.NO.	FIXED RESISTANCE ‘R’(IN KΩ)	VARIABLE RESISTANCE ‘P’	VARIABLE RESISTANCE ‘Q’
1	0.11		
2			
3			
4			
5			

$$P = 1\ \Omega to\ 10\ k\Omega, Q = 1\Omega\ to\ 1M\Omega, R = 0.11k\Omega, S = ?$$

12.9 Graph

Plot the graph between impedance and frequency on graph paper.

12.10 Calculations

To put the all observation value in the given formulae, you get easily value of Inductance, Capacitance and Resistance.

12.11 Result

(i) The inductance of the coil at frequency..........=..........$henry$.

(ii) The capacitance of the capacitor at frequency.......=........μF.

(iii) The resistance of the test coil at frequency ....=.......ohm.

$$\%error = \frac{Experimental\ value - Standard\ value}{standard\ value} \times 100$$

....

12.12 Discussion

12.13 Precautions and Sources of error

(i) The circuit should be check by the teacher.

(ii) Don't touch any open wire, otherwise you get a shock.

(iii) All the value should be based on the logarithmic calculation.

(iv) May be the circuit is connected by you, is wrong. It is very common source of Error.

12.14 Self Learning Exercise-II

Q.1 A full-wave rectifier uses shunt capacitor $C = 12\mu F$. The supply frequency is $f = 50\ Hz$. The angle of conduction $\theta_C = \theta_2 - \theta_1$ has value 27° for a load resistance of $R = 10\ k\Omega$. Find (a) the ripple factor at the output of the filter; (b) ratio of this ripple factor to that for a rectifier with the filter capacitor.

Q.2 A full-wave rectifier uses filter inductance $L = 20\ H$ and a load resistance $R_L = 20k\Omega$. A sinusoidal voltage $v = 300 \sin 2\pi \times 50t$ is applied to the input. Assuming the rectified output to contain second harmonic only, find (a) d c load current; (b) d c output voltage; (c) ripple factor; (d) ratio of ripple to that without inductor filter.

12.15 Glossary

Impedance: In LCR circuit the ratio of total voltage with the total current, is known as Impedance.

Inductance: The property of an electric conductor or circuit that causes an electromotive force to be generated by a change in the current flowing.

Capacitance: The ability of a system to store an electric charge.

Resistance: A measure of the degree to which conductor opposes an electric current through that conductor.

12.16 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Filter circuits are employed to reduce the rectifier output ripple. This is achieved by either by passing the ac output components around the load by a shunt capacitance, or limiting their magnitude to a low value in the load by a series inductance or a combination of these two for more efficient circuits.

The circuit arrangement of the capacitor filter is shown in below given figure $1(a)$. The capacitance is so chosen that $X_C << R,$ and alternating currents find a low-reactance shunt in C. Only a small alternating current component passes in C. Only a small alternating current component passes in R, producing a small ripple voltage. The capacitor alters the conditions under which the diode operates. When the diode output voltage is increasing, the capacitor stores energy, by charging to the peak to the input cycle as shown in Figure $1(b)$. With falling source-voltage, the diode disconnects the source from the load at the instant when the source voltage starts to fall faster than the capacitor voltage can fall, as determined by the time constant of C and the load. The capacitor continues to maintain the load voltage at a higher value and lower ripple than if the capacitor were not present. The diode delivers a charging pulse of current in each cycle and then disconnects source from the load. The circuit is excited by repeated current transients as shown in figure $1(c)$.

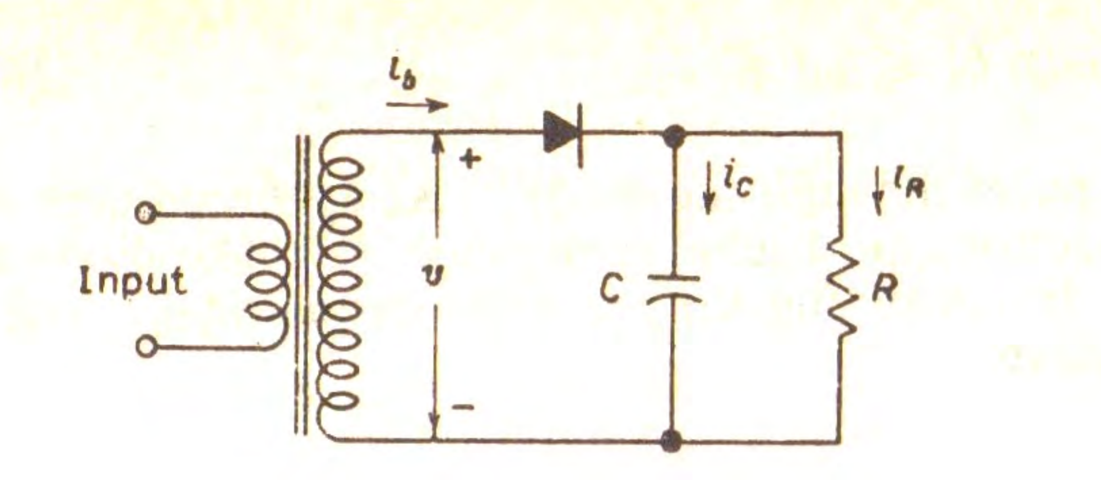


Figure 1(a)

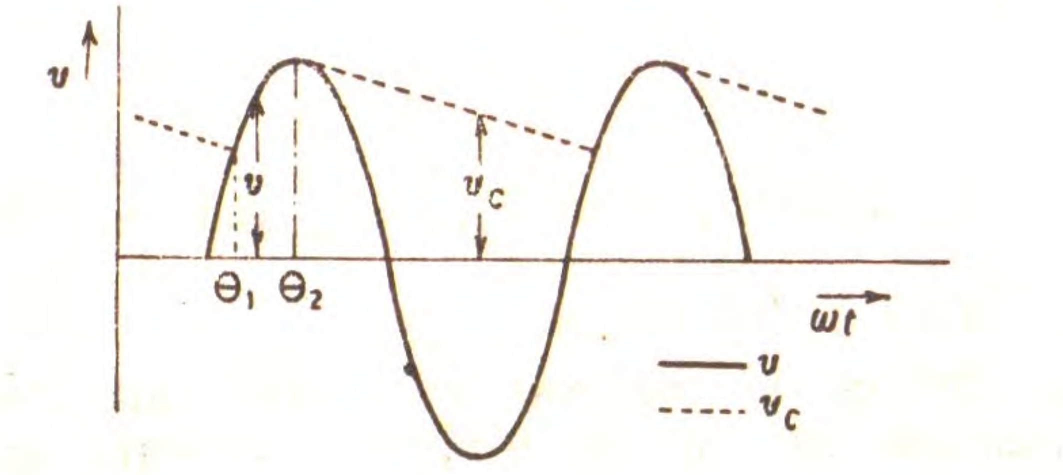


Figure 1(b)

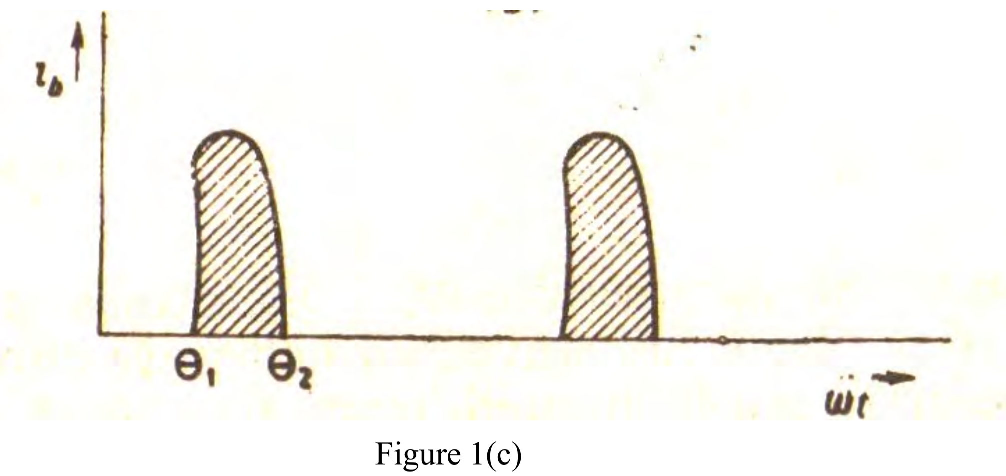


Figure 1(c)

Similarly we can define for full-wave circuit, whose circuit is given below in figure 2.

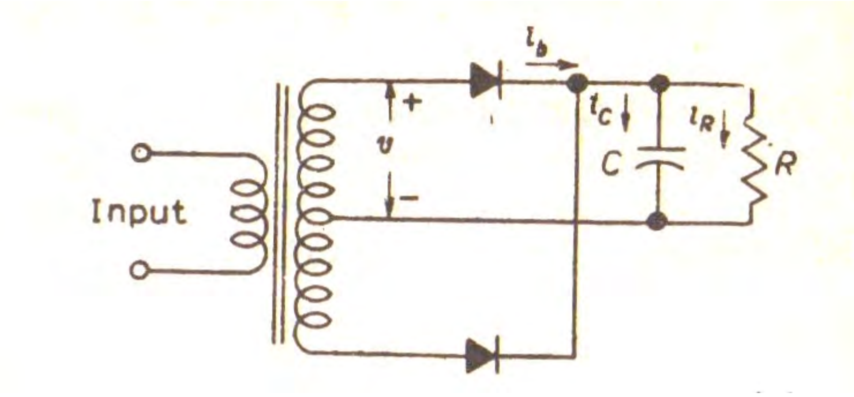


Figure 2(a)

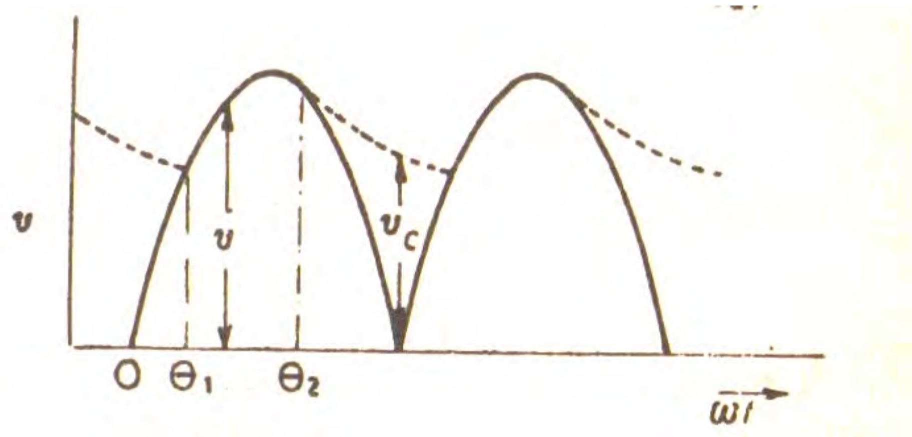


Figure 2(b)

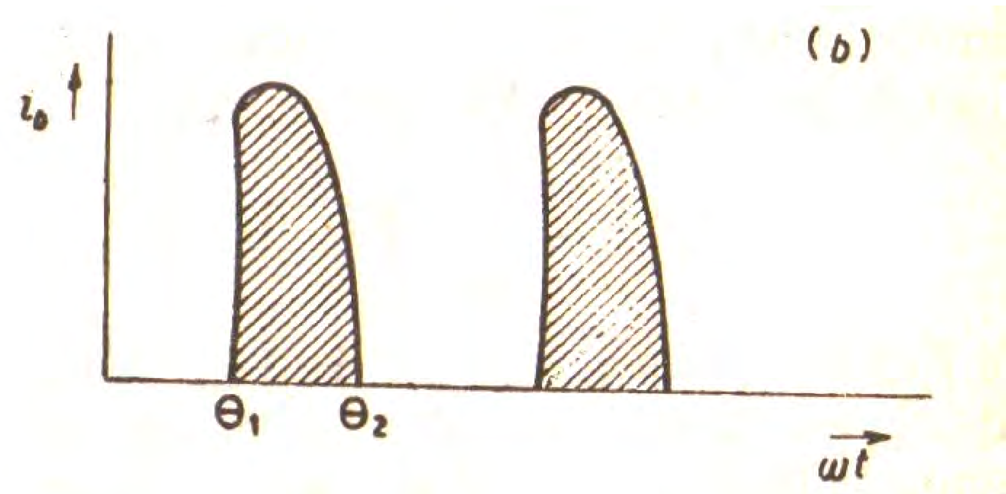


Figure 2(c)

Ans.2: The operation of the inductor filter depends on the fundamental property of an inductor tom oppose any change of current. As a result, any sudden changes that might occur in a circuit without an inductor are smoothed out by the presence of an inductor in the circuit. Suppose that an inductor input filter is applied to the output of a full-wave rectifier. The circuit with load current waveform is shown in below given figure 1.

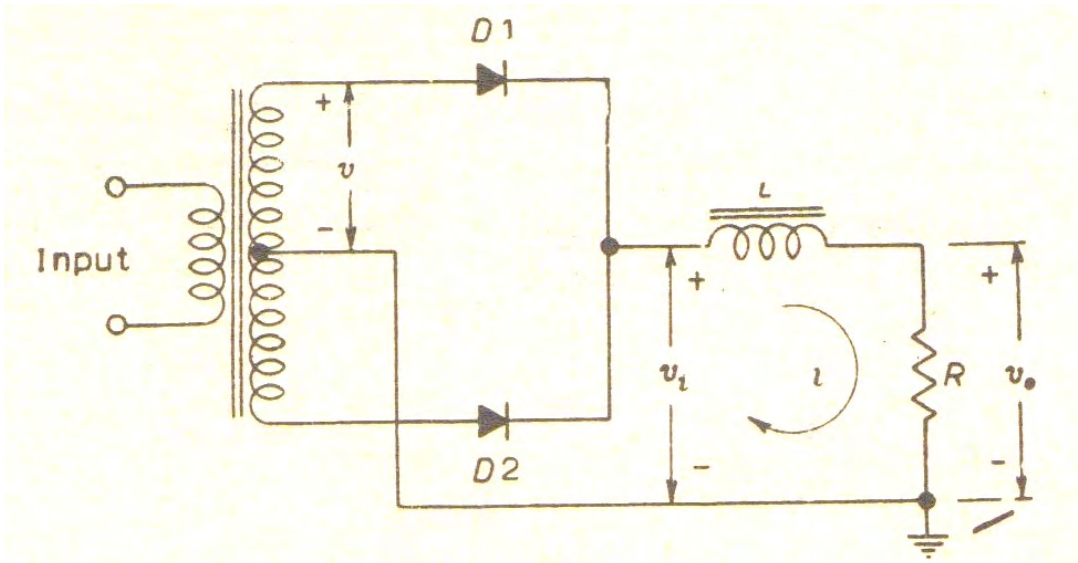


Figure 1(a)

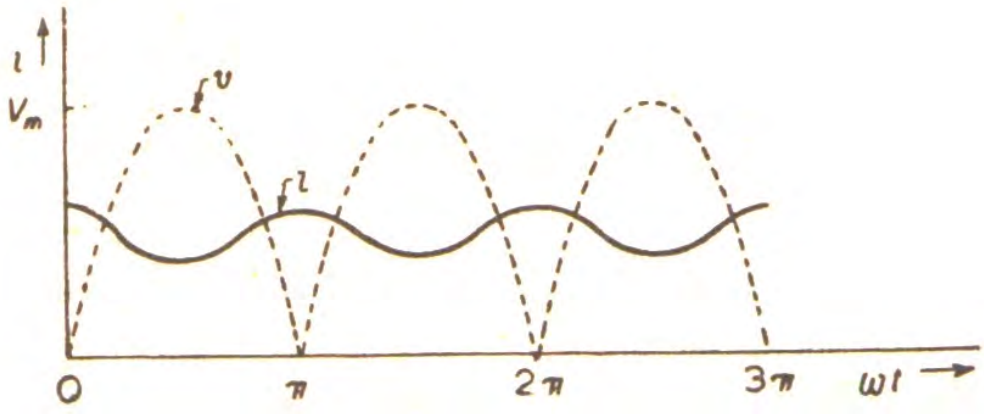


Figure 1(b)

The voltage applied to the circuit comprising the load resistor and the inductor filter is that given in equation

$$i_L = i_{D_1} + i_{D_2} = I_m \left\{ \frac{2}{\pi} - \frac{4}{3\pi} \cos 2\omega t - \frac{4}{15\pi} \cos 4\omega t \right\}$$

With the current replaced by the voltage, since the impedance of the inductor increases with the frequency, better filtering action for the higher-harmonic terms results. It is, therefore, expected that the waveform in the output will be principally of second-harmonic frequency, and we may neglect all harmonics except the first ac term. Under these circumstances, the equivalent circuit of the rectifier is shown in below given figure 2.

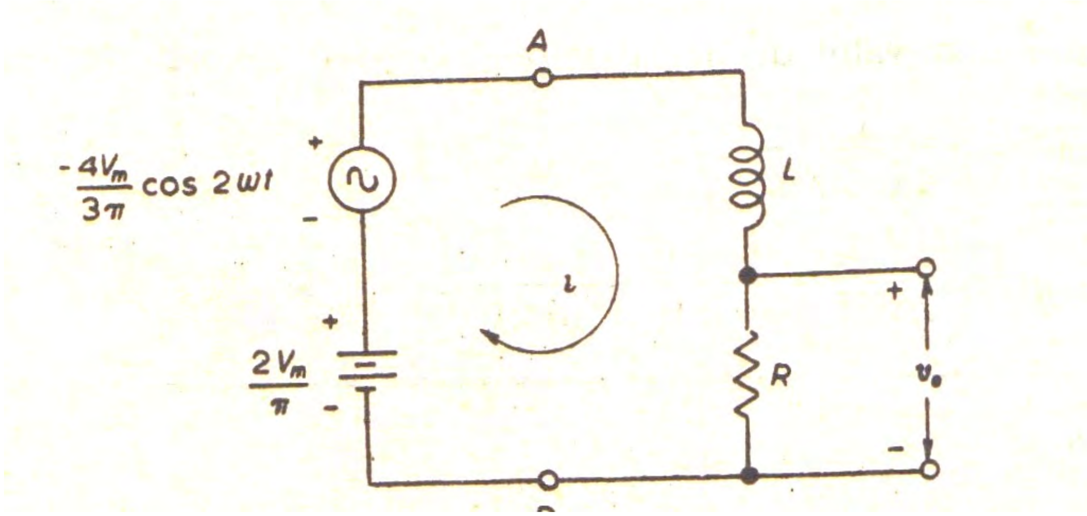


Figure 2

Answers to Self Learning Exercise-II

Ans.1: (a) The ripple factor is given by the equation is

$$r = \frac{\pi - (\theta_2 - \theta_1)}{2\sqrt{3}\ \omega RC} = \frac{\pi - (\theta_2 - \theta_1)}{4\sqrt{3}\ \pi f RC}$$

Here $\theta_C = \theta_2 - \theta_1 = 27^\circ = \frac{27\pi}{180}\ radian$

Now

$$r = \frac{\pi - \frac{27\pi}{180}}{2\sqrt{3}\ \times \pi \times 50 \times (10 \times 10^3) \times (12 \times 10^{-6})}$$

$$r = \frac{1.67}{130.6} = \mathbf{0.02\ or\ 2}\%$$

(b) Ripple factor without filter is 0.482. Therefore, the ratio of ripple factor with filter to that without filter is

$$\frac{0.02}{0.482} = \mathbf{0.04}$$

Ans.2: (a) For the output current, we have

$$I_{dc} = \frac{2V_m}{\pi R_L}$$

$$I_{dc} = \frac{2 \times 300}{\pi \times 20 \times 10^3} = 0.01\ A = \mathbf{10\ mA}$$

(b) For the output voltage, we have

$$V_{dc} = I_{dc} R_L$$
$$V_{dc} = 0.01\ \times 20 \times 10^3 = \mathbf{200\ V}$$

(c) For ripple factor, we have

$$r = \frac{2}{3\sqrt{2}} \frac{1}{\sqrt{1 + 4\omega^2 L^2 / {R_L}^2}}$$

$$r = \frac{2}{3\sqrt{2}} \frac{1}{\sqrt{1 + \left(\frac{2 \times 2\pi \times 50 \times 20^2}{20 \times 10^3}\right)^2}}$$

$$\boldsymbol{r = 0.34}$$

(d) Now ratio of this ripple factor to that without filter is

$$\frac{0.340}{0.482} = \mathbf{0.7}$$

12.17 Viva Questions

Q.1 Give the definition of alternating Current.

Q.2 Give the definition of Direct current.

Q.3 What is the Series circuit of Resistance and formula?

Q.4. What is the parallel circuit of Resistance and formula?

Q.5 Define Dissipation factor.

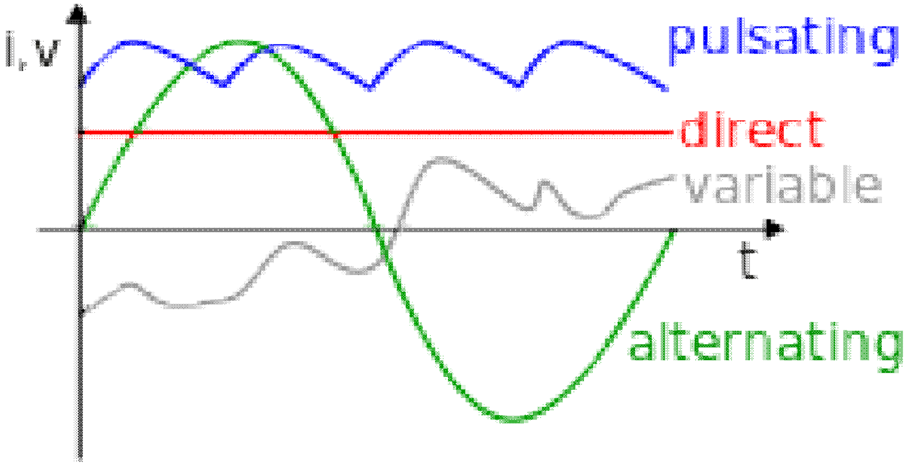
Q.6 Define quality factor.

Q.7 Give the definition of Radio frequency.

Q.8 Give the definition of Audio frequency.

12.18 Answers to Viva Questions

Ans.1: It is the form in which electric power is delivered to businesses and residences. The usual wave form of the alternating current is Sine Wave. In this type of current, electric charge is periodically reverses direction. Audio and radio signals are example of alternating current.



Ans.2: It is the unidirectional flow of electric charge. Direct current is produced by sources such as batteries, thermocouples, solar cells. It may flow in conductor such as a wire, but can also flow through in semiconductors. A term also use for this type of the current is $Galvanic\ current.$

Ans.3: In series circuit all components of the resistor are connected with end-to-end to form only one path for electrons flow through the circuit. In this circuit, all components share the same or equal current. And the formula used for the combination of resistance is

$$R = R_1 + R_2 + R_3$$

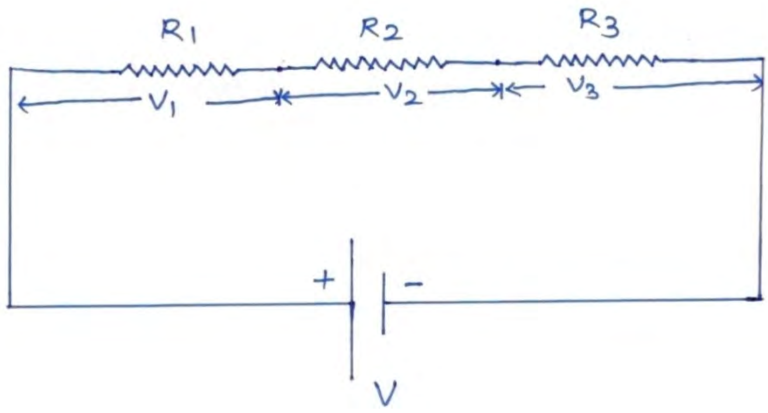


Figure: Series combination

Ans.4: in parallel circuit all components of the resistor are connected between the same two sets of electrically common points, creating multiple paths for electrons to flow from one end of the battery to the other. And the formula which is used for the combination is

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

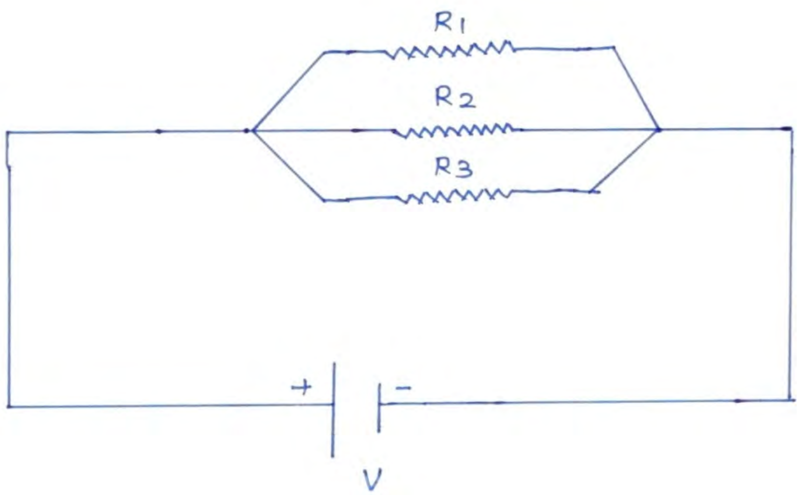


Figure: Parallel Combination.

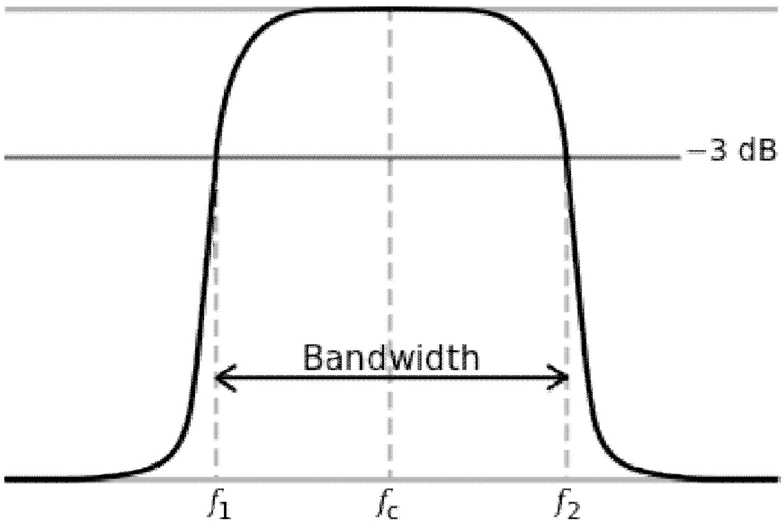
Ans.5: It is the reciprocal of the 'Quality' Q, i.e. the dissipation factor is the ratio of the resistance to reactance. Hence

$$D = \frac{1}{Q} = \frac{R}{X}$$

Here X is the reactance.

Ans.6: The quality factor is a dimensionless parameter that describes how under damped an oscillator or resonators is and it is also defines as well as a resonator's bandwidth relative to higher frequency of resonator. For the loss of low energy, we have the quality factor large.

$$Q = \frac{X}{R}$$



The above given formula is of Quality factor.

Ans.7: Radio frequency is the rate of oscillation in the range of oscillation in the range of around 3 kHz to 300 GHz, which corresponds to the frequency of radio waves, and the alternating current carries the radio signals. RF usually refers to electrical rather than mechanical oscillations.

Ans.8: An audio frequency is defined as a periodic vibration whose frequency is audible to the average human. It is the property of sound that most determines pitch.

The range of audio frequency generally accepted is 20 to 20,000 Hz.

References and Suggested Readings

1. "Electronic devices applications and integrated circuits" by "Satnam P. Mathur" "Durgesh C. Kulshreshtha" and "Prem R. Chadha".
2. Electronics theory and applications by "S.L. Kakani" and "K.C. bhandari".

UNIT-13
RC Coupled Amplifier

Structure of the Unit

13.1 Aim

Design a double stage RC coupled Amplifier and study

(i) Frequency response

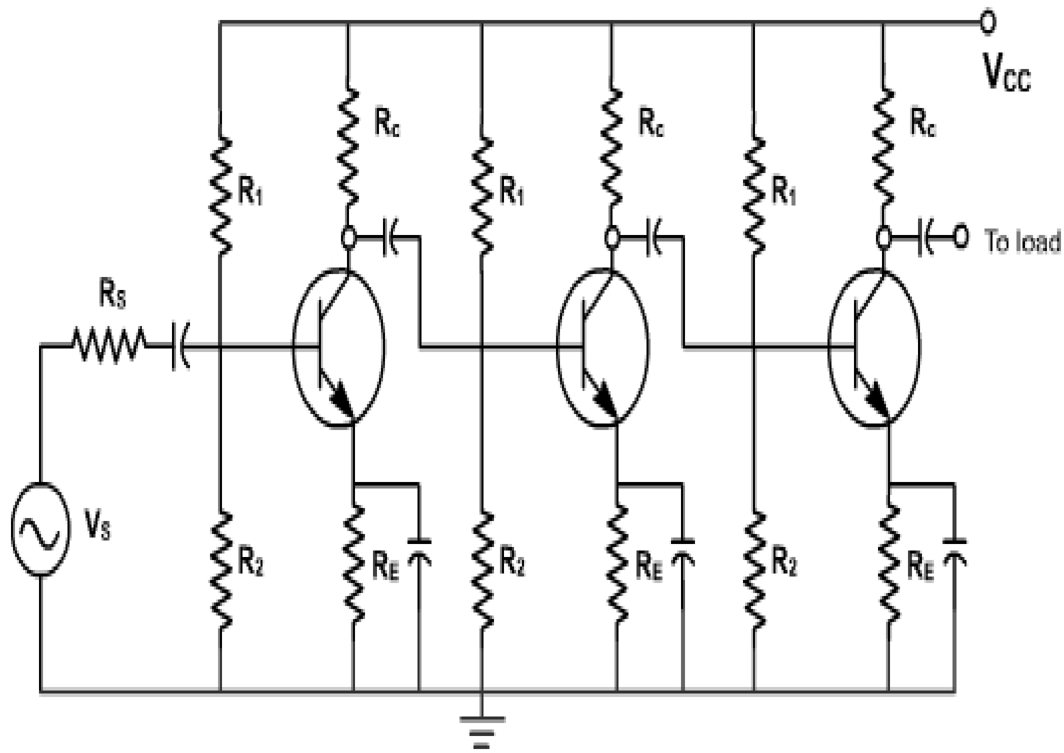
(ii) The amplitude characteristics

13.2 Apparatus

C.R.O. , Power supply (0-15V), Signal Generator (0 – 1 MHz), Bread-board, Resistors, Capacitors, Two identical n-p-n transistors, a. c. milli -voltmeter and connecting wires

13.3 Diagram

Different diagrams for RC coupled amplifier



Figur.1: Circuit diagram of three stage coupled amplifier

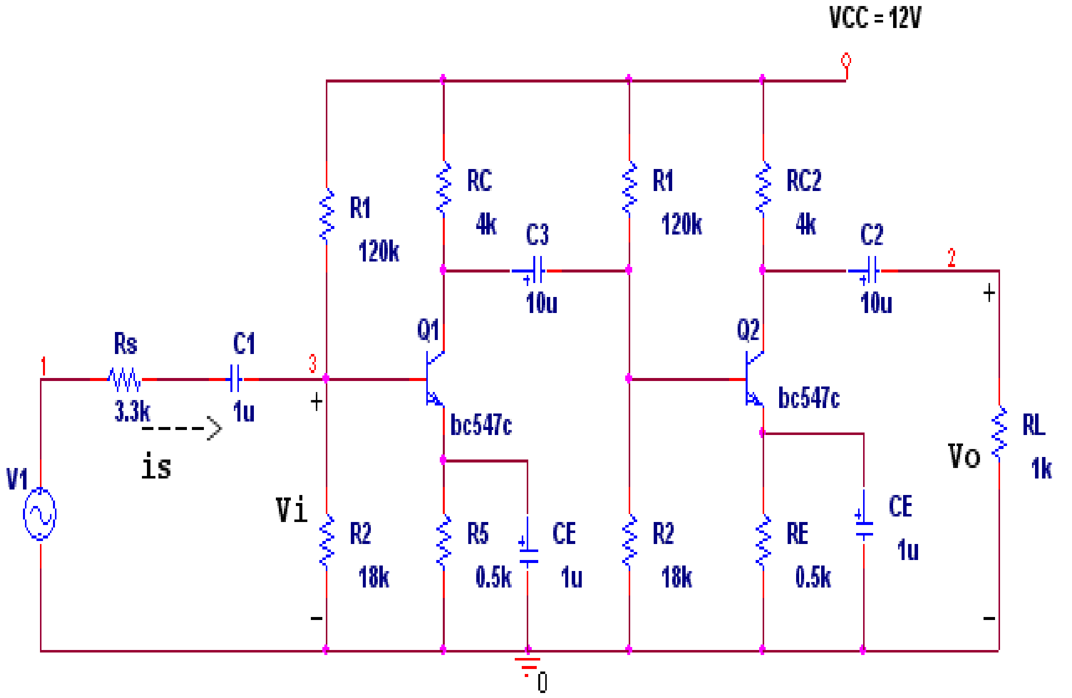


Figure 2: Circuit diagram of two stage coupled amplifier fig.2

13.4 Formula

Voltage Gain (*G*) = V_0 / V_i

Where V_o = Output voltage

V_i = Input voltage

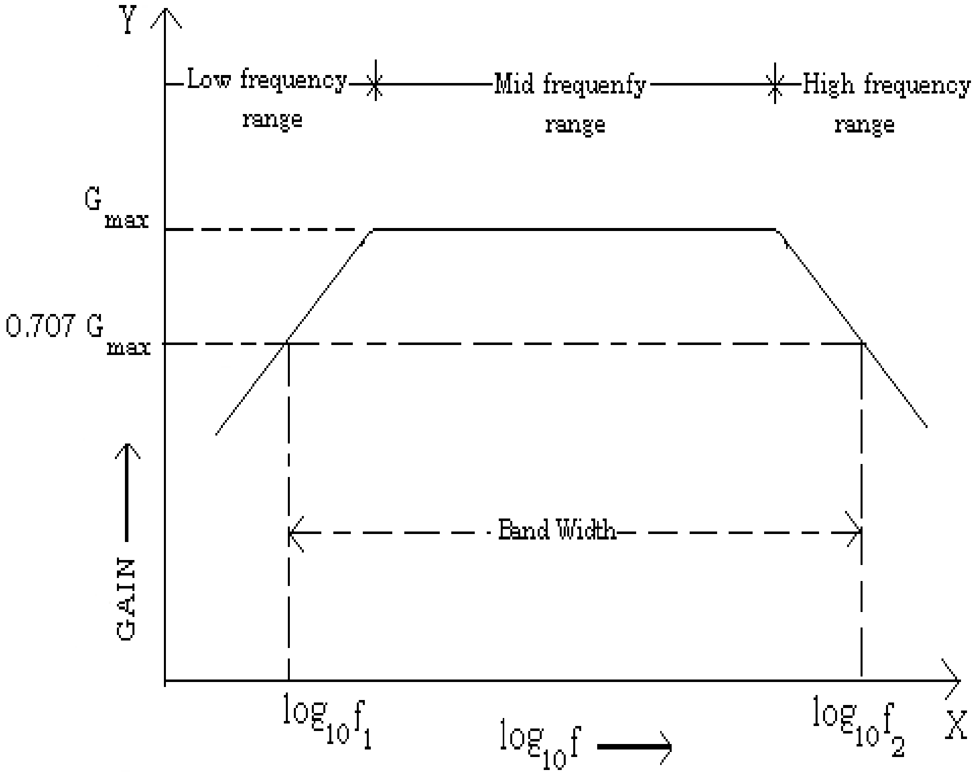
Bandwidth of the amplifier = $f_H - f_L$ KHz

Where f_L = lower half-power (cut-off) frequency

f_H = upper half-power (cut-off) frequency

13.5 Model Graph

Gain versus Frequency Model graph is shown



13.6 Theory and description

Cascade Amplifier:

To increases the voltage gain of the amplifier, multiple amplifier are connects in cascade. The output of one amplifier is the input to another stage. In this way the overall voltage gain can be increased, when number of amplifier stages are used in succession it is called a multistage amplifier or cascade amplifier. The load on the first amplifier is the input resistance of the second amplifier. The various stages need not have the same voltage and current gain. In practice, the earlier stages are often voltage amplifiers and the last one or two stages are current amplifiers. The voltage amplifier stages assure that the current stages have the proper input swing. The amount of gain in a stage is determined by the load on the amplifier stage, which is governed by the input resistance to the next stage. Therefore, in designing or analyzing multistage amplifier, we start at the output and proceed toward the input.

a n-stage amplifier can be represented by the block diagram as shown in **fig.**

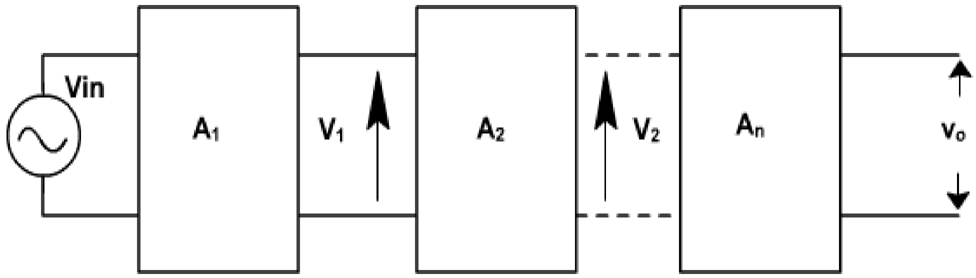


Fig.

In **fig**, the overall voltage gain is the product of the voltage gain of each stage.

Overall Gain A = $A_1 . A_2$

Where A_1 and A_2 are the gain of individual stages.

To represent the gain of the cascade amplifier, the voltage gains are represents in dB. The two power levels of input and output of an amplifier are compared on a logarithmic scale rather than linear scale. The number of bels by which the output power P_2 exceeds the input power P_1 is defined as

$$\text{No of bels} = \log_{10}\left(\frac{P_2}{P_1}\right)$$

$$\text{or No of dB} = 10 * \text{No. of bels}$$

$$= 10\log_{10}\left(\frac{P_2}{P_1}\right)$$

Since,

$$P_1 = \frac{v_1^2}{R_{in}} \ \& \ P_2 = \frac{v_2^2}{R_0}$$

where R_{in} is the input resistance of the amplifier and R_0 is the load resistance

$$dB = 10\log_{10}\left(\frac{v_2^2 / R_0}{v_1^2 / R_{in}}\right)$$

In case R_{in} and R_0 are equal, then power gain is given by

$$dB = 10\log_{10}\left(\frac{v_2}{v_1}\right)^2 = 20\log_{10}\left(-\frac{v_2}{v_1}\right)$$

$$\therefore A_{dB} = A_{dB1} + A_{dB2} + \ldots..$$

Because of dB scale the gain can be directly added when a number of stages are cascaded.

Working Principle:

D.C. power supply, the resistances R_1, R_2 and R_E provides potential divider biasing and stabilization network. i.e. It establishes a proper operating point to get faithful amplification. where we want to use the transistor as a amplifying device so actually, active region is a very important for the amplifying for amplifier circuit. The potential divider bias provides forward bias to the emitter junction and reverse bias to the collector junction. Since the emitter is grounded, it is common to both input and output signals. Therefore, the amplifier is common-emitter amplifier. Capacitor C_{in} (= 10 uF) isolates the d.c. component and the internal resistance of the signal generator and couples the a.c. signal voltage to the base of the transistor. The capacitor C_E connected across the emitter resistor R_E is of large value (= 100 uF) offers a low reactance path to the alternating component of emitter current and thus bypasses resistor R_E at audio frequencies. Consequently, the potential difference across R_E is due to the d.c. component of the current only. The coupling capacitor Cc (=10uF) couples the output of the first stage of amplifier to the input of the second stage. It blocks the d.c. voltage of the first stage from reaching the base of the second stage. The output voltage is measured between the collector and emitter terminals.

When a.c. signal is applied to the base of the first transistor, it is amplified and developed across the out of the first stage. This amplified voltage is applied to the base of next stage through the coupling capacitor C_c where it is further amplified and reappears across the output of the second stage. Thus the successive stages amplify the signal and the overall gain is raised to the desired level. Much higher gains can be obtained by connecting a number of amplifier stages in succession (one after the other). In this case the signal developed across the collector resistor of each stage is coupled into the base of the next stage. The cascaded stages amplify the signal and the overall gain equals the product of the individual gains.

Resistance-capacitance (RC) coupling is most widely used to connect the output of first stage to the input (base) of the second stage and so on. It is the most popular type of coupling because it is cheap and provides a constant amplification over a wide range of frequencies. Fig. shows the circuit arrangement of a two stage

RC coupled common-emitter (CE) mode transistor amplifier where resistor R is used as a load and the capacitor C is used as a coupling element between the two stages of the amplifier.

The coupling capacitors pass ac but block dc Because of this the stages are isolated as far as dc is concerned. This is necessary to avoid shifting of Q-points. The drawback of this approach is the lower frequency limit imposed by the coupling capacitor.

The bypass capacitors are needed because they bypass the emitters to ground. Without them, the voltage gain of each stage would be lost. These bypass capacitors also place a lower limit on the frequency response. As the frequency keeps decreasing, a point is reached at which capacitors no longer look like a.c. shorts. At this frequency the voltage gain starts to decrease because of the local feedback and the overall gain of the amplifier drops significantly. These amplifiers are suitable for frequencies above 10 Hz.

Frequency response of an amplifier

For an amplifier stage the frequency characteristics may be divided into three regions: there is a range called midband frequencies, over which the amplification is reasonably constant and equal to A_o and over which the delay is also quite constant. In the second (low-frequency) region, below midband, an amplifier stage may behave like the simple high-pass circuit. The response decrease with decreasing frequency, and output usually approaches zero at DC(f=0). In the third (high-frequency) region, above midband, the circuit often behaves like a simple low-pass network, and response decreases with increasing frequency.

Low frequency response

$$f_L = 1/2\pi R_1 C_1$$

The magnitude of $|A_L| = 1/\sqrt{(1+(f_L/f)^2)}$

At the frequency $f = f_L$, $A_L = 1/\sqrt{2} = 0.707$, whereas in the midband region ($f >> f_L$), $A_L \rightarrow 1$. Hence f_L is that frequency at which the gain has fallen to 0.707 times its midband value A_o. This drop in signal level corresponds to a decibel reduction of

20 log ($1//\sqrt{2}$), or 3 dB. f_L is that frequency for which the resistance R_1 equals the

capacitive reactance $1/2\pi f_L C_1$.

High frequency response

In the high-frequency region, above the midband, the amplifier stage can often be approximated by the simple low-pass circuit.

$$f_H = 1/2\pi R_2 C_2$$

The magnitude of $|A_H| = 1/\sqrt{(1 + (f/f_H)^2)}$

Since at $f=f_H$ the gain is reduced to $1/\sqrt{2}$ times its midband value, then f_H is called upper 3 dB frequency. It also represents that frequency at which the resistance R_2 equals the capacitive reactance $1/2\pi f_H C_2$.

The curve representing the variation of gain of an amplifier with frequency is known as frequency response curve. It is shown in Fig. The voltage gain of the amplifier increases with the frequency f and attains a maximum value. The maximum value of the gain remains

constant over a certain frequency range and afterwards the gain starts decreasing with the

Increase of the frequency. It may be seen to be divided into three regions.

1) Low frequency Range (<50 Hz)

2) Mid frequency range (50 Hz to 20 KHz) and

3) High frequency range (> 20 kHz).

Calculation of Band Width :

Draw the frequency response curve as said above, by taking the frequency f (or log10f) on

X-axis and voltage gain on Y-axis. Note the maximum gain, Gmax or (A0) and mark the value of 0.707Gmax on the y-axis. From that value draw a line (dashed line) parallel to x-axis. This line cuts the curve at two points, called the half-power points. From those two points draw two perpendicular lines on to x - axis, the feet of two perpendiculars corresponding to two frequencies f1 and f2. These are called as lower half power frequency and the upper half power frequency (or cut-off frequency). The difference between these two frequencies f_1 and f_2 is the bandwidth (BW) of the amplifier.

* Bandwidth of the amplifier = f_2 - f_1 or f_H –F_L

13.7 Self learning exercise-I

Q.1 A transistor is said to be in a quiescent stage when

(a) Emitter junction bias is just equal to collector junction bias.

(b) no currents are flowing

(c) no signal is applied to the input

(d) it is unbiased

Q.2 A transistor in amplifier circuit is biased such that

(a) emitter junction is reverse biased and collector junction is forward biased

(b) emitter junction is forward biased and collector junction is reverse biased

(c) both junctions are forward biased

(d) Both junctions are reverse biased.

Q.3 The CB amplifier has fewer applications because

(a) It exhibits poor current gain

(b) It exhibits very low input impedance.

(c) It exhibits high output impedance

(d) It exhibits poor power gain

Q.4 Which of the following statements is not correct for emitter follower circuit?

(a) It raises power level.

(b) It exhibits high input impedance and low output impedance

(c) It has high current gain.

(d) It has high voltage gain

Q.5 The most striking feature of CE amplifier responsible for its wide use is,

(a) It has high current gain

(b) It has high voltage gain

(c) It has a phase difference of 180o between input and output.

(d) It shows input and output impedances of the same order.

Q.6 Assuming V_{BE} = 0.7V and β= 50 for the transistor in the circuit shown in figure, the value of RB for VCE = 2V is

(a) 200 kΩ

(b) 243 kΩ

(c) 283 kΩ

(d) 300 kΩ

13.8 Procedure

Procedure for Conducting the Experiment

1. Connect the circuit as shown in fig.1. First the signal generator is connected directly to the a.c. milli-voltmeter by keeping signal frequency at about 500 Hz. The amplitude (voltage) of the input signal is adjusted to 0.1V or 0.05V (should be small). This is the amplifier input (V_i).
2. Now the signal generator is disconnected from the a.c. Milli-voltmeter and connected to the input of the of the amplifier and the a.c. millivoltmeter is connected to the output of the amplifier. Set the input frequency at 10 Hz, note the output voltage (V_o) from the a.c.

   Milli-voltmeter keeping the input voltage, V_i constant.
3. keeping the input voltage constant, vary the frequency from 100Hz to 1MHz in regular interval steps and record at least 5 values the corresponding output voltage.
4. Calculate the voltage gain, G of the amplifier for each value of the frequency, f of the input signal, using the relation, Voltage gain, G = V_o / V_i. (take gain also in dB)
5. Plot the graph voltage Vs frequency.
6. Calculate the bandwidth from graph.

13.9 Observation

1.Voltage Gain(if gain in dB then overall gain will be addition of gain of individual stages)

S.N.	Input voltage(V_i) mV (peak to peak)	Output of first stage	Output of second stage	A_1	A_2	Voltage Gain $A=A_1*A_2$
1						
2						
3						

2. **Voltage gain with second stage disconnected**

S.N.	Input voltage(vi)	Output of first stage (Vo) Volt	Voltage Gain in dB A1=20 log10(Vo/Vi)
1			
2			
3			

3. **Gain with frequency(frequency response)**

S.N.	Input voltage(V_i) mV	Input signal frequency f(Hz)	Output voltage(V_o) Volt	Voltage Gain A=20log10(V_o/V_i)
1				
2				
3				

13.10 Graph

Plot the graph between gain versus frequency on graph paper.

13.11 Calculations

13.12 Result

1. Two stage amplifier gain=……..dB
   Single stage amplifier gain =…….dB

Overall voltage gain of two stage amplifier is higher than the single stage amplifier. Gain of two stage amplifier is equal to the product of gains of individual stages. In practice total gain A is less than A1 *A2 due to loading effect of following stages.

2. Bandwidth= Upper cut-off frequency – Lower cut-off frequency=………

13.13 Discussion

13.14 Precautions and Sources of Error

1. Before going to the experiment the input voltage V_i should be measured.
2. The input voltage should be small.
3. The input voltage should be maintained at constant value for frequency response.
4. The connections should be tight.
5. Do not enter in the laboratory with the bare foots.
6. Do not switch ON the circuits without permission of the concerned teacher.
7. Make sure that the circuit is switched OFF before leaving the laboratory.

13.15 Self Learning Exercise-II

Q.1 For a transistor in an amplifying circuit

(a) Emitter-base junction is forwarded biased and collector-base junction is reverse biased.

(b) Emitter-base junction is reverse biased and collector-base junction is forward biased

(c) Both the emitter-base junction and the collector-base junction are forward biased.

(d) Both the emitter-base junction and the collector-base junction are reverse-biased.

Q.2 A small increase in collector reverse bias will cause

(a) A large increase in emitter current.

(b) A large increase in collector current.

(c) A large decrease in collector current

(d) Very small change in collector reverse saturation current.

Q.3 The transistor configuration producing highest output resistance in an amplifying circuit is

(a) CB

(b) CE

(c) CC

(d) Depends on the magnitude of reverse bias voltage of base-collector junction.

Q.4 The transistor configuration producing lowest output resistance in an amplifying circuit is

(a) CB

(b) CE

(c) CC

(d) Depends on the magnitude of reverse bias voltage of base-collector junction

Q.5 Early effect in BJT refers to

(a) Avalanche breakdown

(b) Thermal runway

(c) Base narrowing

(d) Zener breakdown

13.16 Glossary

Cascade: process whereby something, typically information or knowledge, is successively passed on(Arrange a number of devices or objects in a series or sequence)

Avalanche : too many things that arrive or happen at the same time

13.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: (c)	**Ans.2:** (b)	**Ans.3:** (b)
Ans.4: (d)	**Ans.5:** (d)	**Ans.6:** (c)

Answers to Self Learning Exercise-II

Ans.1: (a)	**Ans.2:** (d)	**Ans.3:** (a)
Ans.4: (c)	**Ans.5:** (c)	

13.18 Viva Questions

Q.1 In an RC coupled amplifier, the gain decreases in the frequency response due to the

(a) Coupling capacitor at low frequency and bypass capacitor at high frequency.

(b) Coupling capacitor at high frequency and bypass capacitor at low frequency

(c) Coupling junction capacitance at low frequency and coupling capacitor at high frequency.

(d) Device junction capacitor at high frequency and coupling capacitor at low frequency.

Q.2 A signal may have frequency components which lie in the range of 0.001Hz to 10 Hz. Which one of the following types of couplings should be chosen in a multistage amplifier designed to amplify the signal?

(a) RC coupling

(b) Direct coupling

(c) Transformer coupling

(d) Double tuned transformer coupling.

Q.3 The overall bandwidth of two identical voltage amplifiers connected in cascade will

(a) Remain the same as that of a single stage

(b) Be better than that of a single stage

(c) Be worse than that of a single stage

(d) Be better if stage gain in low and worse if stage gain is high

Q.4 Two amplifiers, one having voltage gain of 40 and the other 20 are coupled with negligible loading. The approximate gain of two-stage amplifier will be

(a) 20 (b) 40

(c) 60 (d) 800

Q.5 In a common emitter amplifier, the unbiased emitter resistance provides

(a) Current series feedback

(b) Voltage series feedback

(c) Voltage shunt feedback

(d) Current shunt feedback

Q.6 An amplifier incorporates negative feedback using voltage-shunt feedback connection. This feedback will result in

(a) Increased input impedance and decreased output impedance

(b) Increased input impedance and increased output impedance

(c) Decreased input impedance and increased output impedance

(d) Decreased input impedance and decreased output impedance

Q.7 In RC coupled amplifier which component is responsible for reduction in voltage gain in high frequency range?

Q.8 What is the application of RC coupled amplifier?

13.19 Answers to Viva Questions

Ans.1: (d)	**Ans.2:** (b)	**Ans.3:** (c)
Ans.4: (d)	**Ans.5:** (a)	**Ans.6:** (a)

Ans.7: Shunt capacitance in the input circuit

Ans.8: It is widely used as a voltage amplifier.

References and Suggested Readings

1. Jacob Millman and C. Halkias, Integrated electronics: analog and digital circuits and systems
2. John D. Ryder ,Electronic Fundamentals and Applications

UNIT-14
Astable Multivibrator

Structure of the unit

14.1 Aim

To study the waveform characteristic of Astable Multivibrator.

14.2 Apparatus

Function generator, Resistors, Capacitors, CRO, Power supply,Bread Board and

Connecting wires.

14.3 Diagram

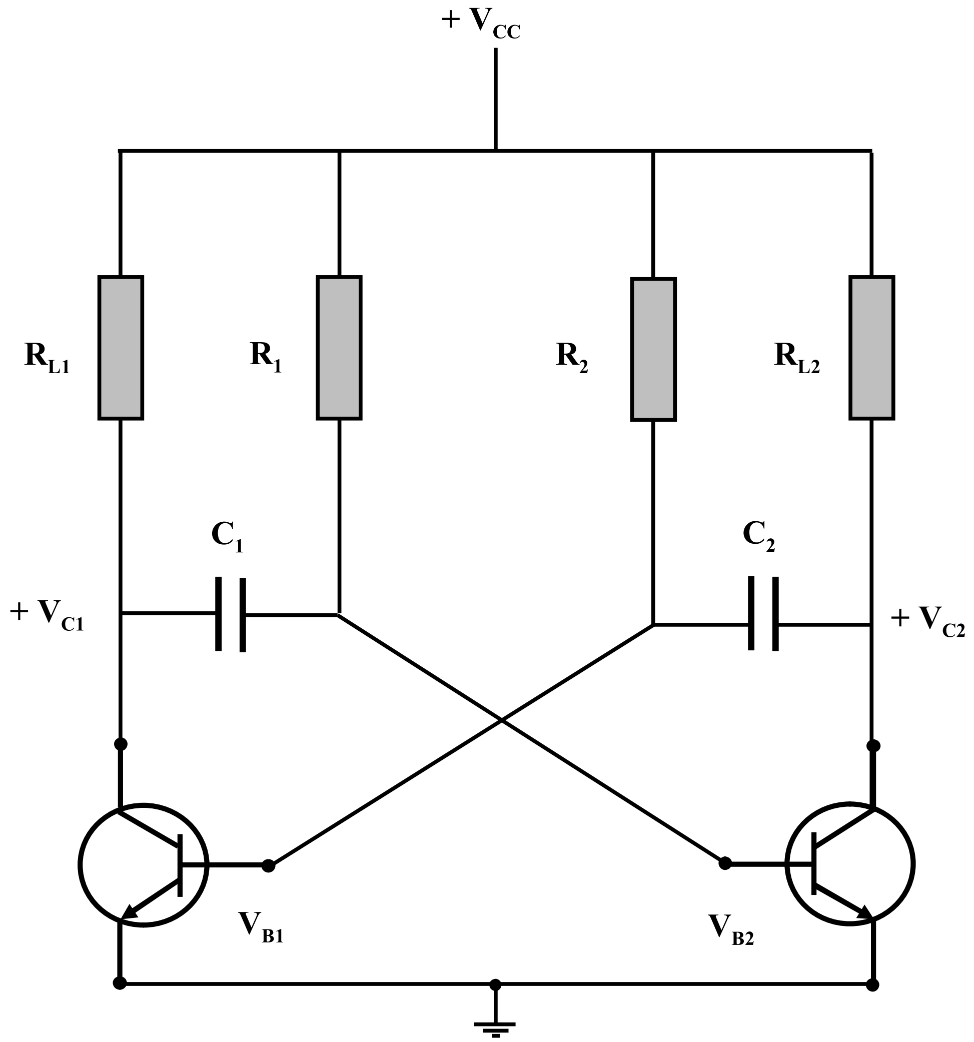


Figure 1: *Circuit for Astable Multi-vibrator using transistors.*

14.4 Formula

Periodic time for Astable Multi-vibrator is

$$T = t_1 + t_2$$

Here: $t_1 = 0.69R_1C_1$ and $t_2 = 0.69R_2C_2$

R is in ohms and C is in farads.

The frequency of oscillation for the Astable Multi-vibrator is

$$f = \frac{1}{T}$$

$$f = \frac{1}{0.69R_1C_1 + 0.69R_2C_2}$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, then the frequency of oscillation is

$$f = \frac{1}{1.38RC}\ Hz$$

This frequency is also known as the "Pulse repetition frequency".

Here

T = Time period of oscillations

f = frequency of astable multivibrator

R_1 = Resistance for discharging of capacitor C_1

R_2 = Resistance for discharging of C_2

14.5 Theory and Description

An astable multivibrator has no stable states it is also called as free running multivibrator. Astable multivibrator has two quasi stable states:

1. State 1: Q_1 is ON (saturation) and Q_2 is OFF.
2. State 2: Q_1 is OFF and Q_2 is ON (saturation).

No external triggering is required in the astable multivibrator. It oscillates between these two quasi stable states. Figure 1 is an astable multivibrator circuit. In this circuit Q_1 and Q_2 are two transistors and are R_{L1} and R_{L2} are the collector resistances for the transistors Q_1 and Q_2 respectively. C_1 and C_2 are two coupling capacitors. R_1 and R_2 are two resistors which provide base current to Q_1 and Q_2 respectively during the saturation region.

Case 1: when $R_{L1} = R_{L2}$, $R_1 = R_2$ and $C_1 = C_2$ i.e. the components in one half of the circuit are equal to the components in the other half circuit, then this type of multivibrator is as known symmetrical astable multivibrator.

Case 2: on the other hand if the components in one half of the circuit are not equal to the components in other half of the circuit then multivibrator is called as asymmetrical astable multivibrator.

Operation of Astable Multivibrator:

When the power is applied to the circuit, the two transistors are completely identical so let the transistors Q_1 conducts more than transistors Q_2 which means that current will follow more through Q_1 than transistor Q_2. In this case the rate of fall of V_{C1} is more than V_{C2}. The base of transistor Q_2 will be negative because of the change of collector voltage of Q_1. The collector voltage V_{C2} increases and approaches towards V_{CC}. Because of the transfer of V_{C2} to the base of the transistor Q_1 through capacitor C_2, the conduction of Q_1 will increase further. The increases in the conduction of Q_1 will decrease V_{C1}, which will make the base of Q_2 more negative. The transistor Q_1 comes in the saturated region and transistor Q_2 come in cut off region.

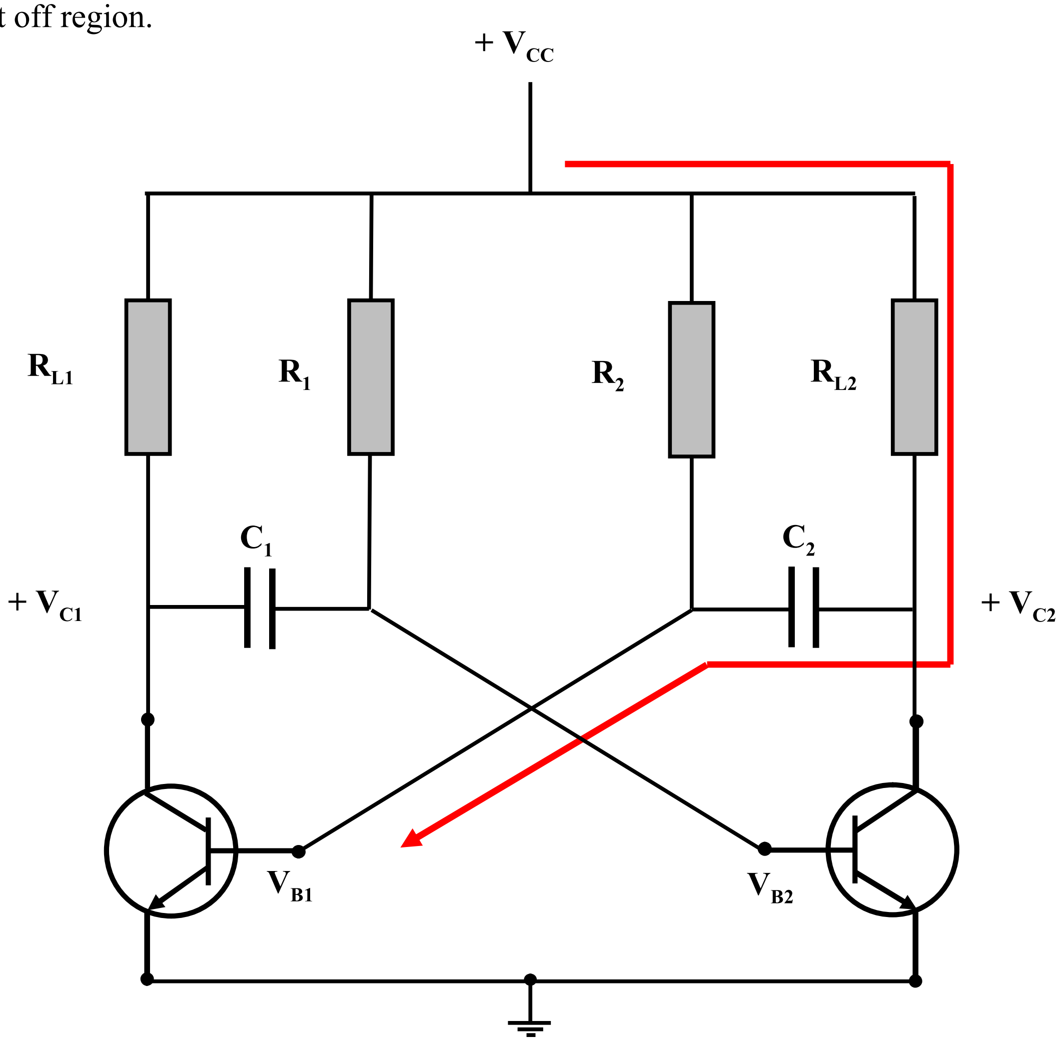


Figure 2: *Charging of capacitor C_2.*

For a moment, Q_1 is in saturation and transistor Q_2 in cut off. This is a quasi stable state. For this state V_{C1} is approximately zero while V_{C2} is approximately equal to V_{CC}. In this case C_2 will charge through R_{L2} and the base emitter junction of Q_1 will be approximately at V_{CC}. The charging path of C_2 is shown in figure 2.

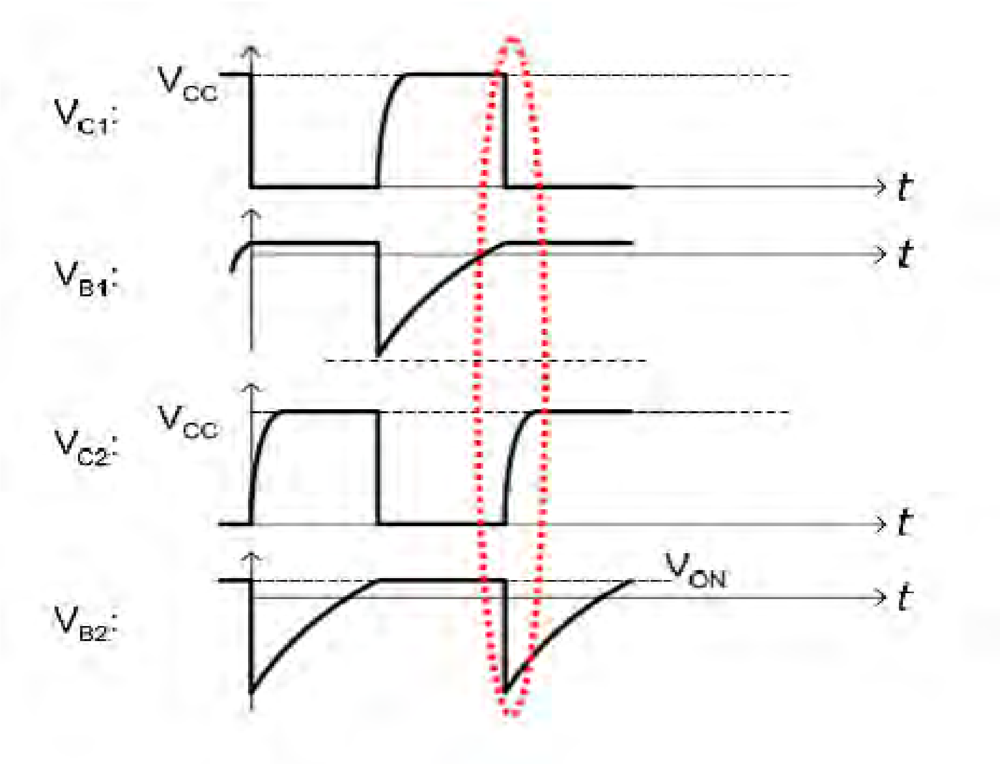


Figure 3: *Waveforms for Astable Multi-vibrator using transistors.*

At the same time the capacitor C_1 will discharge through Q_1 and R_1. It is shown in figure 4.

The initial pulse of the discharge current from C_1 through R_1 makes the base of Q_2 suddenly very negative approximately equal to $-V_{CC}$ as shown in waveform of V_{B2}. The transistor Q_1 is kept in the conducting state by the base current through R_2 so V_{B1} slightly positive. The charging current of C_2 through R_{L2} has now ceased. The length of time for which Q_2 is held off is determined by the time constant of discharge of C_1 through Q_1 and R_1.

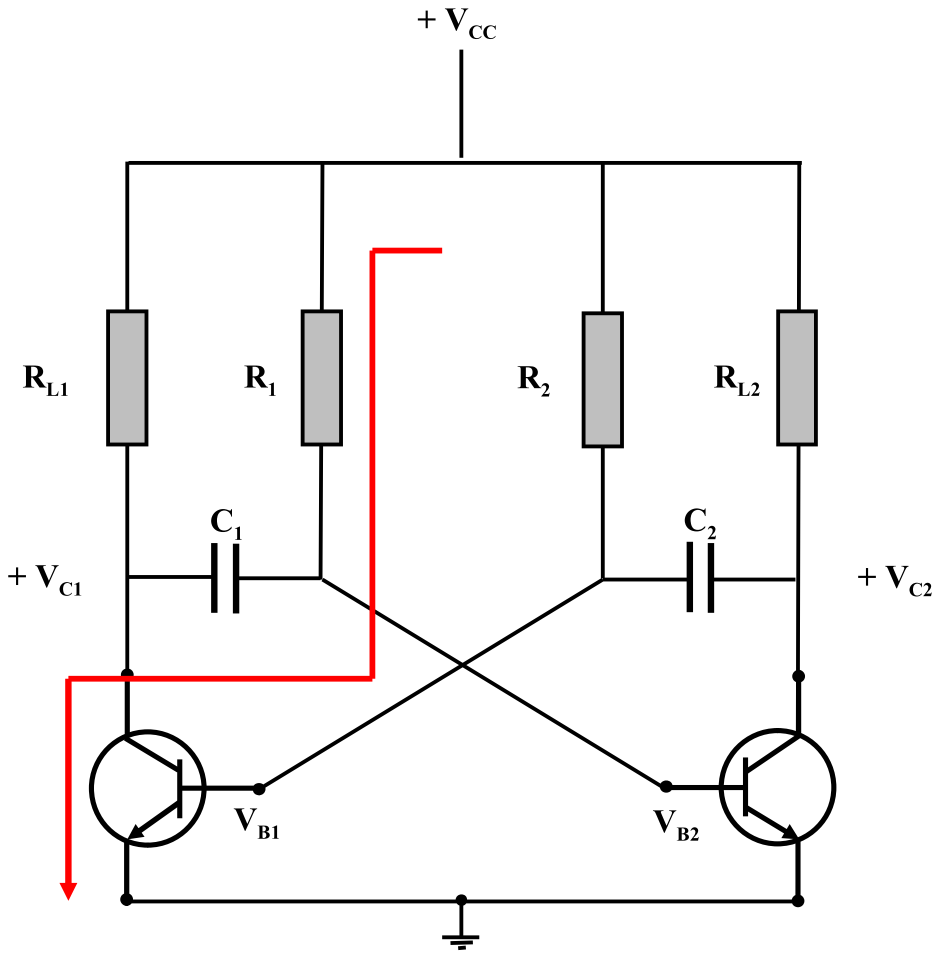


Figure 4: *Discharging of capacitor C_1.*

Now the transistor Q_2 starts conducting ,the collector voltage of Q_2 starts to decrease. It will reduce the base voltage of transistor Q_2 it will transfer to the base of Q_2 via C_1 so the conduction of Q_2 increases. This process will continue till the transistor Q_2 in the saturation region and Q_1 is in cut off region. In this case V_{C1} is approximately equal to V_{CC} and V_{C2} is approximately equal to zero. The capacitor C_1 charges through R_{L1} which is shown in figure 5 so the base voltage of Q_2 is increases. Meanwhile C_2 discharges through Q_2 and R_2 as shown in figure 6.

The time interval in which Q_1 is in non conducting state depends upon R_2*C_2 time constant.

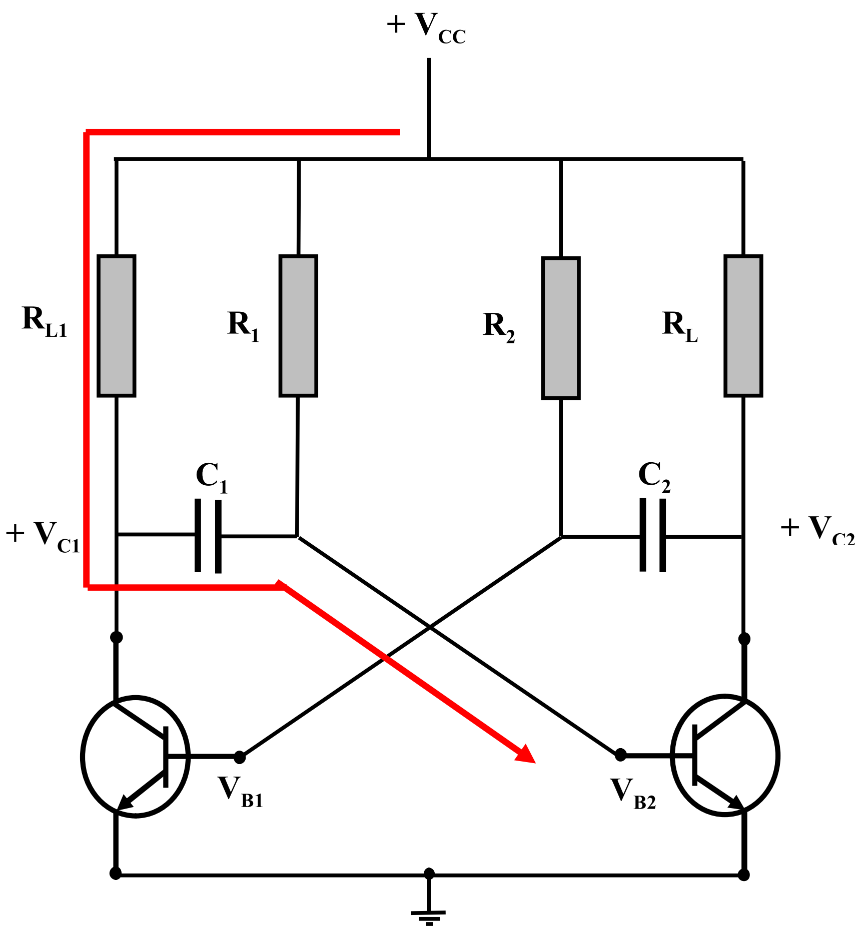


Figure 5: *Charging of capacitor C_1*

Applied voltage across a capacitor C and the resistor R should be equal to the applied voltage, V_{CC}:

$$V_{cc} = IR + \frac{Q}{C}$$

$$V_{cc} = R\frac{dQ}{dt} + \frac{Q}{C}$$

Integrating the above equation, with the condition that at $t = 0$, the voltage across the capacitor is V_0, to give

$$V(t) = V_{cc} - (V_{cc} - V_0)e^{(-t/RC\ \ )}$$

For our case, the initial voltage $V_0 = V_{CC}$ and we have to find out the time *T* at which V(T) = 0. This gives:

$$T = Log(2)RC$$
$$T = 0.693RC$$

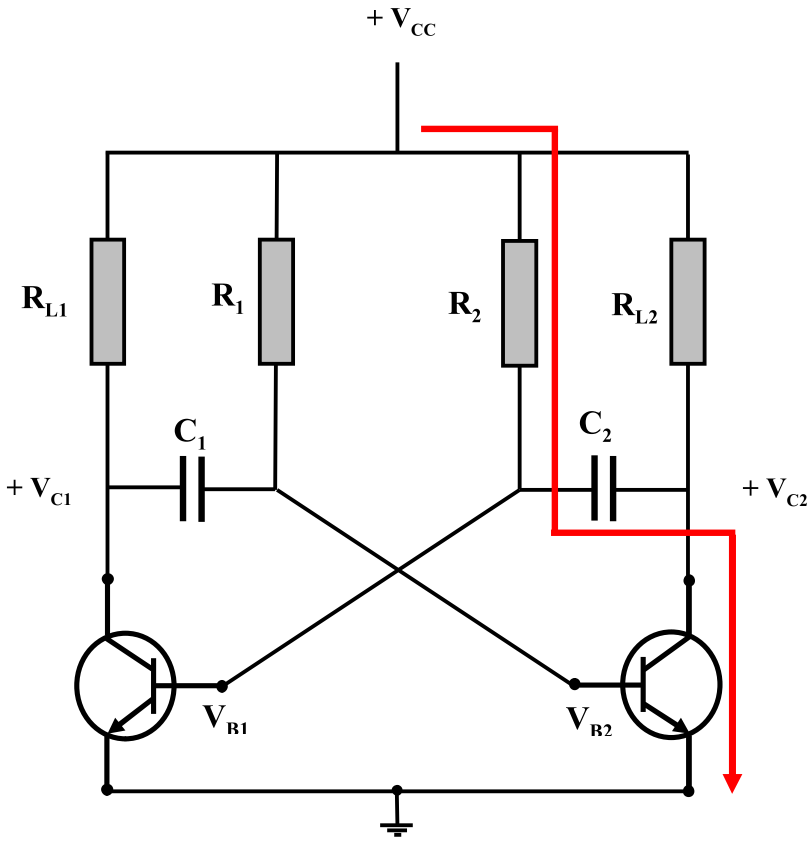


***Figure 6**: Discharging of capacitor C_2*

The Multi-vibrator circuit oscillates between a state in which Q_1 is ON and Q_2 is OFF and a state in which Q_1 is OFF and Q_2 is ON. The time for which either transistor remains ON or OFF is given by:

ON time for Q_2 (or OFF time for Q_1) $T_1 = 0.69\ R_1C_1$
ON time for Q_1 (or OFF time for Q_2) $T_2 = 0.69\ R_2C_2$
Hence, total time of the square wave $T = T_1 + T_2$
$= 0.69\ (R_1C_1+R_2C_2)$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$ i.e., the two stages are symmetrical, then

$$T = 0.69\,(RC + RC) = 1.38\,RC$$

Frequency of Oscillation: Frequency of the square wave is given by the reciprocal of the time period i.e.

$$f = \frac{1}{T} = \frac{1}{1.38RC}\,Hz$$

If $t_1 = t_2$ i.e.$R_1C_1 = R_2C_2$, the mark-to-space ratio (t_1/t_2) will be equal to one making the output waveform symmetrical in shape. By varying the capacitors C_1, C_2 or the resistors R_1, R_2 we can alter the mark-to-space ratio and frequency.

Advantages:

Astable Multivibrators continuously switch between one state and another. This allows Astable Multivibrators to power themselves and perform work at a consistent rate without influence from any outside forces or events. Additionally, Astable Multivibrators are inexpensive to produce, are relatively simple in design, and can remain functional for extraordinary amounts of time.

Disadvantages:

Astable Multivibrators do not transfer the entire output signal to the input. This is due to resistance within the circuit, lack of a completely closed loop at the output terminals, and the tendency for one capacitor or transistor to absorb energy at a slightly different rate than the other. Although the amplifier restores the lost energy when it amplifies the signal, the signal will eventually be too small to be of any use.

Function generator:

A function generator is a very versatile instrument that is used in electronics. Function generator is a device that is used to generate wide range of ac signal. A function generator is also known as signal generator or wave form generator. Function generator can generate a variety of wave forms of different periods and amplitudes. It can produce the wave forms like sinusoidal, square, triangular, ramp pulse etc. With desired frequency.

Figure 6: *Function generator*

Cathode Ray Oscilloscope (CRO):

The CRO is the most versatile tool for the development of electronic circuit. The CRO is a device that allows the amplitude of the electrical signals e.g. voltage, current, etc. To be displayed primarily as a function of time. The main part of the CRO is the Cathode ray tube which also known as the heart of the CRO.

Basically cathode ray tube consists of five main parts which are:

1. Electron gun,
2. Deflection plate system,
3. Fluorescent screen,
4. Glass envelope and
5. Screen

***Figure** 7: Cathode Ray Oscilloscope.*

Capacitors:

The capacitor is an electronic component that stores energy in the form of electric charge. It is a simple passive device.

***Figure 8:** Various types of capacitor*

The capacitor is fabricated of two conducting plates that are separated by dielectric material. These plates accumulate electric charge when connected to power source. One plate accumulates positive charge and the other accumulates opposite charge. The direct current cannot pass through the capacitor while alternate current is allowed by it. It is due to the vibration of dipole charges existing in the dielectric materials.

Resistors:

A resistor is a passive two terminal electrical component that implement electrical resistance as a circuit element the purpose of resistor is to

create specific values of current and voltage in a electrical circuit.

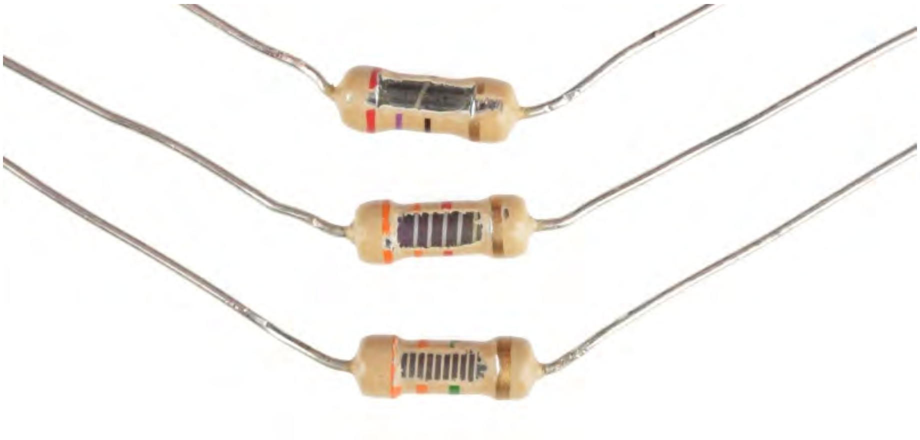


Figure 9: *various types of resistors.*

14.6 Self Learning Exercise-I

Q.1 What are the other names of Astable multivibrator?

Q.2 What is the use of an Astable multivibrator in electronic circuits?

Q.3 What is quasi stable state in a stable multi vibrator?

Q.4 How one state of astable multivibrator transform to another state?

Q.5 How to make asymmetric Astable multi-vibrator?

14.7 Procedure

(i) Two transistors Q_1 and Q_2 are connected in common emitter mode and the biasing to these transistors are given with the help of RL_1, RL_2 and $+V_{CC}$.

(ii) Collector of each transistor is connected to the base of the other transistor through a condenser.

(iii) The condensers C_1 and C_2 are connected to the power supply through the variable resistors R_1 and R_2.

(iv) The collector of any one of the transistor is connected the Y–plates of CRO.

(v) Switch on the power V_{CC}, and the power supply of CRO.

(vi) Observe the square wave on the screen.

(vii) Adjust the values R_1 and R_2 and the band switches of X and Y plates of CRO to get at least one complete wave on the screen.

(viii) Then the length of one complete wave (l) on screen is measured on horizontal scale, this is multiplied with the time base (t).

(ix) The product will give the time period of the wave ($l \times t = T$). The reciprocal of 'T' gives the frequency (f).

(x) The observed values are tabulated. This frequency is experimental frequency.

(xi) Now the Power V_{CC} is switched off and the resistance values of R_1 and R_2 are measured using multi-meter.

(xii) The values R_1, R_2, C_1 and C_2 are also noted in the table. Substituting these values in the above formula we will get the frequency theoretically.

(xiii) The theoretical and experimental frequencies are compared.

(xiv) The experiment is repeated with different values of R_1 and R_2 (the values of C_1 and C_2 can also be changed, if possible).

14.8 Observation

A CRO is used for observing the wave form pattern of an Astable multi-vibrator. First check the wave form pattern in CRO that it is as per the designed frequency and time period and draw this wave form pattern on the trace paper with the help of CRO.

R_1 = ………………… **KΩ**

R_2 = ………………… **KΩ**

S. No.	**R_1 (KΩ)**	**R_2 (KΩ)**	***l* (unit less)**	***t* (sec.)**	**T = *l* × *t* (sec.)**	***f* = 1/T (Hz)**
1						
2						
3						
4						
5						
6						
7						

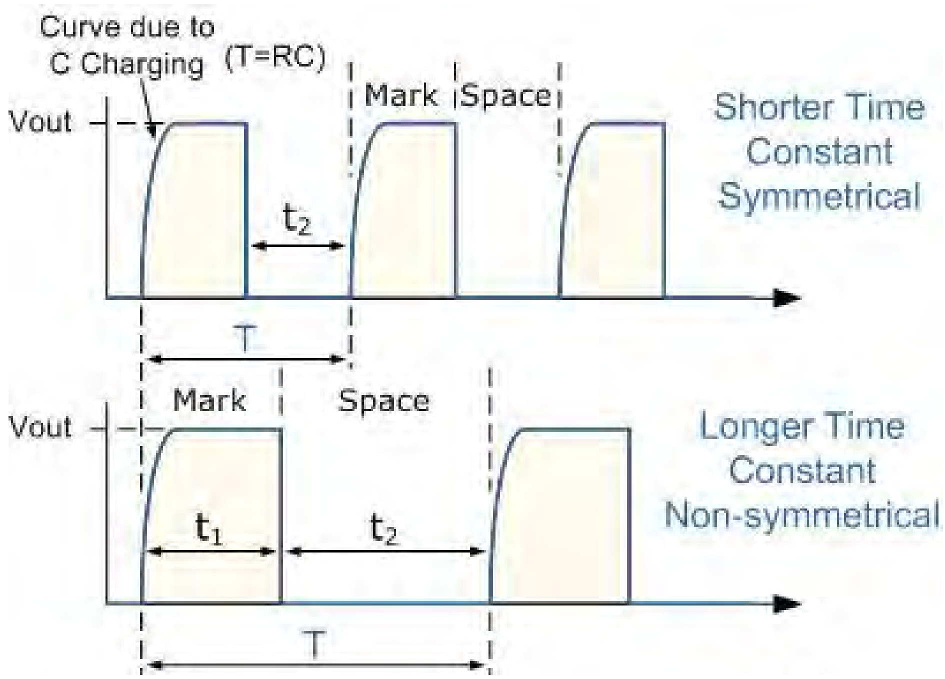
C_1 = …………………μF

C_2 = …………………μF

S. No.	**C_1** (μF)	**C_2** (μF)	***l* (unit less)**	***t* (sec.)**	**T = *l* × *t* (sec.)**	***f* = 1/T (Hz)**
1						
2						
3						
4						
5						
6						
7						

14.9 Graph

Model Graphs/ Tracings



14.10 Calculations

By taking different combination of resistance and capacitor, we can make Astable Multi-vibrator of different frequencies.

Model Calculation

The model calculation for these Astable multi-vibrators of different frequencies is given as below:

Case-1 R = 1 kΩ and C = 1 nF

Frequency $f = \frac{1}{1.38RC}$

f = 724.6 kHz

Case-2 R = 1 kΩ and C = 10 nF

f = 72.46 kHz

We have calculated the frequency in case1 and case 2 and tabulated in the frequency table given below. Fill all the remaining entries of the frequency table as per the procedure followed in the calculation of frequency in case 1 and case 2.

Frequency table

S. No.	**Resistance (kΩ)**	**Capacitance (nF)**		
		1	10	100
1	1	**724.6 kHz**	**72.46 kHz**	**--**
2	10	**--**	**--**	**--**
3	100	**--**	**--**	**--**

14.11 Result

14.12 Discussion

14.13 Precautions and Sources of Error

1. All the connections should be tight.
2. Components i.e. resistors and capacitors should be of proper value.
3. Check all the connecting wires before making the power supply on.

4. Draw the wave form pattern on trace paper carefully.

5. Always be sure of the scale of CRO and check manually, the frequency and time period of the wave form generated by Astable Multi-vibrator.

14.14 Self Learning Exercise-II

Q.1 How can Astable multivibrator be used as a voltage to frequency converter?

Q.2 What is the formula for frequency of oscillations?

Q.3 Calculate the value of capacitance of a symmetric Astable Multi-vibrator having the frequency 152 Hz and corresponding resistance is 47 kΩ.

Q.4 Calculate the capacitance C_2 for an Astable Multi-vibrator, other details are as follows: R_1= 1 kΩ, R_2= 2 kΩ, C_1= 100 nF and f = 7.246 Hz

Q.5 Calculate the frequency and time period of an Astable Multi-vibrator as per the data given below: R_1 = 46 kΩ, R_2 = 34 kΩ, C_1 = 10 nF and C_2 = 50 nF

14.15 Glossary

***Frequency*:** Number of occurrences of a repeating event per unit time.

***Triggering*:** A pulse or circuit that initiates the action of another component.

Amplitude: A measure of change in a periodic variable over a single period.

Pulse: A brief sudden change in a normally constant quantity.

Waveform: The mathematical representation of a wave especially a graph obtained by plotting characteristics of the wave against time.

14.16 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Free Running multivibrator.

Ans.2: In radio equipment to receive and transmit radio signals. Astable multivibrators are also used in morse code generators, timers, and systems that require a square wave, including television broadcasts and analog circuits etc.

Ans.3: Quasi stable state is triggered state, when a trigger pulse is given the vibrator reaches this state.

Ans.4: By charging and discharging of capacitor which runs the On and OFF state of Transistors.

Ans.5: If components in one half of the circuit are not equal to the components in the other half of the circuits.

Answers to Self Learning Exercise-II

Ans.1: As an AC square wave generator.

Ans.2: See in formulas

Ans.3: 0.1 μF

Ans.4: 50 nF

Ans.5: 0.67 KHz

14.17 Viva Questions

Q.1 What are the other names of Astable multivibrator?

Q.2 What are the factors affecting the frequency of an Astable multivibrator?

Q.3 What are the uses of an Astable multi-vibrator?

Q.4 How many quasi stable states are in astable multivibrator?

Q.5 What are the two quasi stable states in an astable multivibrator?

Q.6 What is role of transistor in astable multivibrator circuit?

Q.7 What s the unit of RC?

Q.8 What do you mean by resistance?

Q.9 What do you mean by capacitance?

Q.10 What do you mean by a symmetric Astable multi-vibrator?

Q.11 What do you mean by an asymmetric Astable multi-vibrator?

Q.12 How can we change the frequency of an astable multivibrator?

Q.13 What happens on the frequency of multi-vibrator, if capacitor value is doubled?

Q.14 What happens on the frequency of multi-vibrator, if resistance value is made half?

Q.15 What is bias voltage?

Q.16 Which configuration is used in Astable multi-vibrator?

Q.17 Explain charging and discharging of capacitors in an Astable Multivibrator?

Q.18 How can Astable multivibrator be used as a voltage to frequency converter?

Q.19 What is the formula for frequency of oscillations?

Q.20 How can we use Astable multivibrator ass a pulse generator?

14.18 Answers to Viva Questions

Ans.1: Free running multivibrator,

Ans.2: R and C

Ans.3: Astable multivibrators are used in radio equipment to receive and transmit radio signals. Astable multivibrators are also used in morse code generators, timers, and systems that require a square wave, including television broadcasts and analog circuits etc.

Ans.4: Two

Ans.5: Two quasi stable states in an astable multivibrator are:

A) when Q_1 is ON and Q_2 is OFF.
B) when Q_1 is OFF and Q_2 is ON.

Ans.6: Transistor act as a switch in the circuit.

Ans.7: The unit of RC is second when R is in ohms and C is in farads. RC represents the time constant of a RC circuit.

Ans.8: A resistance is the interruption of electrical current through a conductor; the resistance is defined as the ratio of voltage to current across the conductor.

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

Ans.9: The capacitance is the ratio of charge to potential on an electrical charged isolated conductor. It is given by the symbol C.

$$C = \frac{Q}{V}$$

This is property of circuit element that permits it to store the charge.

Ans.10: In a symmetric Astable Multi-vibrator both the resistors connected to the base of transistor should be equal and capacitors should also be equal i.e.

$R_1 = R_2 = R$ and $C_1 = C_2 = C$.

Ans.11: For an asymmetric the values of resistance and capacitances are not equal.

Ans.12: The frequency of an Astable Multi-vibrator depends on the value of resistance and capacitor. By changing the value of R and C, we can change the frequency of an Astable multivibrator.

Ans.13: When the value of capacitor is doubled the frequency of an astable multivibrator will be half.

Ans.14: When the value of capacitor is doubled the frequency of an astable multivibrator will be half.

Ans.15: The bias voltage is the necessary DC voltage which is required for any active device to operate.

Ans.16: Common emitter configuration of transistors is used.

Ans.17: Q_1 is in saturation and transistor Q_2 in cut off. This is a quasi stable state. For this state V_{C1} is approximately zero while V_{C2} is approximately equal to V_{CC}. In this case C_2 will charge through R_{L2} and the base emitter junction of Q_1. Similarly the capacitor C_1 will charge through R_{L1}.

When the capacitor C_2 will charge at the same time the capacitor C_1 will be discharge through Q_1 and R_1. Similarly at the time of charging of C_1 capacitor C_2 will discharge through Q_2 and R_2.

Ans.18: It generates rectangular wave which can be consider as alternate current hence astable multivibrator can be considered as AC rectangular wavefrom generator.

Ans.19: $$f = \frac{1}{0.69R_1C_1 + 0.69R_2C_2}$$

R_1 = Resistance for discharging of capacitor C_1

R_2 = Resistance for discharging of C_2

Ans.20: By reducing the width of rectangular waveform with the help of R and C.

References and Suggested Readings

1. Doug Lowe, Electronics All-in-One For Dummies
2. Rama Sudha K.; Venkata Rao K.; Manmadha Rao G.,Pulse and Digital Circuits
3. Jerry C. Whitake ,The *Electronics Handbook*
4. Gupta and Kumar ,Handbook of Electronics

UNIT-15
Hartley Oscillator

Structure of the Unit

15.1 Aim

To study Hartley oscillator.

15.2 Apparatus

Bipolar junction transistor (BJT), Resistors, Capacitors, Inductors, dc power supply and Cathode Ray Oscilloscope (CRO).

15.3 Diagram

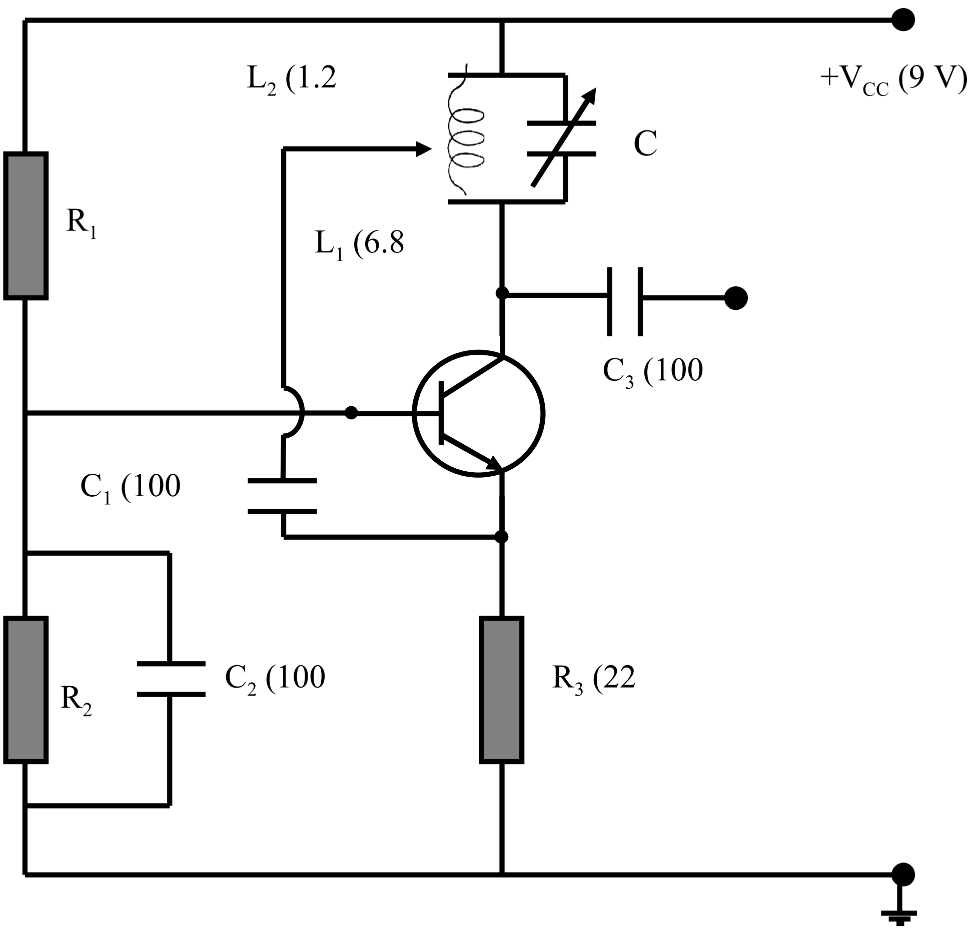


Figure 2: Hartley Oscillator

15.4 Formula

(i) Frequency generated by Hartley Oscillator:

$$f = \frac{1}{2\pi \sqrt{CL_{eq}}}$$

Here:

C = Capacitance of capacitor in tank circuit,

L_{eq} = Equivalent inductance of both coils,

Also $L_{eq} = L_1 + L_2$

However, if the two coils are magnetically coupled the total inductance will be greater because of mutual inductance *M*

$$L_{eq} = L_1 + L_2 + 2M$$

Here:

L_1 = Inductance of feedback coil.

L_2 = Inductance of second coil.

M = Mutual Inductance between coils.

(ii) Barkhausen Criterion:

$$A\beta = 1$$

And also $A = \frac{V_{To}}{V_{TI}}$

A = Gain of Amplifier

V_{TO} = Voltage output by transistor (across Collector point in CE configuration)

V_{TI} = Voltage input at transistor (across base point in CE configuration)

β = Feedback ratio; Ratio of Voltage across feedback coil (L_1) and output voltage at load resistance.

15.5 Theory and description

(i) Oscillator: An electronic circuit that produces alternating current is known as oscillator circuit. In general for an oscillator circuit there is no any input signal. The power to circuit is provided by direct current (dc) source. Hence it can be said that oscillator circuit converts dc power to alternate current (ac) power.

(ii) Alternator: Alternator is also an ac generator electric system e.g. generator. In this system, coils move in magnetic field or vice-versa and ac current generates. In alternator mostly mechanical energy is provided to move the coils or magnets and electric power generates. Alternators cannot produce ac current at high frequencies (>1 KHz). To produce ac current at high frequencies, this system requires higher number of magnetic poles which practically not possible.

(iii) Significances of oscillator: Oscillator circuit have very important role in our daily modern life. To test the performance of a stereo amplifier we require an AC generator in audio frequency range (20 Hz to 20 KHz). Such type of AC generator systems known as AC signal generator. For all type of communication systems such as Mobile, Radio (550 KHz to 22 MHz), FM broadcasting (80 MHz to 108 MHz), DTH-TV (1 to 4 GHz), Radar, etc. we require high frequency current. These high frequency currents are provided by oscillator circuits. The oscillator requires testing of components in laboratory. Microwave ovens consists high frequency tube oscillator circuits. High frequency current are used for induction heating.

(iv) Types of oscillators: There are two types of oscillators

a. Sinusoidal and
b. Non-sinusoidal

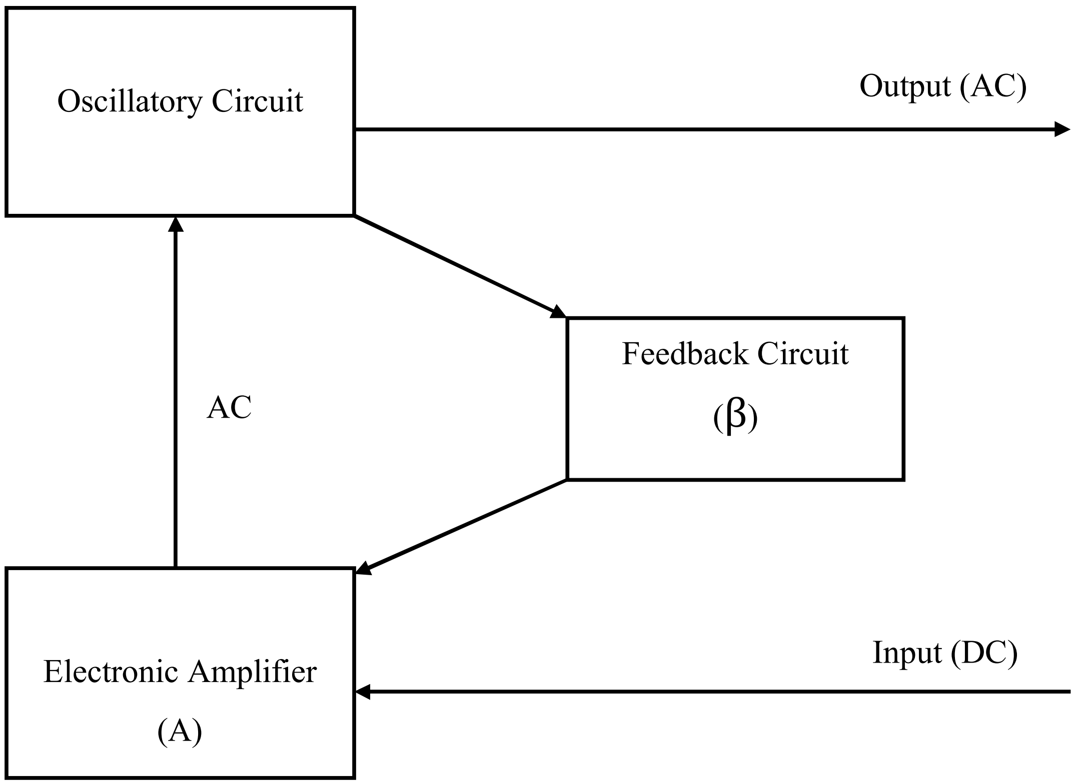
Sinusoidal oscillators produce AC current which change as per sine wave while non sinusoidal can generator produce square waves, triangular waves, saw tooth waves etc. Non-sinusoidal waves have their own significances in various systems such as CRO, Pulse triggering, etc. Sinusoidal oscillators are mostly used in communication systems. On the basis of how oscillations are produced, sinusoidal oscillators can be of following types:

a. LC circuit based
b. RC circuit based
c. Crystal Oscillator
d. Voltage controlled Oscillators (VCO)

(v) Barkhausen Criterion for Oscillators: An oscillator generates ac signal without input signal. There are three essential parts in any oscillator circuit

a. Frequency tuning circuit (oscillation producer)
b. Amplifier
c. Power source

Tuning circuit decide the frequency of oscillations. It can be a resonant type or phase shift or piezo electric crystal. In general during the switch on each and every frequency generates in the circuit known as noise voltage. Such noise voltage is produced by random motion of electrons. The tuning circuit selects one of these, which match to the normal mode of frequency of the tuning circuit. The oscillator circuit is in practice damped type due to the loss of energy in the form of heat and/or radiation. In results the amplitude of oscillations decreases continuously. An amplifier circuit is used with tuning circuit to sustain the amplitude of oscillation. A small part of output (β) is fed back to the input of internal amplifier circuit. The gain of amplifier is set in the way that it amplifies the signal only with that value which is lost due to damping, energy taken out for fed back and at output load. This fed back to the internal amplifier is positive type means in the phase. The amplified current again provided to tuning circuit by ac coupling, hence the amplitude of oscillations sustained.



The necessary condition for the sustained oscillations can be obtained from feedback theory to the circuits

$$A_f = \frac{A}{1 - A\beta}$$

If $A\beta = 1$ then A_f = infinite, which indicate that there is output in the absence of input, in results amplifier circuit will be act as oscillator. This $A\beta = 1$ is known as Barkhausen Criterion of oscillations. If $A\beta > 1$, the oscillations will be grow continuously as shown in figure 2:

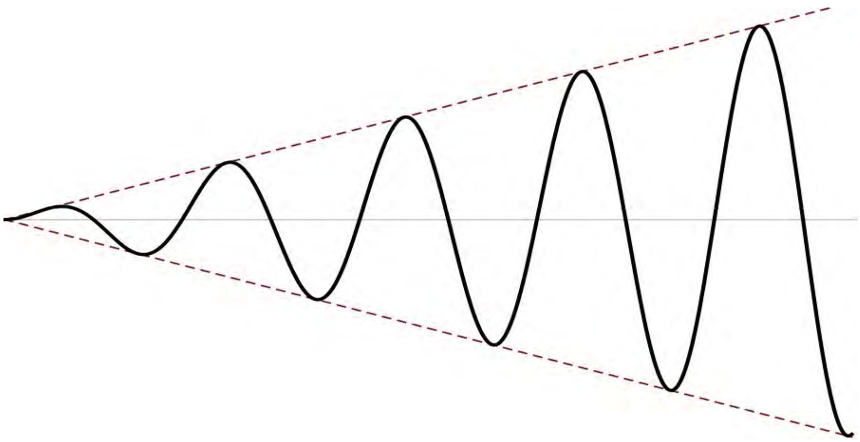


Figure 3: Forced Oscillations

If $A\beta < 1$, the oscillations will be reduced hence damped oscillations

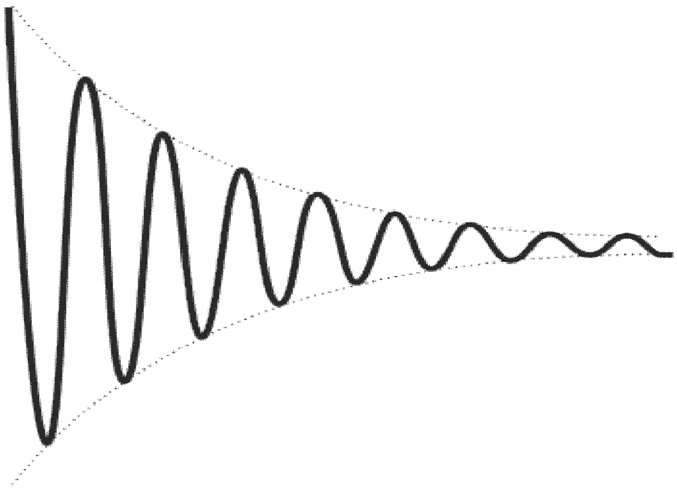


Figure 4: Damped Oscillations

$A\beta = 1$ will give sustain oscillations as require from any oscillator circuit.

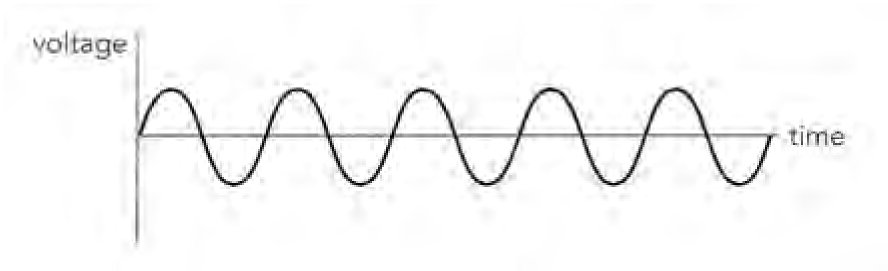


Figure 5: Sustained Oscillations

A DC power source requires for amplifying action. It gives essential power to transistor or tube or FET or any component/s under use for amplification the signal. In the start, as oscillator switched on, Aβ is greater than unity. The oscillations build up and the oscillations achieved at a set level, the gain of amplifier decreases, and the value of the loop get unity [1], hence the oscillations sustained.

(vi) Significance of positive feedback for oscillations: Positive feedback is essential with unity gain to achieve sustained oscillation. As it mentioned earlier that in practice actually the frequency tuning circuit looses the energy, in results the oscillations get damped. Amplifier provides the feedback energy to the frequency tuning circuit in the form of amplified signal.

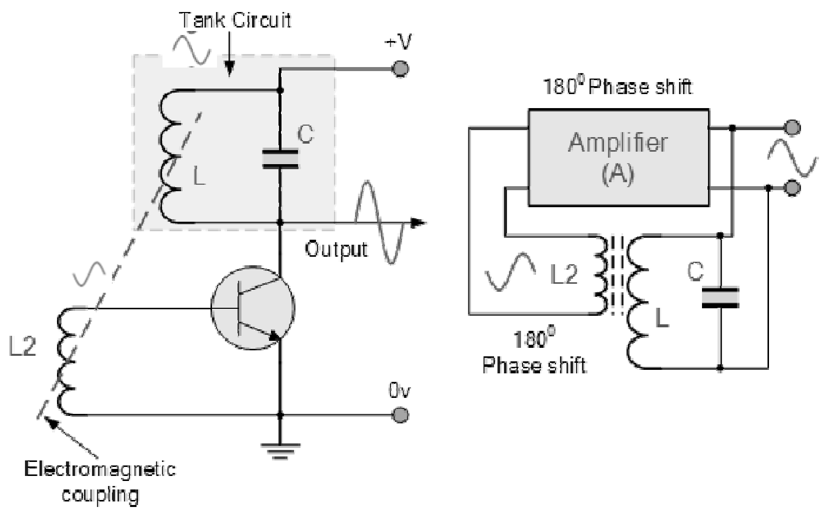


Figure 6: Positive feedback in LC Oscillator [2]

This feedback signal should be in the same phase (0 or 360º) as provided by tuning circuit at output. Since the amplifier circuit (e.g. Common Emitter) mostly revert the phase. This output from amplifier with 180º phase feed to the tuning circuit with ac coupling (e.g. Transformer coupling in LC circuit). This ac coupling again revert the phase and the amplified signal come back in the phase so added to the output. A typical LC oscillator is shown in figure above.

(vii) LC oscillators: In these types of oscillators tuning circuit is based on inductor and capacitor resonance also called as tank circuit or resonant circuit. Frequency tuning circuit consists of an inductor and capacitor in parallel. Such types of circuits are widely used for generating high frequencies upto 500 MHz with possible practical values of inductor and capacitors. Resonant based LC oscillators are commonly used in Radio and TV receivers, RF generators, High frequency induction heating etc.

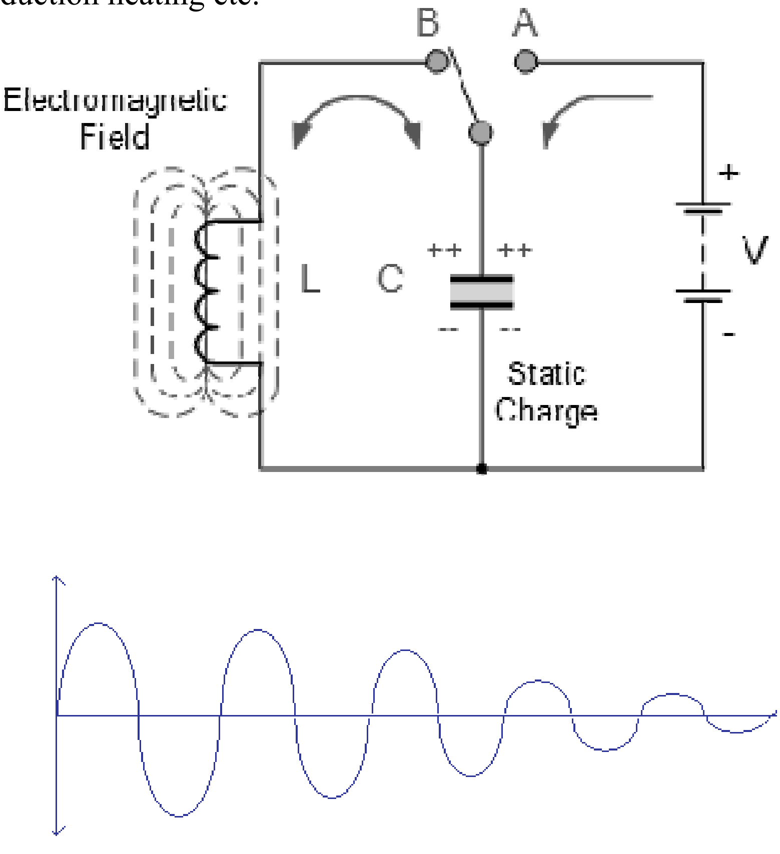


Figure 7: Generation of sinusoidal oscillations in LC tank circuit and generated oscillations [2].

In such oscillators sine waves generated due to charging and discharging of inductor and capacitor alternatively over each other. The capacitor gets fully charged as it is connected to a dc power source. The electric energy stored in the capacitor. Further, the capacitor starts discharging as it is connected to the inductor. The inductor has the property to oppose any change in current, hence the current builds up slowly in the inductor. Maximum current flows in the circuit when the capacitor is fully discharged. The inductor stored the energy in the form of magnetic field. As the capacitor is fully discharged, the magnetic field begins to collapse. The back emf in the inductor keeps the current flowing in the same direction. The capacitor starts charging, but with opposite polarity this time. As the capacitor fully charges, the current starts decreasing in the circuit and the magnetic field across the inductor also decreased. This cycle repeats itself. The charging and discharging of capacitor from inductor follow sinusoidal form; it gives sinusoidal current across it.

(viii) Hartley oscillator: The circuit was invented in 1915 by American engineer Ralph Hartley. If the oscillator consists of two inductors, and one capacitor in the tank circuit then it is called Hartley oscillator. One of the coils is used to feed back the voltage i.e. the voltage across L_1 in actual is used to feedback the signal to the amplifier circuit. In real design of Hartley there was tube amplifier in 1915. The tube is replaced by BJT or FET. BJT in common Emitter (CE) implies in the circuit as an amplifier. The CE amplifier provides a phase shift of 180º and the coil L_1 in the tank circuit provides phase shift of another 180º, this satisfies the required oscillating condition of total phase shift of 360º (known as positive feedback).

The voltage across the YZ part of the coil is feed back to the base of transistor, which is amplified and provided at output. The voltage at point Z is in 180°out-of-phase relative to point X. Extra phase of 180° is created by CE configuration at output (collector). Hence the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained.

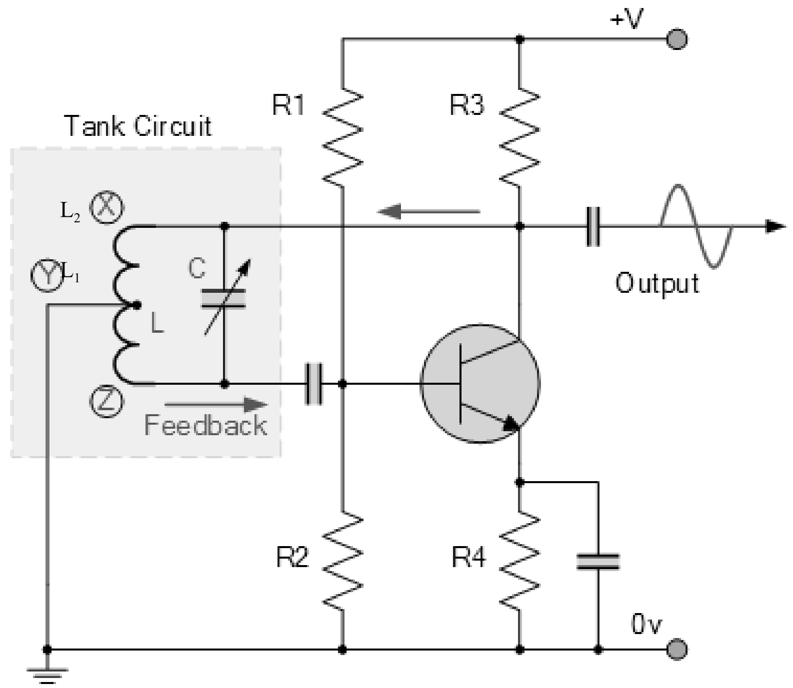


Figure 8: Feedback by coil and phase shifts in Hartley Oscillator [2]

The amount of feedback depends upon the position of the center or tapping point of the inductor. By moving the tapping point the amount of feedback can be changed. If this is moved nearer to the collector the amount of feedback is increased, but the output taken between the Collector and earth is reduced and vice versa. Resistors, R_1 and R_2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitors act as DC-blocking and noise (AC) pass capacitors.

(ix) Voltmeter: Voltmeter is an electronic device to measure the electric potential difference between two terminals. Ideal voltmeter has the infinite resistance.

There are two type of voltmeter

1. Analog voltmeter: An analog voltmeter consist a moving coil and display the reading of voltage in the form of deflection by needle at calibrated scale.

Figure 9: Analog and Digital Voltmeter

2. Digital voltmeter: A digital voltmeter measures potential difference in between two terminals by converting the voltage to a digital value and then displays the voltage in numeric form.

(x) Capacitor: Capacitor is an energy storage device which stores energy in the form of electric charge. Basically the capacitor consists of two parallel metal plates which are separated by dielectric material. The ability of capacitor to store the charge on its plate in the form of electric field is known as capacitance. The capacitance (C) of a capacitor having plates with area 'A', separated by distance 'd' and filled by a dielectric material of K dielectric constant can be write as:

$$C = K\frac{\varepsilon_0 A}{d}$$

The capacitance is measured in Farad (a SI unit). Capacitor blocks the DC current while it allow AC signal through itself. The reactance (X_C; measured in ohms) applied by capacitor on the AC current depends upon the frequency of the signal and it given by

$$X_C = \frac{1}{\omega C}$$

On the basis of used dielectric material the capacitors can be named as polyester, ceramic, paper, electrolytic capacitor etc.

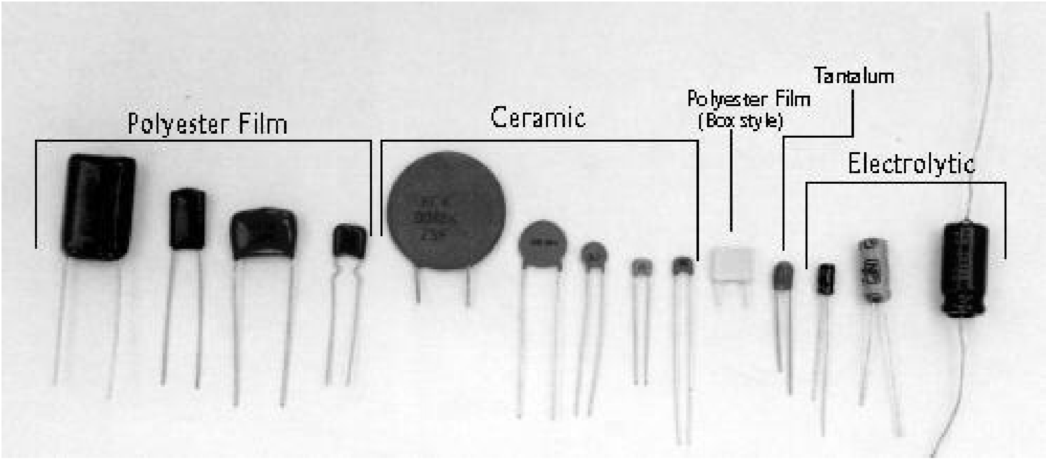


Figure 10: Various types of Capacitors available in market.

(xi) Cathode Ray Oscilloscope (CRO): Cathode ray oscilloscope is an electronic device which is primary used to display of the waveforms. It is possible the direct measurement of the frequency and amplitude of the wave forms with CRO. Two inputs allows the superposition of two waves hence the Lissajou figures can be studied also two wave forms can be compared.

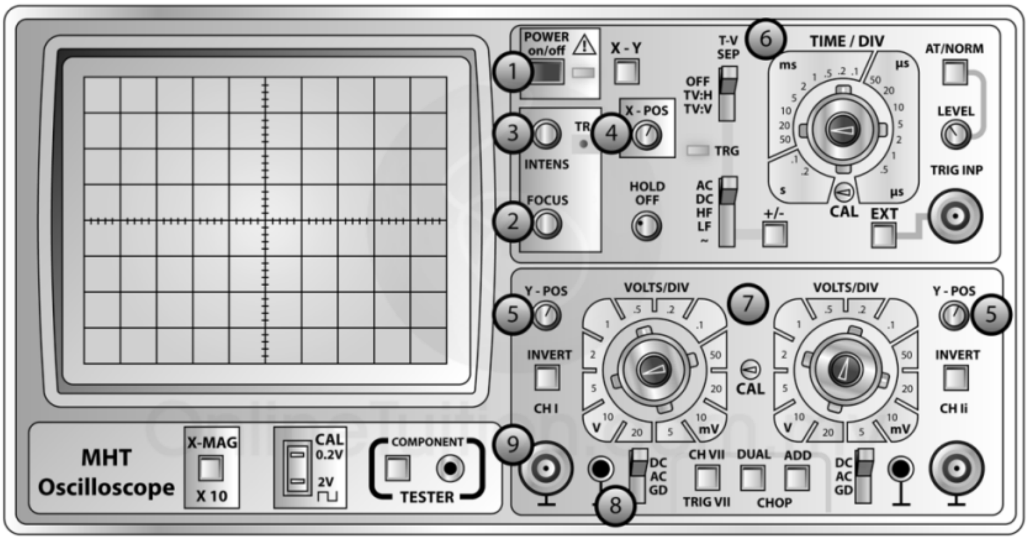


Figure 11: CRO and its functions.

(Courtesy: http://spmphysics.onlinetuition.com.my/2013/06/using-cathode-ray-oscilloscope.html)

Switch in CRO	Function
1. Power switch	To switch on and off of the oscilloscope
2. Focus control	To control the focus of the spot on the screen.
3. Intensity control	To control the brightness of the spot on the screen.
4.X-offset 5. Y-offset	Y-offset moves the whole trace vertically up and down on the screen, while X-offset moves the whole trace from side to side on the screen.
6. Time base control	Whenever we switch on the time-base, we are actually applying a saw-tooth voltage to the X-plates (Figure below). * This make the electron beam sweep across the screen at a constant speed. * By knowing the period of each cycle, T, we can then know how fast the beam is sweeping across the screen. The time-base is thus a measure of time for the oscilloscope.
7. Y gain control	* The "Volts/Div." wheels amplify an input signal so that for a division a given voltage level is in valid. A "division" is a segment, a square on the screen of the oscilloscope.
8. d.c./a.c. switch	d.c. – d.c. and a.c. voltage displayed. a.c. – only a.c. voltage displayed.
9. X-input and Y-input	Electric inputs connect to the X-plate and Y-plate.

15.6 Self Learning Exercise-I

Q.1 What do you understand by an oscillator circuit?

Q.2 What is difference between oscillator and alternator?

Q.3 What are the advantages of oscillator over alternator?

Q.4 What is an audio frequency generator and what is its frequency range?

Q.5 What are uses of oscillator circuit in daily life?

15.7 Procedure

1. Connect the circuit components illustrated in Figure 1.
2. Connect the output from tank circuit to CRO.
3. Switch on biasing power.
4. The oscillator may take a few seconds to stabilize.
5. Trace the waveform at trace paper and note down the time/division from CRO.
6. Measure the frequency of oscillation f_O = 1/T (T = time period of wave).
7. Repeat this experiment with different values of capacitance.
8. Measure the voltage across feedback coil and output voltage across the load resistance by tank circuit (ratio is β)
9. Measure the voltage at output (Collector and earth) of transistor and input (base and earth); (ratio is gain of amplifier A)
10. Calculate the Barkhausen criterion.

15.8 Observation

L_1 = ……………………………………………………… Henery
L_2 = ……………………………………………………… Henery
M = ……………………………………………………… Henery

S. No.	**Capacitance of Capacitor (C)** **µF or pF**	**Calculated value of frequency (f_t)** **Hz**	**Observed value of frequency by CRO (f_O)** **Hz**
1.			
2.			
3.			
4.			
5.			

15.9 Graph

1. **MODEL WAVEFORM AT OUTPUT:**

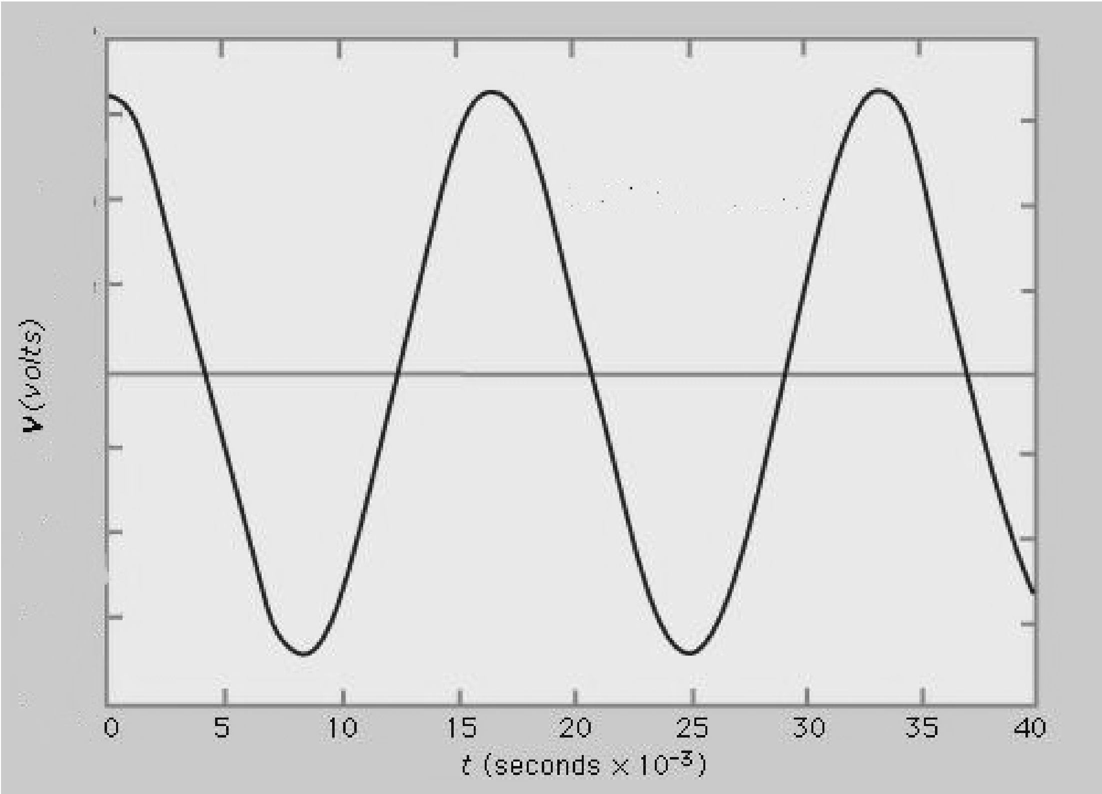


Figure 12: Model output at CRO.

15.10 Calculations

L_1 = 225 mH ,L_2 = 3 mH; M = -25 mH; C = 100 pF

$$f_t = \frac{1}{2\pi\sqrt{C(L_1 + L_2 + 2M)}}$$

$$f_t = \frac{1}{2 \times 3.14\sqrt{100 \times 10^{-12}(225 + 3 - 50) \times 10^{-3}}}$$

$$f_t = 3.8 \times 10^3 \text{ Hz}$$

15.11 Result

Tracings of output

i. If C = ……… μF; Time division scale at CRO….. ……seconds/division

ii. If C = ……… μF; Time division scale at CRO….. ……seconds/division

iii. If C = ……… μF; Time division scale at CRO….. ……seconds/division

iv. If C = ……… µF; Time division scale at CRO….. ……seconds/division

v. If C = ……… µF; Time division scale at CRO….. ……seconds/division

Observed frequency of Hartley oscillator by CRO

i. Frequency f_O = …………………………………….Hz (if C = ……µF).
ii. Frequency f_O = …………………………………….Hz (if C = ……µF).
iii. Frequency f_O = …………………………………….Hz (if C = ……µF).
iv. Frequency f_O = …………………………………….Hz (if C = ……µF).
v. Frequency f_O = …………………………………….Hz (if C = ……µF).

15.12 Discussion

15.13 Precautions and Sources of Error

1. All the connections should be correct.
2. Transistor terminals must be identified properly.
3. Reading should be taken without any parallax error.
4. Biasing voltage should be proper and with accurate polarity.

15.14 Self Learning Exercise-II

Q.1 How many types of oscillator?

Q.2 What is Barkhausen criterion for oscillator?

Q.3 Which feedback is used for oscillator?

Q.4 Why net phase shift in feedback loop should be zero in an oscillator circuit?

Q.5 In general how many parts of a oscillator circuit?

15.15 Glossary

Frequency: the number of cycles or vibrations undergone during one unit of time by a body in periodic motion.

Inductance: It's an electronic property of a coil which oppose to any change in current passing through the coil.

Mutual Inductance: It's an electronics property of magnetically coupled coils where one coil opposes to any change in current due to change in magnetic field of another coil.

Capacitance: capacitance in electronics is defined by capacity of metal to store the charge.

15.16 Answers to Self Learning Exercises

Answers to Self learning exercise -I

Ans.1: An electronic circuit that produces alternating current is known as oscillator circuit.

Ans.2: Oscillator provide ac power source by withdrawing energy from dc power source while in alternator mostly mechanical power is converted in ac power.

Ans.3: Oscillator can provide high frequency range.

Ans.4: Audio frequency generator provides alternate current over audio frequency range from 20 Hz to 20 KHz.

Ans.5: Oscillators are used in communication, induction heating, lab equipment testing etc.

Answers to Self learning exercise -II

Ans.1: Two: Sinusoidal and non sinusoidal

Ans.2: $A\beta = 1$

Ans.3: Positive feedback

Ans.4: To add the amplified signal in the signal generated by tank circuit.

Ans.5: Three: frequency tuning circuit, amplifier and feedback circuit.

15.17 Viva Questions

Q.1 What is Oscillator circuit?

Q.2 What are the applications of oscillators?

Q.3 What are the classifications of oscillators?

Q.4 What are the types of feedback oscillators?

Q.5 What is meant by positive and negative feedback?

Q.6 What are the conditions for sustained oscillator or what is Backhouse criterion?

Q.7 What if the Barkhausen criterion is not fulfilled by oscillator?

Q.8 What is LC oscillator?

Q.9 What do you mean by a tank circuit?

Q.10 What do you understand by damped oscillations?

Q.11 What are the common reasons for damping in the oscillations in an electronic circuit?

Q.12 What is the role of amplifier in oscillator circuit?

Q.13 How does an oscillator differ from an amplifier?

Q.14 Give name of any non-sinusoidal oscillator

Q.15 Why tapping is used in Hartley oscillator?

Q.16 Is it possible to use CB amplifier in Hartley oscillator?

Q.17 What is gain for a oscillator circuit?

Q.18 How energy conserved law follow then?

Q.19 If feedback ratio is changed how the gain can be set so it fulfill the Barkhausen criterion?

Q.20 How can we determine the frequency using CRO?

15.18 Answers to Viva Questions

Ans.1: An electronic circuit that produces alternating current is known as oscillator circuit.

Ans.2: To test the performance of a stereo Amplifier we require an AC generator in Audio frequency range. For all type of communication systems such as Mobile, Radio, FM broadcasting, DTH-TV, Radar, etc. we require high frequency current. These high frequency currents are provided by oscillator circuits. The oscillator requires testing of components in laboratory. Microwave ovens consists high frequency tube oscillator circuits. High frequency current are used for Induction heating.

Ans.3: Sinusoidal and non sinusoidal.

Ans.4: Positive feedback.

Ans.5: The portion of output if feed back to the amplifier in the same phase it is positive feedback and if it out of phase then negative feedback.

Ans.6: $A\beta = 1$.

Ans.7: The oscillations will be not sustained.

Ans.8: The frequency tuning circuit has an inductor and capacitor in parallel to generate oscillations.

Ans.9: Frequency tuning circuit has an inductor and capacitor in parallel to generate oscillations.

Ans.10: If amplitude of oscillations get reduce with time known as damped oscillations.

Ans.11: Energy loss due to radiation and/or heat.

Ans.12: Amplifier amplifies the signal which was lost due to damping and fed to the output that sustains the oscillations.

Ans.13: Amplifier amplifies the signal provided at input while an oscillator provides signal at output in the absence of any input signal.

Ans.14: Multivibrator.

Ans.15: Tapping divides the coil in two parts; one part provides feedback the voltage dropped across it.

Ans.16: In historically arrangement of coils it is not possible as amplifier should provide 180 degree phase shift so rest of 180 is provided by feedback coil to full fill Barkhausen criterion, while CB configuration provide output in the same phase at input.

Ans.17: It is infinite

Ans.18: The dc Energy converted in ac energy.

Ans.19: By changing the biasing resistance.

Ans.20: The time-period of wave can be measured with the help of scale on the screen of CRO and the invert of time-period of wave give the frequency.

References and Suggested Readings

1. Basic Electronics and Linear Circuits by N. N. Bhargava, D. C. Kulshreshtha, S. C. Gupta, 2nd Edition, Mc Graw Hill Publications.
2. ElectronicTutorial;*http://www.electronics- tutorials.ws /oscillator /oscillators.html.*
3. A Text Book of Electrical Technology by B.L. Theraja and A.K. Theraja, S. Chand Publications.

UNIT-16
Pass Filters

Structure of the Unit

16.1 Aim

To study and design of frequency response of phase characteristics of pass filters.

16.2 Apparatus

Capacitor, Inductors, Bread Board, Audio Frequency Generator, Cathode Ray Oscilloscope.

16.3 Diagram

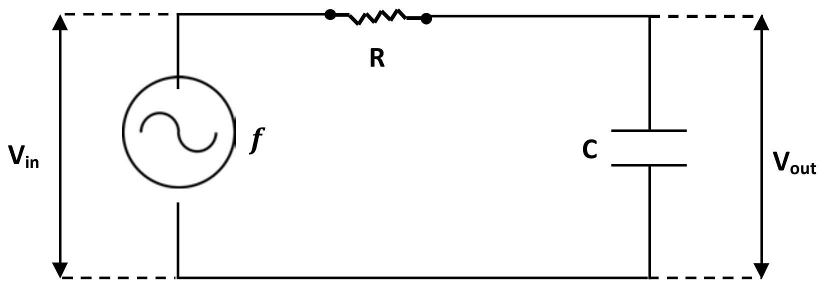


***Fig. 1**: Circuit Diagram of low pass filter.*

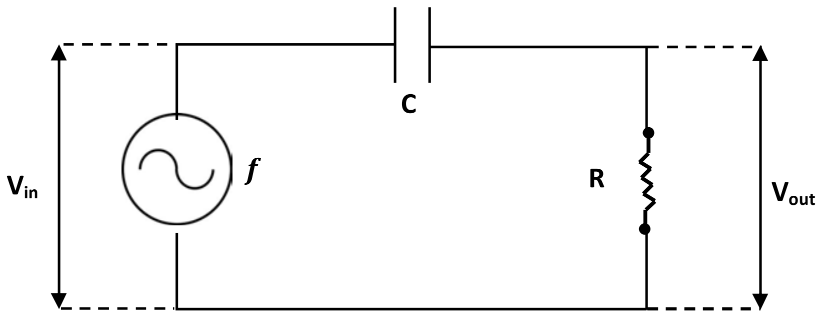


***Fig. 2**: Circuit Diagram of high pass filter.*

16.4 Formula

Voltage Gain $G = \frac{V_{out}}{V_{in}}$

or $G = 20Log_{10}\frac{V_{out}}{V_{in}}$ dB

Here

V_{out} = Voltage at output terminals

V_{in} = Voltage at input terminals (Provided by frequency generator)

(i) RC low pass filter

Voltage gain $G = \sqrt{\frac{1}{1+\left(\frac{f_i}{f_h}\right)^2}}$

Phase $\theta = -tan^{-1}\left(\frac{f_i}{f_h}\right)$

Here

Higher cut off frequency $f_h = \frac{1}{2\pi CR}$

f_i = input frequency provided by frequency generator

(ii) RC High pass filter

Voltage gain $G = \sqrt{\frac{1}{1+\left(\frac{f_l}{f_i}\right)^2}}$

Phase $\theta = tan^{-1}\left(\frac{f_l}{f_i}\right)$

Here

$f_l = \frac{1}{2\pi CR}$ Lower cut off frequency

f_i = Input frequency provided by frequency generator

16.5 Model Graph

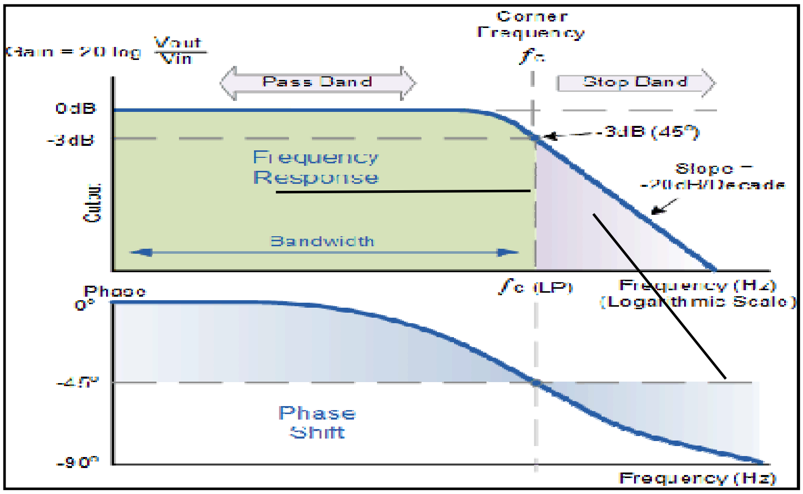


***Fig. 4**: Frequency Response of low pass filter (a) change in gain with input frequency (b) change in phase with input frequency.(Courtesy: http://www.electronics-tutorials.ws/filter/filter_2.html)*

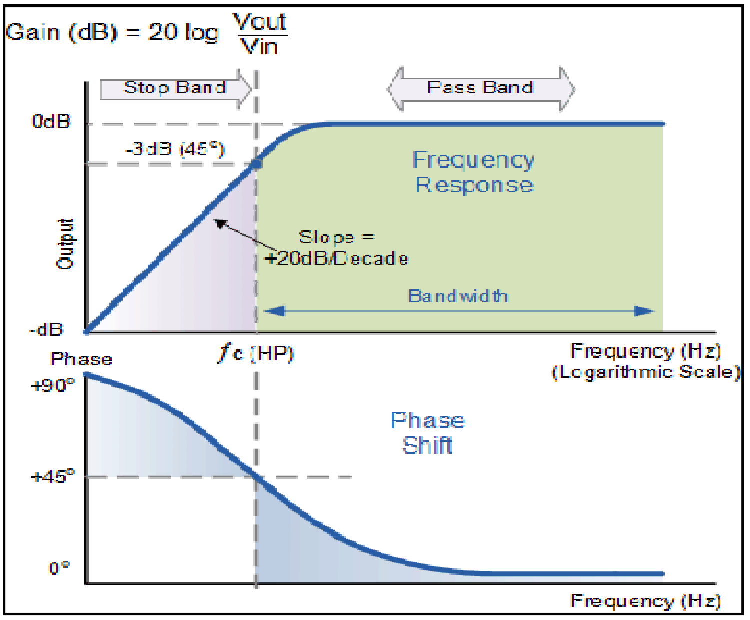


***Fig. 5**: Frequency Response of high pass filter (a) change in gain with input frequency (b) change in phase with input frequency (Courtesy: http://www.electronics-tutorials.ws/filter/filter_2.html)*

16.6 Theory and Description

(i) **Electric Filters:** Electric filter is a frequency selective circuit, which allows specific frequency range and rejects unwanted frequencies.

(ii) **Classification of Filters:** On the basis of components used in the circuit, filters can be classified as:

1. Passive filter: The filter circuit in which only passive components such as resistors, capacitors, inductors are used is known as passive filter.
2. Active filter: The filter circuit in which at least one or more active components like transistor, op-amp are used is known as active filter.

Most commonly used filters are:

- Low pass filters
- High pass filters
- Band pass filter

***1.** Low pass filter*: An electronic filter is a circuit which attenuates all the frequencies higher than selected cut off frequency (f_h) and allows only the lower frequencies as shown in fig. 4. In frequency response, the frequency range below cut of frequency ($f < f_h$) filter indicates a pass band and for $f > f_h$, the filter shows a stop band.

2. *High pass filter*: Filters that attenuate lower frequencies and allow all the frequencies those are higher than f_l as shown in fig 4. In frequency response of high pass filter below cut of frequency ($f < f_l$) filter shows a stop band for $f > f_l$ filter shows a pass band.

3. *Band pass filter*: Filter that stops high and low frequency and allows a particular range of frequencies is known as band pass filter. The pass band for frequency $f_l < f < f_h$ and stop band for $f > f_h$ and $f < f_l$.

RC filter circuit are like voltage divider where one resistance replaced by capacitor we can also calculate on the terminals of capacitor as:

The reactance of capacitor is given by

$X_C = \frac{1}{2\pi f C}$

So resultant impedance of circuit will be

$$Z = \sqrt{R^2 + X_C^2}$$

The voltage on capacitor

$$V_C = V_{in}\,\frac{X_C}{Z}$$

(iii) **Frequency Response*:*** The plot between amplitude (Voltage Gain) and input signal frequency of electric circuit is known as frequency response. The voltage gain of circuit varies with input signal frequency since the reactance by capacitor depends upon frequency.

(iv) **Gain:** the ratio of output electrical measured quantity to the input one of the electronic circuit is called gain. It can be current gain, voltage or power gain accordingly,

Voltage gain in decibel $G = 20Log_{10}\frac{V_{out}}{V_{in}}$

(v) **Voltmeter:** Refer Unit 15

(vi) **Capacitor:** Refer Unit 15

(vii)Frequency Generator: A function generator or frequency generator is an electronic device, which produce simple repetitive waveform. This device contain an electronic oscillator (An electronic oscillator is a circuit that produce a time varying signal such as sine wave, saw tooth wave, square wave etc.) which convert provided DC supply to a desired ac wave form with selected frequency. It is possible to vary the amplitude of the wave also.

Fig. *7: Frequency or function generator.* ***Fig.8****:Cathod eRayOscilloscope (CRO)*

(viii)Cathode Ray Oscilloscope (CRO):

Cathode ray oscilloscope is an electronic device which is primary used to display of the waveforms. It is possible the direct measurement of the frequency and amplitude of the wave forms with CRO. Two inputs allows the superposition of two waves hence the Lissajou figures can be studied. Furthermore, two wave forms can be compared. The CRO consist mainly three basic components electron gun, deflection system, and fluorescent screen.

16.7 Self Learning Exercise-I

Q.1 What is Reactance?

Q.2 What is unit of Reactance?

Q.3 What do you understand by frequency?

Q.4 What is the unit of gain?

Q.5 What is the dimension of phase?

16.8 Procedure

1. Have the electronic bread board and stitch the components R and C of selected

values.

2. Add the frequency generator and set it for sine wave.
3. Complete the circuit and add all components i.e. function generator, R and C as per given circuit diagram.

For low pass filter

1. Measure the voltage difference on the terminals of capacitor with the help of ac voltmeter or CRO.
2. Vary the frequency of input signal from function generator and measure the corresponding output voltage.
3. Find out the voltage gain as a function of frequency.
4. Plot the graph between gain and input frequency (for convenience we can take logarithmic value of frequency).
5. Calculate and plot the phase as a function of input frequency (for convenience we can take logarithmic value of frequency for plot).

For high pass filter

1. Measure the voltage difference on the terminals of resistance with the help of ac voltmeter or CRO.
2. Vary the frequency of input signal from function generator and measure the corresponding output voltage.
3. Find out the voltage gain as a function of frequency.
4. Plot the graph between gain and input frequency (for convenience we can take logarithmic value of frequency).
5. Calculate and plot the phase as a function of input frequency (for convenience we can take logarithmic value of frequency for plot).

16.9 Observation

Value of resistance (R) = …………………………… ………... Ohm

Value of capacitor (C) = ………………………………………. Farad

Table 1: *Observation table for low pass filter.*

S. No.	Input frequency (f_i) KHz	Input Voltage (V_{in}) Volt	Output Voltage across C (V_{out}) Volt	G= V_{out}/V_{in}	Gain in Decibel dB	Phase (θ) degree
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						

Table 2: *Observation table for high pass filter.*

S. No.	Input frequency (f_i) KHz	Input Voltage (V_{in}) Volt	Output Voltage across R (V_{out}) Volt	G= V_{out}/V_{in}	Gain in Decibel dB	Phase (θ) degree
1.						
2.						
3.						

4.						
5.						
6.						

16.10 Graph

1. Low pass Filter

a. Graph between voltage gain (G) and input frequency (f_i):

Scale: on X axis 1 cm = …… Hz

on Y axis 1 cm = ……db

Input frequency(f_i) Hz								
Voltage Gain(G) dB								

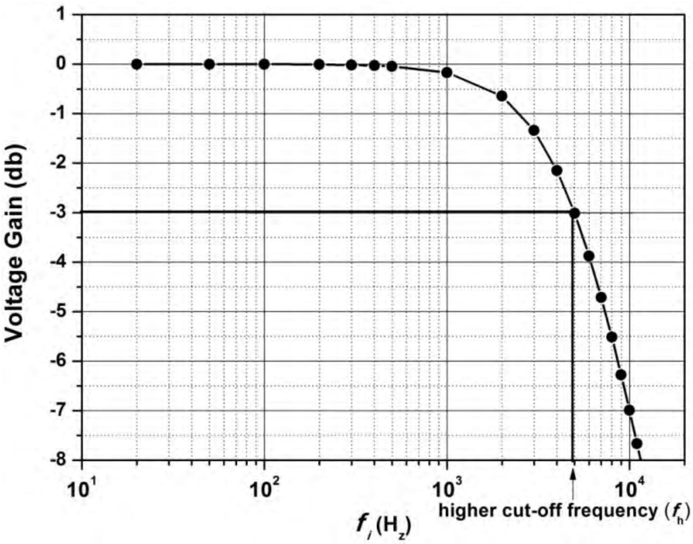


***Fig. 9:** Plot between voltage gain (G) and input frequency (f_i)for low RC pass filter.*

b. Graph between Phase (θ) and input frequency (f_i):

Scale: on X axis 1 cm = …… Hz

on Y axis 1 cm = ……degree

Input frequency (f_i)Hz									
Phase angle (θ) degree									

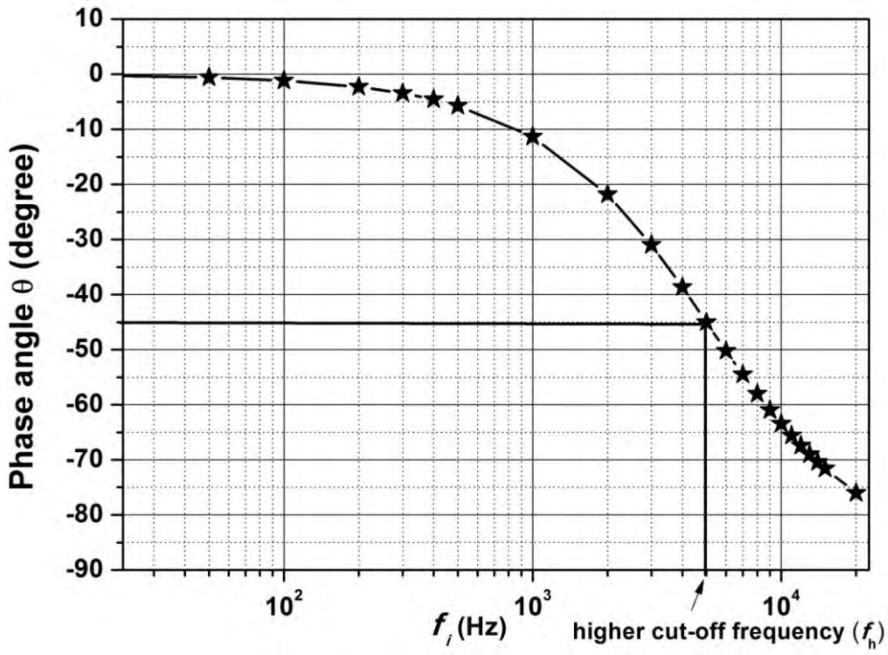


Fig. 10: *Plot between phase angle (θ) and input frequency (f_i) for low pass RC filters.*

2. High pass filter

a. Graph between voltage gain (G) and input frequency (f):

Scale: on X axis 1 cm = …… Hz

on Y axis 1 cm = ……db

Input frequency (f_i) Hz									
Voltage Gain (G) dB									

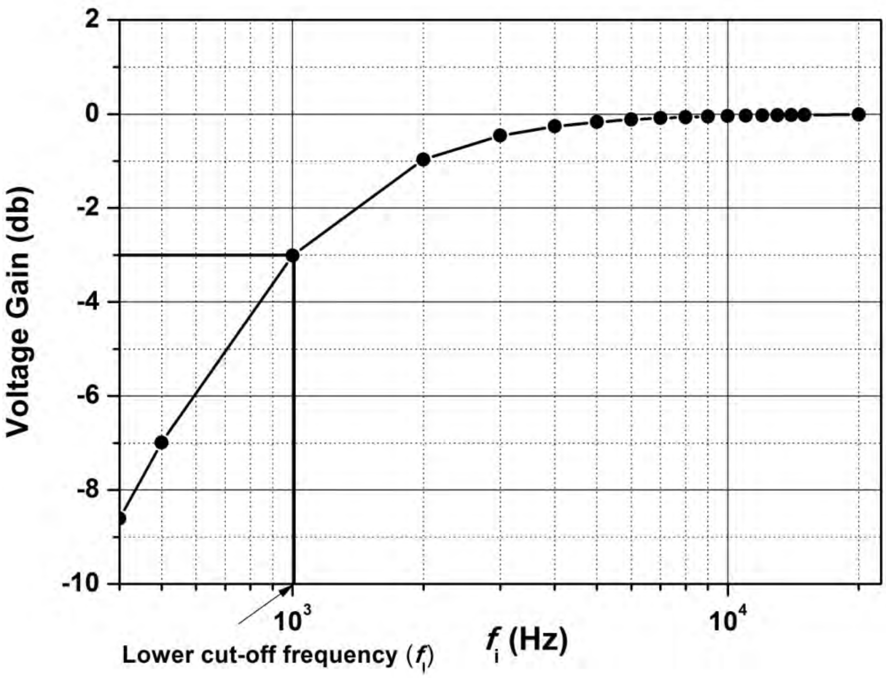


Fig. 11: *Plot between voltage gain (G) and input frequency (f_i) for high pass RC filters.*

b. Graph between Phase (θ) and input frequency (f):

Scale: on X axis 1 cm = …… Hz

on Y axis 1 cm = ……degree

Log$_{10}f_i$ (Hz)									
Phase (degree)									

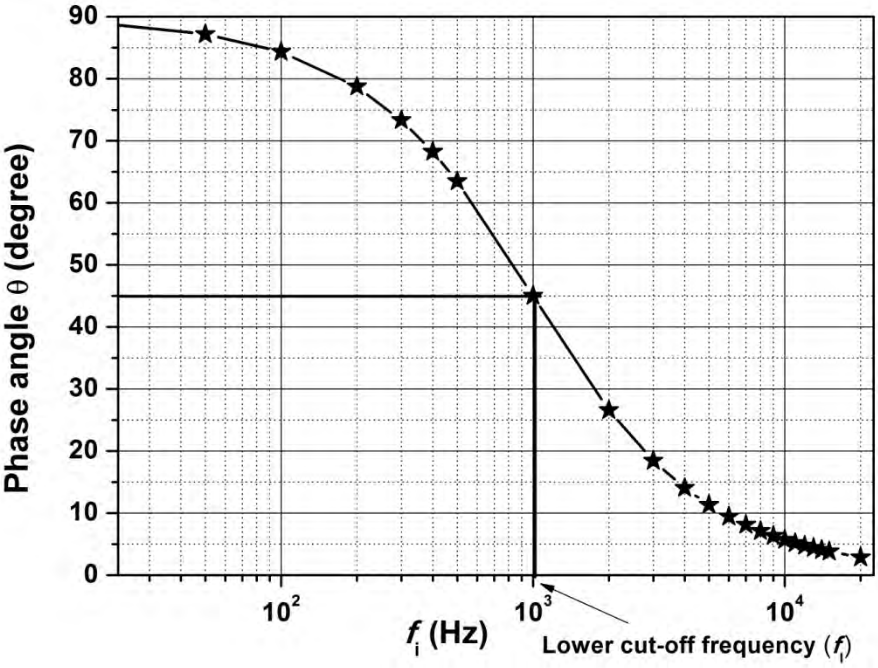


Fig. 12: *Plot between phase angle (θ) and input frequency (f_i) for high pass RC filters.*

16.11 Calculations

Model Calculation:

1. Low pass filter

a. R and C selection

Let :

Input voltage V_{in} = 10 volt

The higher cut of frequency f_h = 5 KHz

The value of capacitance C = 0.47 nF

$$f_h = \frac{1}{2\pi CR}$$

$$R = \frac{1}{2\pi C f_h}$$

$$R = \frac{1}{2 \times 3.14 \times 0.47 \times 10^{-9} \times 5 \times 10^{3}}$$

$$R = 67.7\ K\Omega$$

b. Calculation for gain

(i) Theoretical calculation

if input frequency (f_i)= 4 KHz and

higher cut off frequency (f_h) is already selected = 5 KHz

$$G = \sqrt{\left[\frac{1}{1 + \left(\frac{f_i}{f_h}\right)^2}\right]}$$

$$G = \sqrt{\frac{1}{1 + \left(\frac{4 \times 10^3}{5 \times 10^3}\right)^2}}$$

$$G = 0.78$$

or

$$G = -2.16\ db$$

(ii) Practical calculations

Voltage gain

$$G = 20Log_{10}\frac{V_{out}}{V_{in}}$$

Measured output voltage across capacitor

V_{out} = 7.7 volt (when input frequency f_i = 4 KHz)

$$G = 20Log_{10}\frac{7.7}{10}$$

$$G = -2.27\ db$$

c. Calculation for Phase

(i) Theoretical calculations

Phase $\theta = -tan^{-1}(\frac{f_i}{f_h})$

$$\theta = -tan^{-1}\left(\frac{4\ \times 10^3}{5\ \times 10^3}\right)$$

$$\theta = -38.68°$$

(ii) Practical calculations

Compare the phase difference in between input and output waves with the help of CRO.

2. High pass filter

a. R and C selection

Let: Input voltage V_{in} = 10 volt

The lower cut of frequency f_l = 1 KHz

The value of capacitance C = 0.01 μf

$$f_l = \frac{1}{2\pi CR}$$

$$R = \frac{1}{2\pi C f_l}$$

$$R = \frac{1}{2 \times 3.14\ \times 0.01\ \times 10^{-6} \times 1\ \times 10^3}$$

$$R = 15.9\ K\Omega$$

b. Calculation for gain (G)

(i) Theoretical calculation

if input frequency (f_i) = 2 KHz and

lower cut off frequency (f_l) is already selected = 1 KHz

$$G = \sqrt{\frac{1}{1 + \left(\frac{f_l}{f_i}\right)^2}}$$

$$G = \sqrt{\frac{1}{1 + \left(\frac{1 \times 10^3}{2 \times 10^3}\right)^2}}$$

$$G = 0.89$$
$$G = -0.96\ dB$$

(iii) Observed value of gain

$$G = 20 log_{10} \frac{V_{out}}{V_{in}}$$

Measured output voltage across capacitor

V_{out} = 9.0 volt (when input frequency f_i= 2 KHz)

$$G = 20 log_{10} \frac{9.0}{10}$$

$$G = -0.91\ db$$

c. Calculation for Phase

(i) Theoretical calculations

Phase $\theta = tan^{-1}(\frac{f_l}{f_i})$

$$\theta = tan^{-1}\left(\frac{1 \times 10^3}{2 \times 10^3}\right)$$
$$\theta = 26.56°$$

(iii) Practical calculations

Compare the phase difference in between input and output waves with the help of CRO.

16.12 Result

16.13 Discussion

16.14 Precautions and Sources of error

1. All connections should be tight.
2. The length of connecting wire should not be exceeding too long so experiment can be escape from the heat loss.
3. Keep off the supply to the board and then make interconnections.
4. The input voltage in circuit to be kept of proper magnitude.

16.15 Self Learning Exercise-II

Q.1 What is cut off frequency?

Q.2 What type of RC filter can be considered?

Q.3 Why the capacitors allow the ac current while stops dc current?

Q.4 Why the capacitors attenuate high on low frequency?

Q.5 What is the effect of input frequency on the gain of high pass filter?

16.16 Glossary

Attenuation**:** Any reduction in the strength of a signal.

Frequency: Frequency is the number of occurrences of a repeating event per unit time.

Pass band: The range of frequencies or wavelengths that can pass through a filter without being attenuated.

Stop band: The attenuated range of frequencies or wavelengths by a filter.

16.17 Answers to Self Learning Exercises

Answers to Self Learning Exercises-I

Ans.1: Reactance is an opposition to change of voltage across capacitor or inductor.

Ans.2: Ohm (Ω).

Ans.3: Cycle/second.

Ans.4: Dimensionless.

Ans.5: Time^{-1}

Answers to Self Learning Exercises-II

Ans.1: For low pass filter input frequency where gain is 70.7% of maximum gain.

Ans.2: Passive filter.

Ans.3: Reactance for dc current is infinity and for ac current is low.

Ans.4: Reactance for capacitor $X_c = \frac{1}{\omega C}$ as the frequency is decreases in results the reactance increases so the attenuation by capacitor high at low frequency.

Ans.5: Gain increases as the input frequency increases.

16.18 Viva Questions

Q.1 What is frequency response?

Q.2 What is voltage gain?

Q.3 Where we measure output voltage in RC low pass filter?

Q.4 Where we measure output voltage in RC high pass filter?

Q.5 What will happen if we combine low pass and high filter?

Q.6 What are applications in daily life uses of these filters?

Q.7 How it will affect if the capacitance is high in high pass filter?

Q.8 What is frequency generator?

Q.9 What are the filters?

Q.10 How many types of filters?

Q.11 What are the passive components?

Q.12 What are the active components?

Q.13 What will be the phase between in current and voltage for the capacitor?

Q.14 How the reactance of capacitor change with the frequency?

Q.15 What are the examples of passive filters?

Q.16 What are the examples of active filters?

Q.17 How we represent the gain in decibel?

Q.18 What is band width?

Q.19 What is resonant frequency?

Q.20 How we calculate the resonate frequency for band pass filter.

16.19 Answers to Viva Questions

Ans.1: Curve between gain and input frequency is known as frequency response.

Ans.2: Ratio of output and input voltage is voltage gain.

Ans.3: On the terminal of capacitor.

Ans.4: On the terminal of resistor.

Ans.5: It will form the band pass filter.

Ans.6: LCR filter we use in tuning radio on particular channel.

Ans.7: High value of C result more attenuation.

Ans.8: An electronic device which produce time varying electric signal.

Ans.9: Filter is electronic circuit that remove unwanted frequency and allow required frequency.

Ans.10: On the basis of component use in filter are two type (a) Passive filter and (b) active filter.

Ans.11: Resistance, capacitor and inductor.

Ans.12: Transistor, diode.

Ans.13: $\frac{\pi}{2}$

Ans.14: $X_l \alpha f$

Ans.15: RC, LC RL LCR pi filter T section filter etc.

Ans.16: Transistor, operational amplifier with passive filter circuit.

Ans.17: Gain in decibel $G = 20Log_{10}\frac{V_{out}}{V_{in}}$ db

Ans.18: The difference between higher cut off frequency and lower cut off frequency is called band width.

Ans.19: Resonant frequency $f_r = \sqrt{f_h f_l}$

Ans.20: For band pass filter that input frequency where gain is maximum.

References and Suggested Readings

1. Electronic Fundamentals and Applications by J.D. Ryder, Prentice-Hall Publications.
2. Electronic Principles by A.P. Malvino, Tata McGraw-Hill Publishing Company Limited.
3. Handbook of Electronics by S.L. Gupta and V. Kumar, Pragati Prakashan.

UNIT-17
Planck's Constant using Solar Cell

Structure of the Unit

17.1 Aim

To determine the Planck's constant using solar cell

17.2 Apparatus

The experimental set-up consists of the following:

(i) Optical Bench. (ii) Solar cell

(iii) Optical filters (iv) Convex lens

(v) D.C. microammeter (0-50μA) (vi) Light source with lamp house

(iv) D.C. Power supply

All the components can be mounted on an optical bench with proper alignment.

17.3 Diagram

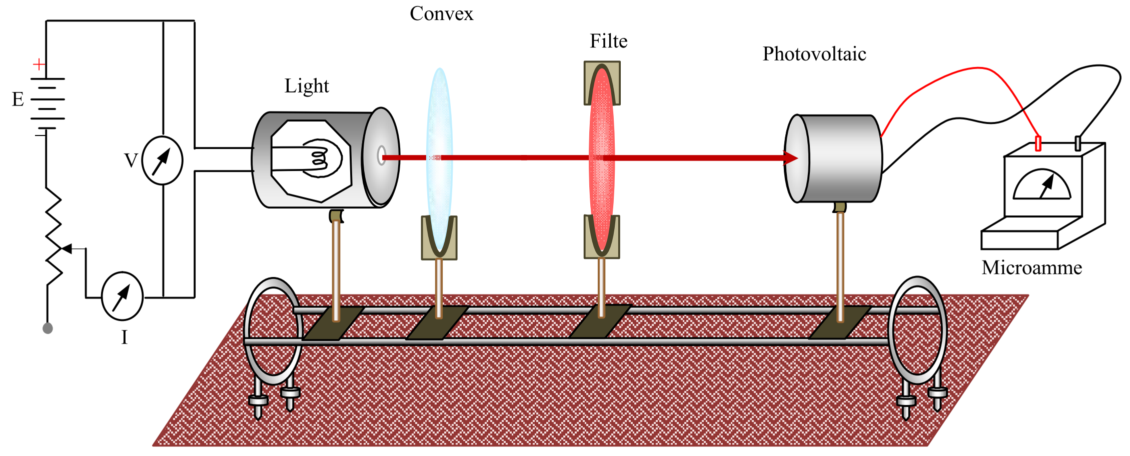


Fig.1. Diagram of experimental Arrangement for the determination of Planck's constant

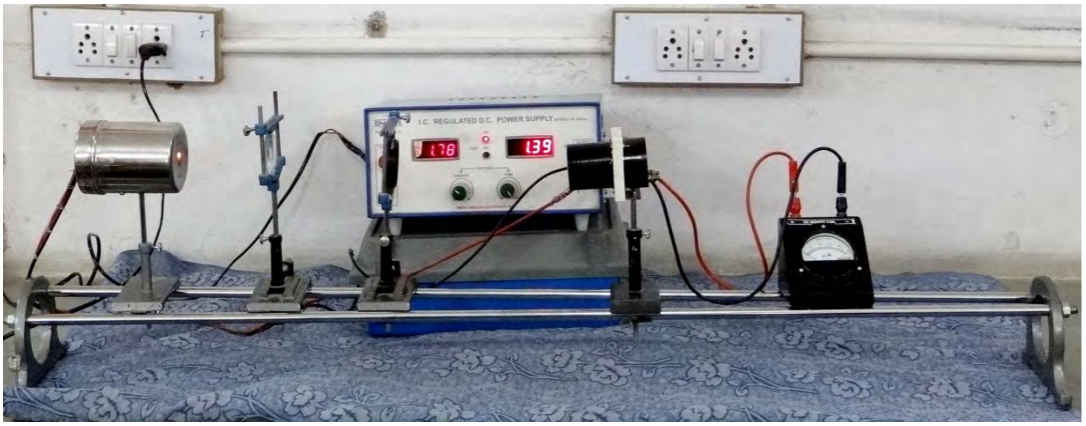


Fig.1. Experimental Arrangement of OMEGA TYPE ES-214

17.4 Formula

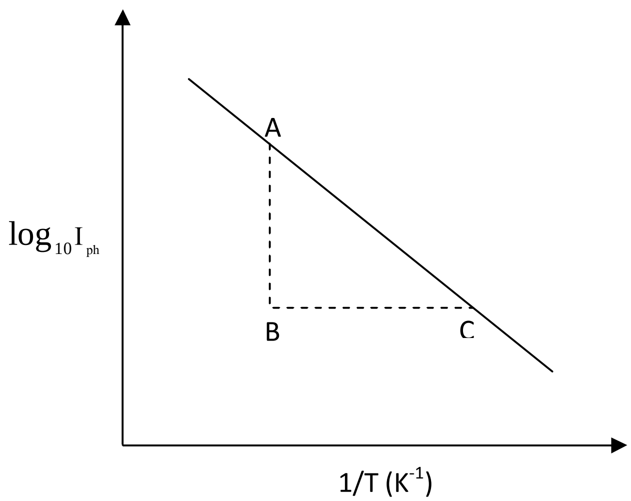
Planck's constant

$$h = \frac{2.3026\, k_B}{\nu}\left(\text{slope}\right)$$

or
$$h = \frac{2.3026\, \lambda\, k_B}{c}\left(\text{slope}\right)$$

Here slope of the curve between 1/T and $\log_{10} I_{ph}$ is taken.

17.5 Model Graph



17.6 Theory and Description

Introduction

Radiation can be defined as a wave that consists of oscillating electric and magnetic field is called electromagnetic wave. It is characterized by its wavelength (λ) and frequency ν (number of oscillations of fields per second). Wavelength and frequency are related as

$$\lambda\nu = c$$

Where c is the velocity of the wave (radiation) and its value is generally 3×10^{8} m/s^{2}.

We know that different solid emit radiations at different rate at the same temperature as a result of thermal motion of particles which they are made (temperature dependent spectra). The rate of emission is maximum when the solid is perfectly black i.e., behaves as blackbody.

A blackbody is a system that converts heat into radiant energy. By heating an object to different temperatures causes that object to radiate energy of different wavelengths. Wavelength depends only on temperature not on type of material.

The electromagnetic radiation emitted by a black body is called blackbody radiation. By definition, a perfect blackbody can absorbs all radiation that fall on it. For practical purpose a hollow enclosure with small hole through which radiation from outside is absorbed completely due to repeated reflection inside the enclosure.

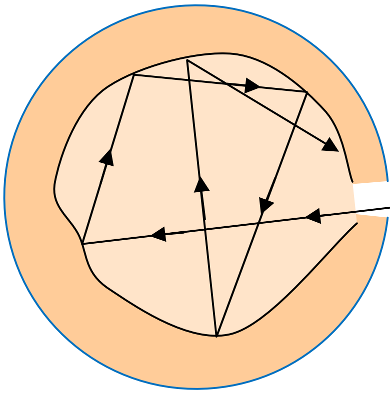


Fig. Blackbody Radiation

Theory of blackbody radiation was successfully explained by Max Planck based on idea of photon concept. Planck's proposed that energy that emitted from a blackbody is quantized. The oscillators can absorb or emit energy in discrete multiples of the fundamental quantum (h) of energy given by

$$E_n = nh\nu,$$

where n is an integer, ν is the frequency, and h is called Planck's constant.

$$h = 6.6261 \times 10^{-34}\,\mathrm{J-S}$$

The Planck's law gives us the energy density of radiation per unit in the frequency range ν to $\nu + d\nu$. This is denoted as $U(\nu)d\nu$.

$$U(\nu)d\nu = \frac{8\pi h\nu^3}{c^3}\frac{d\nu}{\exp\left(\frac{h\nu}{kT}\right) - 1} \qquad (1)$$

With the symbols have usual meaning:

T (Temperature) – °C

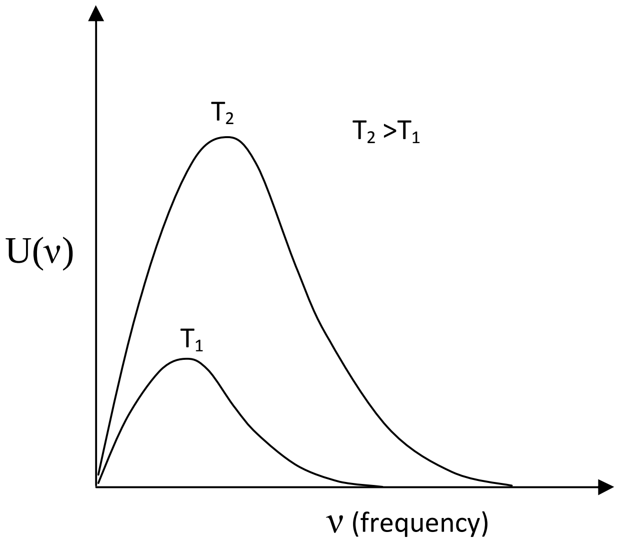
c (speed of light) – 3×10^{8} m/s

k (Boltzmann constant) – 1.38×10^{-23} J/K

h (Planck's constant) – 6.62×10^{-34} J-s

$U(\nu)\,d\nu$ (spectral radiance) – W/m^2 Hz sr

Fig shows the graph between $U(\nu)$ vs. ν(frequency) for a given temperature T.



In high frequency region (visible), where $\frac{h\nu}{kT} >> 1$ eqn.1 can be approximated as

$$U(\nu) = \frac{8\pi h\nu^3}{c^3}\exp\left(-\frac{h\nu}{kT}\right) \qquad (2)$$

eqn.2 is called Wien's formula

If $A = \frac{8\pi h\nu^3}{c^3}$, then

$$U(\nu) = A\exp\left(-\frac{h\nu}{kT}\right) \qquad (3)$$

Taking log on both side of eqn.3

$$\log U(\nu) = \log A - \frac{h\nu}{kT} \qquad (4)$$

In this experiment, a tungsten filament lamp is used as black body radiator. A monochromatic filter is selected for radiation of frequency in the visible region. It is known that the radiation energy is directly proportional to photocurrent (I_{ph}). Thus

$$U(\nu) \propto I_{ph}$$

or $$U(\nu) = BI_{ph} \quad (5)$$

Taking log on both side of eqn.4, we get

$$\log U(\nu) = \log B + \log I_{ph} \quad (6)$$

From eqn.4 and 5, we obtain

$$\log B + \log I_{ph} = \log A - \frac{h\nu}{kT}$$

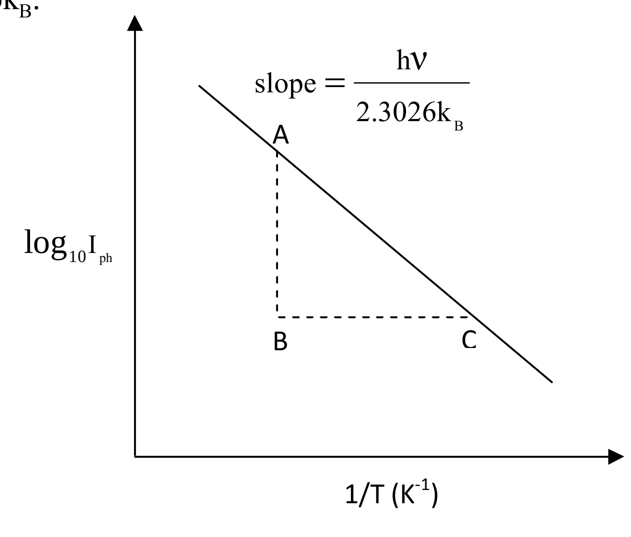
$$\log I_{ph} = (\log A - \log B) - \frac{h\nu}{kT}$$

or $$\log_{10} I_{ph} = (\log_{10} C) - \frac{h\nu}{2.3026\,kT} \quad (7)$$

where

$$\log_{10} C = (\log_{10} A - \log_{10} B)$$

Hence this eqn.7 is analogous to equation of straight line y=mx+c. Therefore, the graph between $\log I_{ph}$ vs. 1/T will be a straight line with slope of magnitude $h\nu/2.3026k_B$.



Therefore,

$$h = \frac{2.3026\, k_B}{\nu}\left(\text{slope}\right) \quad (8)$$

Substituting values of all constants ν, K_B and slope we can determine the value of Planck's constant.

Determination of Temperature of filament of the tungsten bulb.

By applying potential V across the bulb filament the current I flow through it. Then the resistance R can be find out as

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

The resistance of bulb filament depends on the temperature as well. Therefore the resistance of filament at the temperature T is

$$R_T = R_0[1 + \alpha(T - T_0)] \quad (9)$$

where

α: thermal resistance coefficient

for tungsten α=4.5×10^{-3} K^{-1} (at room temperature)

R_T= Resistance of filament at the temperature T K.

R_0= Resistance of filament at the room temperature (T_0=300K).

This formula can only be used at the low temperature but at high temperature

$$\frac{R_T}{R_0} = \left(\frac{T}{T_0}\right)^x$$

Here x can be determined by curve fitting technique. For best fitting it is found at x=1.2, thus

$$T = T_0\left(\frac{R_T}{R_0}\right)^{1/1.2} = T_0\left(\frac{R_T}{R_0}\right)^{0.833} \quad (10)$$

This is called as *Langmuir formula*.

In Laboratory it is difficult to find out the resistance of filament at the room temperature (300K) because when a current flows through the filament, it gets heated and temperature rises. Below 798K which corresponds to infrared region (By Wien displacement law), the filament does not bright. As we increase the temperature above 798K, the filament starts to glow up which corresponds to the visible region (i.e., filament switches from infrared region to the visible region). This temperature is called draper temperature or draper point.

The *Draper point* is the approximate temperature (525˚ C, 977˚ F) above which bulb filament just starts to glow as a result of blackbody radiation.

Now using T_D instead of T_0

$$T = T_D\left(\frac{R_T}{R_D}\right)^{1/1.2} = T_D\left(\frac{R_T}{R_D}\right)^{0.833} \qquad (11)$$

where R_D is draper resistance.

Solar Cell

A solar cell is a semiconductor device that converts sunlight (solar light) from the sun into electricity based on the principles of photovoltaic effect. In general a solar cell that includes both solar and non-solar sources of light (such as photons from incandescent bulb) is termed as photovoltaic cell. When light strikes on the photovoltaic cell then it is absorbed by semiconducting materials. This absorption of light creates charge carriers (electron-hole pairs) generating electrical power.

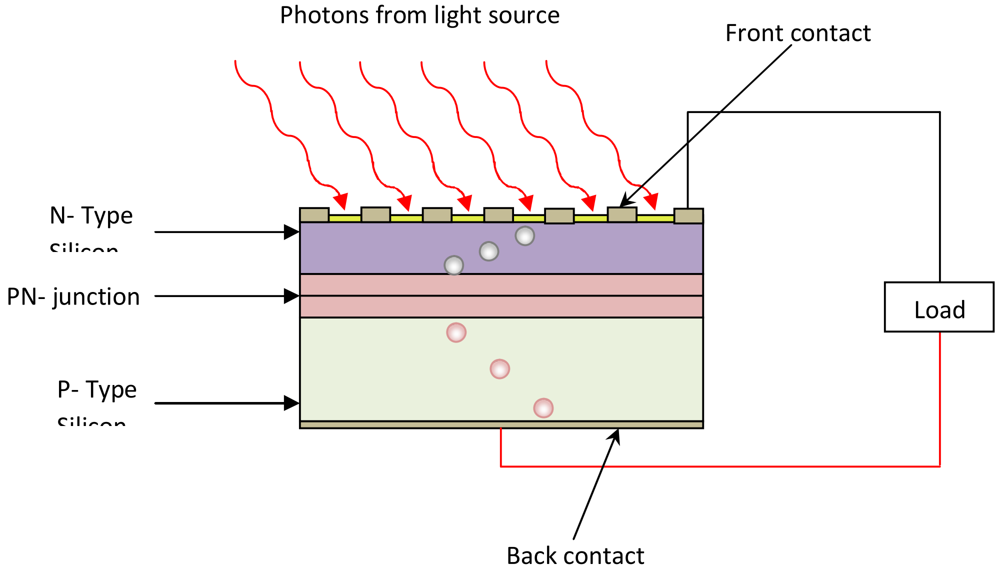


Fig. Solar cell structure

Light Bulb (incandescent lamp)

A tungsten light bulb is an artificial source of light in home. It converts the electric power into light energy by passing current through the tungsten filament coil by causing Joule heating effect. Light bulb is usually is filled with an inert gas like argon. Incandescent light bulbs are spatially and temporally incoherent light sources. A light bulb emits incoherent light of different wavelengths. There is no fixed phase relationship between the wavelengths.

Collimator

A collimator is an optical device that filters the stream of rays or optical beam so that they travel parallel or narrow (minimum spread) along the specified direction through it. In experiment, a collimator consists of a convex lens with a light bulb and apertures (a simple hole is made at the centre of circular surface of the steal cane) which collects light from bulb and redirects it.

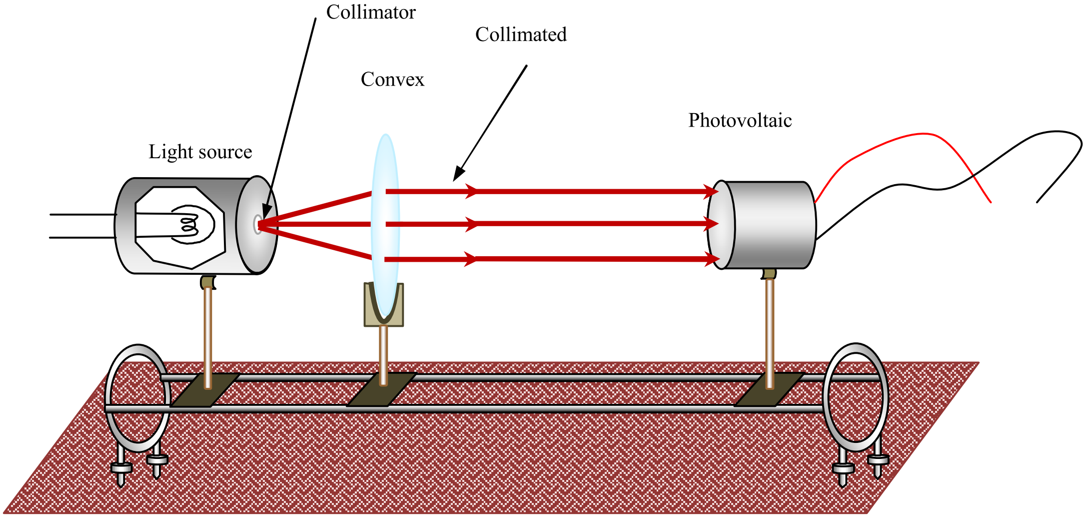


Fig. parallel light from collimator

Color Filters

A colour filter is an optical element which absorbs a band of wavelength of light and transmits different wavelength. The emitted radiations from filter are temporally coherent (monochromatic). For example, a red filter transmits only red light, this is because the red filter only allows red light pass through it. The experiment can be performed with the different colour of filters. The wavelength of three primary coloures filters are

Filter colour	Approximate Transmitted Wavelength(Å)
Blue	4300 - 4900
Green	4900 - 5800
Red	6200 - 7500

17.7 Self Learning Exercise-I

Q.1 Define Black body radiation.

Q.2 Define black body.

Q.3 What is Wien's law?

Q.4 What is Draper point?

Q.5 What is formula of Planck for a blackbody?

17.8 Procedure

This experiment setup is designed to determine the value of Planck's (h) constant using a incandescent light bulb (60 watt) as a source of black-body radiation. An optical filter is used for selecting a particular wavelength in the visible range. A solar cell (Photovoltaic cell) is used as photodetector to measure photointensity at the different illumination of incandescent light bulb.

Firstly students will measure the temperature of the incandescent bulb filament and then will determine the value of Planck's constant by taking into account the varied intensities and temperatures of bulb filament.

1. **To find resistance of the bulb filament when it just starts glowing**:

   Connect the set-up as shown in figure and switched it ON. Now apply current to the bulb filament by power supply in such a way that it just starts glowing (draper point). Note the reading of filament current and voltage to determine the resistance at the draper point. Take at least three readings to the get the better value of R_D.

2. **To find R_T/R_D of bulb filament**:

   It is known that the bulb filament attains different intensities and temperature at the different currents and voltages. Now further increase the filament current and note down the corresponding values of filament voltages to determine the R_T/R_D. Same time photo current is also measured by microammeter. Record all these readings in table-II as shown below.

3. Plot the curve between 1/T and $\log_{10} I_{ph}$and it will be straight line with negative slope. Calculate the Planck's constant from the slope of the curve.
4. Repeat the experiments for other filters (green, yellow etc.).

17.9 Observation

1. Draper point temperature, T_D= 798 K

2. TABLE.1. for resistance (R_D) of bulb filament, when it just starts glowing.

S.No.	Filament Voltage V (Volt)	Filament Current I (Amp)	R_D (Ohm)	Average R_D
1				
2				
3				

3. Average value of R_D=…….ohm.

4. TABLE.2. for R_T/R_D, of bulb filament.

S.No.	Filament Voltage V (Volt)	Filament Current I (Amp)	R_T (Ohm)	$T = T_D\left(\frac{R_T}{R_D}\right)^{0.833}$	Photo Current I_{ph}(μA)
1					
2					
3					
4					
5					

6					
7					
8					
9					
10					
…					

5. Make the same table.2. for other filters (green, yellow etc.).

17.10 Graph

Plot the curve between 1/T and $\log_{10} I_{ph}$ on graph paper and determine the slope the curve.

17.11 Calculations

1. Resistance of bulb filament at the draper point

$$R_D = \frac{V_D}{I_D} = ...\Omega$$

2. Plot the curve between 1/T and $\log_{10} I_{ph}$ and determine the slope the curve

$$m = \frac{\Delta\left(\log_{10} I_{ph}\right)}{\Delta\left(\frac{1}{T}\right)} = ...$$

3. Planck's constant

$$h = \frac{2.3026\, k_B}{\nu}\left(\text{slope}\right) = ...$$

or
$$h = \frac{2.3026\, \lambda\, k_B}{c}\left(\text{slope}\right) = ...$$

4. Repeat the same procedure for other wavelengths (filters).

Thus the Planck's constant can be obtained for filters of three primary colors as

(a) For blue filter (4360Å)

$$\lambda = 4360\times10^{-10}\ \text{m}$$

Putting $$K_B = 1.38\times10^{-23}\ \text{J/K}$$

$$c = 3\times10^{8}\ \text{m/s}$$

$$h = \frac{2.3026\,(4360\times10^{-10}\,\text{m})(1.38\times10^{-23}\ \text{J/K})}{(3\times10^{8}\ \text{m/s})}(\text{slope})$$

$$h(\text{blue}) = 4.62\times10^{-36}\,(\text{slope})$$

Similarly,

(b) For green filter (5460Å)

$$h(\text{blue}) = 5.79\times10^{-36}\,(\text{slope})$$

(c) For red filter (7200Å)

$$h(\text{blue}) = 7.63\times10^{-36}\,(\text{slope})$$

Mean value of Planck's constant (m_{ean})

$$h = \frac{h(\text{blue}) + h(\text{green}) + h(\text{red})}{3} = \ldots\ldots\ \text{J - sec}$$

17.12 Result

The measured value of Planck's constant h =…………..

The standard value of Planck's constant h $=6.62\times10^{-34}$ J-s

% error in the experiment = $\dfrac{h_{\text{Standard}} - h_{\text{exp}}}{h_{\text{Standard}}}\times100$

17.13 Discussion

17.14 Precautions and Sources of error

(1) Experiment must be performed in the dark room to avoiding interfere of extra light.

(2) Alignment of all mounted objects should not be disturbed during experiment.

(3) Draper point must be observed carefully.

(4) Optical elements, light bulb, solar cell and lens must be clean because deposition of dust particle leads to scattering of light.

(5) This experiment should be performed at least with three colour of filters.

17.15 Self Learning Exercise-II

Q.1 What are the Planck's assumptions?

Q.2 At the high frequency Planck's law reduced into which law?

Q.3 What is the standard value of Planck's constant?

Q.4 What type of lens is used to concentrate the light on solar cell in this experiment?

Q.5 What is LED?

17.16 Glossary

LED : Light Emitting Diode

Draper point : it is the approximate temperature (525˚ C, 977˚ F) above which bulb filament just starts to glow as a result of blackbody radiation.

17.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: The electromagnetic radiation emitted by a black body (heating object) is called blackbody radiation.

Ans.2: A black body is a theoretical object that absorbs all of the radiation that falls on it. Therefore it reflects no radiation and appears perfectly black.

Ans.3: The wavelength of radiation emitted by blackbody is inversely proportional to the temperature of blackbody and product is a universal constant

Ans.4: The *Draper point* is the approximate temperature (525˚ C, 977˚ F) above which bulb filament just starts to glow as a result of blackbody radiation.

Ans.5: $U(\nu)d\nu = \frac{8\pi h\nu^3}{c^3}\frac{d\nu}{\exp\left(\frac{h\nu}{kT}\right)-1}$

Answers to Self Learning Exercise-II

Ans.1: Planck postulated that the electromagnetic energy is emitted in discrete manner not continuously (like by vibrating oscillators), by small entity "photon"

Ans.2: For short wavelength, Planck's radiation law approaches the Wien's Law.

Ans.3: 6.62×10^{-34} Joule-sec.

Ans.4: Double convex lens.

Ans.5: Light emitting diode is a semiconductor opto-electronic device which converts the electrical energy into light energy.

17.18 Viva Questions

Q.1 What is radiation?

Q.2 The dimension of Planck's constant is equivalent to which physical quantity?

Q.3 What is the value of Planck's constant in CGS unit?

Q.4 What is incandescent lamp? How does it work?

Q.5 The filament of bulb is made up of which metal?

Q.6 What is the meaning of the quantity $U(\nu)$ and $U(\nu)\,d\nu$ in the Planck's law?

Q.7 What is unit of the quantity $U(\nu)\,d\nu$?

Q.8 Write the Planck's radiation law in terms of wavelength?

Q.9 What is the role of filter in this experiment?

Q.10 Which electronic device can be used in place of solar cell in the experiment?

Q.11 Can we use other light sources in place of light bulb (incandescent lamp).

Q.12 What is the temperature of tungsten filament when bulb glows?

Q.13 What is emitted wavelength by tungsten filament bulb if temperature of filament is 2700K.

Q.14 Why does use tungsten as a filament in light bulb?

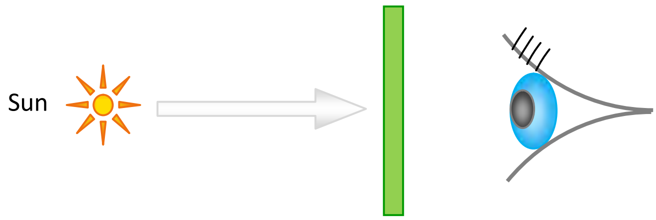
Q.15 What are three primary colors?

Q.16 Define Stefan Boltzmann's law.

Q.17 What is Kirchhoff's Law?

Q.18 What is the range of visible region?

Q.19 What colour of light will transmit through the green filter as shown in figure below?



17.19 Answers to Viva Questions

Ans.1: Radiation is the process of energy transfer in the space without necessity of transfer medium.

Ans.2: Angular momentum.

Ans.5: Tungsten

Ans.6: Radiation energy and energy density.

Ans.7: From Planck's radiation law

$$U(\nu)d\nu = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{\exp\left(\frac{h\nu}{kT}\right)-1}d\nu \quad = \frac{(J\text{ - }s)(s^{-1})^3}{(m.s^{-1})^3}(s^{-1}) = J/m^2$$

which is unit of an energy density.

Ans.8: The Planck's radiation law in terms of frequency

$$U(\nu,T)\,d\nu = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{\exp\left(\frac{h\nu}{kT}\right)-1}d\nu$$

By frequency and wavelength relationship

$$\nu = \frac{c}{\lambda} \quad \Rightarrow \quad d\nu = -\frac{c}{\lambda^2} d\lambda$$

$$U(\lambda, T)\, d\lambda = \frac{8\pi}{c^3}\left(\frac{c^2}{\lambda^2}\right)\frac{hc}{\lambda}\frac{d\lambda}{\exp\left(\frac{hc}{\lambda kT}\right)-1}\left(-\frac{c}{\lambda^2}\right)$$

$$U(\lambda, T)\, d\lambda = \frac{8\pi hc}{\lambda^5}\frac{d\lambda}{\exp\left(\frac{hc}{\lambda kT}\right)-1}$$

Ans.9: Filter absorbs a specific band of wavelengths of light and transmits the other wavelengths. For example red filter transmits light in red wavelength and blue transmits blue. Color glasses refer to as optical filter glasses, known for its specific absorption at visible wavelengths region. These optical filters appear colored when their absorption occurs at visible region.

Ans.10: LDR (Light dependent resistor).

Ans.11: Yes. For example, Light emitting diode (LED), sodium light, mercury light, Fluorescent etc.

Ans.12: ~ 2700K.

Ans.13: Wien displacement law

$$\lambda_{max}\, T = 2880\ \mu mK$$

$$\lambda_{max} = \frac{2800 \times 10^{-6}}{2700} \approx 1.04 \times 10^{-6}\, m$$

Ans.14: Tungsten has low vapor pressure and high melting point provide a specific utility in light bulb. Because tungsten can stay with high temperature (the filament temperature is 2700K) of the filament of bulb when glow it.

Ans.15: Red, Green and blue

Ans.16: The total blackbody emission radiance (power per unit surface area) is proportional the fourth power of the absolute temperature, T. This result is known as "Stefan's law."

$$I = \sigma T^4$$

where Stefan -Boltzmann's constant is given by

$$\sigma = 5.67 \times 10^{-8}\, Wm^{-2}K^{-4}$$

Ans.17: For any radiating objects (hot objects), the emissivity and absorbitvity are equal to each other:

$$\varepsilon_\lambda = a_\lambda$$

Ans.18: Blue to red/ VIBGYOR (4000-7000Å).

	Colour	**Wavelength(Å)**
VIBGYOR	Violet	3800 - 4500
	Indigo	4200 - 4500
	Blue	4500 - 4950
	Green	4950 - 5700
	Yellow	5700 - 5900
	Orange	5900 - 6200
	Red	6200 - 7500

Ans.19: Green, because sun is white light source which consisting of seven colour. When sunlight pass through the filter only green light transmits and rests are absorbed.

References and Suggested Readings

1. H.S.Palsania, Sardar Singh, "Practical Physics". College Book House, Jaipur (2014).
2. Omega electronics manual, " Determination of Planck's constant by solar cell". OMEGA TYPE ES – 214.
3. Gupta & Kumar, "Practical Physics".

UNIT-18
Field Effect Transistor

Structure of the Unit

18.1 Aim

To study the characteristics of Field Effect Transistor.

18.2 Apparatus

FET, Two variable power supplies, two voltmeters, Milli-ammeter and connecting terminals.

18.3 Diagram

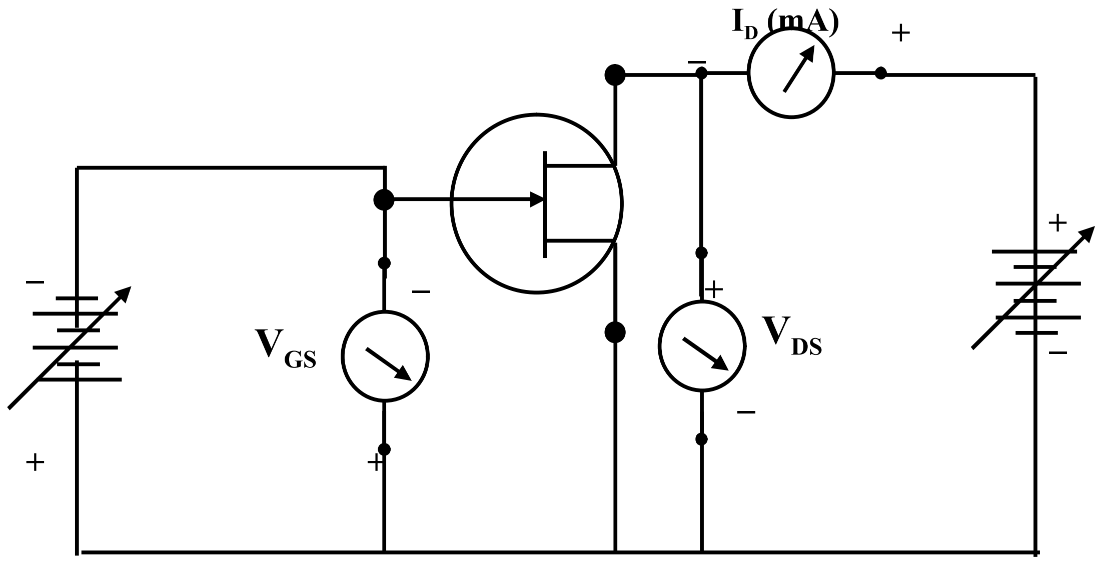


***Figure 1**: Circuit diagram for FET characteristics*

18.4 Formula

(i) ON resistance of FET (r_{ON}): Reciprocal of the slope drawn to the output characteristics curve near the origin.

$$r_{ON} = \frac{\Delta V_{DS}}{\Delta I_D} \text{ (At constant } V_{GS}\text{)}$$

(ii) Drain resistance of FET (r_d):

$$r_d = \frac{\Delta V_{DS}}{\Delta I_D} \text{ (At constant } V_{GS}\text{)}$$

This slope includes both Ohmic and saturation regions.

(iii) Transconductance or mutual conductance (g_m): The slope drawn to the transfer characteristics curve

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \text{ (At constant } V_{DS}\text{)}$$

(iv) Amplification factor (μ):

$$\mu = r_d \times g_m$$

V_{DS} = Drain Voltage

V_{GS} = Source Voltage

I_D = Drain Current

18.5 Model Graph

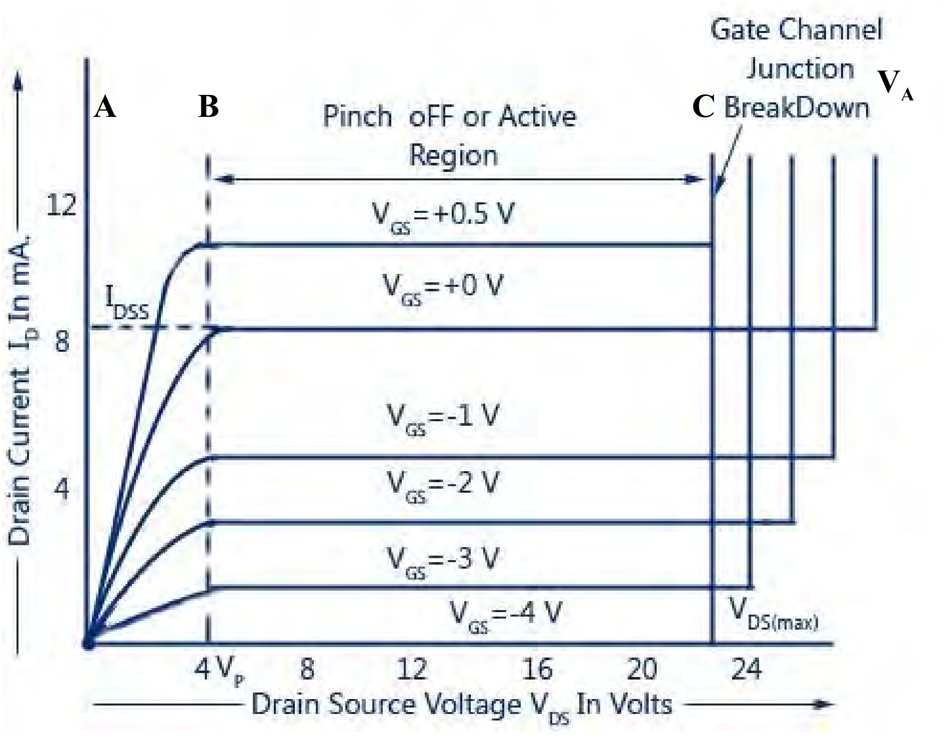


Figure 2: *Drain characteristics*

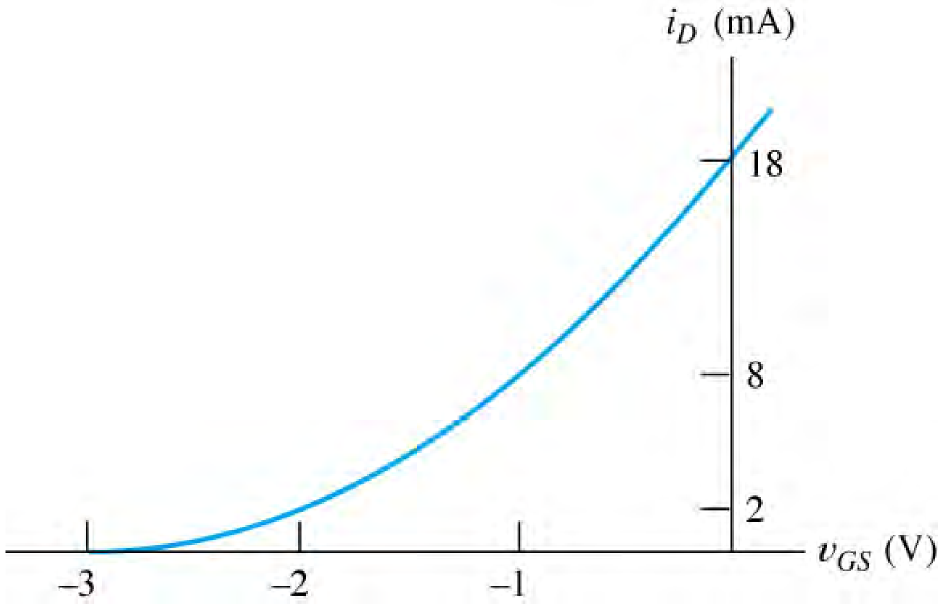


Figure 3: *Mutual characteristics*

18.6 Theory and Description

(i) Introduction:

The field effect transistor (FET) is a three terminal semiconductor device in which the current is controlled by an applied electric field. The name field effect is derived from the fact that the current flow in the device is controlled by an electric field applied by an externally applied voltage source [2].

There are two main categories of field effect transistors:

(a) Junction field effect transistor (JFET)

(b) Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

MOS transistor requires small area on a chip in comparison to BJT and also digital logic memory functions can be implemented using these MOS type transistor. It is the reason for very large integrated circuits MOSFET presented itself as a basic building block of chip [2]. FET also called as 'unipolar transistor' because the current is carried by one type of carriers in the FET (The majority charge carriers) while in BJT current is carried out by both type of charge carriers (electrons and holes).

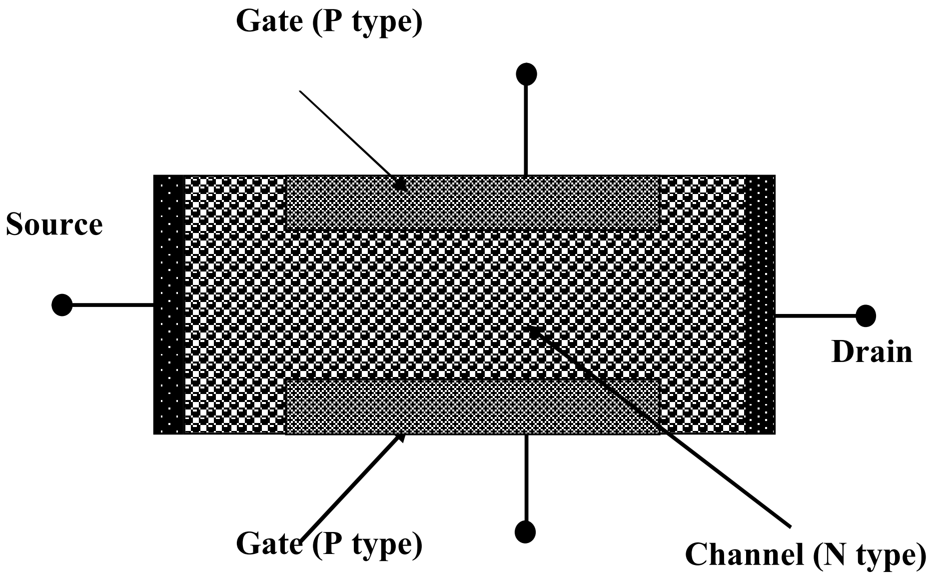


Figure 4: *Structure of N channel JFET*

(ii) Structure:

The junction field-effect transistor (JFET) consists of a segment of semiconductor material (Either N -type or P-type) resulting in either an N-channel JFET or a P-channel JFET. The basic structure of an N-channel JFET is shown in figure 4. Two metal Ohmic contacts are deposited to the two ends of the semiconductor bar and current flows along the length of the bar in the influence of applied voltage between the two ends. The left end of the bar is called the *source* (S), through which the majority charge carriers enter the channel and the right end is called the *drain (D)* through which the charge carriers leave the bar [3]. On the transversal edges of semiconductor *N-type* bar, near to its centre, heavily doped P-type material is diffused. These junctions form two *P-N* diodes and are called the *gate (G),* which control the carrier flow. The region of semiconductor material (N-type in this case) material between the two gate regions is called channel through which the majority charge carriers move from source to drain. The source, drain, and gate terminals in FET are analogues to that of emitter, collector and base terminals, respectively, in case of BJT. The source and drain terminals are interchangeable *i.e.,* either end can be used as source and the other end as drain. The voltage between the gate and source is such that the gate is reversed biased.

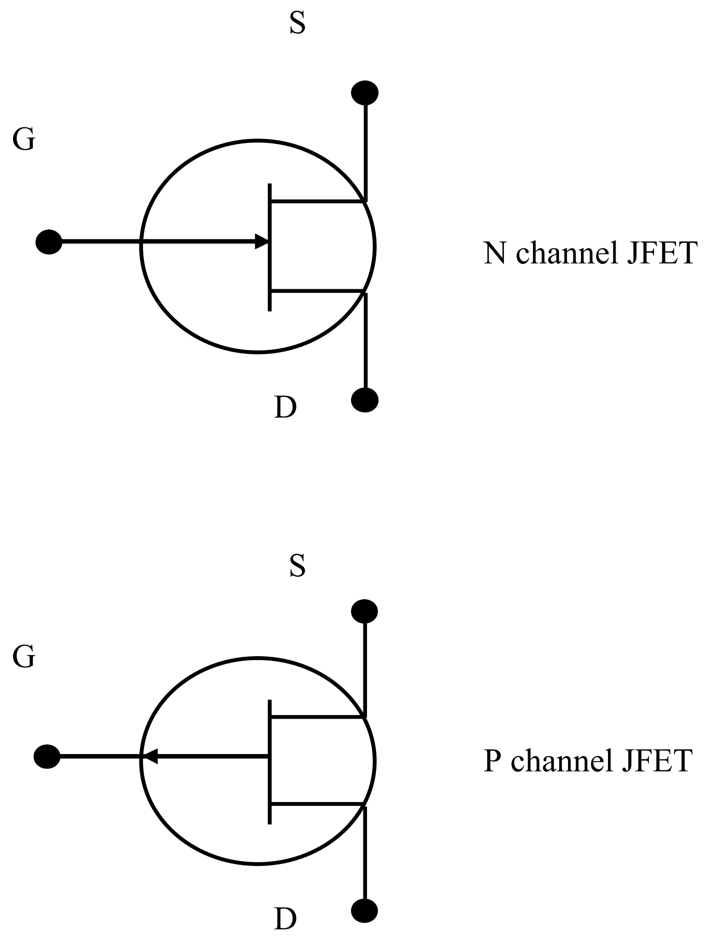


Figure 5: *Symbols of N channel and P channel JFET*

The P-channel JFET is similar in construction that it uses P-Type bar and two N type junctions. The majority carriers in this case are holes which flow through the channel. Schematic symbols for N-channel and P-channel JFETs are shown in figure 5. The vertical line in the symbol represents the channel to which source S and drain *D* are connected. The gate arrow always points to *N-type* material.

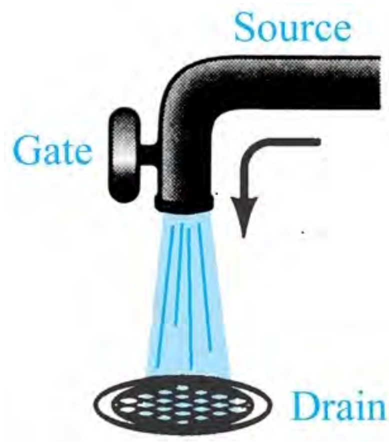


Figure 6: *Understanding of working of JFET through a faucet [5].*

(iii) Working:

JFETs are often used as switches or voltage-controlled resistors, and their operation can easily be compared to that of a faucet as shown in figure 6. If we consider that we can control the flow of water through a faucet by adjusting a valve, we can then compare a JFET by assigning the source terminal as the water source, the gate as the valve, and the drain as the physical drain [5].

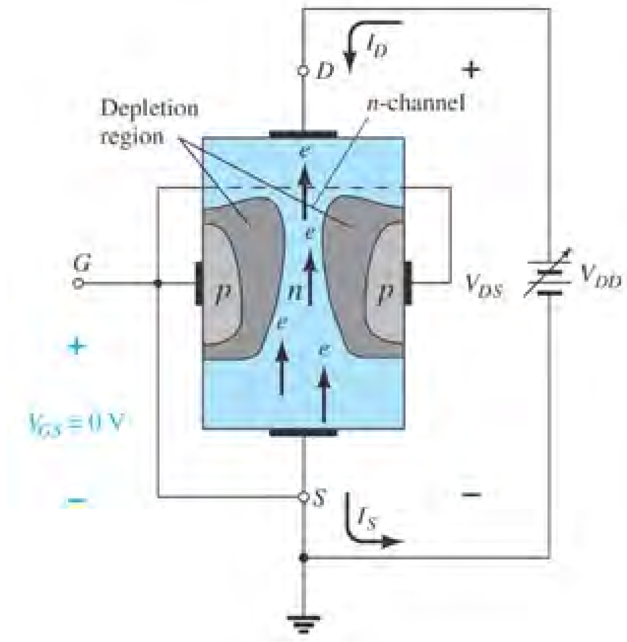


Figure 7a: Working of JFET [5].

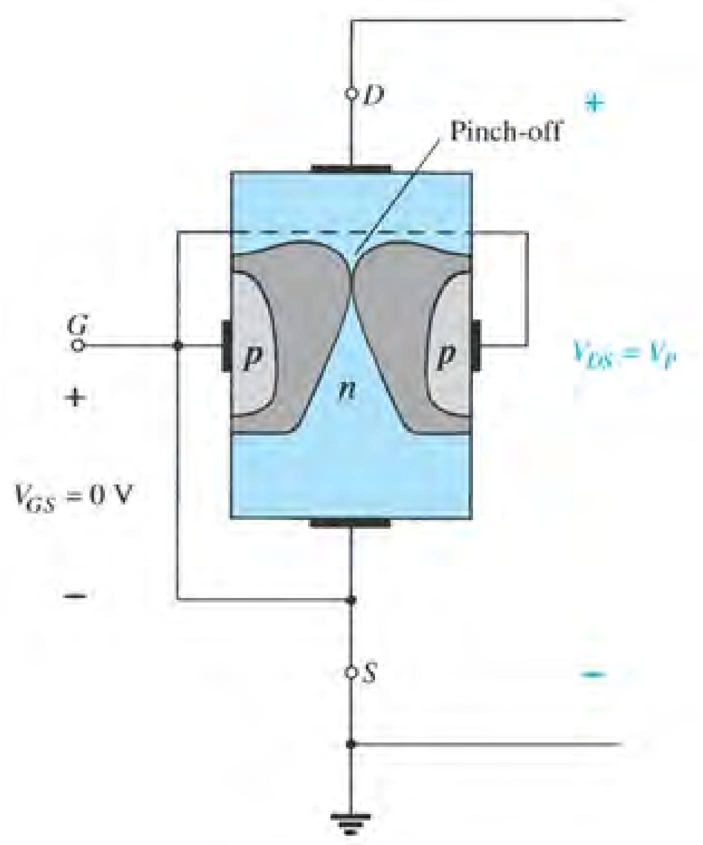


Figure 7b: *Working of JFET [5].*

In the electronic functioning of JFET, the voltage applied between drain and source force the electrons to flow through the channel.

The drain current I_D can be determined initially by the value of V_{DS}, since FET is just like an Ohmic resistor from source to drain. The potential close to drain –gate junction is higher than drain-source junction. The source-gate junctions (*P-N* junctions) are applied reverse-bias for functioning of JFET. The reverse biased *P-N* junction develops depletion regions, as shown in figure 7. The depletion region interrupts the flow of electrons from source to drain. As the reverse bias is increased, the size of the depletion regions increases and the drain current is reduced. When the reverse current is large enough for the two depletion regions (upper and lower) to meet, the channel becomes almost closed and the drain current pinches off [3]. The reverse bias required for pinch off is called as pinch off voltage V_p. The channel do not completely off the current, at pinch off voltage and the channel width reduces to a constant minimum value. It is because, if the current will be stopped completely by channel there will be no any voltage across source and drain hence there would be no voltage drop along the length of the channel. Thus the reverse bias would become uniform along the channel length in results the channel will straight in shape and will open at the drain end [2]. The drain current through the channel depends upon the degree to which the electric field applied to the channel which decreases the conductance of the transistor. Hence the name 'field-effect transistor (FET) has given to this device.

(iv) Characteristics curves:

- ***Drain characteristics:*** The drain current I_D increase proportionally for the lower values of drain source voltage (V_{DS}) following Ohm's law as shown in figure 3. In this region (AB) the JFET behaves like an ohmic resistor. If V_{GS} is increased (it's more negative to n-channel), depletion will be immediately generated in the channel so that the current required to pinch off the channel will be decreased. The drain source voltage above which drain current becomes constant is called the pinch off voltage (V_P) and the point B is called pinch off or knee point**.** As the V_{DS} further increases beyond this pinch off voltage, the drain current becomes saturates for maximum drain current and denoted by I_{DSS}. The region BC is called saturation region or pinch off region.

If V_{DS} is increased beyond avalanche breakdown voltage V_A corresponding to point C, JFET enters the breakdown region where small changes in V_{DS} produce very large changes in I_D and it is due to the avalanche breakdown of reverse-biased gate-channel P-N junction [3, 4].

- ***Transfer characteristics:*** Another characteristic curve for JFET is transfer characteristic curve. This is a variation curve of drain current I_D corresponding to gate-source voltage V_{GS} while the drain-source voltage V_{DS} is constant. Two points, I_{DSS} and V_P are the most important points in this transfer characteristic curve. The pinch-off voltage (V_P) can also be known from this graph.

$$I_D = I_{DSS}(1 - \frac{V_{GS}}{V_P})^2$$

18.7 Self Learning Exercise-I

Q.1 JFET is a current operating or voltage operating device?

Q.2 What is difference between current controlled and voltage controlled device?

Q.3 What is the difference between JFET and a bipolar transistor?

Q.4 How many Diodes a JFET have?

Q.5 In which mode JFET is work?

18.8 Procedure

To study the output and transfer characteristics of FET the essential components are connected as shown in figure 1 by keeping in mind the polarity of devices. In the start the voltage through DC power supply should be at minimum level.

a. Output or drain characteristics:

(i) Keeping the gate voltage (V_{GS}) constant at appropriate value, the drain voltage (V_{DS}) is varied in steps and corresponding drain current I_D is noted in the Table 1.

(ii) This process is repeated for at least two more but different values of gate voltage.

(iii) Plot the graph between V_{DS} and I_D for different values of gate voltages V_{GS}. These curves are known as drain characteristics.

b. Transfer or mutual Characteristics:

(i) To obtain mutual characteristics curve keep fix the drain voltage at appropriate value and vary the gate voltage V_{GS} and note down the corresponding drain current I_D.

(ii) Repeat this process at least for two more but different values of drain voltage.

(iii) Plot the graph between V_{GS} and I_D for different values of drain voltage V_{DS}. These curves are known as mutual characteristics.

(iv) Find the cut off voltage V_P for which the drain current is zero.

18.9 Observation

a. Output or drain characteristics:

Table 1: Drain Characteristics

S. No.	V_{GS} = ……….volt		V_{GS} = ……….volt		V_{GS} = ……….volt	
	V_{DS} (Volt)	I_D (mA)	V_{DS} (Volt)	I_D (mA)	V_{DS} (Volt)	I_D (mA)
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						

b. Mutual Characteristics:

Table 2: Mutual Characteristics

S. No.	V_{DS} = ……….volt		V_{DS} = ……….volt		V_{DS} = ……….volt	
	V_{DS} (Volt)	I_D (mA)	V_{DS} (Volt)	I_D (mA)	V_{DS} (Volt)	I_D (mA)
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						

18.10 Graph

Model graph

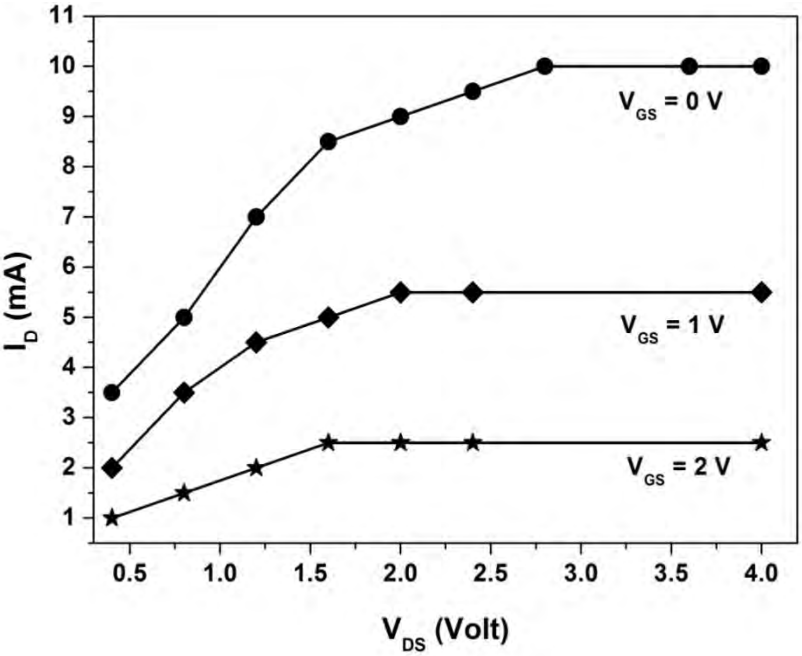


Figure 8: *Drain Characteristics*

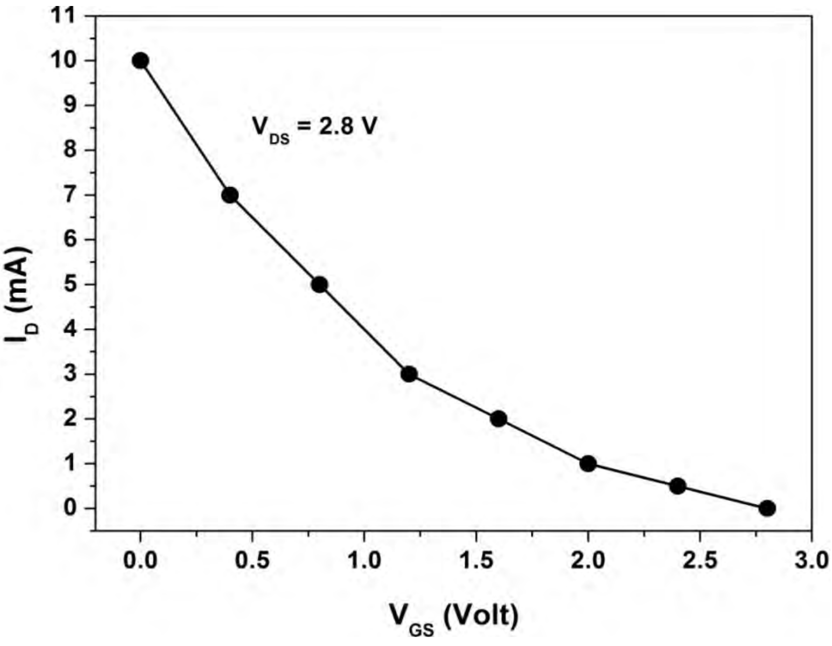


Figure 9: Mutual Characteristics

18.11 Calculations

Model Calculations

(i) Drain resistance:

From figure 8 corresponding to V_{GS} = 1 V (including both saturation and ohmic regions)

$$\Delta I_D = 1\ mA$$

$$\Delta V_{DS} = 0.8\ V$$

$$r_d = \frac{\Delta V_{DS}}{\Delta I_D}$$

$$r_d = \frac{0.8}{1 \times 10^{-3}}$$

$$r_d = 800\ \Omega$$

(ii) Mutual conductance (g_m):

From figure 9 corresponding to V_{DS} = 2.8 Volt

$$\Delta I_D = 2.0\ mA$$

$$\Delta V_{gS} = 0.4\ V$$

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$g_m = \frac{2 \times 10^{-3}}{0.4}$$

$$g_m = 5 \times 10^{-3}\ Siemen$$

(iii) Amplification factor (μ):

$$\mu = r_d \times\ g_m$$

$$\mu = 800 \times\ 5 \times 10^{-3}$$

$$\mu = 4$$

18.12 Result

(i) Short gate drain current I_{DSS}, i.e. saturation drain current for V_{GS} = 0V:
I_{DSS} = …………………mA

(ii) Pinch off voltage V_P: The minimum V_{DS} for saturation drain current
V_P = ………………….. V

(iii) ON resistance of FET
r_{ON} = ………………….. Ω

(iv) Drain resistance of FET
r_D = ……………………Ω

(v) Transconductance:
g_m = …………………. siemen

(vi) Amplification factor:
μ = …………………….

18.13 Discussion

18.14 Precautions and Sources of error

1. Check the continuity of the connecting terminals before going to connect the circuit.
2. Identify the source, drain and gate terminals of the FET properly before connecting it in the circuit.

3. While taking the readings in the table-1(for output characteristics) V_{DS} should also be increased after I_D attaining saturation value.

18.15 Self Learning Exercise-II

Q.1 What are the applications of JFET?

Q.2 What is the difference between MOSFET and JFET?

Q.3 What is unit of transconductance?

Q.4 What do you mean by pinch off voltage?

Q.5 What are the advantages of FET over BJT?

18.16 Glossary

Source: The source is terminal which the majority carriers

Drain: the drain is the terminal through which the majority carriers leave the bar

Gate: on both sides the N type bar, heavily doped P regions are formed, these regions are called gates. Usually, the two gates are joined together to form a single gate.

Channel: The region between the source and drain, sandwiched between the two gates, is called channel. The majority carriers move from source to drain through this channel.

18.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: JFET is a voltage operating device.

Ans.2: In a current controlled device output is controlled by current while in a voltage controlled device the output depends upon applied field.

Ans.3: BJT is a current controlled device while JFET is a voltage operating device, in BJT current is carried by both types of charge carries while in JFET current is carried only one type of charge carriers, JFET occupy smaller area on chip in comparison to BJT.

Ans.4: Two.

Ans.5: Active mode.

Answers to Self Learning Exercise-II

Ans.1: Mostly JFET is used as switch or as voltage controller device.

Ans.2: MOS transistor requires small area on a chip in comparison to BJT and also digital logic memory functions can be implemented using these MOS type transistor. It is the reason for very large integrated circuits MOSFET presented itself as a basic building block of chip.

Ans.3: The voltage at which drain current attains its saturated value and further no change even drains source voltage is increased.

Ans.4: Siemen.

Ans.5: The advantages of FET over BJT are as follows:

(i)In FET "thermal runaway" never occurs but in BJT it occurs easily. Thermal runaway means overheating and damage of transistor due to different biasing voltages.

(ii)Since FET is a uni-polar device so only one carrier type is required here, but BJT is a bipolar device.

(iii)FET is smaller in size than BJT of same rating. In a approximation in the same space of 10 BJTs we can use 90 FETs. Hence the area consumption is less.

18.18 Viva Questions

Q.1 What is the value of drain current I_D for gate-to-source voltages V_{GS} less than the pinch-off level??

Q.2 When the depletion region will uniform?

Q.3 What is the ratio of I_D / I_{DSS} for $V_{GS} = 0.5\ V_P$?

Q.4 Which applied voltage controls the level of I_D?

Q.5 What is name of the region to the left of the pinch-off ?

Q.6 What are the names of three terminals of the JFET ?

Q.7 A "U" shaped, opposite-polarity material built near a JFET-channel centre is called?

Q.8 Why is FET known as a unipolar device?

Q.9 What are the advantages and disadvantages of JFET over BJT?

Q.10 What is a channel?

Q.11 Define pinch-off voltage?

Q.12 At what conditions the level of V_{DS} will equal to the pinch-off voltage?

Q.13 Which of the following represent(s) the cut-off region for an FET?

Q.14 What is the input impedance of a common-gate configured JFET??

Q.15 What are the trans-conductance curves?

Q.16 What is the name of process, if an input signal reduces the channel size?

Q.17 What is name of effect if applied input voltage varies the resistance of a channel?

Q.18 When the JFET is no longer able to control the current, this point is called the?

Q.19 How many types of FET exist?

Q.20 What is role of MOSFET in chip fabrication?

18.19 Answers to Viva Questions

Ans.1: Zero amperes.

Ans.2: No bias.

Ans.3: 0.25

Ans.4: V_{GS}

Ans.5: Ohmic

Ans.6: Gate, drain and source.

Ans.7: Gate

Ans.8: The current flow through device only by one type of charge carriers (majority charge carriers).

Ans.9: In FET "thermal runaway" never occurs but in BJT it occurs easily. Thermal runaway means overheating and damage of transistor due to different biasing voltages. Since FET is a uni-polar device so only one carrier type is required here, but BJT is a bipolar device. FET is smaller in size than BJT of same rating. In a approximation in the same space of 10 BJTs we can use 90 FETs. Hence the area consumption is less.

Ans.10: The junction field-effect transistor (JFET) consists of a segment of semiconductor material. The area of this material in between gates known as channel.

Ans.11: When the reverse current is large enough for the two depletion regions (upper and lower) to meet, the channel becomes almost closed and the drain current pinches off [3]. The reverse bias required for pinch off is called as pinch off voltage V_p.

Ans.12: If I_D becomes equal to I_{DSS}, If V_{GS} is zero volts, and I_G is zero.

Ans.13: $I_D = 0$, $V_{GS} = V_P$, $I_G = 0$

Ans.14: Very low

Ans.15: This is a variation curve of drain current I_D corresponding to gate-source voltage V_{GS} while the drain-source voltage V_{DS} is constant.

Ans.16: Depletion.

Ans.17: Field effect.

Ans.18: Breakdown region

Ans.19: Two Types: JFET and MOSFET

Ans.20: In very large integrated circuits MOSFET presented itself as a basic building block of chip.

References and Suggested Readings

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UNIT-19
Study of Characteristics of Klystron

Structure of the Unit

19.1 Aim

To study the characteristics of Reflex Klystron and hence to determine mode number, electronic Tuning Range (ETR) and Electronic Tuning sensitivity (ETS).

19.2 Apparatus

Regulated Klystron power supply, Reflex Klystron with mount and cooling fan, Variable attenuator, Frequency meter, wave guide detector mount with detector, Microwave power meter/Microammeter/CRO, wave guide stands and accessories. All the above mentioned apparatus should be arranged as shown in figure. 1 below.

19.3 Diagram

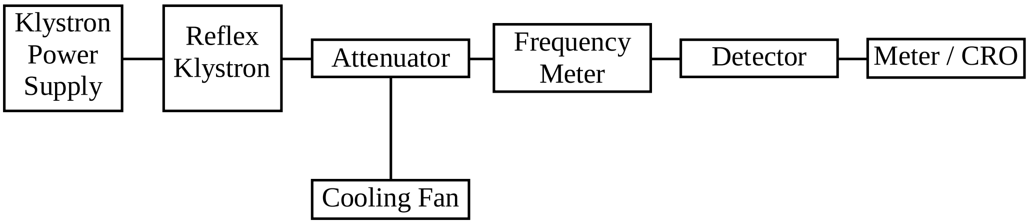

Figure-1 : Typical Microwave test bench for studying Klystron characteristics

19.4 Formula

The optimum transit time for the bunch to arrive at the cavity is $\left(n+\frac{3}{4}\right)$ cycles after the beam initially left the cavity and given by the relation :

$$T = \frac{n+\left(\frac{3}{4}\right)}{f_0}$$

where f_0 is the fundamental frequency of oscillations and *n* is any natural number or zero. These different transit times are referred as modes and are labelled as per the value of *n*,

Mode number $N_n = \left(n + \frac{3}{4}\right)$

For fixed value of voltage in cavity and at a constant frequency, the repeller voltage and mode number may be related as :

$$\frac{V_1}{V_2} = \frac{N_2}{N_1}$$

For two adjacent modes of operation of Klystron we can measure the repeller voltages at each of two adjacent modes and we can complete the number of each mode using :

$$\frac{V_1}{V_2} = \frac{n+1+\left(\frac{3}{4}\right)}{n+\left(\frac{3}{4}\right)}$$

The ETS is measured in mega Hertz/Volts :

$$\text{ETS} = \frac{f_2 - f_1}{V_2 - V_1} \frac{\text{MHz}}{\text{Volt}}$$

where f_1 and f_2 are frequency in MHz measured at the points where power falls to half of its maximum power values.

For Klystron output efficiency (η):

$$\eta = \frac{P_{out}}{V_0 I_0} \times 100\%$$

where

P_{out} is output power

I_0 is anode current

V_0 is anode voltage

19.5 Theory and description

The reflex klystron is an Microwave oscillator (low power generator of 10 to 500 mW) at a frequency range of 1 to 25 GHz. The efficiency of this oscillator is only 20 to 30%. The part of output power is feedback to input by satisfying oscillation condition AB = 1 with a phase shift of 2π radians to sustain the oscillations. The klystron of Reflex type, has been widely used source of microwave power in laboratories. It consists of an electron gun producing a collimated electron beam ,which is being accelerated towards the reflector (repeller) by a negative DC voltage V_0, while passing through the positive resonator grids. In a laboratory Klystron only one cavity resonator is used. The cavity resonator and anode are at the same potential and collect the repeller electrons.

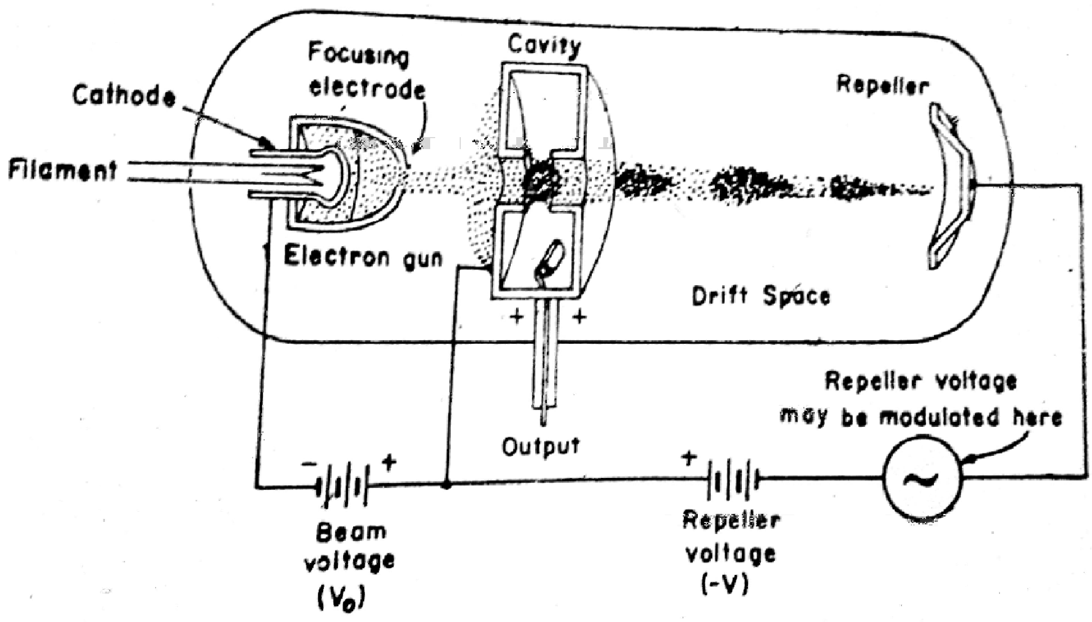

Figure-2 : The cross sectional view of a Reflex Klystron.

(1)Basic Principle of Operation : Upon acceleration, the accelerated electron beam attains the velocity, which will be :

$$v_0 = \sqrt{\frac{2eV_0}{m}} \text{ using } \frac{1}{2}mv_0^2 = eV_0$$

e and m are electronic charge and mass respectively. The repeller is placed at a negative potential with respect to cathode and consequently it retards and finally reflects the electrons through the resonator grids.

Assume that the resonator cavity is oscillating slowly, causing an AC potential, say V_1sinwt in addition to V_0 , appear across the cavity grids. These initial oscillations may be caused by any small disturbance in the electron beam. In the presence of this AC field, the electron traversing towards the repeller will acquire the velocity

$$V_1 = v_0\sqrt{1+\frac{V_1}{V_0}\sin\omega t}\text{, where } V_1 << V_0$$

Thus we have a velocity modulated beam travelling towards the repeller having velocities between $v_0\sqrt{1+\frac{V_1}{V_0}}$ and $v_0\sqrt{1-\frac{V_1}{V_0}}$. Hence we can say electrons leaving the cavity during the positive half cycle of A.C. field are accelerated and those leaving in negative half cycles are decelerated.

Obviously the electrons with higher velocity shall penetrate to larger distance into the region of the repeller field (known as drift space) as compared to the electrons with lower velocity. But the faster electrons as traverse large distance in repeller field region take longer time to return to cavity resonator and therefore catch up with slow electrons in the cavity, finally group together in the form of bunches. The bunching action of electrons is shown below in figure-3.

REPELLER NEGATIVE VOLTAGE

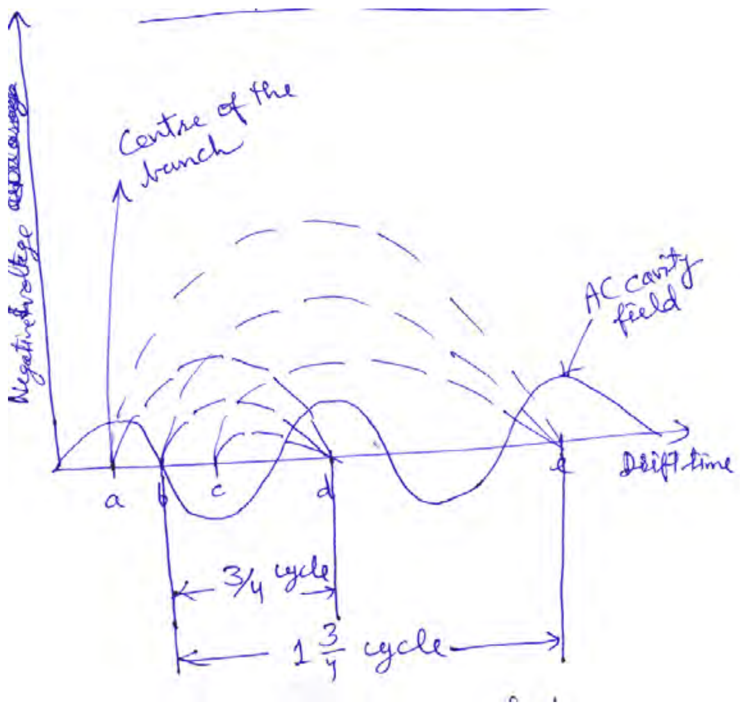

Figure-3 : The bunching of electrons in a Reflex Klystron.

As the electron bunches reach the cavity, the interaction between electrons and the voltage between cavity takes place. In the cavity the electrons are severally decelerated, give up their energy to the cavity and this energy reinforces the cavity oscillations and we obtain the conditions for sustained oscillations.

We can see that during its normal operation the repeller electrode does not carry any current and in case of electron bombardment the repeller may be severally damaged. Hence to protect repeller from such damage, the repeller voltage in always applied prior to the application of accelerating voltage V_0.

(2) Transit time and Mode number : The transit time is the time taken by the electrons to traverse the distance up to the repeller region and then back to the cavity. This time depends upon the time of the electron in relation to the node-anti node position of AC field.

The optimum transit time for the bunch to arrive at the cavity is $\left(n + \frac{3}{4}\right)$ cycles after the beam initially left the cavity and given by the relation :

$$T = \frac{n + \left(\frac{3}{4}\right)}{f_0}$$

where f_0 is the fundamental frequency of oscillations and *n* is any natural number or zero. It is clear from above equation that reflex Klystron can be operated at different frequencies, corresponding to different value of *n*. These different transit times are referred as modes and are labelled as per the value of *n*,

Mode number $N_n = \left(n + \frac{3}{4}\right)$

Hence for n = 0, the mode is $\frac{3}{4}$ mode, for n = 1, the mode is $1\frac{3}{4}$ mode and so on. The mode used for Klystron operation is the most convenient mode. The earlier the mode, the larger will be the output.

For fixed value of voltage in cavity and at a constant frequency, the repeller voltage and mode number may be related as :

$$\frac{V_1}{V_2} = \frac{N_2}{N_1}$$

Which decides the repeller voltages required to operate the Klystron in the said mode numbers. For two adjacent modes of operation of Klystron we can measure the repeller voltages at each of two adjacent modes and we can complete the number of each mode using :

$$\frac{V_1}{V_2} = \frac{n+1+\left(\frac{3}{4}\right)}{n+\left(\frac{3}{4}\right)}$$

Alternatively by just knowing the mode numbers and the corresponding repeller voltages, we can predict the repeller voltage of any adjacent mode.

(3) Power-Frequency Characteristics :

The cavities used in reflex Klystron do not have a large infinite Q, and hence each mode of operation will be spreaded over a certain range of repeller voltages .The variation of frequency and power output as a function of repeller voltages along with mode number is shown in figure-4.

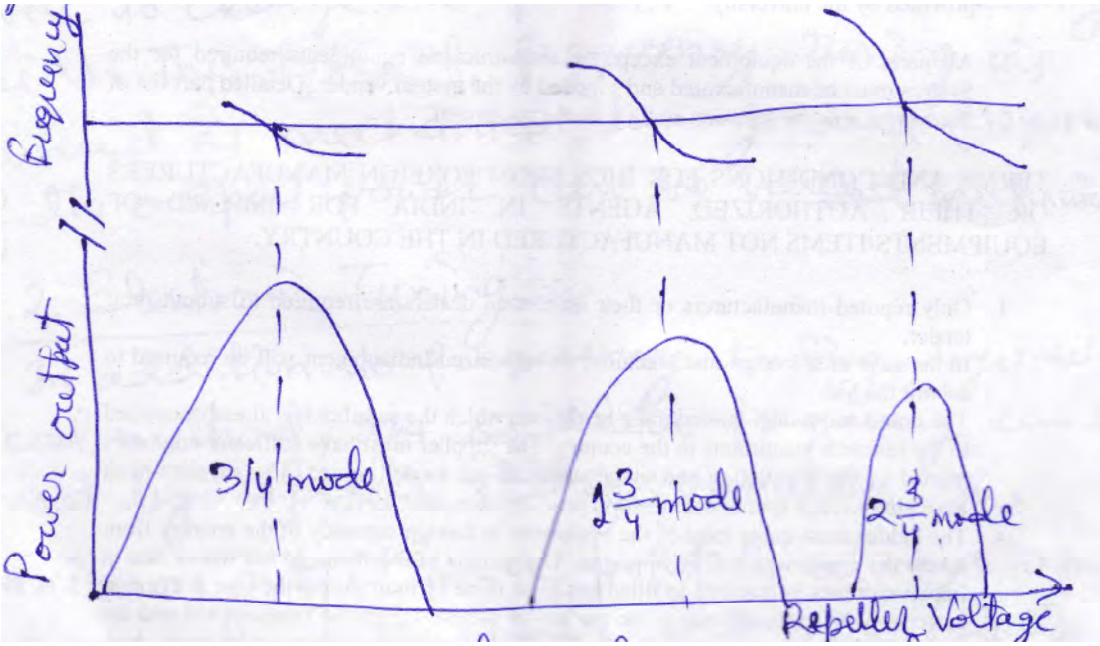

Figure-4 : A typical mode curves for a reflex Klystron.

For figure-4 we can see the variation of frequency and output power with repeller voltages, in the figure mode number correspondence is valid only at the peak of the node, where the maximum power output is there. The variation in repeller voltage from the peak of the mode changes the transit time due to which debunching starts, thereby output power is decreased and a slight change in frequency is also observed.

(4) Tuning in Klystron :

(I) Mechanical Tuning : The cavity dimension of Klystron basically decides the frequency of oscillations of the Klystron. On every reflex Klystron a screw is given to change the space between the cavity grids. This type of frequency tuning is tuned as mechanical tuning and frequency of the output power can be varied mechanically.

(II)Electronic Tuning : In addition to frequency tuning by mechanical method, the oscillator frequency can be tuned by repeller voltage variations. The maximum output power point is always referred as the peak of the mode and any change in repeller voltage leads to change in transit time due to which the Klystron operates at a different frequency.

(5) Same important parameters :

(i) Electric Tuning Range (ETR) : For a particular mode, the ETR is defined as the total charge in frequency from one end of the mode to the other end. The ETR is measured in GHz.

(ii)Electric Tuning Sensitivity (ETS): The ETS is associated with the corresponding change in frequency with the change in repeller voltage values. The ETS is measured in mega Hertz/Volts :

$$\mathrm{ETS} = \frac{f_2 - f_1}{V_2 - V_1} \frac{\mathrm{MHz}}{\mathrm{Volt}}$$

where f_1 and f_2 are frequency in MHz measured at the points where power falls to half of its maximum power values. It is clear from the figure-4, that ETS is higher for higher modes even through the output power is small.

(ii)Output Efficiency : Another quantity which can be measured for a reflex Klystron is output efficiency (η) defined as :

$$\eta = \frac{P_{out}}{V_0 I_0} \times 100\%$$

where

P_{out} is output power

I_0 is anode current

V_0 is anode voltage

(6) Hysteresis in Klystron : We can also see hysteresis during Klystron operation. The hysteresis in Klystron refers to the change in mode characteristics of Klystron when the repeller voltage is varied in reverse direction, i.e., from minimum to maximum.

The reason behind hysteresis in Klystron are :

• Multi-transit of the electrons in the gap

• dependence of oscillation amplitude on beam phase shift and cathode current.

•Variation of electronic admittance, which is a function of oscillation amplitude.

(7)Advantages of Reflex Klystron : Although a Klystron has a very low efficiency (a few percent around 20-30%), it is extensively used in laboratories due to the following reasons :

• Wide frequency range.

• Simple connecting and mounting systems.

• Accurate mechanical and electronic frequency controls.

• Low initial and operating costs.

(8)Firing of the reflex Klystron :

For successful operation of Klystron, adopt the following procedure :

(i) Start the cooling fan to blow air across the Klystron.

(ii) Now turn on the Klystron power supply and wait for a few minutes.

(iii) Set the attenuator at a level of 3dB value.

(iv) Apply the repeller voltage to its maximum value, say –235 Volts.

(v) Now apply beam voltage (as per the operating instruction given with the Klystron), say at minimum it is 235 Volts. Observe beam current on the meter by changing switch to beam current position. The beam current should not be more than the given value, say 30mA. Now the Klystron is said to oscillate and power output is indicated.

(vi) For the best setup, the attenuator must have maximum value corresponding to the peak in output meter.

19.6 Self learning exercise-I

Q.1. Show frequency and power Characteristics of Reflex Klystron and determine the ETR and ETS for the Klystron operation.

Q.2. How bunching takes place in a reflex Klystron.

Q.3. Why only discrete modes of operation are possible in reflex Klystron.

19.7 Procedure

Mode Characteristics study.

1. Connect the components and equipments as shown in figure-1.
2. Keep the Klystron power supply as mentioned below :

   For CW operation

Mode switch	:	CW
Beam Voltage knob	:	Minimum (Fully anticlockwise)
Repeller voltage knob	:	Maximum (Full clock wise)
Meter switch	:	Cathode voltage position

3. Rotate the frequency meter at one side.
4. Fire the Klystron correctly as discussed in point no. 12.
5. Now change the meter switch to repeller voltage position.
6. Select proper range for power meter so that power output of maximum mode will not exceed the meter range.
7. Now decrease the repeller voltage in steps of 1V and record output power and frequency in table-1.
8. For measurement of frequency switch the mode switch of Klystron to AM mode and observe output of CRO display. Obtain the maximum output on CRO by matching the detector with tuning parts. Use AM amplitude, frequency controls and CRO controls to get clear display on CRO for output wave. By rotating the frequency meter, observe the dip in the output each time and note the corresponding frequency.
9. The frequency meter should be detuned each time while measuring power.

10. Plot the curve between power output versus repeller voltage and also frequency vs. repeller voltage to observe the power and frequency characteristic mode curves for Klystron.
11. Compute various parameters from the graph.

19.8 Observation

Observation Table :

Beam voltage : _________ Volts

Beam current : _________ mA

Table-1

S. No.	Repeller voltage (in volts)	Power meter / Micro ammeter reading (in μ A)	Frequency meter reading (in GHz)
	For First Mode		
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			

10.			
	For Second Mode		
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

…………………… and so on.

19.9 Graph

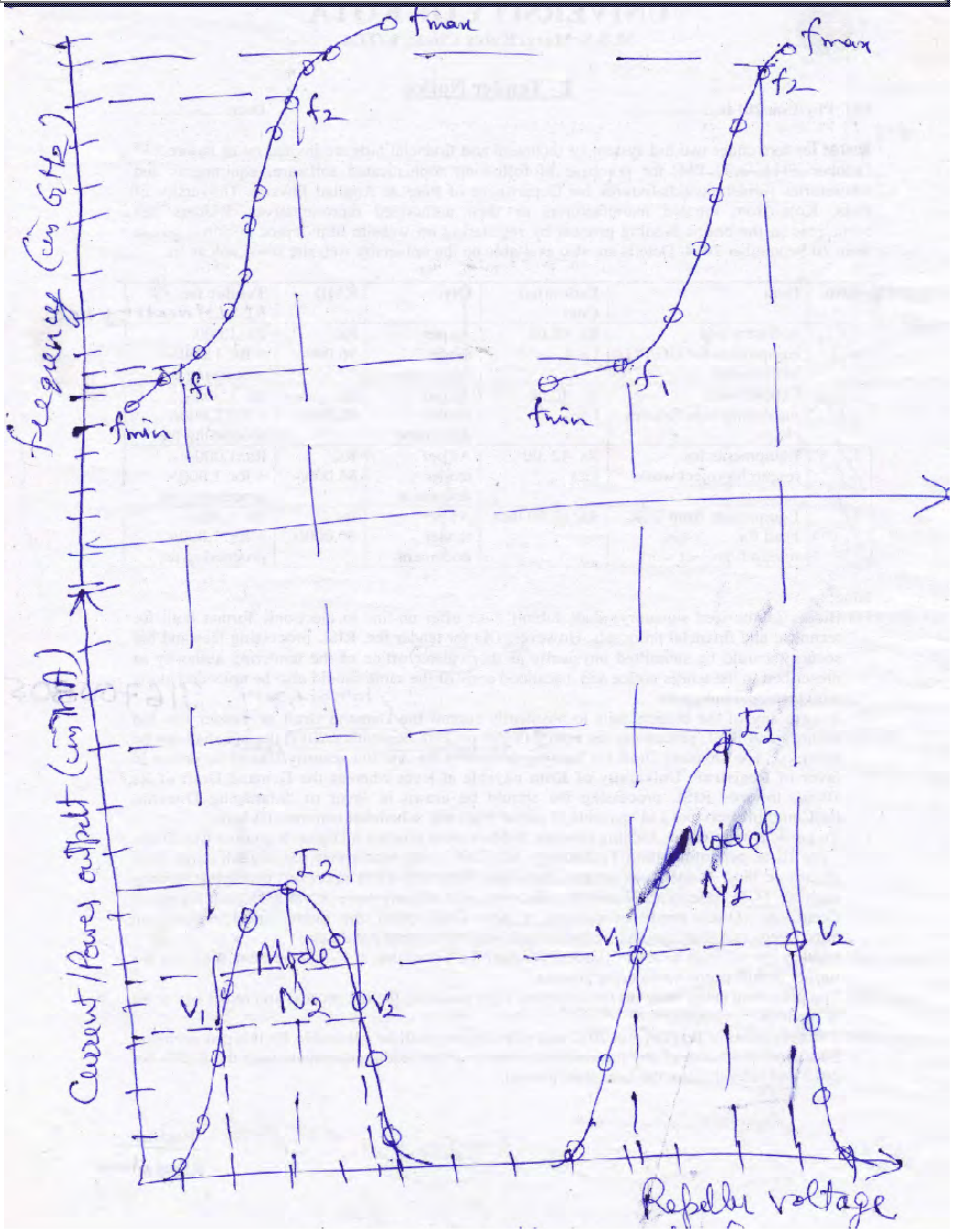

Figure-5 : Observed power output and frequency characteristics of reflex Klystron.

19.10 Calculations

(i) As per figure-5 determine the peak voltages of two adjacent modes, mode number of modes may be computed as :

$$\frac{N_2}{N_1} = \frac{V_1}{V_2} = \frac{(n+1)+\frac{3}{4}}{n+\frac{3}{4}}$$

and in this way determine the practical available mode numbers.

(ii) After having mode numbers, we can also determine the transit time for each mode, which can be calculated as :

$$t_1 = \frac{\left(n+\frac{3}{4}\right)}{f_{01}} = \frac{N_1}{f_{01}}\text{seconds}$$

Similarly we can calculate for other modes.

(iii) Now we calculate the electronic tuning range (ETR), which is the frequency band from one end to another for a mode. Looking to figure-5, we can calculate for each mode

ETR = $(f_{max.} - f_{min})$GHz

(iv) Now we will calculate the Electronic tuning sensitivity (ETS), for this on each mode determine the half power points and obtain the repeller voltages V_1 and V_2 ,then for calculated V_1 and V_2, determine the frequencies in frequency vs. repeller voltage graph as f_1 and f_2. Finally we get.

$$\text{ETS} = \frac{(f_2 - f_1)}{(V_2 - V_1)}\frac{\text{MHz}}{\text{Volts}}$$

The mode number, corresponding transit time, ETR and ETS we have to calculate for each mode and tabulate them in the following table.

Table-2 : The calculated parameter for the reflex Klystron.

S. No.	Mode Number	Transit Time	ETR	ETS
	For First Mode			
1.	$\left(n+\frac{3}{4}\right)$			
2.	$\left(n+1+\frac{3}{4}\right)$			
3.	$\left(n+2+\frac{3}{4}\right)$			
4.	$\left(n+3+\frac{3}{4}\right)$			

19.11 Result

The practically obtained values for various parameters for reflex Klystron are shown in table-2. The frequency and power characteristics of reflex Klystron are shown in graph in figure-5 and which are as per given in literature.

19.12 Discussion

19.13 Precautions and Sources of error

Basic operating a reflex Klystron we have to take care of the following :

(i) Cooling fan should be allowed to blow before switching on the power supply of Klystron.

(ii) During Klystron operation, the repeller should not carry any current as it can severely be damaged by electron bombardment. For protection, the repeller voltage should be always applied before anode voltage.

(iii) The repeller voltage should be varied in one direction only to avoid hysteresis in Klystron

(iv) The heater voltages should be applied first and other voltages should be applied there after taking precautions (i) & (ii).

(v) During power measurement, the frequency meter should be detuned every time to avoid the dip in power.

(vi) An isolator or same 3dB attenuation should invariable be used in between Klystron and the rest of the setup to avoid loading of the Klystron.

19.14 Self Learning Exercise-II

Q. 1. What do you mean by ETS and ETR ?

Q. 2. Why repeller voltage should be applied before anode voltage ?

Q. 3. Why is it necessary to cool the Klystrons ?

19.15 Glossary

Microwaves: Electromagnetic waves having frequencies of the order of few GHz and wavelength of the order of few cms.

Reflex Klystron*:* Microwave oscillator (low power generator of 10 to 500 mW) at a frequency range of 1 to 25 GHz.

Velocity Modulation*:* Electrons leaving the Klystron cavity during the positive half cycle of A.C. field are accelerated and those leaving in negative half cycles are decelerated.

Transit time: The transit time is defined as the time taken by the electrons to traverse the distance up to the repeller region and then back to the cavity.

***Repeller**:* Reflector plate in a Reflex Klystron, maintained at higher negative potential.

Mechanical Tuning: The cavity dimension of Klystron basically decides the frequency of oscillations of the Klystron, which can be tuned using a screw given to change the space between the cavity grids.

Electronic Tuning: The oscillator frequency can be tuned by repeller voltage a variation is known as electronic tuning.

Electric Tuning Range (ETR) : For a particular mode, the ETR is defined as the total charge in frequency from one end of the mode to the other end, measured in GHz.

Electric Tuning Sensitivity (ETS): The ETS is defined as corresponding change in frequency with the change in repeller voltage values.

19.16 Answers to Self Learning Exercises

Answer of Self Learning Exercise-I

Ans.1: Draw graph (if possible practically) as shown in section-19.5.

and do the necessary calculations.

Ans.2 : Discuss formation of bunches in Klystron from section-19.5.

showing Basic principle of operation.

Ans. 3: The formation of discrete modes of operation of reflex Klystron is due to following reasons.

• The time taken by the bunches to form and deliver energy to the resonator cavity.

• The maximum absorption of energy is always possible at a particular frequency of cavity.

Answer of Self Learning Exercise-II

Ans.1 : Define, see section-19.5.

Ans.2 : See precautions (ii).

Ans.3 : To control the temperature of Reflex Klystron so that continuous operation may be ensured.

19.17 Viva Questions

Q. 1. Discuss tuning in Klystron.

Q. 2. What do you mean by transit time ?

Q. 3. Discuss operation of a Klystron with a labelled cross-sectional diagram of Klystron.

Q. 4. What do you mean by velocity modulation ?

Q. 5. Why power output decreases with increase of ETS value ?

Q. 6. Why do we need to detune frequencymeter while taking reading ?

Q. 7. What are the advantages of using reflex Klystron as a Microwave laboratory source ?

Q. 8. What do you mean by hysteresis in Klystron ?

19.18 Answers to Viva Questions

Ans.1 : For your answer, see section-19.5.

Ans.2 : Define in your words, see section-19.5.

Ans.3 : Including figure-2 in your answer discuss the basic principle of operation of Klystron as per section-19.5.

Ans.4 : See velocity modulation in section-19.5and explain how it is changing with the sinusoidal oscillation of cavity voltage.

Ans.5 : Look at the formula for ETS in section-19.5and explain your answer.

Ans.6 : So that when frequency is tuned with the frequency of the microwave generated the output power get minimized and we cannot record the data.

Ans.7 : Find your answer as per section-19.5.

Ans.8 : Find your answer as per section-19.5.

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UNIT-20
Silicon Controlled Rectifier (SCR)

Structure of the Unit

20.1 Aim

To study the characteristic of SCR

20.2 Apparatus

SCR, Two variable DC supplies, (0-10V) (0 – 200V), DC voltmeter (0-10V), (0-200V), DC ammeter (0-100 mA), Two resistance (1 K ohm), connecting wires.

20.3 Diagram

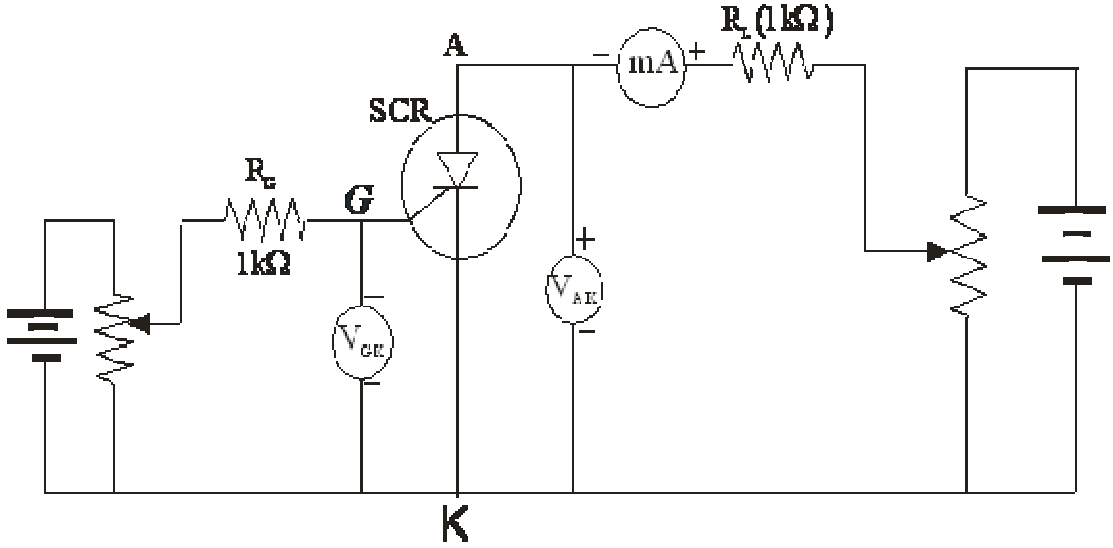


Fig. 1 Circuit for forward characteristics

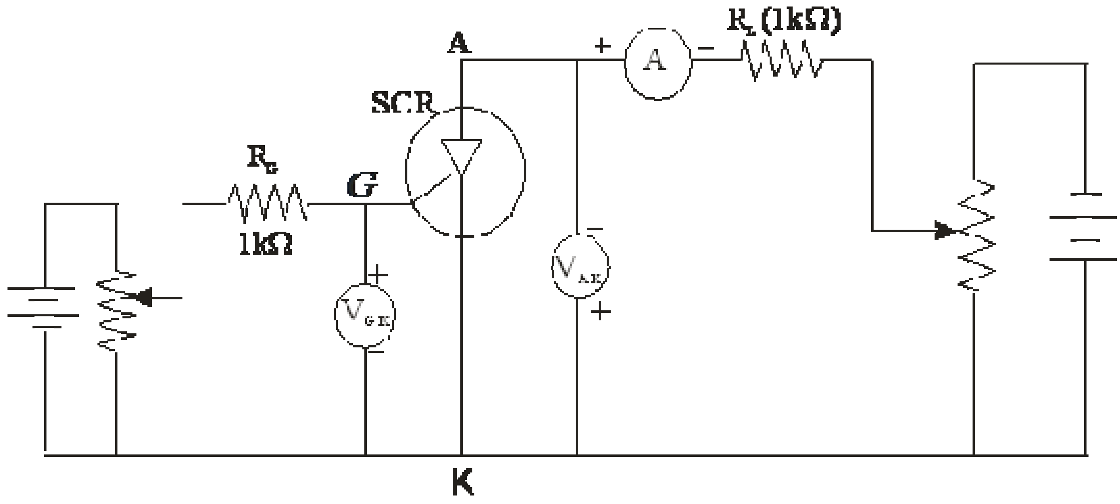


Fig.2 Circuit for reverse characteristics

20.4 Model Graph

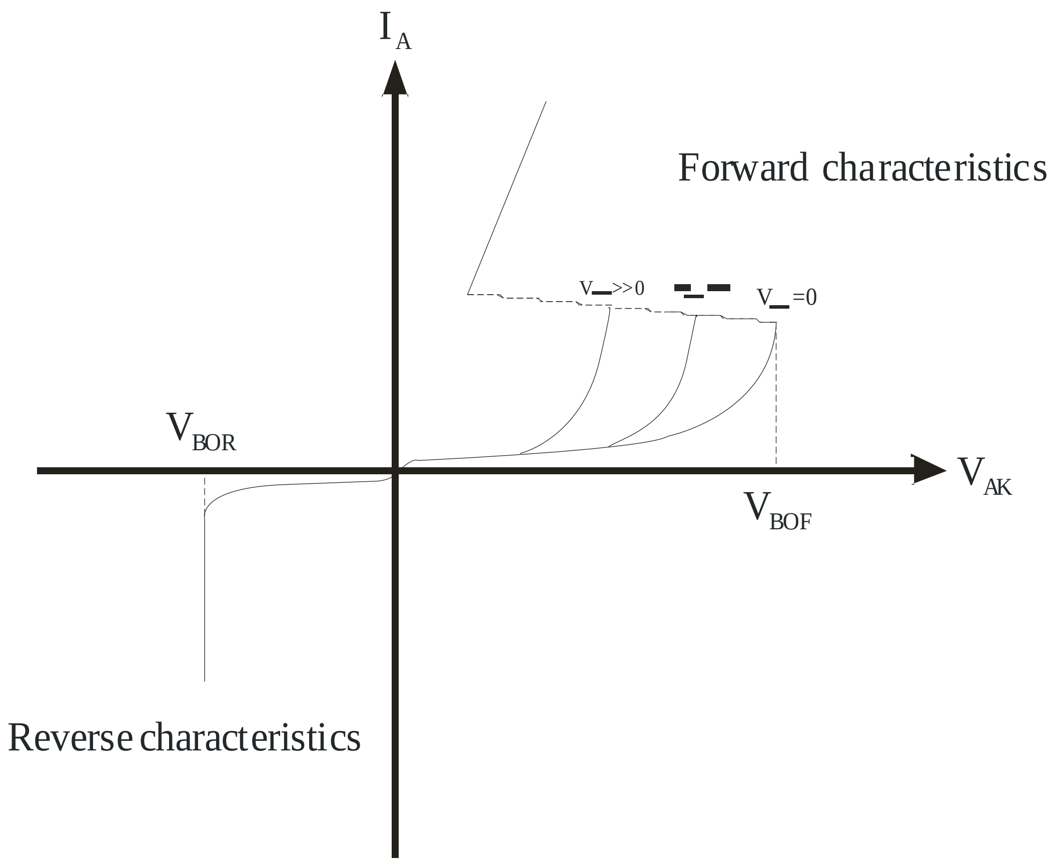


Fig.3 V-I characteristics

20.5 Theory and description

Silicon Controlled Rectifier (SCR) is an electronic device consisting of four layers of $p-$, $n-$, $p-$, $n-$ semi conductors respectively; three p-n junctions J_1, J_2, J_3 are made between layers. It has three terminals anode A (connected to outer p-layer), cathode K (connected to outer n-layer), and gate G (connected to middle p-layer near to cathode) [fig.4]

Circuit symbol of SCR is shown in fig 5.

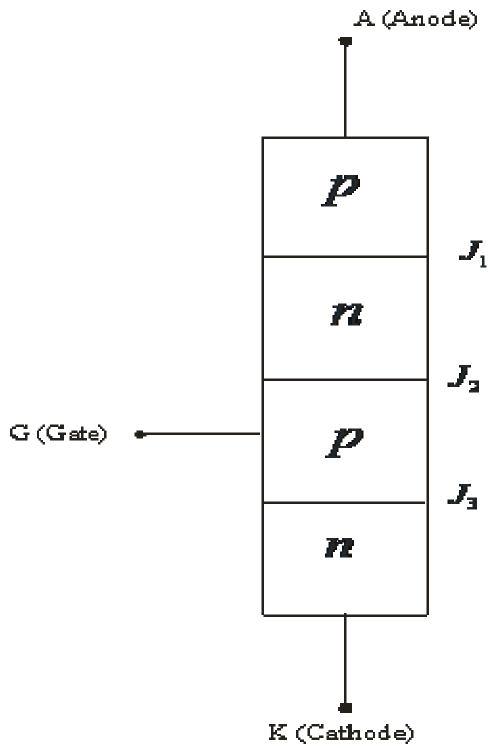


Fig. 4 Block diagram

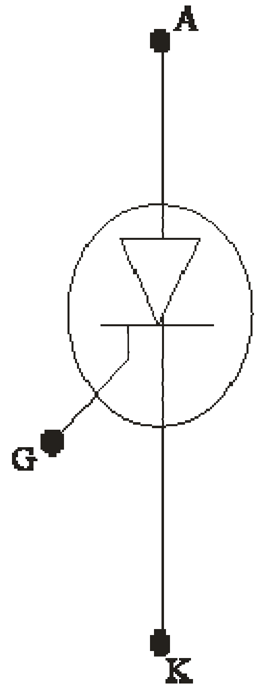


Fig. 5 Circuit Symbol

A SCR is thought to be consisting of one p-n-p and n-p-n transistor, such that base of p-n-p transistor is connected to emitter of n-p-n transistor and collector of p-n-p transistor is connected to base of n-p-n transistor as shown in fig 6.

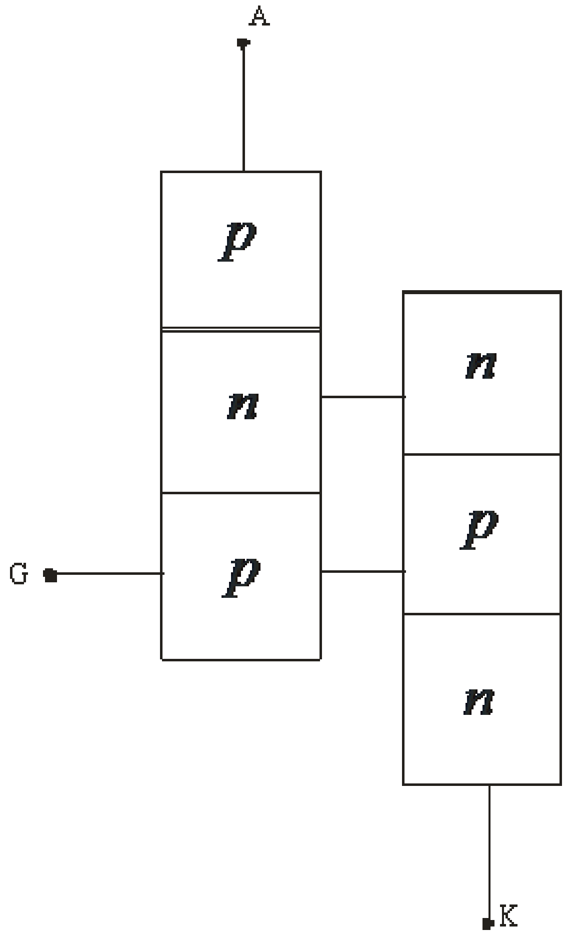


Fig.6 Two Transistor equivalent block diagram

Forward biased SCR

In normal condition anode made positive with respect to cathode then junction J_1 and J_3 is forward biased and J_2 is reversed biased, hence no significant current (except small leakage current) will flow in anode circuit, so, SCR is in non conducting state known as OFF-state.

If V_{AK} (Anode to cathode voltage) is increased sufficiently, reverse biased junction J_2 would break down. At this breakdown (known as avalanche breakdown), occurred at forward breakdown voltage V_{BOF}, A large anode current flows and SCR comes in conducting state which known as ON-State.

However, if a small positive voltage is applied at gate G, then large forward current will flow at a lower value of V_{AK} (much less then V_{BOF}). (Fig 3)

The conducting SCR remains in on-state even if gate voltage is removed but when anode current is decreased below a minimum current, known as holding current, SCR turn off.

Reversed biased SCR

When cathode is made positive with respect to anode, junctions J_1 and J_3 is reverse biased and J_2 is forward biased, then only small leakage current will flow in circuit, however at a sufficiently high positive cathode voltage V_{BOR}, reverse breakdown occurred this results in large current .(Fig 3)

Since SCR has two states- ON and OFF hence this is used as a switch or control device.

20.6 Self Learning Exercise-I

Q.1 What is full form of SCR?

Q.2 How many layers it consist of?

Q.3 How many p-n junction it has?

Q.4 Is SCR a three terminal device?

Q.5 Give name of these terminals of SCR.

20.7 Procedure

A) To draw forward characteristics-

(i) Connect the circuit as shown in fig.1

(ii) Initially set V_{GK} at some (+) ve value, record anode current I_A with increasing voltage (V_{AK}) across anode and cathode.

(iii) Set V_{GK} at a higher value then in step (ii), record I_A and V_{AK} by changing applied voltage across anode A and cathode K.

(iv) Repeat step (3) for one more value of V_{GK} higher than in step(iii)

(v) Plot graph taking V_{AK} on X-axis and I_A on Y-Axis for different sets of V_{GK} .

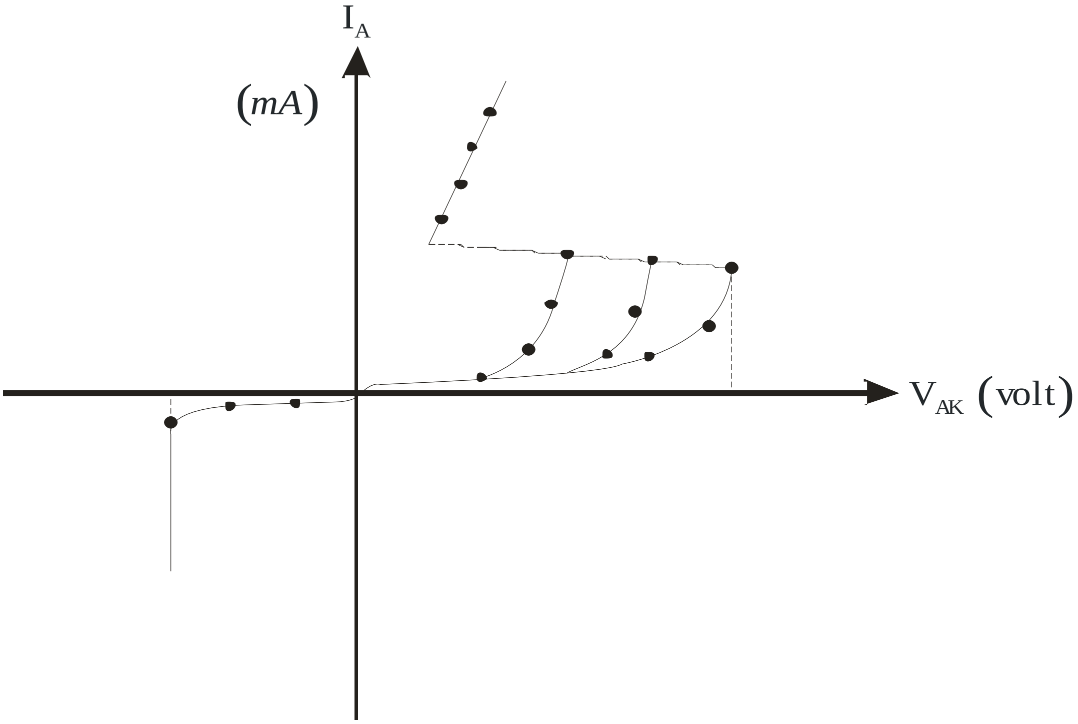
B. To Draw reverse characteristics –

1) Connect the circuit as shown in fig 2
2) Set V_{GK} at some (+) ve value, record I_A and V_{AK}.
3) Plot I_A and V_{AK}

20.8 Observation

	FORWARD CHARACTERISTICS						REVERSE CHARACTERISTICS			
S.No	V_{GK}		V_{GK}		V_{GK}		V_{GK}		V_{GK}	
	V_{AK} V	T_A mA	V_{AK} V	T_A mA	V_{AK} V	T_A mA	V_{AK} V	T_A mA	V_{AK} V	T_A mA
1										
2										
3										
4										
5										
6										
7										
8										

20.9 Graph



20.10 Result

Forward and reverse characteristics of SCR has been plotted.

20.11 Discussion

20.12 Precautions and Sources of error

1. All connections should be tight.
2. Do not apply voltages higher then rated values
3. Take readings carefully near breakdown.
4. Care should be taken while connecting (+) ve and $(-)$ ve terminals of voltmeter and ammeter.
5. There terminals of SCR should be identified carefully.

20.13 Self Learning Exercise-II

Q.1 What is leakage Current?

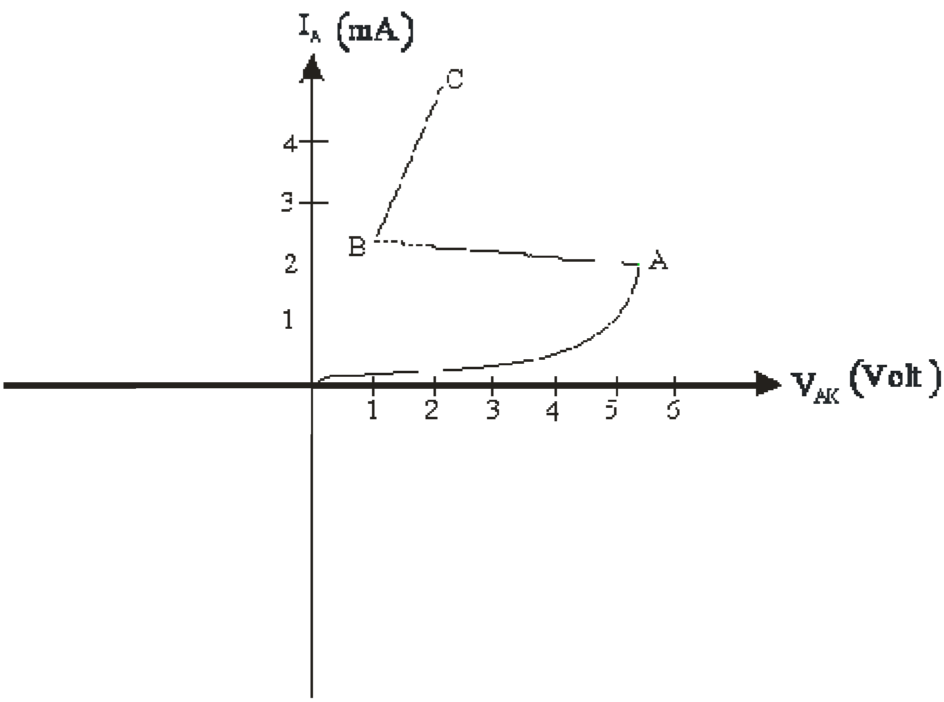
Q.2 What is a forward characteristic?

Q.3 What is reverse characteristic?

Q.4 What happens if voltage across anode and cathode is very high?

Q.5 What is breakdown?

Q.6 Determine the resistance in AB region of the characteristics curve of a p-n-p-n device shown in figure-



20.14 Glossary

Leakage Current: Small current flows due to minority charge carriers

Forward characteristics : Relationship between voltage and current in forward biased condition

Reverse characteristics : Relationship between voltage and current in reverse biased condition

Junction Breakdown : Sudden rise in current due to p-n junction breaks down and flows of large charge carriers through junction

N-type semi-conductor: Semiconductor doped with Pentavalent impurity atoms heaving high concentration of electrons as majority charge carriers

***P-type semi-conductor*:** Semi conductor's doped with trivalent impurity atoms having high concentrations of holes

Device ratings : Maximum tolerable voltages/ powers of device data provide by manufactures

Electronic switch: An electronic device that has ON and OFF states only hence working as a switch

Unidirectional switch: current flows in one direction only

Negative resistance : When voltage decrease with increasing current, then resistance of such device is assumed to be negative, known as negative resistance

Holding current: Maximum anode current with open gate, at which SCR is turn OFF from ON-State

Forward breakdown voltage : In open gate, forward applied voltage where avalanche breakdown occurred.

Reverse breakdown voltage : Reverse applied voltage where breakdown occurred

Semi conductor: Material that have band gap between conduction and valance band of the order of *ev*

p-n junction : Region without mobile charge carriers between p-type and n-type semiconductor regions

Majority charge carrier: Charge carriers responsible for forward current ***Minority***

charge carriers : Charge carriers responsible for leakage current

20.15 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Silicon Controlled Rectifier

Ans.2: Four

Ans.3: Three

Ans.4: Yes

Ans.5: Anode, cathode, Gate

Answers to Self Learning Exercise-II

Ans.1: Small current flows due to minority charge carriers.

Ans.2: Relationship between voltage and current in forward biased condition.

Ans.3: Relationship between voltage and current in reverse biased condition.

Ans.4: Avalanche breakdown will occur.

Ans.5: Sudden rise in current due to p-n junction breaks down

Ans.6: At V_{AK} (Anode to cathode voltage)= 5.5 V (point A in the graph), the value of biasing voltage across J_2 is increased sufficiently, so, reverse biased junction J_2 would break down, resulting in a reduction of voltage (at point B in the graph) and a large anode current flows and SCR comes in conducting state which known as ON-State.

From graph,

Voltage at point A $V_A = 5.5$ V

Voltage at Point B $V_B = 1.25$ V

Current at point A $I_A = 2.0$ mA

Current at point B $I_B = 2.25$ mA

Change in voltage $\Delta V = V_B - V_A$

$= 1.25 - 5.50$

$= -4.25$ V

Change in current $\Delta I = I_B - I_A$

$= 2.25 - 2.00$

$= 0.25$ mA

Hence, resistance R= $\Delta V / \Delta I$

$= -4.25/(0.25 \times 10^{-3})$

$= 17 \times 10^{3}\ \Omega$

$= 17\ K\Omega$

20.16 Viva Questions

Q.1 What is n-type semi-conductor?

Q.2 What is p-type semi-conductor?

Q.3 What do you mean by $1K\Omega$?

Q.4 What do you mean by device ratings?

Q.5 What is SCR?

Q.6 What is an electronic switch?

Q.7 Is SCR unidirectional switch?

Q.8 What is negative resistance?

Q.9 What is forward breakdown voltage?

Q.10 What is reverse breakdown voltage?

Q.11 What do you understand by holding current?

Q.12 What is meant by ON State?

Q.13 What is meant by OFF State?

Q.14 Why breakdown is harmful for a device?

Q.15 What are the uses of SCR?

Q.16 What are you doing?

Q.17 How do you perform this experiment?

Q.18 What is bias voltage?

Q.19 What do you mean by resistance?

Q.20 What is a resistance of a connecting wire?

Q.21 What is the resistance of the SCR in the ON-Stats?

Q.22 What is the resistance of the SCR in the OFF-Stats?

Q.23 Give difference between SCR and transistor.

Q.24 What is other name of SCR?

Q.25 What are uses of SCR?

20.17 Answers to Viva Questions

Ans.1: Semiconductor doped with pentavalent impurity atoms heaving high concentration of electrons as majority charge carriers.

Ans.2: Semi conductor's doped with trivalent impurity atoms having high concentrations of holes.

Ans.3: The magnitude of resistance is 1 Kilo OHM.

Ans.4: Maximum tolerable voltages/ powers of device data provide by manufactures.

Ans.5: SCR is a four layer p-n-p-n electronic device.

Ans.6: An electronic device that has ON and OFF states only.

Ans.7: Yes, because current flows in one direction only

Ans.8: When voltage decrease with increasing current, then resistance of such device is assumed to be negative, known as negative resistance.

Ans.9: In open gate, forward applied voltage where avalanche breakdown occurred.

Ans.10: Reverse applied voltage where breakdown occurred.

Ans.11: Maximum anode current with open gate, at which SCR is turn OFF from ON-State.

Ans.12: State in which SCR is conducting large current

Ans.13: State in which SCR is non-conducting

Ans.14: Because it may damage an electronic device permanently

Ans.15: SCR used as switch, control device etc.

Ans.16: Study the characteristics of SCR.

Ans.17: Details given in Procedure.

Ans.18: It is the necessary DC voltage which is required for any active device to Operate.

Ans.19: A resistance is the interruption in flow of electrical current through a wire/conductor and defined as the ratio of voltage to current across wire.

Ans.20: A connecting wire has very low resistance.

Ans.21: Since a large anode current slows during ON-Stats hence the resistance becomes very low in this state.

Ans.22: Since a very small current flows through SCR during OFF-State hence the resistance becomes very large during this State.

Ans.23: A SCR has three junctions whereas a transistor has two junctions, actually SCR is a device consisting of four layers of p-n, p-, n- semiconductors respectively, while transistor consisting three layers of p-, n-, p- or n-, p-, n-.

Ans.24: Thyristors

Ans.25: It is used as an electronic switch, speed controller of home appliances.

References and Suggested Readings

1. John D. Ryder, Electronic Fundamentals and Applications (Integrated and Discrete Systems), PHI, 1990.

2. V.K.Mehta , Principles of Electronics, S. Chand and Company Ltd., 2001.

3. Gupta and Kumar, Hand Book of Electronics, Pragati Prakashan, 2006

UNIT-21
Transistor Bias Stability

Structure of the Unit

21.1 Aim

To study: (i) Leakage current variation with temperature of common emitter configuration.

(ii) Shift of ‘Q’ point with temperature.

(iii) Distortion in a single state amplifier as a result of change in ‘Q’ point.

21.2 Apparatus

Electronic board with Micro and Mili-Ammeter, Voltmeter, Capacitor, Audio Frequency Generator, Cathode Ray Oscilloscope (CRO).

21.3 Diagram

Circuit Diagrams:

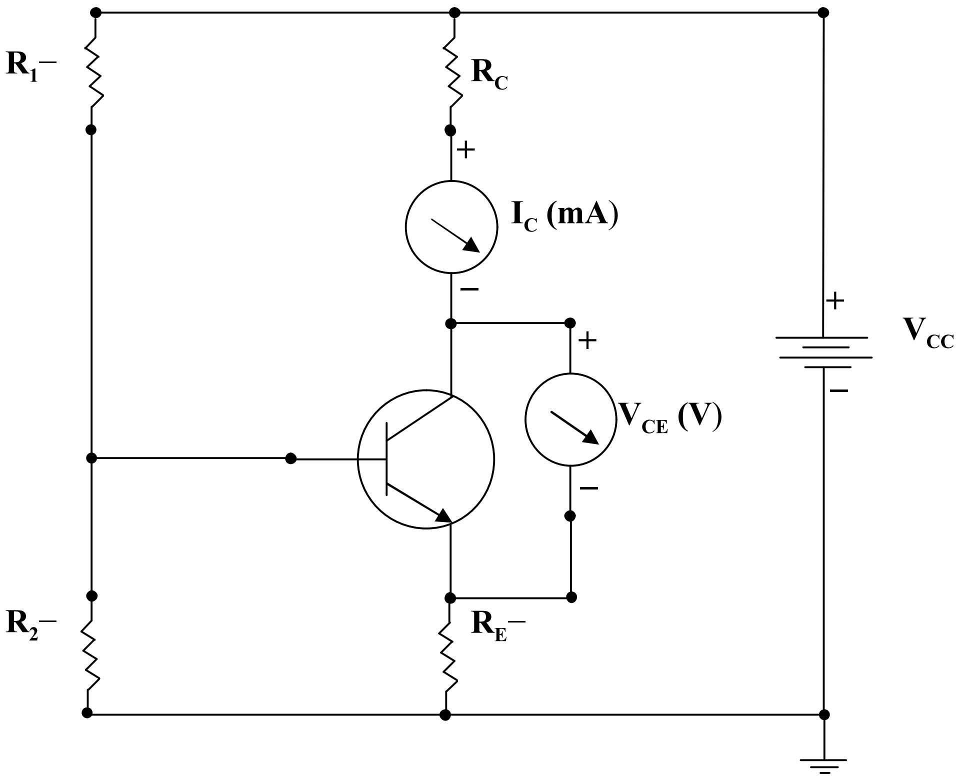


Fig.1: *To study the shift of ‘Q’ point with temperature.*

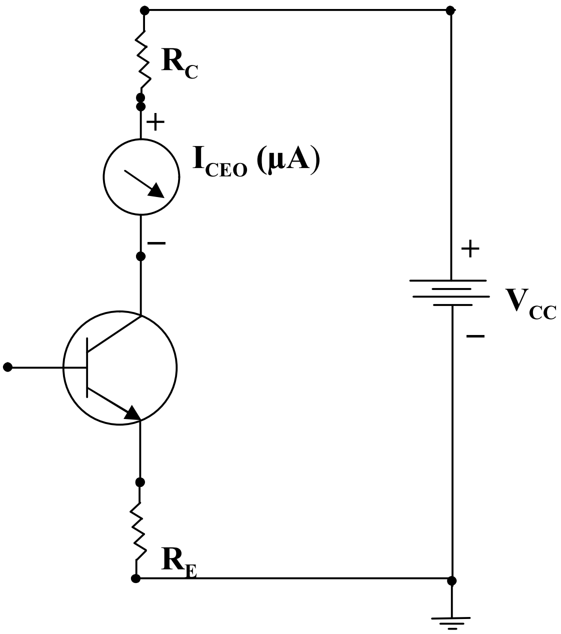


Fig. 2: *To study the variation of collector current (I_C) with leakage current (I_{CEO}) for a self biased transistor.*

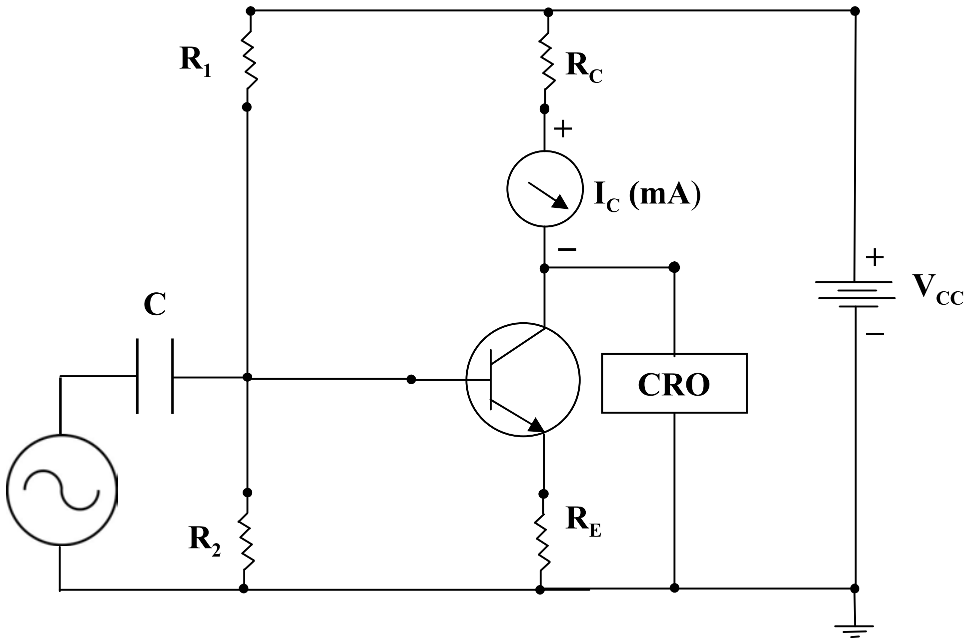


Fig. 3: *To study the distortion in a single stage amplifier as a result of change in q point with temperature.*

21.4 Formula

For Common Emitter Configuration

1. Collector current (output current): It is given by

$$I_C = \beta_{dc} I_B + I_{CEO}$$

2. Q point: A point with set of I_C and V_{CE} in output characteristics curve of Transistor is denoted as Q point or operating point (in the absence of input ac signal). The relation in output current (I_C) and voltage (V_{CE}) is given by

$$I_C = \frac{-V_{CE} + V_{CC}}{R_L}$$

3. Stability Factor (s): The rate change of collector current I_C w.r.t. collector leakage current I_{CO} at constant current gain (β). For self biasing the stability factor is

$$s = \frac{1 + \beta_{dc}}{1 + \cfrac{\beta_{dc}}{1 + \cfrac{R_1 R_2}{(R_1 + R_2) R_E}}}$$

Here:

β_{dc} = dc current gain of transistor

R_L = Load Resistance

I_B = Input current (Base current)

I_{CEO} = Leakage Current

V_{CE} = Voltage difference between collector and emitter terminal

V_{CC} = DC power supply

R_1, R_2 and R_E = Biasing resistors

21.5 Model Graph

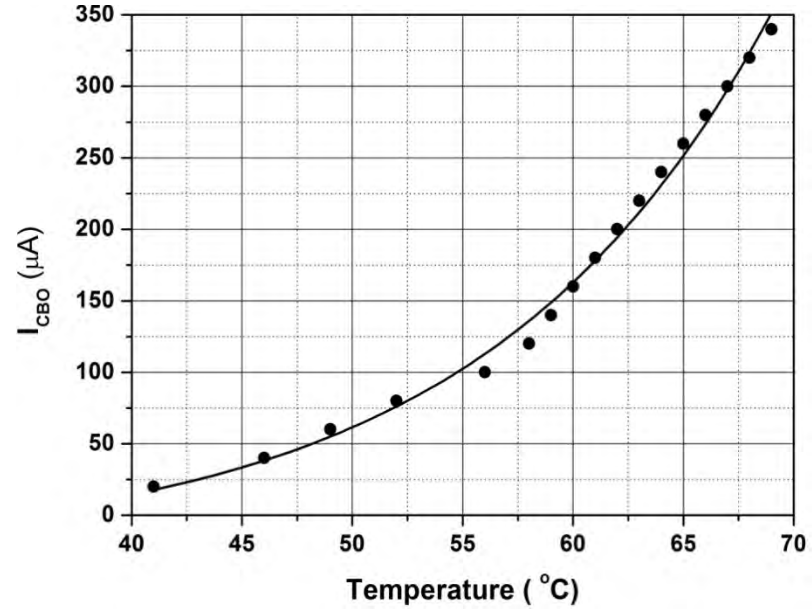


Fig. 11: *Curve between temperature and leakage current.*

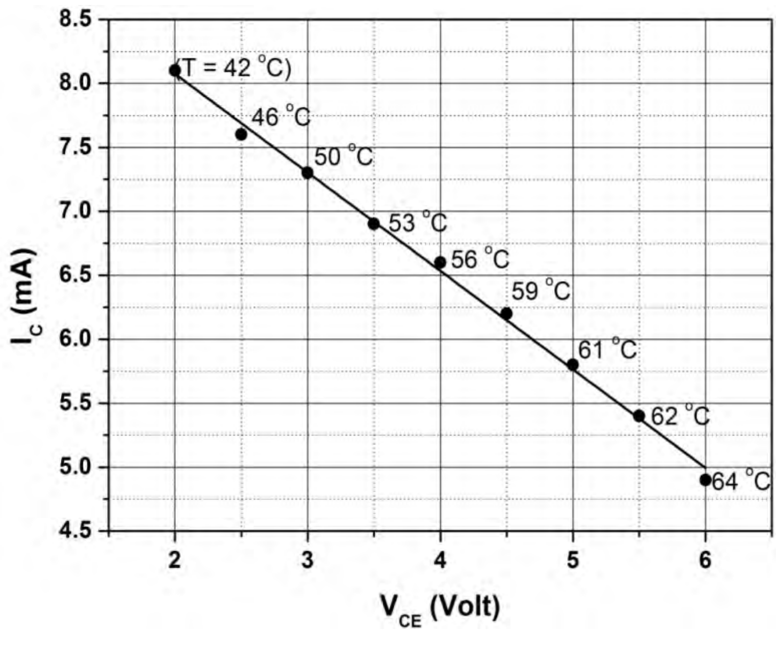


Fig. 12: *Curve between V_{CE} voltage and collector current at different temperatures*

21.6 Theory and description

(i) Transistor: The transistor is a semiconductor device was invented by John Bardeen, Walter Brattain and William Shockley in 1948. The important characteristic of transistor is ability to “transfer the resistor” means the transistor can transfer the same value of current from low resistance to high resistance. Hence, there is amplification of voltage and/or power (P= VI) by transistor, However, this transfer of current from low to high resistance terminals is only possibly by the help of external electric field which is known as Bias Power Supply (commonly DC supplies by batteries).

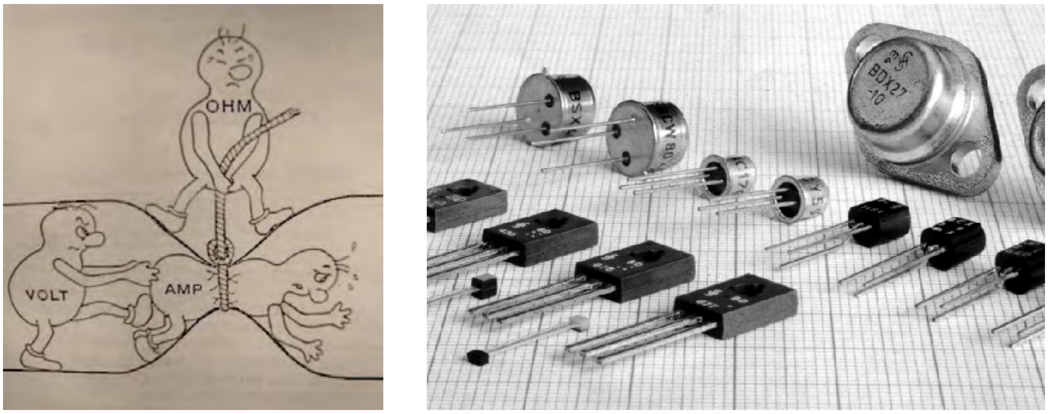
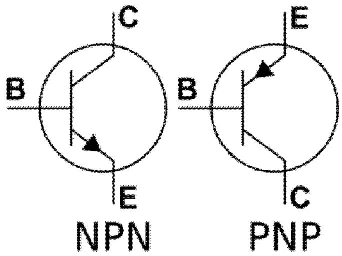


***Fig. 4**: (a) Pictorial explanation for working of Transistor (a famous picture) (b) Different forms of transistors available in market.*

In the physical structure of a transistor containing three separate regions, the middle region named as base, and two outer regions are named as emitter and collector and so three currents are counted I_E as an emitter current, I_B base current and I_C collector current concerning with these regions. In a transistor the collector and emitter regions are of same types (N or P) while base is with different polarity, hence NPN and PNP two types of combination are possible. In both types there are two PN junctions in a transistors *emitter junction* (emitter and base) and *collector junction* (base and collector). The collector region is made physically larger than the emitter region since it is required to dissipate more heat. Base is very thin since it is required that the same value of current which was entered should be transferred at output (i.e. I_B should be very low).

$I_C = I_E + I_B$



(ii) Configurations in Transistor: In any electronic circuit wherever a transistor exist, it works to amplify the input signal or as an electronic switch controlled by outer trigging. Three configuration are possible for functioning of transistor

(a) *Common Base (CB):* In this configuration the Base is grounded or common. It generally called as voltage amplifier since input current is injected through emitter (I_E act as an input current) and collected at collector (I_C as an output current). Output current I_C is little bit smaller than I_E. However, this current ($I_E \sim I_C$) is transfer from low resistance terminals to high resistance terminals hence the voltage (V= RI) is amplified.

(b) *Common Emitter (CE):* The emitter is grounded for this configuration. This configuration known as power amplifier since in this circuit the voltage and current both are amplified. I_B is input current while I_C is output current also $I_B >> I_C$, so the current is amplified. Moreover, the current is injected to high resistance terminals hence current is also amplified.

(c) *Common Collector (CC):* This configuration is used as an impedance matching device in electronic circuits. In this configuration I_B is taken as input current and output is taken at emitter terminal.

(iii) Biasing of Transistor: Two external DC power supplies (or power divider) are required for the operation of transistor one for emitter junction and another one for collector junction. The biasing batteries are termed as V_{CC}, V_{BB} and V_{EE} depends where the power supplies are used in circuit

There are four possible ways of biasing for two junctions of transistor using external power supplies:

Table 1: *Possible ways for biasing of transistor junctions.*

Emitter Junction	Collector Junction	Regionof operation	Biasing
Forward Biased	Reverse Bias	Active	FR
Forward Biased	Forward Biased	Saturation	FF
Reverse Bias	Reverse Bias	Cut off	RR
Reverse Bias	Forward Biased	Inverted	RF

For the amplification action of transistor biasing is set in this way that the transistor always being in the active region. In the active region the emitter junction is forward biased (low resistance terminals) and collector region is reverse biased (high resistance terminals). The input current is pushed from this low resistance terminals to high resistance terminals by the electric force by biasing power supplies. The cut off and saturation regions are used for switching action of transistor. The transistor acts as open and closed switch in cut off and saturation regions respectively. Inverted region commonly not used for amplification.

(iv) Current Parameters of Transistor:

(a) The ratio of the charge carrier current transported in base to total emitter current is defined by emitter injection ratio (γ). Typically for a transistor γ is around to 0.995.

(b) The ratio of the number of charge carriers arriving at collector to the number of emitted by emitter known as *base transportation factor* (β'). Furthermore, the ratio of collector current to base current is denoted by β_{dc} (here dc indicate the absence of input ac signal; $\beta_{dc} = \frac{I_C}{I_B}$

β_{dc} is defined as current gain in CE configuration. Hence in CE configuration

Output current (I_C) = β_{dc} × Input current (I_B)

$$I_C = \beta_{dc} I_B \qquad \textbf{(1)}$$

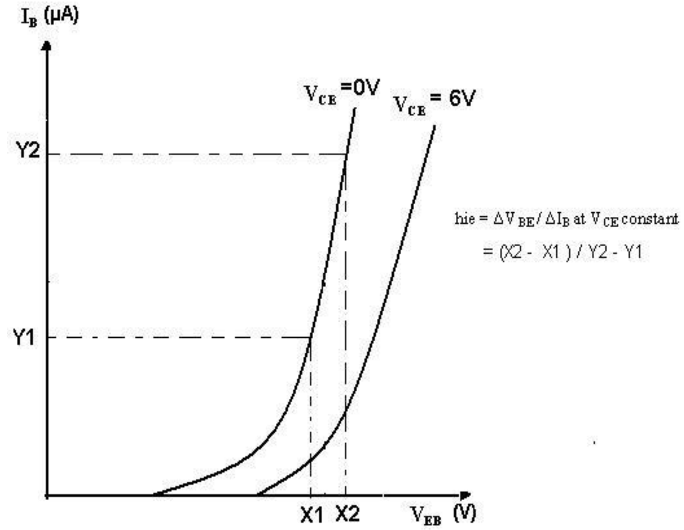
(c)The ratio of the collector current to the emitter current is denoted by α_{dc}.

$$\alpha_{dc} = \frac{I_C}{I_E}$$

α_{dc} is defined as current gain in CB configuration. Hence in CB configuration

Output current (I_C) = α_{dc} × Input current (I_E)

(v) Characteristic Curve of Transistor: The characteristic curves are mean to curve drawn in between voltage and current for a semiconductor device. In the transistor there are two PN junctions so there are two characteristics curves to describe the behaviour of a particular transistor in given configuration.



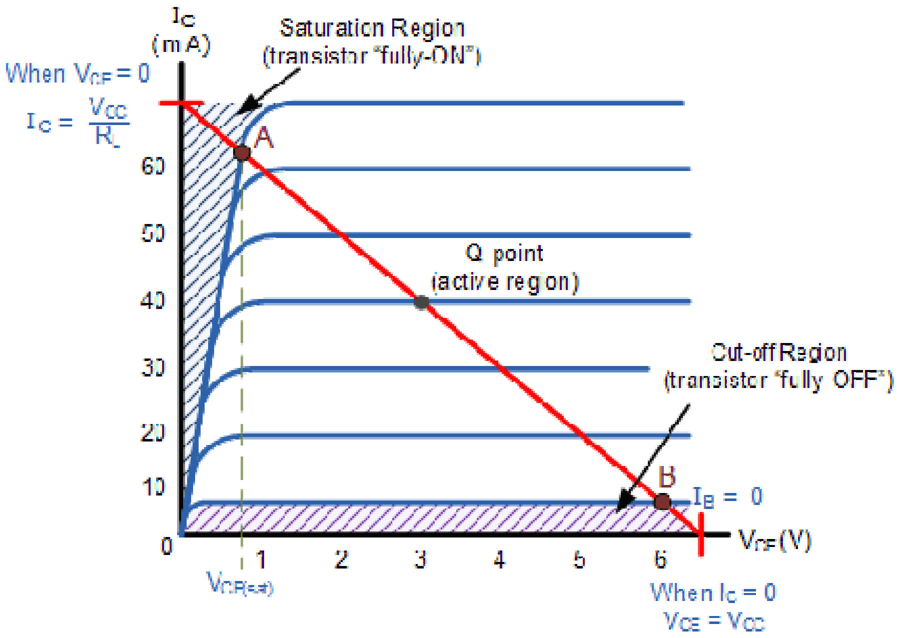


Fig. 5(a)(b): *Input and output Characteristics curves for Transistor (CE configuration).*

One input characteristic curve plotted in between input current and input voltage while keeping constant the voltage at output terminals (e.g. plot between I_B and V_{BE} while V_{CE} constant for CE configuration). The output characteristic curves which are plotted in between output current and output voltage while keeping constant input current (e.g. plot between I_C and V_{CE} while I_B is constant for CE configuration).

These characteristics curves describe the behaviour of particular transistor with the help of these curves one can select the range of voltage and current for desired operation.

(vi) Operating Point (quiescent point or Q Point) and Load Line: According to application first of all the configuration is select then the biasing is fixed in such a way that the transistor works only in desired region of operation. For the amplification the given will be designed either in CB or CE configuration and the transistor should be biased by external power supplies for active region of operation (emitter junction forward and collector junction reverse). For switching action the biasing should be according to operation either in cut off (switch on) or saturation region (switch off). Hence, the voltages are applied by biasing batteries (V_{BB}, V_{CC} and/or V_{EE}) in such a way that the transistor keeps remain in desire region of operation (Active, Cut off or Saturation). This selection of biasing voltage is determined from output characteristics of given transistor.

In output characteristic curves the set of two parameters i.e. output voltage and current describe a line named as *load line*. In the absence of any input ac signal (to be amplified) not applied this line is called as *dc load line*. The biasing voltages are fixed in such a way that transistor give desired voltage and current at outputs (e.g. V_{CE} and I_C in CE configuration). Furthermore, if input current is also fixed so there is a set of three parameters gives a point in output characteristics named as quiescent point or Q point (e.g. in fig. 6 of output characteristics from CE amplifier Q point fixed at V_{CE} = 5.8 volt, I_C = 4.8 mA and I_B = 46 μA).

(vii) Bias stabilization: The Q point is fixed in the middle of desired region of operation with the help of biasing batteries. If an ac signal applied on input (ac signal to be amplified) then the transistors outputs hence Q point (e.g. V_{CE} and I_C in CE configuration) will be changed by the signal current by following the path of load line (here in the presence of input signal the load line named *ac load line*). If the Q point is initially fixed in the middle region of operation, even it is driven by ac signal still remains in desired region of operation (as it must be remain in the selected region of operation to achieve desired outputs). The input current (in figure 6 the Q point will vary between M and N with input signal current.

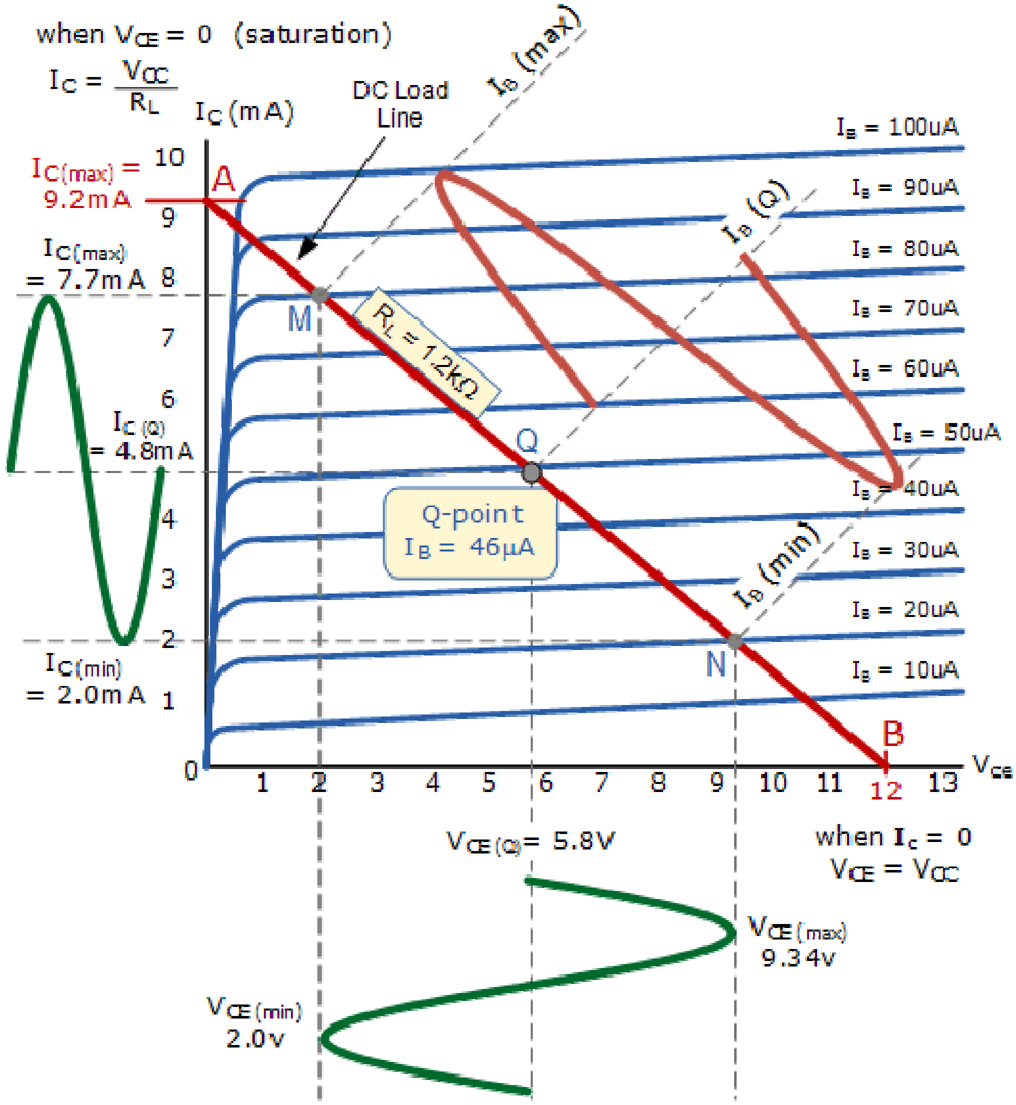


Fig. 6: Output characteristics of transistor: Change in Q point due to input signal (Courtesy: http://www.electronics-tutorials.ws/amplifier/amp_2.html)

Hence, a proper biasing is very important to fix the operation point in particular region of operation (Active, Cut off or saturation). Furthermore, it must also be ensured that it remains fixed in selected region of operation. However, in the transistor circuits during the operation the operating point shifts with the use of the circuit. Such a shift of operating point may drive the transistor into an undesirable region.

There are two reasons for the operating point to shift

- The transistor parameters extremely depend on temperature e.g. leakage current.
- The parameters change from transistor unit to other transistor unit means if the transistor damaged and it replaced by another transistor the 'Q' point may be shift.

  So we need a biasing circuit due to following reasons:

- To fix the Q point in the centre of the active region of the output characteristics, so that even on applying the inputs signal the operating point do not move in another undesired region of operation.
- To stabilise the collector current against temperature variations
- To achieve Q point independent from transistor parameters so it does not vary even if the transistor replaced by another transistor.

(viii) Leakage Current: The leakage current in transistor is due to flow of minority charge carrier. In NPN type of transistor, emitter contains electrons as majority charge carriers (due to doping) while holes are minority charge carrier (due to intrinsic property of used semiconductor material). Similarly holes and electrons are minority charge carriers in base and collector respectively.

The presence of minority charge carriers is an intrinsic property of semiconductor material. At every temperature above than 0K, electron and hole pairs are generated in the semiconductor material (due to breakage of bonds). The numbers of these pairs are increased with the temperature of surrounding and/or device. The doping elements provide majority type of charge carriers while thermally generated opposite type (other than provided by doping element) of charge carriers act as minority charge carriers. Flow of these minority type charge carriers produces leakage current in the reverse direction to the bias current (Bias current flow due to majority charge carriers inside the semiconductor).

In CB configuration, it is found that the collector current is non zero while emitter is open (I_E = 0), it is reverse leakage current. Similarly in CE configuration a reverse leakage current flow tin between collector and emitter while base is open (IB = 0). The leakage current is denoted by I_{CBO} (or I_{CO}), I_{CEO} for common base and common emitter configuration respectively. Here in subscript 'CB' or 'CE' shows the junction through leakage current is flowing while 'O' indicates that emitter is open in CB configuration and base is open in CE configuration. I_{CBO} is too sensitive to temperature and normally fifty times more than the I_{CEO}. I_{CBO} and I_{CEO} are related as

$$I_{CEO} = \frac{I_{CBO}}{1 - \alpha_{dc}}$$

$$Or\ \ I_{CEO} = (1 + \beta_{dc})I_{CBO}$$

In the presence of leakage current equation (1) will be modified as

$I_C = \beta_{dc} I_B + I_{CEO}$ (for CE configuration)

Or $\quad I_C = \beta_{dc} I_B + (1+ \beta_{dc}) I_{CBO}$ .... (2)

(ix) Thermal Runway: The leakage current is enormously depending on temperature. Its value almost doubles for every 6 °C rise in temperature in Ge and for every 10 °C increase in Si. Any increase in I_{CBO} is magnified (1 + β) times i.e. 300 to 500 times. Even a slight increase in I_{CBO} will affect output current (I_C) considerably. As I_C increases, collector power dissipation increases which raises the operating temperature that leads to further increase in I_C. If this succession of increases is allowed to continue, soon I_C will increase beyond safe operating value thereby damaging the transistor itself—a condition known as thermal runaway. Hence, stabilization of bias is necessary to prevent this thermal runaway.

(x) Temperature dependence of Bias stabilisation: As we discussed earlier the Q point should be fixed in the middle of region of operation so that transistor operate in the desired region of operation. But an important factor temperature increases the leakage current hence the 'Q' point shifts. To study the effect of temperature on Q point becomes important. We must know how the Q point is shifted with device or environment temperature.

In particular CE configuration (most commonly used circuit for amplification) flow of current in collector circuit produces heat at the collector junction. This increase the temperature of device and results in more minority charge carriers are generated in base-collector region. It increase I_{CBO} and hence I_{CEO} also increased. It further increase collector current hence, rising of the collector base junction. There are several bias stabilization circuit

1. Fixed bias circuit
2. Collector to base bias circuit
3. Bias circuit with emitter resistor
4. Voltage divider or self bias circuit
5. Emitter bias circuit

The voltage or self bias circuit most widely used circuit. By using this bias circuit operating point can be made almost independent from current gain (β).

(xi) Stability factor (s): the rate change of collector current I_C w.r.t. collector leakage current I_{CO} at constant current gain (β)

$$s = (\frac{\Delta I_C}{\Delta I_{CEO}})_\beta$$

For CE configuration the output current (collector current) can be written as

$$I_C = \beta_{dc} I_B + I_{CEO}$$

or

$$I_C = \beta_{dc} I_B + (1 + \beta_{dc}) I_{CBO}$$

Differentiating w.r.t. collector current I_C

$$1 = \beta_{dc}\left(\frac{\partial I_B}{\partial I_C}\right) + (1 + \beta_{dc})\left(\frac{\partial I_{CBO}}{\partial I_C}\right)$$

$$1 = \beta_{dc}\left(\frac{\partial I_B}{\partial I_C}\right) + \frac{(1 + \beta_{dc})}{s} \qquad \text{Since } s = \left(\frac{\partial I_{CBO}}{\partial I_C}\right)$$

$$s = \frac{1 + \beta_{dc}}{1 + \frac{\beta_{dc}}{1 + \frac{R_1 R_2}{(R_1 + R_2) R_E}}}$$

This is known as stabilisation factor for transistor. Higher the value of s indicates low bias stability of transistor. For better bias stability, s = 1, hence,

$$\frac{R_1 R_2}{(R_1 + R_2)} \ll R_E$$

Voltmeter: Refer unit-15

A**mmeter:** An ammeter is a measuring instrument used to measure the electric current in a circuit. It used in the series of an electric circuit to measurement of current and electric currents are measured in amperes (A). An ideal ammeter has zero resistance.

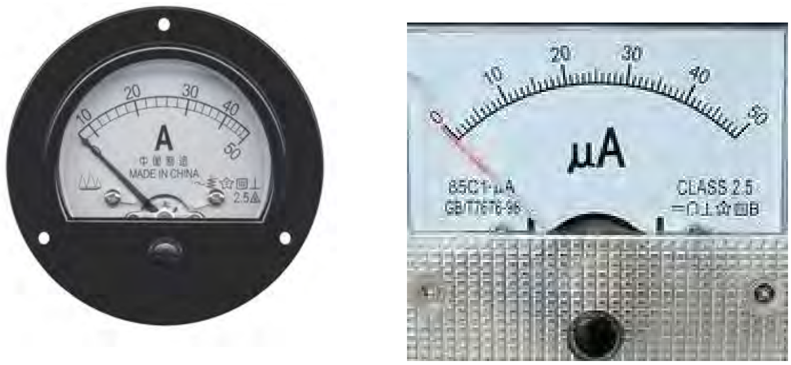


Fig. 8: *Ammeter and micro ammeter.*

Cathode Ray Oscilloscope (CRO): Refer unit15

Function Generator: A function generator or frequency generator is an electronic device, which produce desired repetitive waveform. This device contain an electronic oscillator (An electronic oscillator is a circuit that produce a time varying signal such as sine wave, saw tooth wave, square wave etc.) which convert provided DC supply to a desired ac wave form with selected frequency. It is possible to vary the amplitude of the wave also.

Fig. 10: *Function generator.*

21.7 Self Learning Exercise-I

Q.1 What is transistor?

Q.2 Why a transistor works in an electronic circuit?

Q.3 How it work as an amplifier?

Q.4 Which configuration used as power amplifier?

Q.5 Why CC configuration is not used for amplification?

21.8 Procedure

Select appropriate values of R_1, R_2, R_C and R_E with combination of V_{CC} so the operating point is in the middle of active region.

To study the leakage current with temperature:

1. Design circuit as per shown in Fig. 2 on the bread board.
2. Vary the temperature by switch on the oven and measure the leakage current at different temperature.
3. Plot the curve between leakage current and temperature.

To study the shift of Q point with temperature:

1. Design the circuit on bread board according to figure 1
2. Vary the temperature by switch on the oven.
3. Measure the collector current (I_C) and voltage drop between collector and emitter terminals (V_{CE}) at different temperature.
4. Plot the curve between leakage current and temperature.

To study the distortions in output signal with temperature:

1. Design the circuit on bread board according to figure 3

2. Switch on the oven and fix any appropriate sufficient high temperature.
3. Watch the output signal on CRO also the input signal.
4. Trace input and output signal on a trace paper.

21.9 Observation

Transistor type = ………….

V_{CC} = …………………….

R_1 =………………………

R_2 =………………………

R_E =……………

R_C =……………

R_{BB} =…………...

(i) To study the leakage current with temperature:

Table 1: *To study the leakage current variation with temperature:*

S. No.	Temperature (°C)	I_{CEO} (µA)
1.		
2.		
3.		
4.		
5.		
6.		
7.		

(ii) To study the shift of Q point with temperature:

Table 2: *To study the shift of 'Q' point with temperature:*

S. No.	Temperature (°C)	V_{CE} (volt)	I_C (mA)
1.			
2.			
3.			
4.			
5.			
6.			
7.			

(iii) To study the distortions in output signal with temperature:

Due to thermal runway of Q point in undesired region of operation the output signal is obtained in distorted form (generally clipped) as shown in figure below:

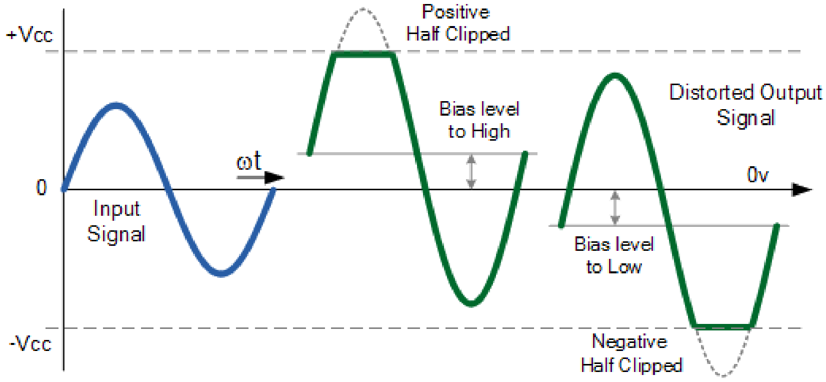


Fig.13: *Distorted output signal (e.g. at 55 °C V_i = 0.1 V and V_O = 5 V)*

21.10 Graph

Plot the curve between leakage current and temperature.

Plot the curve between leakage current and temperature.

21.11 Calculations

Model Calculations:

Let R_1 = 40 KΩ, R_2= 5 KΩ, R_E = 1 KΩ, R_C = 5 KΩ and V_{CC} = 12 V and β = 60 (at 25 °C)

Stability factor

$$s = \frac{1 + \beta_{dc}}{1 + \frac{\beta_{dc}}{1 + \frac{R_1 R_2}{(R_1 + R_2) R_E}}}$$

$$s = \frac{1 + 60}{1 + \frac{60}{1 + \frac{40 \times 5 \times 10^6}{(40 + 5) \times 10^6}}}$$

$$s = 4.2$$

21.12 Result

1. The graph between leakage current and temperature show that leakage current increases exponentially with temperature.
2. Q point shifts up as temperature increase.
3. At higher temperature due to shift Q point some of the amplified voltage goes in to saturation region and we get distorted value.
4. The stabilisation factor for used biasing is obtained 4.2.

21.13 Discussion

21.14 Precautions and Sources of error

1. All the connections should be tight.
2. The applied voltage should not be more than peak value prescribed for the given transistor.
3. The polarity of connections for transistor should be accurate.
4. Various Resistors used should be appropriate value.
5. Temperature should not be rise beyond 65 $^{\circ}$C otherwise function transistor can be damage.

21.15 Self Learning Exercise-II

Q.1 Why biasing required for a transistor?

Q.2 How many types of biasing possible?

Q.3 Which biasing is mostly used for amplification action of transistor?

Q.4 What is Q point?

Q.5 What do you understand by bias stabilisation?

21.16 Glossary

Frequency: Frequency is the number of occurrences of a repeating event per unit time

Signal: In alternating current (AC, also ac), the flow of electric charge periodically reverses direction

Biasing: Biasing in electronics is the method of establishing predetermined voltages or currents at various points of an electronic circuit for the purpose of establishing proper operating conditions in electronic components.

21.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: An electronic device capable to transfer the same value of current from low resistance to high resistance.

Ans.2: Either as an amplifier or an electronic switch.

Ans.3: It capable to transfer the same or higher value of current from low resistance to high resistance terminals using external power supplies.

Ans.4: Common emitter.

Ans.5: It is only for impedance matching not able to amplify the signal.

Answers to Self Learning Exercise-II

Ans.1: To fix the Q point in the centre of the active region, to stabilise the collector current against temperature variations, to achieve Q point independent from transistor parameters.

Ans.2: Four types: FF, RR, FR, and RF.

Ans.3: When base and emitter junction is forward bias and base collector junction is reverse biased.

Ans.4: In the absence of signal and at a fix input current the set of output voltage and output current is known as Q point.

Ans.5: An external electronic circuit to the transistor which keep fix the Q point in the desired region of operation.

21.18 Viva Questions

Q.1 What is leakage current in a transistor?

Q.2 How the temperature affects leakage current?

Q.3 Why leakage current increases with temperature?

Q.4 How the leakages current affect the action of transistor?

Q.5 What do you understand by Operating point?

Q.6 Why do we choose the Q point at the centre of the load line?

Q.7 Name the two techniques used in the stability of the Q point?

Q.8 Define stability factor?

Q.9 List out the different types of biasing.

Q.10 What do you meant by thermal runway?

Q.11 Why BJT (Bipolar Junction Transistor) is called as a current controlled device?

Q.12 Define current amplification factor?

Q.13 What are the requirements for biasing circuits?

Q.14 When does a transistor act as a switch?

Q.15 What is d.c. load line?

Q.16 Explain about the various regions in a transistor?

Q.17 Explain about the characteristics of a transistor?

Q.18 What is an amplifier?

Q.19 What is phase difference between in input and output current for CE configuration?

Q.20 What is phase difference between in input and output current for CB configuration?

21.19 Answers to Viva Questions

Ans.1: The flow of minority charge carrier causes leakage current.

Ans.2: Temperature increase the number of minority charge due to breakage more covalent bonds carriers hence increase leakage current.

Ans.3: Due to breakage of covalent bonds of semiconductor material.

Ans.4: The leakage current increase the collector current hence operation point changed.

Ans.5: In the absence of signal and at a fix input current the set of output voltage and output current is known as Q point.

Ans.6: The position of q point is affected by temperature, input signal still it should be remain in the desired region of operation so it selected in middle of region.

Ans.7: Fixed bias circuit and self biasing circuit.

Ans.8: The rate change of collector current I_C w.r.t. collector leakage current I_{CO} at constant current gain (β).

Ans.9: Fixed bias circuit, Collector to base bias circuit, Bias circuit with emitter resistor, Voltage divider or self bias circuit, Emitter bias circuit.

Ans.10: The leakage current increase the collector current hence operation point changed which further increase the temperature of transistor in result the transistor move to undesired region of operation.

Ans.11: A BJT is a current controlled device because its output characteristics are determined by the input current.

Ans.12: The ratio of output current and input current to transistor.

Ans.13: To fix the Q point in the centre of the active region, to stabilise the collector current against temperature variations, to achieve Q point independent from transistor parameters.

Ans.14: In saturation and cut off region.

Ans.15: In output characteristic curves the set of two parameters i.e. output voltage and current describe a line named as *load line*. Till then any input ac signal (to be amplified) not applied this line is so called *dc load line*.

Ans.16: Active, cut off and saturation region

Ans.17: Input and output characteristic curves. One input characteristic curve plotted in between input current and voltage while keeping constant the voltage at output terminals Another are output characteristic curves which are plotted in between output current and output voltage while keeping constant input current.

Ans.18: Amplifier is an electronic circuit which amplify the input signal.

Ans.19: Common emitter transistor gives 180° phase between input and output.

Ans.20: Common base transistor gives 0° phase between input and output.

References and Suggested Readings

1. Basic Electronics and Linear Circuits by N.N. Bhargava, D.C. Kulshreshtha, S.C. Gupta, 2nd Edition, Mc Graw Hill Publications.
2. A Text Book of Electrical Technology by B.L. Theraja and A.K. Theraja, S. Chand Publications.

UNIT-22
A/D and D/A Conversion

Structure of the Unit

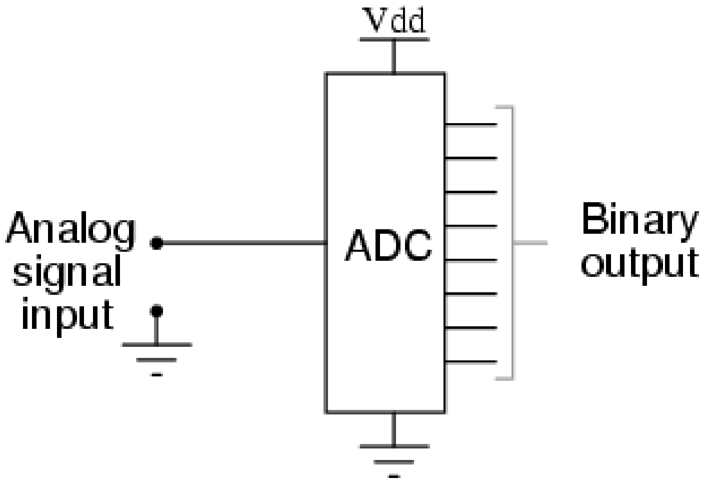
22.1 Aim

1. To understand the principle of Digital to analog and Analog to digital principle.
2. To measure the parameters of R-2R Ladder Digital to Analog Converter Circuit.
3. To study parameters of IC: ADC0804 (Analog to Digital Converter).

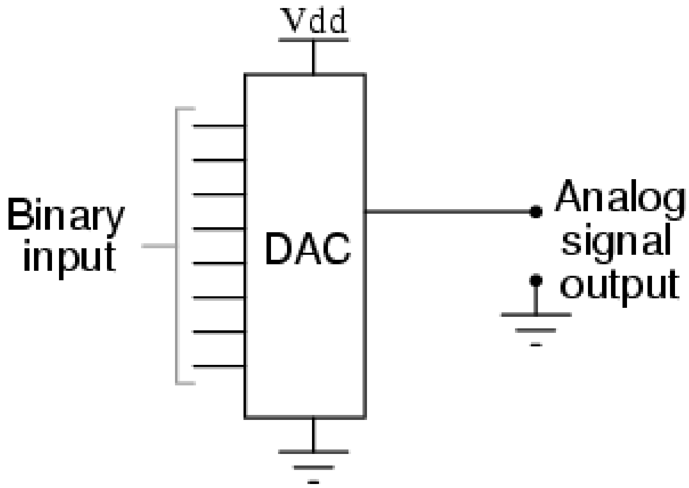
22.2 Apparatus

DC Power Supply, Digital Multimeter, Digital Board.

22.3 Diagram



Analog to Digital converter



Digital to Analog converter

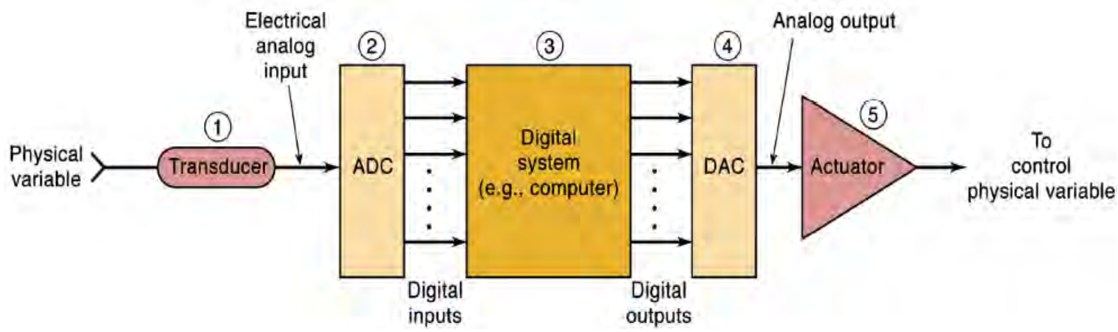
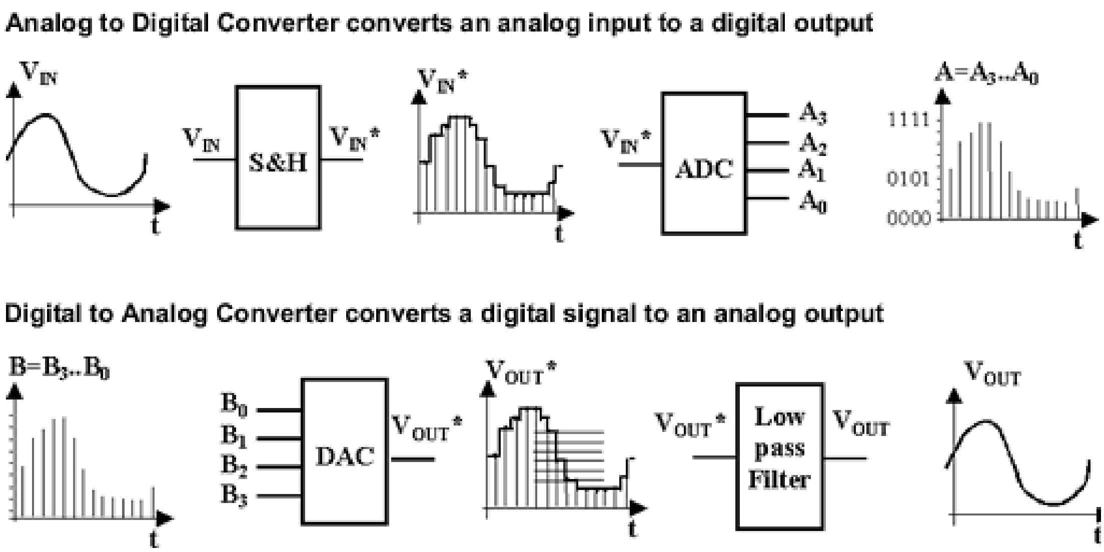


Figure: Temperature Control System

In above figure Analog to digital converter (ADC) and digital to analog converter (DAC) are used to interface a computer to the analog world so that the computer can monitor and control a physical variable.

22.4 Model Graph



22.5 Theory and description

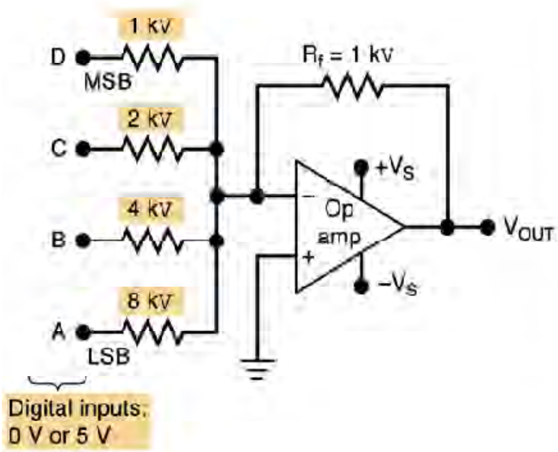
A digital to analog converter (DAC) is a device that outputs a voltage proportional to an input binary number. This device is frequently required in applications where a digital computer must generate a signal that has an influence on the 'real' world.

Real world signals are continuously variable i.e. analogue signals, whereas signals within a computer have a finite number of values i.e. discrete signals. A DAC is used to perform the necessary conversion.

Analog to Digital converters (ADC) are widely used by many engineers and scientists. One of the most widely used features of computer interface systems is the ability to change an analog voltage in the "real world" into a digital representation (a binary number) inside the computer.

Digital to Analog Converter:

There are several methods and circuits for producing the D/A operation that has been described. Figure shows the basic circuit for one type of four bits DAC. The input A, B, C and D are binary inputs that are assumed to have the values of either 0 or 5 V. The operation amplifier is employed as a summing amplifier, which produces the weighted sum of this input voltage.



(a)

Input code				
D	C	B	A	V_{OUT} (volts)
0	0	0	0	0
0	0	0	1	−0.625 ← LSB
0	0	1	0	−1.250
0	0	1	1	−1.875
0	1	0	0	−2.500
0	1	0	1	−3.125
0	1	1	0	−3.750
0	1	1	1	−4.375
1	0	0	0	−5.000
1	0	0	1	−5.625
1	0	1	0	−6.250
1	0	1	1	−6.875
1	1	0	0	−7.500
1	1	0	1	−8.125
1	1	1	0	−8.750
1	1	1	1	−9.375 ← Full-scale

The Amplifier output can thus be expressed as

$$V_{out} = -\left(\frac{R_f}{R1}.A + \frac{R_f}{R2}.B + \frac{R_f}{R3}.C + \frac{R_f}{R4}.D\right)$$

The Amplifier output can thus be expressed as

$$V_{out} = -\left(\frac{1}{8}.A + \frac{1}{4}.B + \frac{1}{2}.C + \frac{1}{1}.D\right)$$

R/2R Ladder:-

One of the most widely DAC circuits that use R/2R Ladder network, where the resistance values span a range of only 2 to 1. One such DAC is shown in the Figure.

There are two different values are used R and 2R. The current output I_{out} depends on the positions of the four switches, and binary inputs B_3 B_2 B_1 B_0 control the state of the switch .

This current is allowed to flow through an op-amp current to voltage converter to develop V_{out}. The value of V_{out} is given by the expression

$$V_{out} = -\frac{V_{ref}}{8} \times B$$

where B is the value of the binary input.

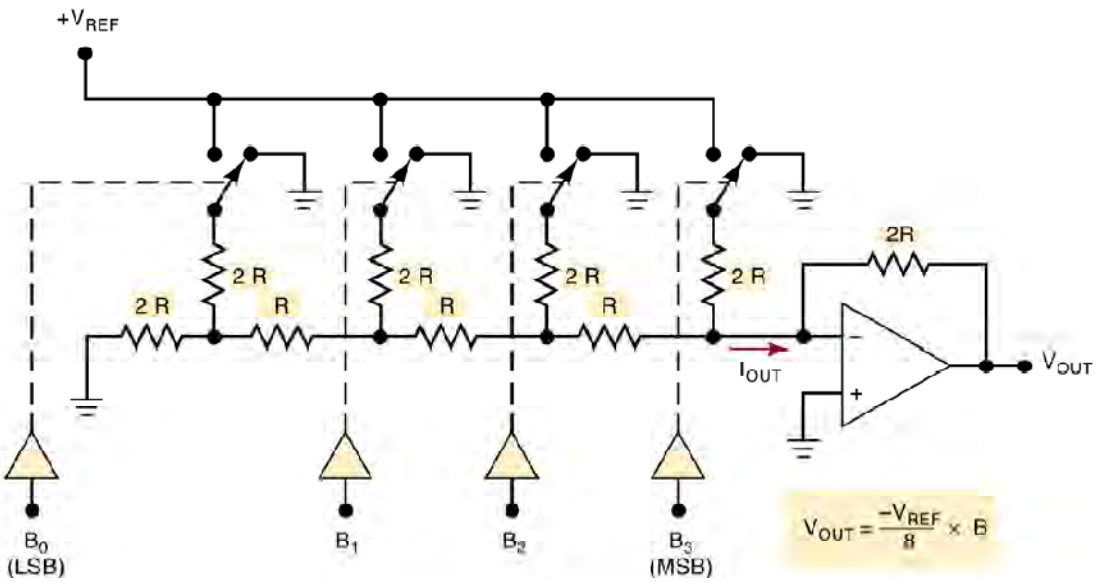
Analog to Digital Conversion:-

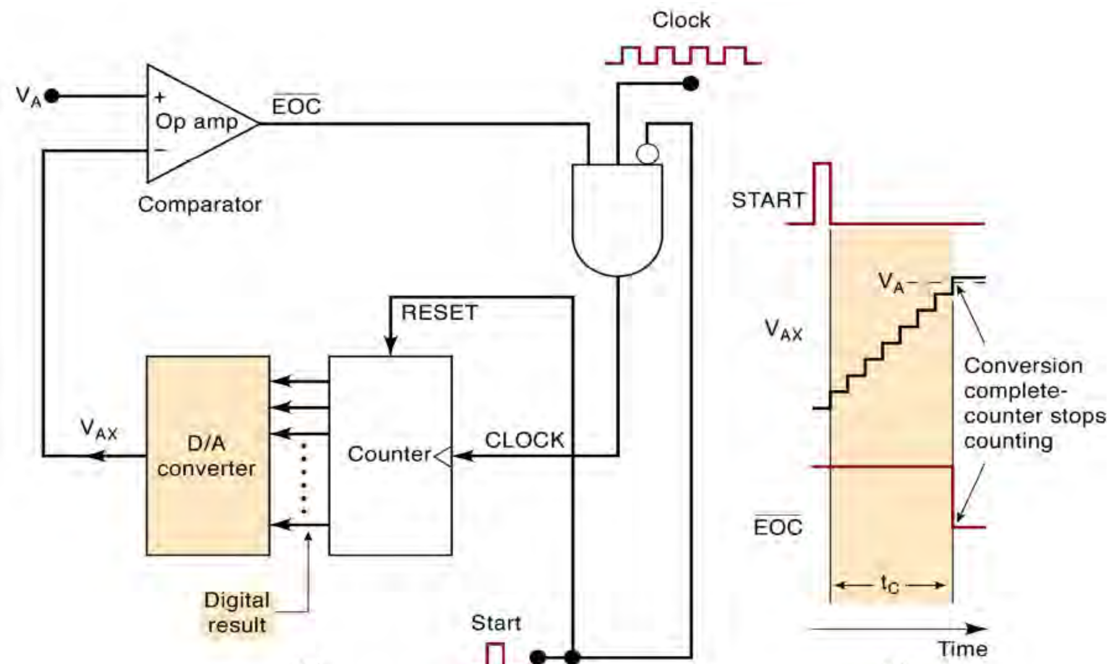
An analog to digital converter take an analog input voltage and, after a certain amount of time, produces a digital output code that represents the analog input. The A/D conversion process is generally more complex and time consuming than the D/A process, and many different methods have been developed and use.

Digital Ramp ADC:

One of the simplest versions of the general ADC of Figure uses a binary counter as the register and allows the clock to increment the counter one step at a time until $V_{AX} \geq V_A$.

It is called digital ramp ADC because the wave form at V_{AX} is a step by step ramp like the one shown in Figure.



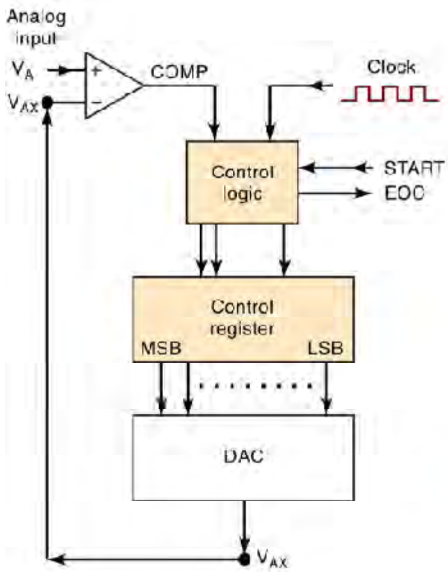


(a)

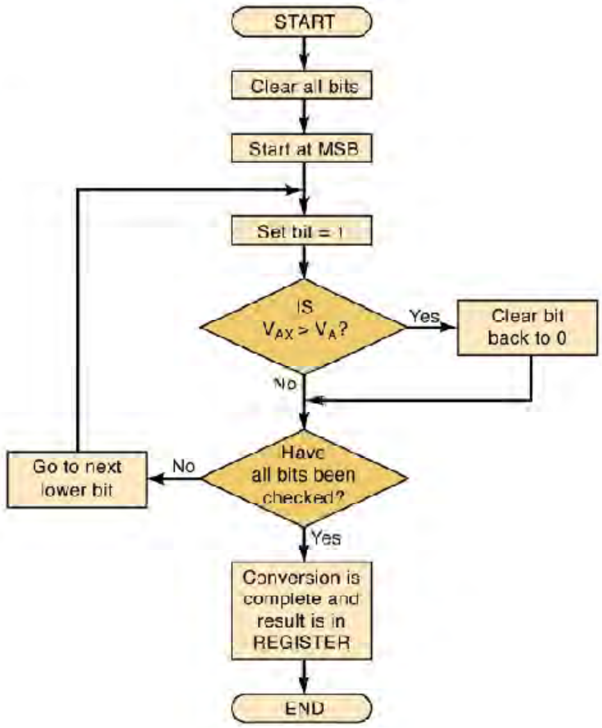
(b)

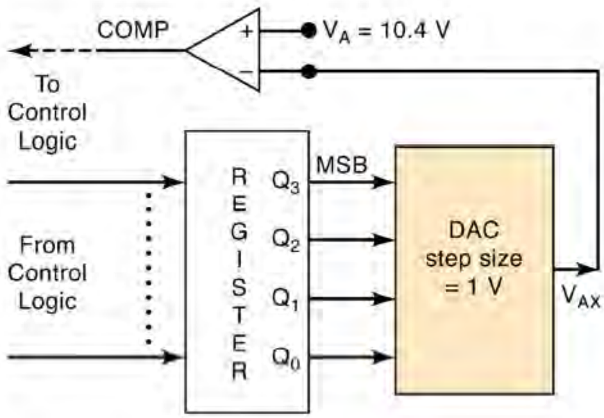
Successive-Approximation ADC:

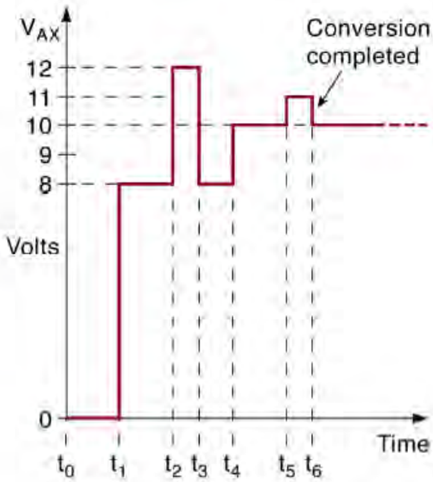
The successive-approximation converter is one of the most widely used types of ADC. It has more complex circuitry than the digital-ramp ADC but a much shorter conversion time. In addition, successive-approximation converters (SACs) have a fixed value of conversion time that is not dependent on the value of the analog input. The basic arrangement, shown in the Figure, is similar to that of the digital-ramp ADC. The SAC, however, does not use a counter to provide the input to the DAC block but uses a register instead. The control logic modifies the contents of the register bit by bit until the register data are the digital equivalent of the analog input VA within the resolution of the converter. The basic sequence of operation is given by the flowchart in Figure. We will follow this flowchart as we go through the example illustrated in Figure.



(a)







22.6 Self learning exercise-I

Q.1 What is Analog to digital converter?

Q.2 How many types of Analog to digital converters are there?

Q.3 Why to use Analog to digital converter?

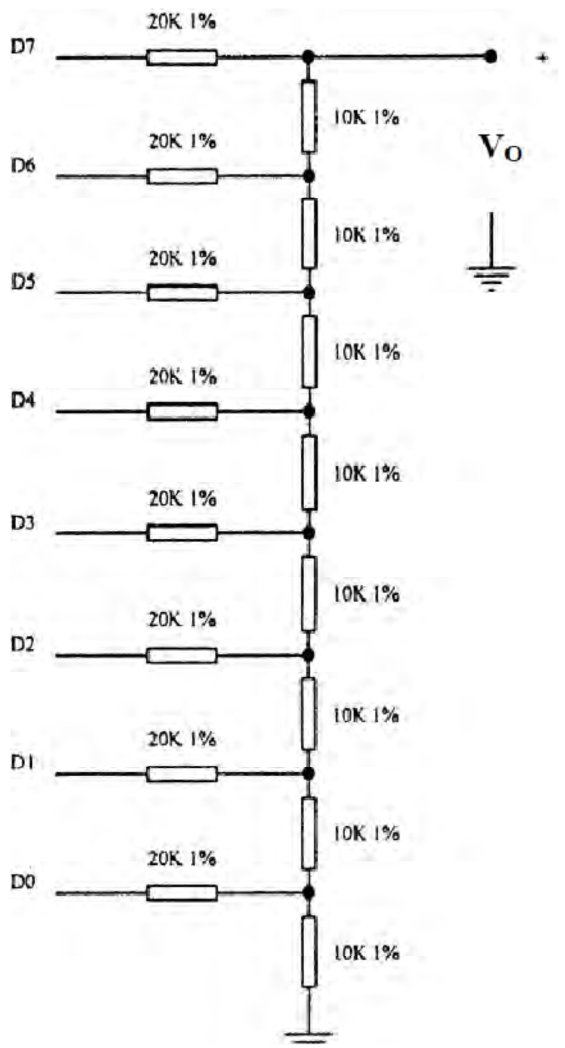
Q.4 What are the steps to execute the process of Analog to digital converter?

Q.5 What is the resolution of a digital to analog converter?

22.7 Procedure

Digital to Analog Converter (R/2R Ladder) Circuit:

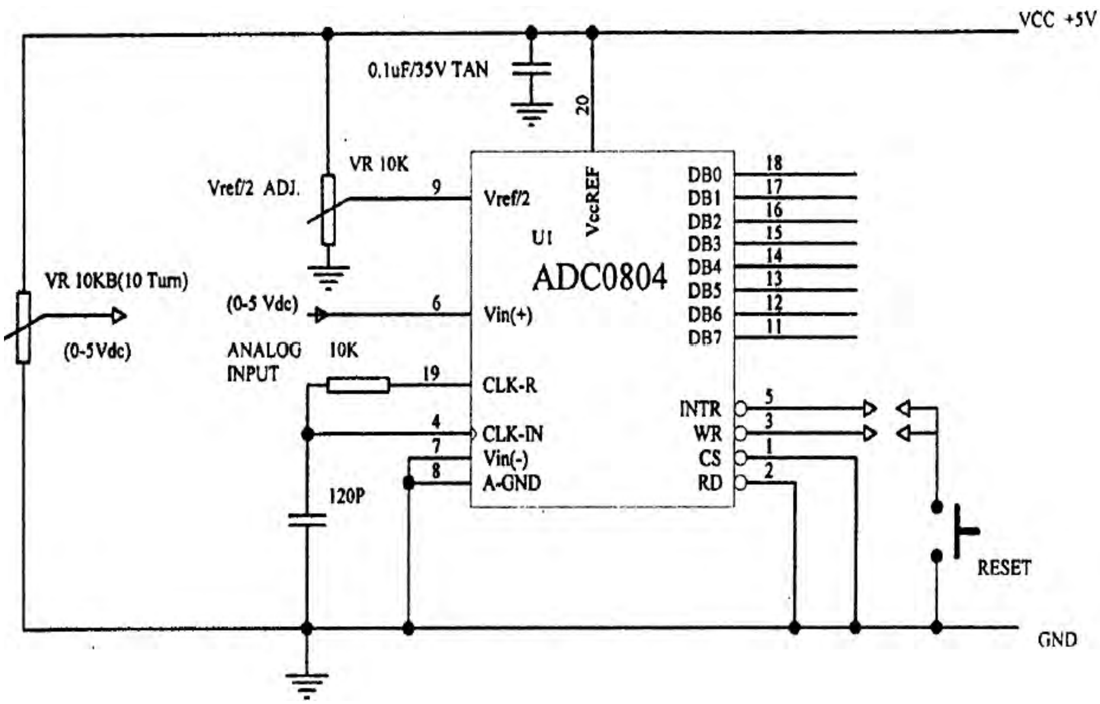
1. Making a connection of a 8 Bits DAC circuit shown in Figure.



2. Connecting 8-logic switches to 8-digital inputs (D7 D6 D5 …….D0).
3. Setting the digital input as shown in Table 1 and record the output voltage (V_o) in Table 1.
4. Calculating the output voltage V_o (cal) using the schematic circuit given in Fig and calculate an error (%) between the measurement and the calculation, write them down in the Table 1.

Analog to Digital Converter (Successive Approximation ADC:

1. Connecting the 8 Bits ADC circuit shown in Figure



2. Connecting DC power supply to V_i and then vary V_i from 0 V to 5 V.
3. Find the minimum value of V_i that can set the digital outputs (DB7 DB6 DB5 ….. DB0) as listed in Table.
4. Using the schematic given in Fig, calculate the input voltage V_i(cal) and an error (%) between the measurement and the calculation; write them down in the Table 2.

DAC and ADC

1. Making a connection between the above two circuits as shown in Figure.
2. Filling in the missing values in Table 3.

22.8 Observation

Table 1

a. Step Size ……………………………….

Digital Input										
D7	D6	D5	D4	D3	D2	D1	D0	Vo	Vo(cal)	%error
0	0	0	0	0	0	0	0			
0	0	0	0	0	0	0	1			
0	0	0	0	0	0	1	0			
0	0	0	0	0	0	1	1			
0	0	0	0	0	1	0	0			
0	0	0	0	0	1	0	1			
0	0	0	0	0	1	1	0			
0	0	0	0	0	1	1	1			
0	0	0	0	1	0	0	0			
0	0	0	1	0	0	0	0			
0	0	1	0	0	0	0	0			
0	1	0	0	0	0	0	0			
1	0	0	0	0	0	0	0			
1	0	0	0	1	1	1	0			
1	1	1	1	1	1	1	1			

a. Full Scale Output Voltage V_0 ……………………………

b. Number of Step……………………………….

c. Output Voltage when input voltage is $(10001110)_2$
V_0………………………………

d. Percent Error of this DAC circuit
% *Error* =………………………………

Table 2:

a. Step Size ………………………………

	Digital Output									
V_i (min)	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	Vi (cal)	%error
	0	0	0	0	0	0	0	0		
	0	0	0	0	0	0	0	1		
	0	0	0	0	0	0	1	0		
	0	0	0	0	0	0	1	1		
	0	0	0	0	0	1	0	0		
	0	0	0	0	1	0	0	0		
	0	0	0	1	0	0	0	0		
	0	0	1	0	0	0	0	0		
	0	1	0	0	0	0	0	0		
	1	0	0	0	0	0	0	0		
	1	1	1	1	1	1	1	1		

a. Minimum Full Scale Output Voltage V_0 ...

b. Number of Step………………………………

c. Digital Output Voltage when input voltage is 2V…….

d. Quantization error=……

e. Percent Error of this ADC circuit

   $\% \; Error =$……………………………….

f. Measure voltage at $V_{ref}/2$ (IC ADC0804) pin…….

g. Adjust voltage $V_{ref}/2 = 2V$ and find the step size.

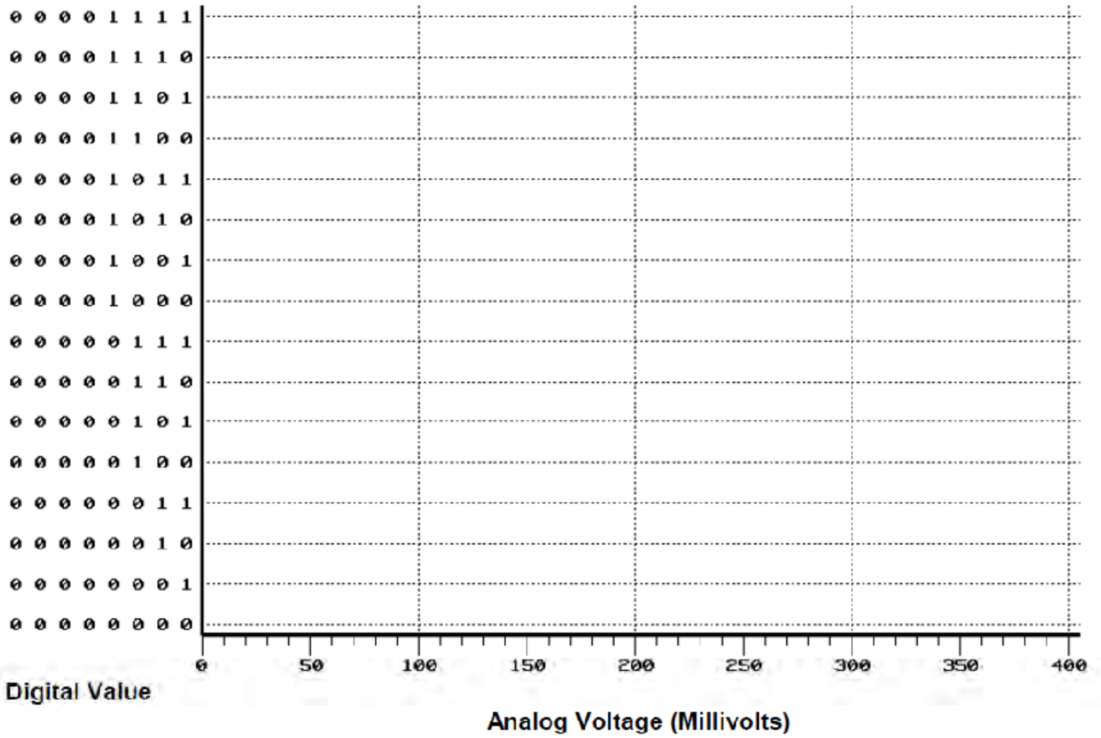
   $step \; size =$ ……………………………….

Table 3:

Digital Input								Digital Output								V_0
D7	D6	D5	D4	D3	D2	D1	D0	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	
0	0	0	0	0	0	0	0									
0	0	0	0	0	0	0	1									
0	0	0	0	0	0	1	0									
0	0	0	0	0	0	1	1									
0	0	0	0	0	1	0	0									
0	0	0	0	0	1	0	1									
0	0	0	0	0	1	1	0									
0	0	0	0	0	1	1	1									
0	0	0	0	1	0	0	0									
0	0	0	1	0	0	0	0									
0	0	1	0	0	0	0	0									
0	1	0	0	0	0	0	0									
1	0	0	0	0	0	0	0									
1	1	1	1	1	1	1	1									

22.9 Graph

On the graph below plot the analog voltage versus the binary value.



22.10 Calculations

22.11 Result

22.12 Discussion

22.13 Precautions and Sources of error

1. Connections should be neat and tight.
2. The voltage should be less than the breakdown voltage.
3. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.

22.14 Self Learning Exercise-II

Q.1 What do you mean by sampling?

Q.2 What is sampling theorem?

Q.3 Which of the following is a type of error associated with digital to analog converters?

Q.4 A 4 bit R/2R digital to analog converter has a reference of 5 volts. What is the analog output for the input code 0101.

Q.5 The practical use of binary weighted digital to analog converters is limited to:

22.15 Glossary

A/D Converter **:** (also A/D or ADC) Short for analog-to-digital converter. This device converts real-world analog signals into a digital format that can be processed by a computer. Video-speed A/D converters are those able to digitize video bandwidth signals (greater than 1MHz): some are capable of sampling at rates up to 500 million samples- per-second (Msps) and beyond. The most common architectures for video-speed A/D converters are "flash" and "subranging."

Analog Ground **:** In high-speed data acquisition applications, system ground is generally physically separated into "analog" and "digital" grounds in an attempt to suppress digital switching noise and minimize its effect on noise-sensitive analog signal processing circuitry. Input signal conditioners, amplifiers, references, and A/D converters are usually connected to analog ground.

D/A Converter **:** (also D/A or DAC). Short for digital-to-analog converter, this is a device that changes a digitally-coded word into its "equivalent" quantized analog voltage or current. Just like the A/D device, there are very high-speed D/A's available, capable of converting at data rates up to 1GHz.

Switching Time **:** The time required for the DAC analog switch to change to a new state from the previous one.

Analog Positive: Voltage Positive analog power supply used to power the DAC, op-amp, and reference. (if external)

Analog Negative **:** Voltage Negative analog power supply used to power the DAC, op-amp, and reference. (if external)

22.16 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Analog to digital converters is a device that converts continuous signals to discrete digital numbers.

Ans.2: Analog to digital converter is commonly of two types;

a. Linear Analog to digital converter is designed to produce an output which is a linear function or proportional to the output.
b. The other common type of Analog to digital converter is the Logarithmic Analog to digital converter, which functions by using voiced communications systems to increase the entropy of the digitized signal.

Ans.3: A digital signal is superior to an analog signal because it is more robust to noise and can easily be recovered, corrected and amplified. For this reason, the tendency today is to change an analog signal to digital data.

Ans.4: Analog to digital converter process is executed in three steps;

a. Sampling
b. Quantizing
c. Coding

Ans.5: It is the smallest analog output change that can occur as a result of an increment in the digital input.

Answers to Self Learning Exercise-II

Ans.1: To convert continuous time signal to discrete time signal, a process is used call as sampling.

Ans.2: The sampling theorem states that a signal can be exactly reproduced if it is sampled at a frequency Fs, where Fs is greater than twice the maximum frequency Fmax in the signal.

Fs>2Fmax

Ans.3: nonmonotonic and offset error.

Ans.4: 3.125 V

Ans.5: 4 bit D/A converters.

22.17 Viva Questions

Q.1 The difference between analog voltage represented by two adjacent digital codes, or the analog step size, is the:

Q.2 What is the primary disadvantage of flash analog-to digital converter?

Q.3 What is the major advantage of the R/2R ladder digital to analog, as compared to a binary weighted digital to analog DAC converter?

Q.4 The resolution of a 0-5 V 6-bit digital to analog converter is?

Q.5 In a flash analog to digital converter, the output of each comparator is connected to an input of a?

Q.6 Which is not an analog to digital conversion error?

Q.7 Sample and hold circuits in analog to digital converters are designed to:

Q.8 A 4 bit R/2R digital to analog converter has a reference of 5 volts. What is the analog output for the input code 0101.

Q.9 What is the resolution of a digital to analog converter?

Q.10 The practical use of binary weighted digital to analog converters is limited to:

22.18 Answers to Viva Questions

Ans.1: Resolution

Ans.2: A large number of comparators are required to represent a reasonable sized binary number.

Ans.3: It only uses two different resistor values.

Ans.4: 1.56%

Ans.5 : Priority Encoder

Ans.6: Differential nonlinearity

Ans.7: Stabilize the input analog signal during the conversion process

Ans.8: 3.125 V

Ans.9: It is the smallest analog output change that can occur as a result of an increment in the digital input.

Ans.10: 4 bit digital to analog converters

References and Suggested Readings

1. CMOS Integrated Analog-to-Digital and Digital-to-Analog Converters, by Rudy J. Van De Plassche, 2005.
2. Principles of data acquisition and conversion, Burr-Brown, 1994.
3. Digital electronics practice using integrated circuits by R. P. Jain, M. M. S. Anand
4. Electronics Instrumentation, by H S Kalsi, Second Edition,Tata McGraw Hills.

UNIT-23
Uni-Junction Transistor (UJT)

Structure of the Unit

23.1 Aim

To study UJT as saw tooth wave generator

23.2 Apparatus

UJT 2N2616, Resistors (47 Ω, 220 Ω, 47 KΩ), Capacitor (0.1, 0.01, 0.001 μF), DC power supply (0-20V), Connecting wires, CRO.

23.3 Diagram

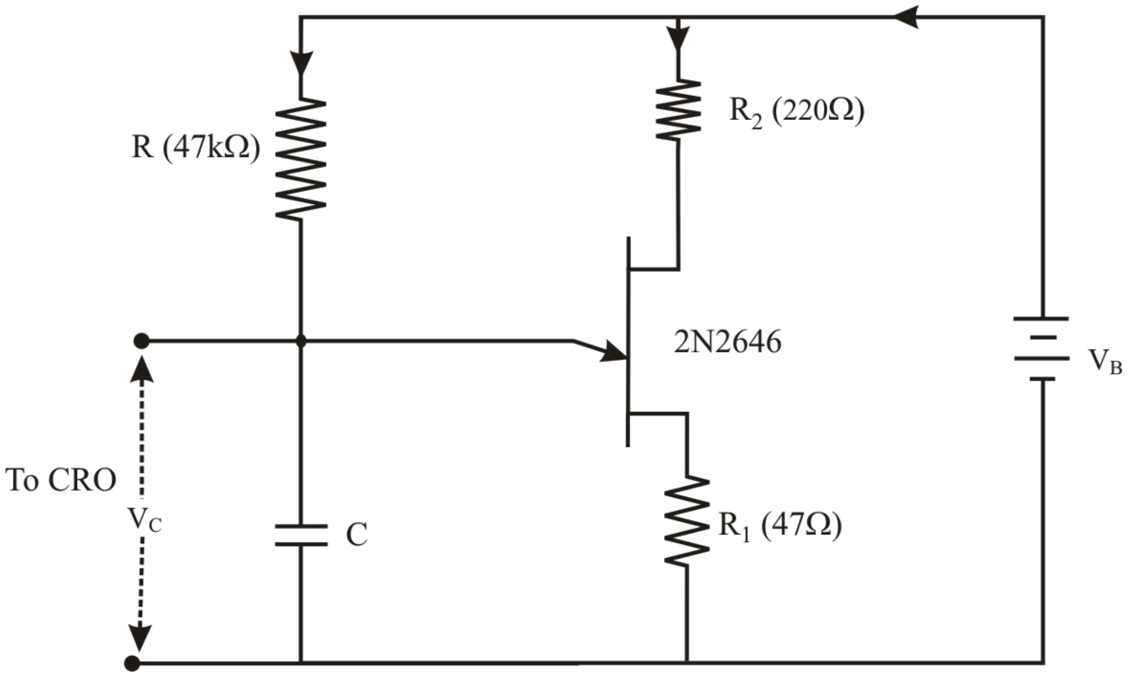


Fig.-1 Circuit for Saw tooth Wave Generator

23.4 Formula

Time Period of Saw tooth wave

$$T = 2.303RC\log_{10}\left(\frac{1}{1-\eta}\right)$$

Where R- resistance, C- capacitor in the circuit and η - standoff ratio of UJT given as,

$$\eta = \frac{Peak\,voltage}{Supply\,voltage} = \frac{V_\rho}{V_B}$$

23.5 Model Graph

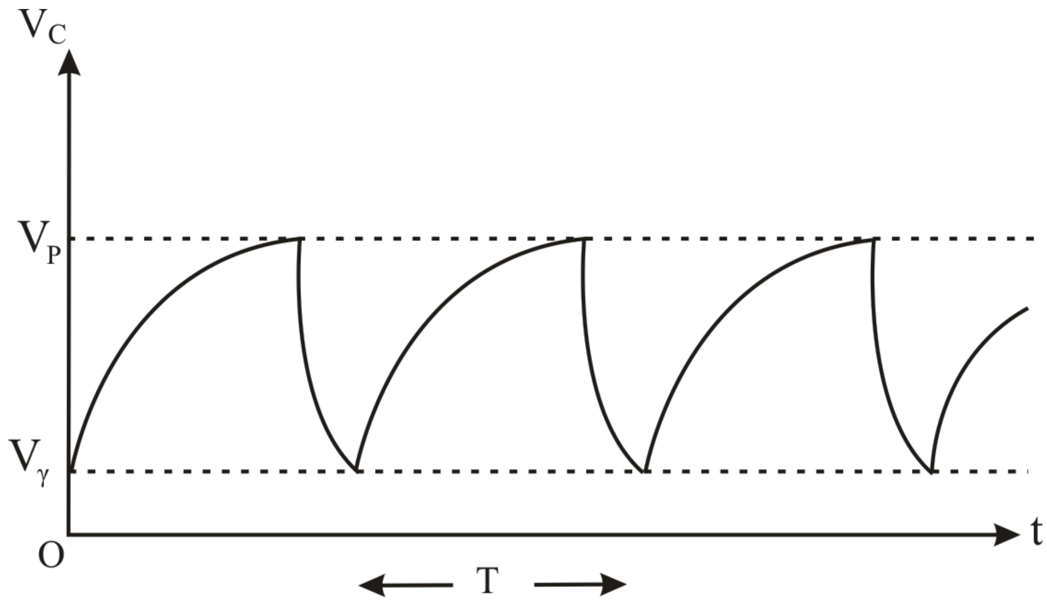


Fig.-1 Saw tooth Wave

23.6 Theory and description

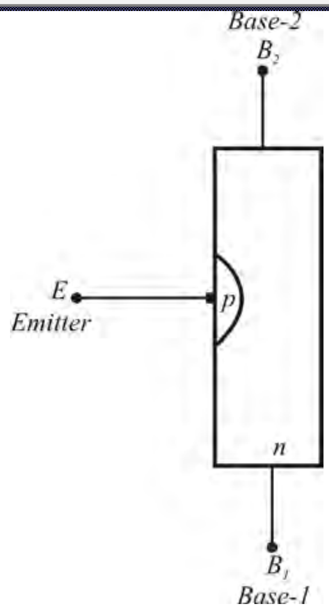


Fig.-3 Block Diagram

A uni-Junction Transistor (UJT) is consist of a long bar of n-type semiconductor that doped with a small part of p-type semi-conductor which form a p-n junction between them.

It has three terminal, emitter terminal E connected to the small p-type region and other two terminals B_1 and B_2 (known as Base) are connected with two ends of n-type bar.(fig.3)

Circuit symbol of UJT is shown in fig. 4

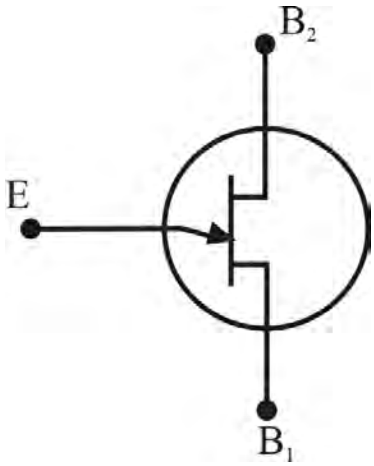


Fig.-4 Circuit Symbol

The basic operation of UJT can be understand using fig 5, n type bar of UJT is assumed to be consist of two ohmic resistances R_{B_1E} and R_{B_2E} between base B_1 and B_2. Voltage drop across E and B, terminal is (peak voltage)

$$V_p = V_B\left(\frac{R_{B_1E}}{R_{B_1E} + R_{B_2E}}\right) + V_r$$

Or $$V_p = \eta\ V_B + V_r$$

where $\eta = \dfrac{R_{B_1E}}{R_{B_1E} + R_{B_2E}}$ is known as standoff ratio of UJT and V_r is cut in voltage $(\sim 0.7V)$

Since

$$V_r << \eta V_B,$$

Hence $$V_p = \eta V_B \qquad \text{----- (1)}$$

Now if applied voltage across emitter and base $V_E < V_p$ then p-n junction is reverse biased and no significant current (except small package current) will flow in emitter circuit.

But when $V_E \geq V_p$ then p-n junction is forward biased and a large current with decreasing voltage will flow in emitter circuit, which shows negative resistance region.

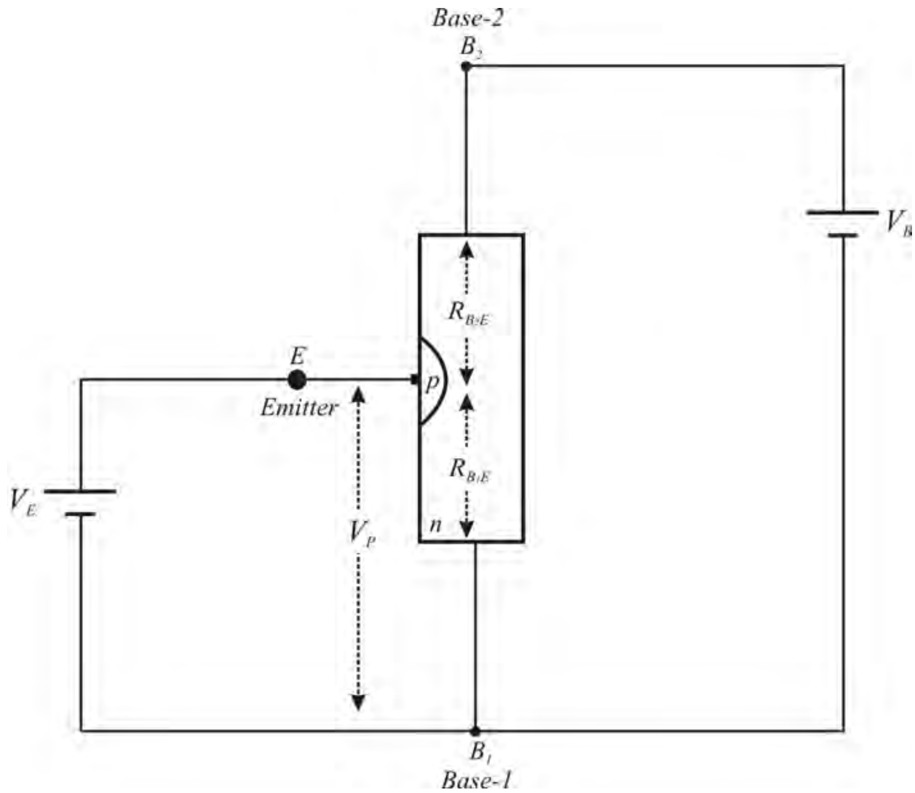


Fig.-5

UJT saw tooth wave generator is shown in fig. 1

If voltage on capacitor 'V_c' is less then V_p (i.e. reserve biased condition) then capacitor C charged through R towards V_B hence charging equation of capacitor is

$$V_C = V_B\left(1 - e^{-t/RC}\right) \qquad \text{----- (2)}$$

where RC is time constant.

When capacitor voltage V_C is equal to V_p, then p-n junction is forward biased hence a large current flows and capacitor will discharge suddenly.

Since $$V_C = V_p \quad at \; t = T$$

then from equation (2) $$V_p = V_B \left(1 - e^{-T/RC}\right)$$

from equation (1) $$\eta = 1 - e^{-T/RC}$$

or $$\eta - 1 = e^{-T/RC}$$

or $$\ln(\eta - 1) = \ln(e^{-T/RC})$$

or $$\ln(\eta - 1) = -T / RC$$

or $$T = -RC \ln(\eta - 1)$$

or $$T = RC \ln\left\{\frac{1}{1-\eta}\right\}$$

or $$T = 2.303 \;\; RC \;\; \log_{10}\left(\frac{1}{1-\eta}\right)$$

These cycles of charging and discharging of capacitor appears as saw tooth wave when observed using CRO.

23.7 Self Learning Exercise-I

Q.1 What is full form of UJT?

Q.2 How many part it consist of?

Q.3 How many p-n junction it has?

Q.4 Is UJT a three terminal device?

Q.5 Give name of three terminals of UJT

Q.6 Write time period for waves generated by UJT.

Q.7 What is a capacitor?

Q.8 What is a resistor used in circuits?

Q.9 What is the resistance of a connecting wire? Explain.

Q.10 Write charging equation of a capacitor.

23.8 Procedure

(i) Connect the circuit as shown in fig-1 with a capacitor of a fixed capacitance.

(ii) Observe the wave form across capacitor using CRO, trace them with proper scales.

(iii) Change the capacitor of different values and repeat step (ii)

(iv) Calculate time period theoretically and experimentally.

23.9 Observation

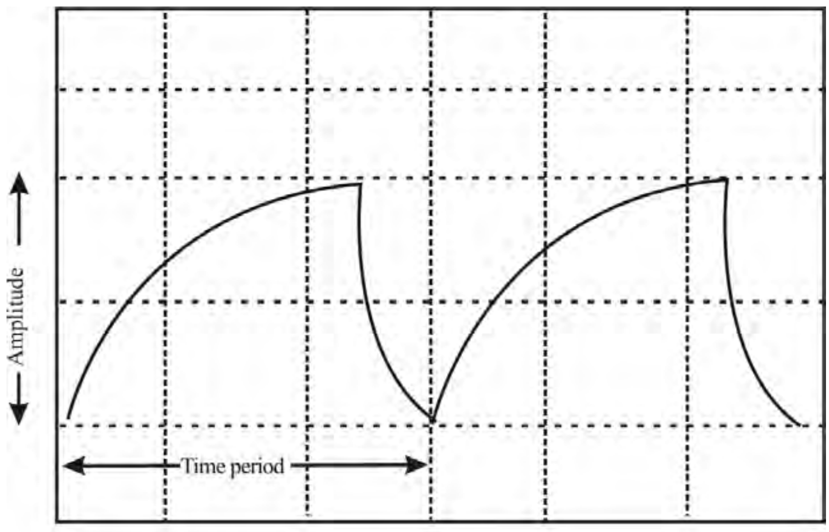
Observation should be taken on trace papers with proper scales of time and voltage axis of CRO.

From CRO,

Scale on X-axis --

Scale on Y-axis ---

Observation taken on trace paper



Time

CRO Screen

23.10 Graph

Plot the graph .

23.11 Calculations

Model calculation:Since time period

$$T = 2.303 \quad RC \quad \log_{10}\left(\frac{1}{1-\eta}\right)$$

Let $\eta = 0.5$ stand off ratio. (generally given in data sheet)

(i) When $R = 47k\Omega, C = 0.001\mu F$

$$T = 2.303\left(47\times10^{3}\right)\left(0.001\times10^{-6}\right)\log_{10}(2)$$
$$= 2.303(47)\left(10^{-6}\right)(0.3)$$
$$= 32.47\times10^{-6}$$
$$= 0.03247mS$$

(ii) When $R = 47k\Omega, \quad C = 0.01\mu F$

$$T = 2.303\left(47\times10^{3}\right)\left(0.01\times10^{-6}\right)\log_{10}(2)$$
$$= 32.47\times10^{-5}$$
$$= 0.3247mS$$

(iii) When $R = 47k\Omega, \quad C = 0.1\mu F$

$$T = 2.303 \ \left(47\times10^{3}\right)\left(0.1\times10^{-6}\right)\log_{10}(2)$$
$$= 32.47\times10^{-4}$$
$$= 3.247mS$$

23.12 Result

UJT as saw tooth wave generator is observed.

23.13 Discussion

23.14 Precautions and Sources of error

1. All connections should be tight
2. Do not apply voltage higher then rated values.
3. Three terminals of UJT should be identified carefully
4. Adjust scales of CRO properly.
5. Parallax error should be minimized.

23.15 Self Learning Exercise-II

Q.1 What is the name of small current flows in reverse biased condition ?

Q.2 What is the unit of capacitance of a capacitor?

Q.3 What is η stand for?

Q.4 What is time period?

Q.5 What is the relationship between frequency and time period?

Q.6 What is mean by device rating?

Q.7 What is parallax error?

Q.8 A UJT circuit contain resistance R=1 KΩ, capacitance C= 40 μF. Calculate time period and frequency for saw tooth wave generated by the UJT.(Stand off ratio of UJT – 0.75)

23.16 Glossary

Leakage Current : Small current flows due to minority charge carriers

Forward characteristics : Relationship between voltage and current in forward biased condition

Reverse characteristics : Relationship between voltage and current in reverse biased condition

Junction Breakdown : Sudden rise in current due to p-n junction breaks down and flows of large charge carriers through junction.

N-type semi-conductor **:** Semiconductor doped with Pentavalent impurity atoms heaving high concentration of electrons as majority charge carriers

P-type semi-conductor **:** Semi conductor's doped with trivalent impurity atoms having high concentrations of holes

Device ratings **:** Maximum tolerable voltages/ powers of device data provide by manufactures

***Electronic switch*:** An electronic device that has ON and OFF states only hence working as a switch

Connecting wire **:** wire used to connect different parts of the circuit

Negative resistance **:** When voltage decrease with increasing current, then resistance of such device is assumed to be negative, known as negative resistance

Cut in voltage **:** Specific forward voltage at which forward current will starts to flow through the UJT

Forward breakdown voltage **:** In open gate, forward applied voltage where avalanche breakdown occurred.

Reverse breakdown voltage **:** Reverse applied voltage where breakdown occurred

Semi conductor **:** Material that have band gap between conduction and valance band of the order of $|ev$

p-n junction **:** Region without mobile charge carriers between p-type and n-type semiconductor regions

Majority charge carrier **:** Charge carriers responsible for forward current

Minority charge carriers **:** Charge carriers responsible for leakage current

23.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise -I

Ans.1: Uni- Junction Transistor.

Ans.2: Two, one n-type bar, another p type doped region.

Ans.3: One.

Ans.4: Yes.

Ans.5: Emitter, Base one, Base Two.

Answers to Self Learning Exercise -II

Ans.1: Leakage current

Ans.2: Farad (micro Farad, Pico Farad)

Ans.3: Standoff ratio of UJT

Ans.4: Time required for completion of one full cycle

Ans.5: $Freequency = \frac{1}{TimePeriod}$

Ans.8: Given R=1 KΩ = 10^3 Ω

C= 40 μF = 40 x 10^{-6} F

So,

$$T = 2.303 \quad RC \quad \log_{10}\left(\frac{1}{1-\eta}\right)$$

or T=2.303x10^3 x40x10^{-6}xlog$_{10}${1/(1-0.75)}

or T=2.303x10^3 x40x10^{-6}xlog$_{10}${1/0.25}

or T=2.303x10^3 x40x10^{-6}xlog$_{10}${100/0.25}

or T=2.303x10^{3-6} x40xlog$_{10}${4}

or T=2.303x80x0.301x10^{-3}

or T=55.45x10^{-3}

or T= 55.45 mS

Since frequency of oscillation

f=1/T

So, f=1/(55.45x10^{-3})

or f=(1/55.45)x10^3

or f= 18 Hz

23.18 Viva Questions

Q.1 What do you mean by semi conductor?

Q.2 What is p-n junction?

Q.3 What are majority charge carriers?

Q.4 What are minority charge carriers?

Q.5 Why biasing of p-n junction is necessary?

Q.6 What is cut in voltage?

Q.7 What is UJT?

Q.8 Define standoff ratio?

Q.9 Define peak voltage?

Q.10 Define time constant for R-C circuit?

Q.11 What is the nature of charging curve of a capacitor?

Q.12 If $\ln x = 'y' \ \log_{10} x$, what is value of $'y'$?

Q.13 What do you mean by CRO?

Q.14 What is negative resistance?

Q.15 What is general shape of A.C. Signals?

Q.16 How UJT is differ from an ordinary diode?

Q.17 What is bias voltage?

Q.18 What do you mean by resistance?

Q.19 What do you mean by capacitance?

Q.20 What is unit of RC?

Q.21 It R is doubled, then what is the value of time period of Saw tooth wave?

Q.22 If C is doubled, then what is the value of time period Saw tooth wave?

Q.23 If R is halved, then what is the value of time period of saw tooth wave?

Q.24 If C is halved, then what is the value of time period of saw tooth wave?

Q.25 Write formula for frequency of Saw tooth wave.

23.19 Answers to Viva Questions

Ans.1: Material that have band gap between conduction and valance band of the order of 1 eV?

Ans.2: Region without mobile charge carriers between p-type and n-type semiconductor regions?

Ans.3: Charge carriers responsible for forward current.

Ans.4: Charge carriers responsible for leakage current.

Ans.5: Biasing of junction is necessary for flow of large current through it.

Ans.6: Minimum voltage required for flow of significant current through junction.

Ans.7: UJT is an electronic device that has one p-n junction.

Ans.8: The ratio of internal resistance between emitter to base-1 and base-2 is known as standoff ratio $\left[\eta = \frac{R_{B_1E}}{R_{B_1B_2}}\right]$

Ans.9: Minimum voltage required to for conducting p-n junction in UJT.

Ans.10: Product of value of resistance (R) and capacitance (C) is called time constant for R-C circuit.

Ans.11: Exponential

Ans.12: $y = 2.303$

Ans.13: Cathode Ray Oscilloscope used for display of waves.

Ans.14: When slope of curve which plotted between voltage and current is negative, then resistance in this case is called as negative resistance.

Ans.15: Sinusoidal

Ans.16: UJT has three leads whereas diode has two leads.

Ans.17: It is necessary DC voltage which is required for any active device to operate.

Ans.18: A resistance is the interption in flow of electrical current through a wire/conductor. It is defined as the ratio of voltage to current across wire.

Ans.19: The capacitance is the ratio of charge on plate to potential between the plates of the capacitor.

Ans.20: When R is in ohms and C is in farads then unit of RC is second.

Ans.21: Since $T = 2.303\,\mathrm{RC}\ \log_{10}\left(\frac{1}{1-\eta}\right)$

So if $R^1 = 2R$, then $T^1 = 2T$

i.e. time period is also doubled.

Ans.22: Since $T = 2.303\,\mathrm{RC}\ \log_{10}\left(\frac{1}{1-\eta}\right)$

So if $C^1 = 2C$, then $T^1 = 2T$

i.e. time period is doubled.

Ans.23: Since $T = 2.303\ \mathrm{RC}\ \log_{10}\left(\frac{1}{1-\eta}\right)$

So if $R^1 = \frac{R}{2}$, then $T^1 = \frac{T}{2}$

i.e. time period is halved.

Ans.24: Since $t = 2.303\ \mathrm{RC}\ \log_{10}\left(\frac{1}{1-\eta}\right)$

So if $C^1 = \frac{C}{2}$, then $T^1 = \frac{T}{2}$

i.e. time periods is halved.

Ans.25: Formula for frequencies $F = \dfrac{1}{2.303\ RC\ \log_{10}\left(\frac{1}{1-\eta}\right)}$

Where R-resistances,

C-capacitance and

η - stand off ratio

References and Suggested Readings

1. D. Chattopadhyay, P.C. Rakshit, B. Saha, N.N. Purkait, Foundations of Electronics (Second Edition), (New Age International Pub. Ltd.) Wiley Eastern Limited, 1988.

2. V.K. Mehta, principles of Electronics, S. Chand and company Ltd, 2001

UNIT-24
Triode by Bridge Method

Structure of the Unit

24.1 Aim

Determine the μ, g_m & r_p of a triode by bridge method and study the variation of these quantities with grid voltage.

24.2 Apparatus

Triode valve, two power supply, three standard resistance box, Low impedance head phone, Signal generator, DC voltmeter.

24.3 Diagram

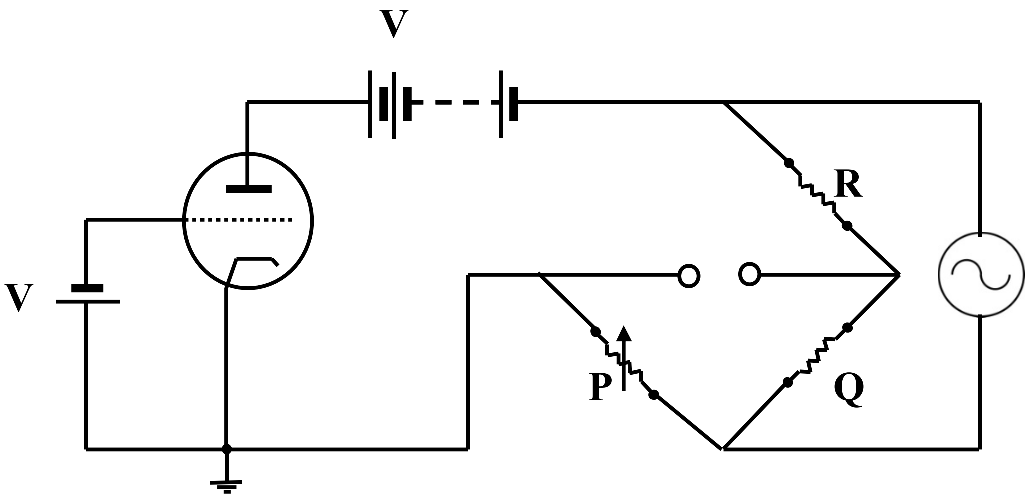


Figure 24.1: *Bridge method to determine the A.C. resistance of the triode [2].*

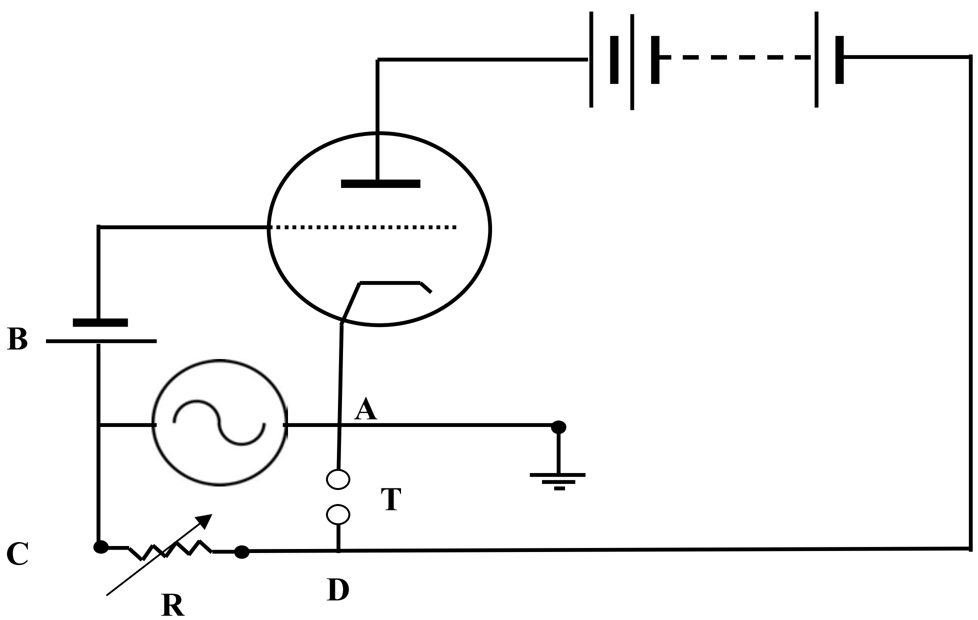


Figure 24.2: *Circuit diagram to determine the mutual conductance of the triode*

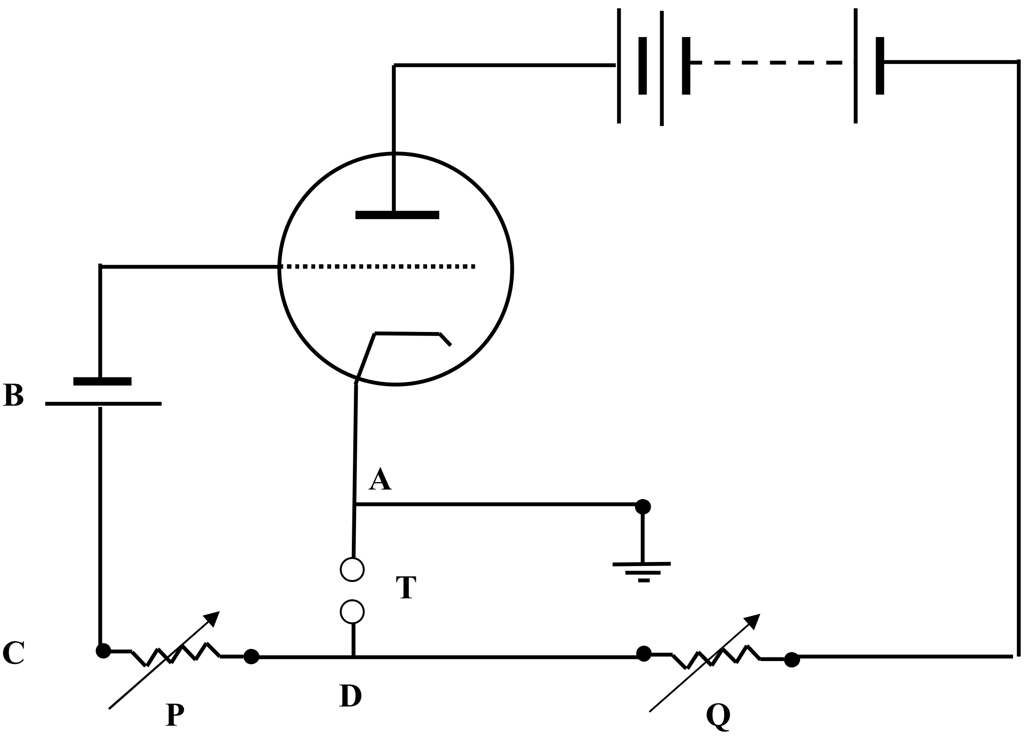


Figure 24.3: *Circuit diagram for the measurement of the amplification factor of the triode [2].*

24.4 Formula

(i) Plate ac (or dynamic) Resistance

$$r_p = \frac{\Delta V_p}{\Delta I_p} \text{ (at constant } V_G\text{)}$$

(in Ohm)

(ii) Mutual conductance (or grid-plate transconductance)

$$g_m = \frac{\Delta I_p}{\Delta V_G} \text{ (at constant } V_p\text{)}$$

(in Mho)

(iii) Amplification factor

$$\mu = -\frac{\Delta V_p}{\Delta V_G} \text{ (at constant } I_p\text{)}$$

Here:

V_p = Plate voltage,

I_p = Plate current, and V_G = Grid voltage.

24.5 Theory and description

(i) Thermionic Emission: Thermionic emission is the emission of electrons from a heated filament or substance. If a filament like tungsten is heated to high temperature, some electrons acquire sufficient energy and are able to break away from the surface of the material and get in free space. This process is accelerated if the filament is heated in a vacuum. The electrons emitted are also called thermions. The rate of emission of electrons depends on [5]:

- The material used for the filament.
- The temperature of the filament
- The surface area of the filament

(ii) Triode: A triode is an electronic amplification device, which consists of three electrodes: the filament or cathode, the grid, and the plate or anode. It was invented by De Forest in 1906, who inserted a third electrode, called the grid in the vacuum diode. He found that the current in the triode could be controlled by adjusting the grid potential with respect to the cathode. The grid acts as a valve that reduces current as it becomes more negative. A sufficient negative grid voltage will put the triode in its cutoff condition, where no current will flow [1, 2]. Maximum current will flow when the grid is at 0 volts.

(a) Construction: All triodes have a cathode heated by a filament, which releases electrons, and a flat metal plate electrode (anode) to which the electrons are attracted, with a grid consisting of a screen of wires between them to control the current. These are sealed inside a glass container from which the air has been removed to a high vacuum, about 10^{-9} atm. [6].

(b) Operation: In the triode, cathode emits electrons by a process called thermionic emission. The electrons are attracted to the positively-charged plate (anode), and flow through the spaces between the grid wires to it, creating a current through the tube from cathode to plate. The voltage on the grid controls the flow of electrons from the cathode to the plate.

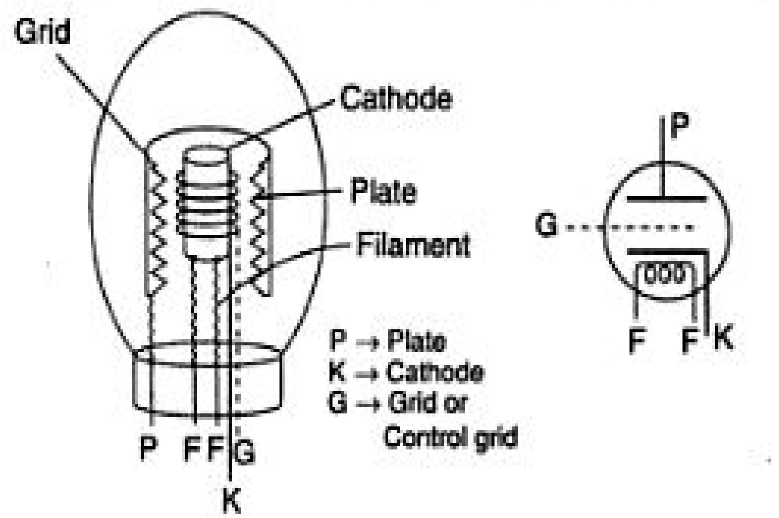


Figure 24.4: *Construction and symbol of triode [2].*

(iii) Triode characteristic Curve:

In a triode we are interested in three electrical quantities. These are the plate voltage V_p, the plate current I_p, and the grid voltage V_G. They are interrelated.

For every value of anode voltage there is now a whole range of possible anode currents, depending on the grid voltage. The static anode characteristics of a triode can therefore be drawn as a family of curves, each corresponding to a different grid voltage, so they are called the grid curves. We can plot the following curves:

- Between V_p and I_p for constant value of V_g. -- Static plate characteristics.
- Between V_G and I_p for constant values of V_p. – Mutual or transfer characteristics.
- Between V_G and V_P for constant values of I_p. -- Voltage transfer or current transfer characteristic.

(a) Static Plate Characteristics: The plate characteristics are graphs between plate current and plate voltage when the grid voltage is constant. The experimental circuit to determine these is given below:

Procedure: Set the grid voltage V_G at a convenient value (say, 0 volts). Now increase the plate voltage V_p from zero in a number of steps. At each step, note the plate current I_p. Change the grid voltage (say, -1 V) and repeat the measurements. The plot of these values gives a family of curves as shown in the figure. The curves are linear over much of their range. The operation of triode is limited in this linear part [1].

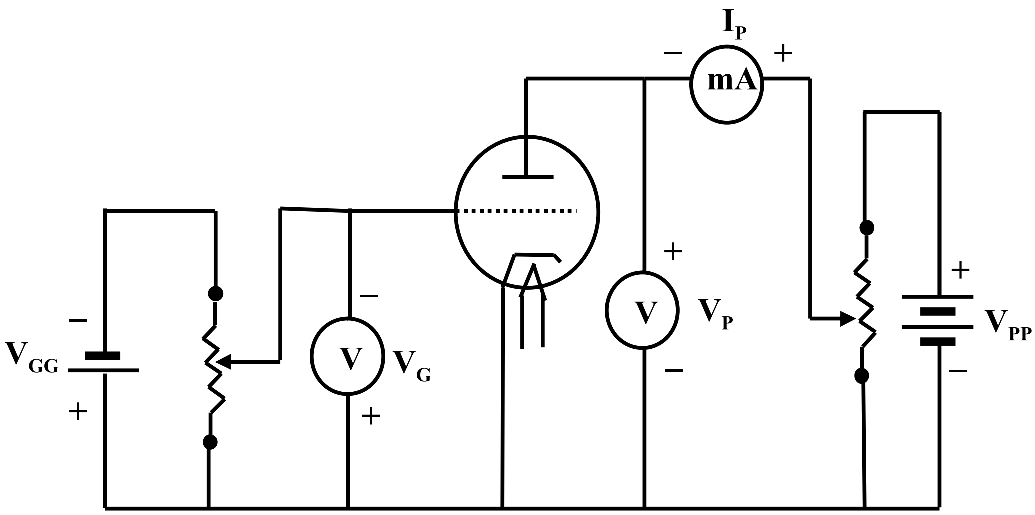


Figure 24. 5: *circuit Diagram for determination of the static characteristics of a triode [1].*

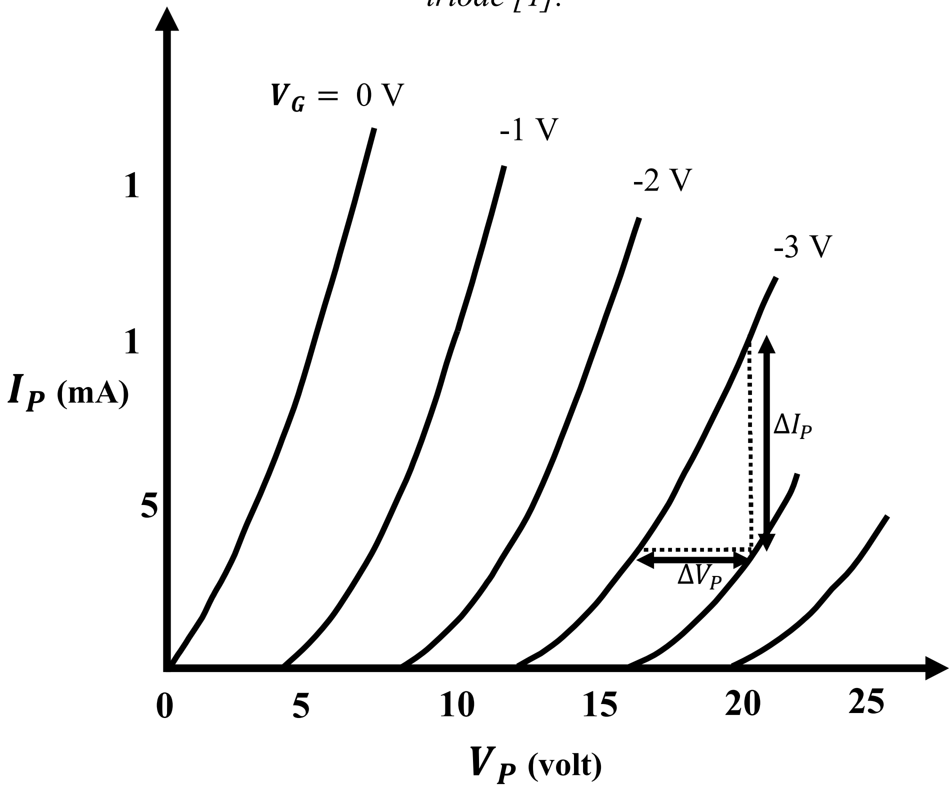


Figure 24.6: *Static plate characteristics of a triode [1].*

(b) Mutual characteristics: The mutual or transfer characteristics are plot of plate current against grid voltage for constant values of plate voltage. They can also be determined using the experimental circuit given above.

Procedure: First the plate voltage is set at a convenient value (say, 100 V). The grid voltage is then increased negatively, starting from zero, in steps. At each step the plate current is noted. The plate voltage is set to other different values and then the procedure is repeated. The plot of these curves gives a family of curves given in the figure. The point at which the curves meet the V_G axis gives the cut off voltage [1].

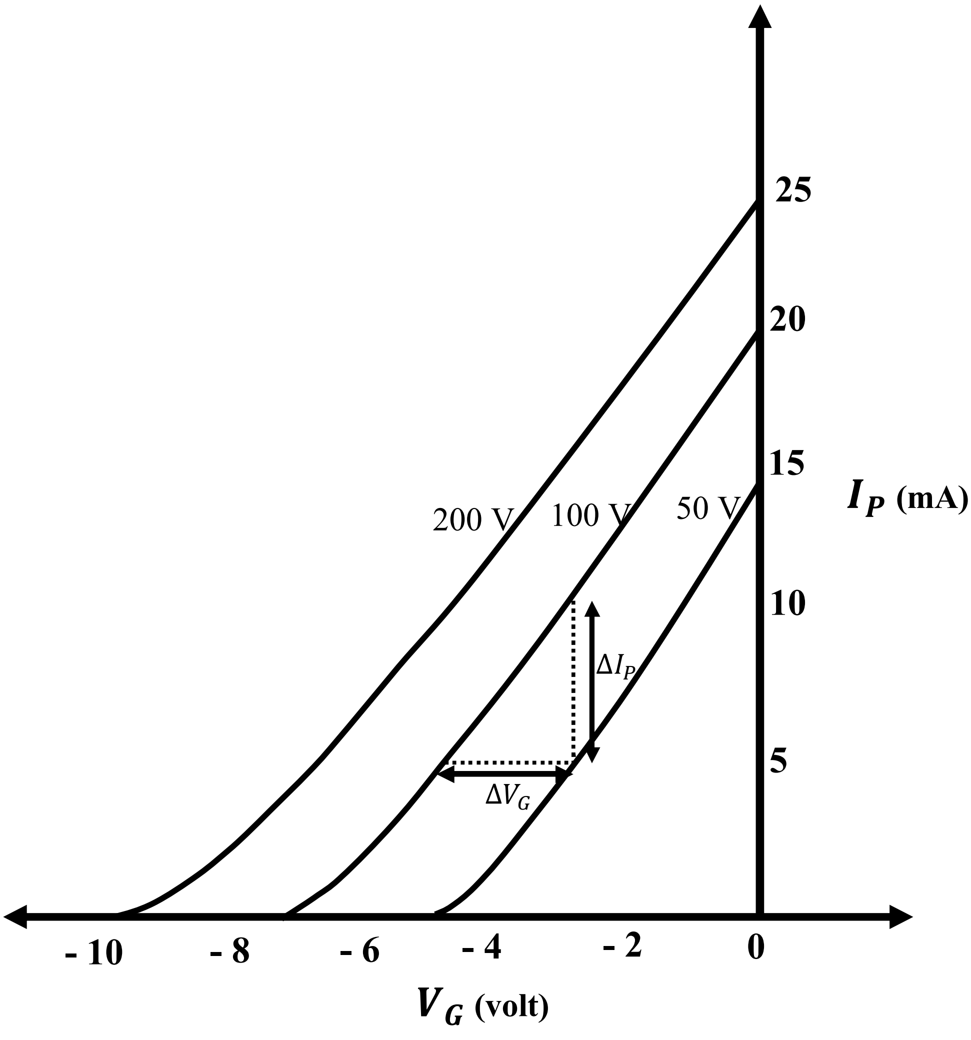


Figure 24.7: *Mutual characteristics of a triode [1].*

(iv) Triode parameters: A triode tube has three useful parameters:

(a)Plate ac (or dynamic) resistance, r_p

(b)Mutual conductance or transconductance, g_m

(c)Amplification factor, μ

a. Plate ac (or dynamic) Resistance (r_p)

It is the ratio small change in plate voltage v_p to the small change in plate current i_p when grid voltage V_G is kept constant. It is generally denoted by r_p.

$$r_p = \frac{\Delta V_p}{\Delta I_p} \qquad \text{(at constant } V_G\text{)}$$

The value of $\mathbf{r_p}$ can be obtained from the plate characteristic and its value remains constant along the linear portion of the characteristic.

b. Mutual Conductance (g_m)

The mutual conductance (or grid-plate transconductance) is the incremental change in the plate current divided by the incremental change in the grid voltage when plate voltage v_p is kept constant. It is denoted by g_m.

$$g_m = \frac{\Delta I_p}{\Delta V_G} \qquad \text{(at constant } V_p\text{)}$$

c. Amplification Factor (μ)

The maximum voltage amplification which a valve is capable of giving under ideal conditions is called the amplification factor. It is denoted by μ. The amplification factor is defined as the ratio of incremental in plate voltage V_p to the small change in the grid voltage V_G when plate current I_p is kept constant. Mathematically, μ is given by the relation

$$\mu = -\frac{\Delta V_p}{\Delta V_G} \qquad \text{(at constant } I_p\text{)}$$

As V_p and V_g are changed in opposite direction to keep i_p constant, therefore the ratio $\Delta V_p/\Delta V_G$ is negative sign appearing in the formula for μ to make this ratio positive.

The relation between μ, r_p and g_m:

$$\boldsymbol{\mu = g_m \times r_p}$$

24.6 Self Learning Exercise-I

Q.1 Describe how the grid controls the plate current.

Q.2 Define the triode parameters.

Q.3 What are plate characteristic of triode?

Q.4 The control grid in a triode is

(a) very near to plate
(b) very near to cathode
(c) midway between plate and cathode
(d) None of these

Q.5 A triode can be used as an amplifier because

(a) It has three terminals and any three-terminal device can act as an amplifier
(b) any small change in grid voltage can cause a large change in plate voltage
(c) high power source is available in plate circuit
(d) None of these

24.7 Procedure

Determination of valve constants: Bridge method

(i) Measurements of A.C. resistance:

1. Connect the valve in the unknown arm of the bridge as shown in *figure 24.1*.
2. Supply an alternating current to the bridge. Since the valve circuit contains no alternating source the bridge will measure its alternating impedance. The reactive component must be balanced out by connecting a variable resistance across P.
3. By varying P, an exact balance condition for a valve, which acts as a pure resistor, can be found out.
4. Make an experiment by keeping the voltage applied to the plate at a constant value V_p, and by measuring the valve resistance, S, for different values of V_G.
5. S is given by the usual bridge relation at balance: $S = \frac{PR}{Q}$
6. Plot a graph of S against $V_{G.}$ For different values of V_p, other graphs can be

obtained.

(ii) Measurements of mutual conductance

The mutual conductance (g_m) is the ratio of small change in the plate current (I_p) to the change in the grid voltage (V_G) producing it while the plate voltage (V_p) is constant. In the method described below the ratio of these two quantities are measured directly.

1. Connect the apparatus as shown in *figure 24.2*.
2. Introduce an alternating EMF into the grid circuit. The amplitude of the EMF must not be large enough to cause the grid potential to become positive.
3. Connect a variable resistance R in series with the anode circuit.
4. Connect one end of the headphone to the cathode and the other end to the variable resistance R. The impedance of the headphone should be smaller than that of the valve so that the plate potential difference is appreciably constant.
5. When the potential difference between A and D is zero, there is no sound in the headphone. In this case along ABCD, the EMF in AB is ΔV_G is equal to the potential difference in CD i.e. RI_p.
6. The mutual conductance is then given by: $\frac{\Delta I_p}{\Delta V_G} = \frac{1}{R}$
7. Draw a graph of the ratio for the grid potential ranging from -10 volts to 0 volt.

(iii) Measurements of amplification factor

1. Connect the valve including a fixed resistance P in the grid circuit and a variable resistance Q in the anode circuit as shown in *figure 24.3*.
2. Connect the headphone between the filament of the valve and a point between P and Q.
3. Introduce an alternating EMF across PQ. The part of this affecting the grid must not be so large that the grid potential difference becomes positive.
4. Vary Q and find the point where the headphone is silent. In this condition the EMF in the plate circuit which results from the change in the potential in the grid circuit owing to the alternating current in P is balanced by the alternating current in Q.
5. Thus: $\frac{\Delta V_p}{\Delta V_g} = \frac{Q}{P}$

The ratio measures the average amplification factor for this range of the variation under the condition at which the valve is working.

6. For different values of grid potential difference, ranging from -10 volts to 0 volt, a series of observations can be made.
7. A graph can then be plotted between the amplification factor and grid voltage.

24.8 Observation

Type number of the triode =

Information from the data book:

(a) Pin connections:

Connections for Pin number

Cathode

Plate

Control grid

Heater filament

(b) Maximum plate current rating = --------------- mA

(c) Maximum plate dissipation rating = ---------------Watt

Table 1: *A.C. resistance measurements:*

S. No.	**Grid voltage V_G (volts)**	**Resistance of the unknown arm S = PR/Q**				
		V_a = --V	V_a = --V	V_a = --V	V_a = --V	V_a = --V
1.						
2.						
3.						
4.						
5.						

Table 2: *Mutual conductance measurements:*

S. No.	Grid voltage V_G (volts)	Resistance R (when there is no sound in the headphone)	Mutual conductance 1/R
1. 2. 3. 4. 5.			

Table 3: *Amplification factor measurements:*

S. No.	Grid voltage V_G (volts)	Resistance Q (when there is no sound in the headphone)	Amplification factor Q/P
1. 2. 3. 4. 5.			

24.9 Graph

1. A.C. resistance measurement: A graph of S vs. V_G can be plotted for various values of plate voltage v_p.
2. Mutual conductance measurement: A graph of the ratio $\Delta i_p/\Delta V_G$ for various values of grid potential.
3. Amplification factor: A graph of amplification factor vs. grid voltage.

24.10 Calculations

24.11 Result

The triode parameters obtained from bridge method are as below:

Parameter	Value determined
r =	……………………………………………KΩ
g_m =	……………………………………………mS
μ =	……………………………………………

24.12 Discussion

24.13 Precautions and Sources of error

1. The applied EMF should not be large enough to make the grid positive.
2. Resistance should be varied until there is no sound in the headphone.
3. Specifications of the given valve about maximum plate voltage, heating voltage, and grid voltage prescribed by the makers must be strictly adhered to.
4. For study of A.C. resistance, the plate voltage must be constant for each set of observations.
5. The impedance of the headphone should be smaller than that of the valve.

24.14 Self learning Exercise-II

Q.1 For a triode, amplification factor usually ranges from

(a) 10 to 100

(b) 100 to 1000

(c) 1 to 10

(d) None of these

Q.2 Thermionic valves are evacuated because

(a) A lot of heat is produced if air is present

(b) Free path of electron is negligible in air

(c) Electrons cannot be produced in presence of air

(d) None of these

Q.3 An oxide coated filament is used in vacuum tubes because

(a) It increases the life time of the filament

(b) It can withstand higher voltage

(c) It protects the cathode from overheating.

(d) It emits electrons at lower temperature.

Q.4 Why we make grid bias negative?

Q.5 What is the unit of mutual conductance?

24.15 Glossary

Field emission: In field emission a large electric field is applied across the metal. The electrons then experience the forces due to the electric field and hence are emitted from the metal surface.

Thermionic Emission: Thermionic emission is the emission of electrons from a heated filament or substance

24.16 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: Please see the section theory and description.

Ans.2: Please see the section theory and description.

Ans.3: Please see the section theory and description.

Ans.4: (b) Very near to cathode.

Ans.5: (b) Any small change in the grid voltage can cause a large change in the plate voltage.

Answers to Self Learning Exercise-II

Ans.1: (a) 10 to 100

Ans.2: (b) Free path of electrons in air is negligible.

If a thermionic valve is not evacuated, the electrons will collide with the gas molecules and will lose their energy which will further cause in deflection from their path and ionization of filled gas.

Ans.3: (d) It emits electrons at lower temperature.

Due to oxide coating the work function gets lowered and it emits electrons at lower temperature.

Ans.4: There are two major reasons to make grid bias generally negative

- Current flowing in the grid circuit can distort the shape of the output voltage with respect to the shape of input voltage
- Positive grid voltage can cause excessive plate current and result in damage to the tube.

Ans.5: The unit of mutual conductance is 'Siemens'.

24.17 Viva Questions

Q.1 What is thermionic emission?

Q.2 What are the differences among Field emission, Photoelectric effect, and Thermionic emission?

Q.3 Explain the working of a triode.

Q.4 What are plate characteristics of a triode?

Q.5 Describe the function of the grid?

Q.6 Define the terms, plate resistance (r_p), amplification factor(μ) and mutual conductance(g_m)?

Q.7 What is the relation between r_p, μ and g_m?

Q.8 Why the grid is always kept at negative potential with respect to cathode?

Q.9 What is Anode characteristic curve?

Q.10 What does the amplification factor tells us?

Q.11 What is the unit of amplification factor?

Q.12 On what things the amplification factors depend?

Q.13 What is the typical range of the amplification factor value?

Q.14 What are the dynamic characteristics of the valve?

Q.15 What is the basic principle behind the working of triode as an amplifier?

24.18 Answers to Viva Questions

Ans.1: In thermionic emission the metal is heated. Due to this the kinetic energy of electron is increased and if the kinetic energy is sufficient enough to overcome the binding energy, then the electrons are free from columbic attraction and hence emitted by the metal surface. The classical example of thermionic emission is the emission of electrons from a hot cathode in a vacuum tube.

Ans.2: *Field emission:* In field emission a large electric field is applied across the metal. The electrons then experience the forces due to the electric field and hence are emitted from the metal surface.

Photoelectric emission: Emission of electrons from a metallic surface by the application of light is known as photoelectric effect. When a beam of light strikes the surface of metal, the energy contained in the light is absorbed by the electrons within the metal giving the electrons sufficiently free energy to be knocked out of, which is emitted from the surface of the metal.

Thermionic emission: Please see the answer to question 1.

Ans.3: When the cathode is heated, it emits electron. The electron first emitted repels other electrons which follow. So that a cloud of electron (space charge) is formed near the cathode. When the plate is given a positive potential with respect to cathode, electrons flow from cathode towards the plate passing through the grid. A plate current thus flows in the circuit. As the plate potential is increased, more electrons move towards it so that the space charges decreases and the plate current increases. When all the electrons emitted by the cathode are attracted by the plate, saturation is reached.

Ans.4: Please see the section theory and description.

Ans.5: Grid influences the space charge and controls the flow of current.

Ans.6: Please see the section theory and description.

Ans.7: Please see the section theory and description.

Ans.8: The negative charge on the control grid repels the electron in the vacuum. Because of this it controls the flow of current between the anode and cathode. When the grid is given a negative potential with respect to the cathode, it repels the electrons escaping from the cathode and increases the effect of space charge, at sufficiently negative grid potential the plate current falls to zero. This value of grid potential for which the plate current falls to zero is called cut off grid bias.

Ans.9: Please see the section theory and description.

Ans.10: The amplification factor tells us the relative effectiveness of the grid with respect to plate. If μ=20 then the grid is twenty times more effective than the plate.

Ans.11: Amplification factor is a pure number. It has no units.

Ans.12: The amplification factor depends on the geometry of the valve, the separation between the electrodes and their structures.

Ans.13: The amplification factor μ is always greater than unity. It's typical value lies in the range of 10 to 100.

Ans.14: The characteristic curves of valve in presence of the load (i.e. under practical condition) are called dynamic characteristics of the valve.

Ans.15: The amplifying action of the triode is based on the fact that a small change in grid voltage causes a large change in the plate current.

References and Suggested Readings

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2. Jacob Millman, and Christoph C. Halkias John D. Ryder, Electronic Devices and Circuits by Electronic Fundamentals and Applications
3. B. L.Worsnop and H. T. Flint, Advanced Practical Physics for Students
4. http://www.preservearticles.com/
5. http://en.wikipedia.org/wiki/Triode.

UNIT- 25
Cathode Follower Amplifier

Structure of the Unit

25.1 Aim

To study the frequency response of cathode follower amplifier.

25.2 Apparatus

Electronic board with Micro and Mili-Ammeter, A.C. Mili-Voltmeter, Audio Frequency Generator, Cathode Ray Oscilloscope (CRO).

25.3 Diagram

Circuit Diagrams :

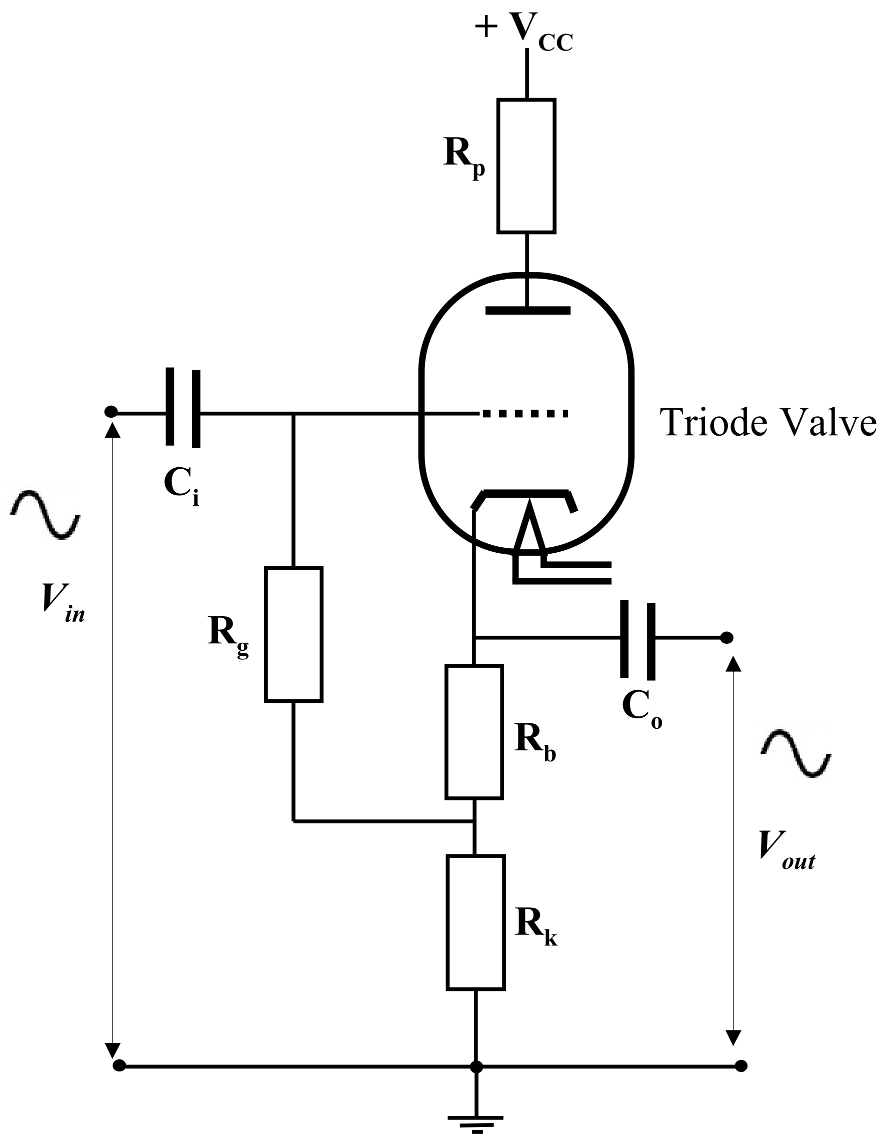

Fig. 1: *AC coupled Cathode Follower circuit diagram.*

25.4 Formula

Voltage Gain $G = \frac{V_{out}}{V_{in}}$

or $G = 20Log_{10}\frac{V_{out}}{V_{in}}$ dB

Here

V_{out} = Voltage at output terminals

V_{in} = Voltage at input terminals (Provided by frequency generator)

For the cathode follower circuit shown in figure 1

$$I_a = g_m(V_{in} - V_{out})$$

Gain $G = \frac{V_{out}}{V_{in}}$

$$G = \frac{g_m R_l}{1 + g_m R_l}$$

If $g_m R_l \gg 1$

$$G \cong 1$$

Here:

I_a = Cathode current

g_m = mutual conductance of the tube

$R_l = (R_b + R_k)$ Load resistance

25.5 Model Graph

The frequency response curve for a cathode follower circuit can be obtained as shown below:

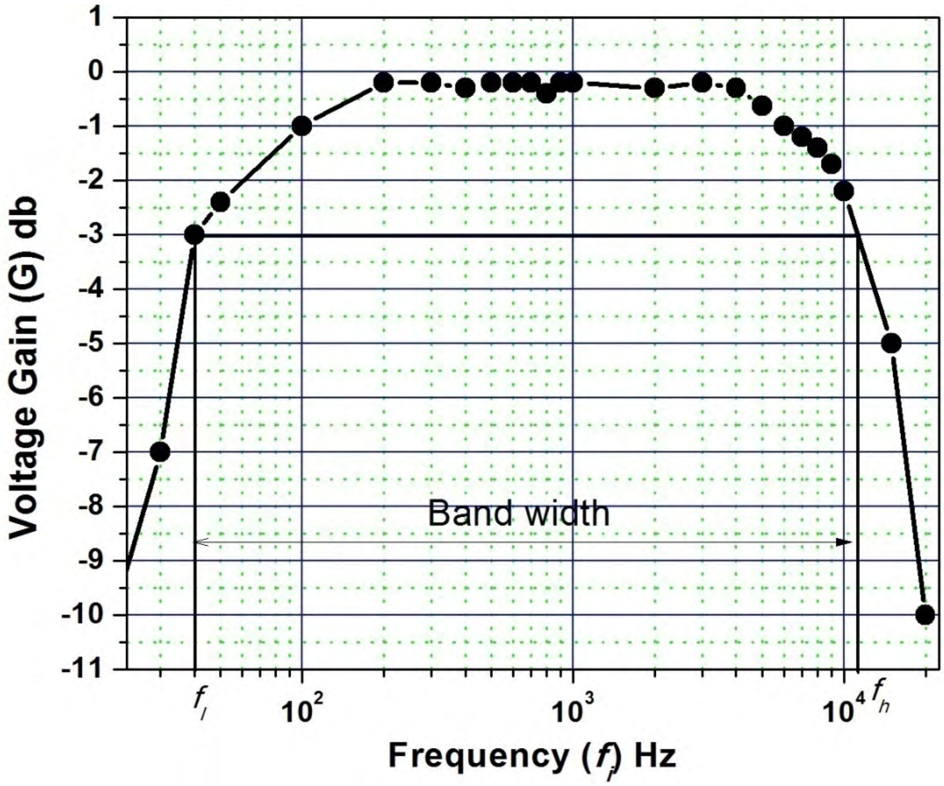

Fig. 2: *Model Frequency response curve for a cathode follower circuit.*

- This curve is plotted in between voltage gain (at Y Axis) and the frequency (at X axis) of input current.
- The voltage gain will be always in negative db, as the voltage gain is always less than unity for cathode follower.
- Lower cut off frequency and higher cut off frequency is determined by points lying at curve for which gain is falling by 3 db.
- Difference of higher cut off frequency and lower cut off frequency is known as band width.

25.6 Theory and Description

(i) Frequency response curves: frequency response of an electric or electronics circuit allows us to see exactly how the output gain or the phase changes with the frequency of input current. The frequency response analysis of a circuit or system is in actual a plot of circuit gain (which is mostly the voltage of output signal to its input signal) against a frequency scale over which the circuit or system is expected to operate this curve which represent behavior of circuit with changes in the input signal frequency.

The horizontal X-axis with frequency is usually plotted on a logarithmic scale while the vertical Y-axis is with the voltage gain in decibel units, is usually drawn as a linear scale. Since the gain from system (amplifier or circuit) can be either positive or negative, the Y-axis can therefore have both positive and negative values. Graphical representations of frequency response curves are called **Bode Plots**. These Bode plots are generally said to be a semi-logarithmic graphs because one scale (x-axis) is logarithmic and the other (y-axis) is linear as shown in figure 3 [4].

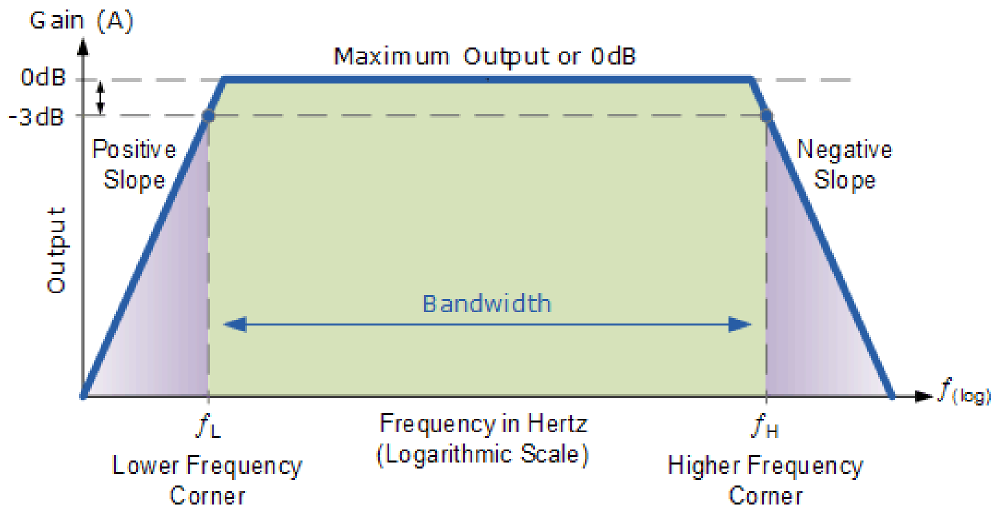

Fig. 3*: A model frequency response curve of any amplifier [4].*

Frequency points f_l and f_h relate to the lower cut-off frequency and the upper cut-off frequency points respectively were the circuits gain falls off by 3 db at high and low frequencies. These points on a frequency response curve are known commonly as the -3dB (decibel) points. The bandwidth is simply defined the difference between this lower and higher cut off frequency. The physical significance of the band width is that it represents almost constant output gain by circuit in the frequency range covered by band width. The output gains drops sharply beyond the band width. This fall or reduction in gain is known commonly as the roll-off region of the frequency response curve [4].

These -3 dB corner frequency points define the frequency at which the output gain is reduced to 70.71% of its maximum value. The amount of output power delivered to the load is effectively half at the cut-off frequency and as such the bandwidth (BW) of the frequency response curve can also be defined as the range of frequencies between these two half-power points [4].

(ii) The Triode value (tube):

Thermionic Emission: Thermionic emission is the emission of electrons from a heated filament or substance. If a filament like tungsten is heated to high temperature, some electrons acquire sufficient energy and are able to break away from the surface of the material and get in free space. This process is accelerated if the filament is heated in a vacuum. The electrons emitted are also called thermions. The rate of emission of electrons depends on [5]:

- The material used for the filament.
- The temperature of the filament
- The surface area of the filament

Triode: A triode is an electronic amplification device, which consists of three electrodes: the filament or cathode, the grid, and the plate or anode. It was invented by De Forest in 1906, who inserted a third electrode, called the grid in the vacuum diode. He found that the current in the triode could be controlled by adjusting the grid potential with respect to the cathode. The grid acts as a valve that reduces current as it becomes more negative. A sufficient negative grid voltage will put the triode in its cut-off condition, where no current will flow [1]. Maximum current will flow when the grid is at 0 volts.

a. Construction: All triodes have a cathode electrode heated by a filament, which releases electrons, and a flat metal plate electrode (anode) to which the electrons are attracted, with a grid consisting of a screen of wires between them to control the current. These are sealed inside a glass container from which the air has been removed to a high vacuum, about 10^{-9} atm. [6].

b. Operation: In the triode, cathode emits electrons by a process called thermionic emission. The electrons are attracted to the positively-charged plate (anode), and flow through the spaces between the grid wires to it, creating a current through the tube from cathode to plate. The voltage on the grid controls the flow of electrons from the cathode to the plate.

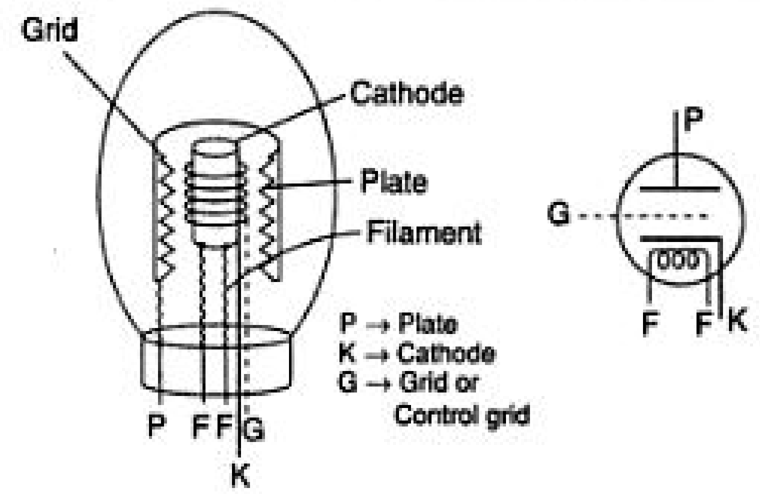

Fig. 4: *structure of a triode valve.*

(iii) Cathode Follower: The cathode follower is a negative feedback amplifier circuit, as shown in figure 1. The effective input voltage in this circuit $V_{in}-V_{out}$. The whole output is fed back to the input side giving very low non-linear distortion and a very linear response from very low to very high frequencies. It is reason that the gain of this amplifier is drastically decreased and always less than unity. The output voltage will be always less than the input voltage for cathode follower amplifier; so, the cathode follower can be regarded purely as a current amplifier. In this sense it has an advantage over transformer coupling, which cannot step up current without stepping down voltage.

The output signal is taken off at the cathode and also the output signal is in-the phase with the input signal means follows the input, it is reason this circuit named as cathode follower. This circuit is typically used for impedance matching, especially where a low impedance output is desired, since the output impedance of most valve circuits is rather high (equal to the value of the plate load resistor). For the cathode follower circuit the input impedance is very high while output impedance is very low while gain is around unity. Hence, it works as buffer circuit; convert high impedance (at output of an electronic circuit) to the desired low impedance. In solid state electronics, the common collector is equivalent circuit to the cathode follower and known as emitter follower, where the output taken at emitter and collector junction (forward biased junction hence low resistance at output) and input is given at base and collector junction (reverse biased junction hence high resistance at input).

Simply attaching a load having low impedance to a signal amplifier (having high output impedance) will cause the output level to be drastically reduced, so the cathode follower is a useful as a final stage of signal amplifier. As it is the final circuit of a signal amplifier circuits it become important to study the frequency response of this electronic circuit. The output impedance of the circuit of Figure 1 can be expected to be about $1/10^{th}$ the value of the cathode resistance R_k - but this is highly dependent on the valve itself, and its operating current.

Fig. 5: *Cathode follower circuit on printed board.*

The cathode follower possessing two types of electronic configuration: AC coupled and DC coupled. The AC-coupled cathode follower is normally used as a means of coupling high output impedance to the low input impedance with minimal loss of signal amplitude. The cathode follower has very low input capacitance and a very high input impedance so it will not load down the previous stage, and very low output impedance so very little signal is lost even when driving a fairly low input impedance.

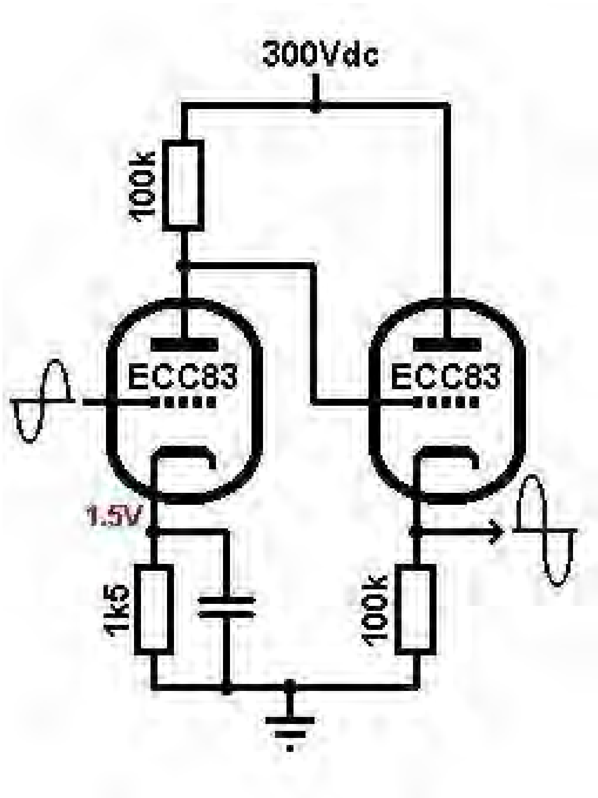

Fig. 6: *DC coupled Cathode Follower (Courtesy: http://valvewizard.co.uk/)*

"The cathode follower is an excellent buffer stage for driving a tone stack or effects loop, or any circuit which would otherwise present a heavy load to a "normal" stage. In addition, the DC-Coupled cathode follower can also be used to produce a unique compressive quality, and is to be found in most of the classic amplifier designs. The AC-coupled version is not so useful for this, since the input coupling cap prevents the flow of quiescent grid current. The AC-coupled version is therefore used as a tonally transparent stage, usually [7].

(iv) Description of cathode follower circuit shown in figure 1:

- Capacitor C_i is the input coupling capacitor. It is used to isolate the grid circuit from the DC voltage at the output of the previous circuit. This capacitor, in conjunction with the grid resistor, controls the frequency response of the stage.
- R_k is the cathode resistor, which is used to develop the cathode bias voltage. Since the grid resistor references the control grid to ground potential, this positive cathode voltage across R_k creates an effective negative grid voltage with respect to the cathode, providing the bias operating point for the tube. This resistor controls the headroom of the stage (output before clipping) and linearity, or distortion level, of the stage.
- R_p is the plate resistor to bias the plate electrode in the triode valve.
- R_g is the grid resistor. Voltage drop on this resistor is used to control the grid potential.
- R_b is biasing resistor. Voltage drop off on this resistor is fed back to input.
- $R_l = (R_b + R_k)$ is load resistance. Output voltage taken off on this combination of resistors.
- Capacitor C_o is the output coupling capacitor. It is used to isolate the plate DC voltage from the next stage it is driving. This capacitor, in conjunction with the input resistance of the following stage, also controls the frequency response of the stage.

(v) Electronic instruments used in circuit:

(a)Voltmeter: Refer unit 15

***(b)Ammeter:* Refer unit 25**

(c)Cathode Ray Oscilloscope (CRO): Refer Unit 15

(d)Function Generator: A function generator or frequency generator is an electronic device, which produce desired repetitive waveform. This device contain an electronic oscillator (An electronic oscillator is a circuit that produce a time varying signal such as sine wave, saw tooth wave, square wave etc.) which converts DC supply to a desired ac wave form with selected frequency. It is possible to vary the amplitude of the wave also.

Fig. 10: *Function generator.*

25.7 Self Learning Exercise-I

Q.1 What do you understand by a signal amplifier?

Q.2 What is the job of a cathode in triode valve?

Q.3 What is a cathode follower amplifier?

Q.4 What is importance of cathode follower in the electronic circuits?

Q.5 What is normal gain of a cathode follower amplifier?

25.8 Procedure

(i) Switch on A.C. generator and measure its output using A.C. Voltmeter.

(ii) Adjust the frequency of Generator at any value e.g. 100 Hz.

(iii) Adjust the output ac signal voltage of AC. Generator (around 1 volt or as per tube specifications). It should be constant throughout the experiment,

(iv) Now connect the A.C. generator at input terminals (V_{in}) of Cathode follower circuit and A.C. voltmeter at out terminal of the circuit across the load resistance. Output signal distortion can be check by CRO.

(v) Vary the frequency of generator from 20 Hz to 20 KHz.

(vi) Measure the output voltage through this voltmeter at different frequencies.

(vii) Repeat this experiment for different values of input voltages (V_{in}).

(viii) Calculate the voltage gain using given formula.

(ix) Plot the graph between $log f_i$ on X axis and voltage gain (in db) on Y axis.

(x) Determine lower cut off and higher cut off frequency.

25.9 Observation

Following observations should be made before experiment

- Least count of AC mili-voltmeter:.. volt
- Frequency range of AC signal Generator:................... Hz to .... Hz

Observation tables to study frequency response in cathode follower at different input voltage levels

(I) V_{in} = ...**Volt**

S. No.	Input frequency (f_i) Hz	Log (f_i)	Output Voltage (V_{out}) Volt	$G = V_{out}/V_{in}$	Gain in Decibel dB
1.	20				
2.	30				
3.	40				
4.	50				
5.	100				
6.	200				
7.	300				
8.	400				
9.	500				

10.	600				
11.	700				
12.	800				
13.	900				
14.	1,000				
15.	2,000				
16.	3,000				
17.	4,000				
18.	5,000				
19.	6,000				
20.	7,000				
21.	8,000				
22.	9,000				
23.	10,000				
24.	15,000				
25.	20,000				

(II) V_{in} = ...**Volt**

S. No.	**Input frequency (f_i) Hz**	**Log (f_i)**	**Output Voltage (V_{out}) Volt**	**G = V_{out}/V_{in}**	**Gain in Decibel dB**
1.	20				
2.	30				
3.	40				
4.	50				
5.	100				

6.	200				
7.	300				
8.	400				
9.	500				
10.	600				
11.	700				
12.	800				
13.	900				
14.	1,000				
15.	2,000				
16.	3,000				
17.	4,000				
18.	5,000				
19.	6,000				
20.	7,000				
21.	8,000				
22.	9,000				
23.	10,000				
24.	15,000				
25.	20,000				

25.10 Graph

Plot the graph between $log f_i$ on X axis and voltage gain (in db) on Y axis.

25.11 Calculations

Calculate voltage gain for each value of frequency

Voltage gain

$$G = 20Log_{10}\frac{V_{out}}{V_{in}}$$

Measure the output voltage at each frequency e.g.

V_{out} = 1.7 Volt (when input frequency f_i = 4 KHz)

V_{in} = 2 Volt

$$G = 20Log_{10}\frac{1.7}{2.0}$$

$$G = -1.41\ dB$$

(In the similar way gain can be calculate for each frequency)

25.12 Result

5. The frequency response of Cathode follower is shown in graph.
6. The lower cut of frequency for give cathode follower circuit is
   f_h = ...Hz.
7. The higher cut of frequency for give cathode follower circuit is
   f_h= ....Hz.
8. The band width of this circuit is
   W = $f_h - f_l$= .... Hz

25.13 Discussion

25.14 Precautions and Sources of error

6. The amplitude of input signal should be low and maintained constant for one set of measurements.
7. Connections should be tight.

8. Note the reading after warming up the valve.
9. Various Resistors used should be appropriate value.

25.15 Self Learning Exercise-II

Q.1 What do you understand by frequency response curve?

Q.2 What is importance of such curves?

Q.3 What is band width?

Q.4 How can we decide the lower cut off and higher cut off frequency points in frequency response curves?

Q.5 Why the lower and higher cut-off frequency points are taken on reduction of gain by 3 dB?

25.16 Glossary

Frequency: Frequency is the number of occurrences of a repeating event per unit time

Signal: In alternating current (AC, also ac), the flow of electric charge periodically reverses direction

Value: vacuum tubes such as diode, triode, tetrode, and pentode some time commonly known as by valves in electronics.

Phase: If a wave as having peaks and valleys with a zero-crossing between them, the phase of the wave is defined as the distance between the first zero-crossing and the point in space defined as the origin [6].

Impedance: measure of the total opposition that a circuit or a part of a circuit presents to electric current. Impedance includes both resistance and reactance. The resistance component arises from collisions of the current-carrying charged particles with the internal structure of the conductor. The reactance component is an additional opposition to the movement of electric charge that arises from the changing magnetic and electric fields in circuits carrying alternating current. Impedance reduces to resistance in circuits carrying steady direct current [8].

25.17 Answers to Self Learning Exercises

Answer to Self Learning Exercise-I

Ans.1: An electronic device which increase the magnitude of voltage, current or power of the input signal without changing in its frequency.

Ans.2: Cathode is source of electrons in a vacuum tube.

Ans.3: The cathode follower is a negative feedback amplifier circuit, for impedance matching.

Ans.4: This circuit is used for impedance matching. It is outer most circuit mostly in signal generator. With the help of this circuit signal generator give constant performance without getting effect by output load.

Ans.5: The gain of cathode follower amplifier always less than unity.

Answer to Self Learning Exercise -II

Ans.1: Frequency response curve for an electronic circuit is plot between output gains with frequency of input current.

Ans.2: It reflects how the behaviour of circuit changes with frequency of input signal. Using these curves a circuit can be design to work in particular frequency range with maximum performance.

Ans.3: The difference of higher frequency and lower cut-off frequency is known as bandwidth. In this region the performance of circuit and gain ideally does not vary with frequency.

Ans.4: The points which lie on curve at fall of gain with 3 db are pointed as lower and higher cut of frequencies.

Ans.5: For this falling in gain of 3 db, the power at output reduced exactly half from its maximum value. These points corresponding to half power points.

25.18 Viva Questions

Q.1 What are you doing ?

Q.2 How do you perform this experiment ?

Q.3 What is cathode follower amplifier ?

Q.4 Why is called cathode follower ?

Q.5 What are the names of electrodes in triode except cathode ?

Q.6 What is role of cathode in triode valve ?

Q.7 Where this circuit is used ?

Q.8 What is the voltage gain of cathode follower amplifier ?

Q.9 Which is equivalent circuit using transistor ?

Q.10 What are advantage using tubes instead of transistor ?

Q.11 How much change in phase at output with respect to input signal by this amplifier ?

Q.12 What are the Bode plots ?

Q.13 Why the impedance matching is required in electronic circuits ?

Q.14 How many types of cathode follower circuits are there as per coupling?

Q.15 Where the AC coupled cathode follower used ?

Q.16 What are the benefits of DC coupled cathode follower over AC coupling ?

Q.17 What do you understand by frequency response curves ?

Q.18 How can you determine band width ?

Q.19 Is large band width good or shorter for an amplifier ?

Q.20 Why it so ?

25.19 Answers to Viva Questions

Ans.1: Studying the frequency response of cathode amplifier.

Ans.2: (Procedure)

Ans.3: The cathode follower is a negative feedback amplifier circuit, for impedance matching.

Ans.4: The output signal is taken off at the cathode and also the output signal is in-the phase with the input signal means follows the input, it is reason this circuit named as cathode follower.

Ans.5: Grid and Plate.

Ans.6: As a source of electrons.

Ans.7: This circuit is typically used for impedance matching, especially where a low impedance output is desired, since the output impedance of most valve circuits is rather high.

Ans.8: Less than one always.

Ans.9: Emitter follower.

Ans.10: Tubes can handle high power as well as high frequencies.

Ans.11: No change in phase by cathode follower.

Ans.12: Graphical representations of frequency response curves are called **Bode Plots** and as such Bode plots are generally said to be a semi-logarithmic graphs because one scale (x-axis) is logarithmic and the other (y-axis) is linear.

Ans.13: Simply attaching a low impedance load to a signal amplifier (having high output impedance) will cause the output level to be drastically reduced.

Ans.14: Two types AC and DC coupled cathode follower.

Ans.15: The AC-coupled cathode follower is normally used as a means of coupling a high output impedance to a low input impedance with minimal "insertion loss".

Ans.16: The DC-Coupled cathode follower can used to produce a unique compressive quality, and is to be found in most of the classic amplifier designs. The AC-coupled version is not so useful for this, since the input coupling capacitor prevents the flow of quiescent grid current.

Ans.17: Frequency response curve for an electronic circuit is plot between output gains with frequency of input current.

Ans.18: The difference of higher and lower cut off frequencies.

Ans.19: Larger band width is better.

Ans.20: Long frequency range available with maximum gain and less and distortion.

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UNIT-26
e/m by Zeeman Effect

Structure of the Unit

26.1 Aim

The purpose of this experiment is to observe the splitting of spectral lines in a magnetic field and to determine charge to the mass ratio (e/m) of the specific elementary charge.

26.2 Apparatus

A cadmium lamp with holder, An electromagnet, A red filter, Lummer-Gehrcke plate, A polarization filter, A telescope.

26.3 Diagram

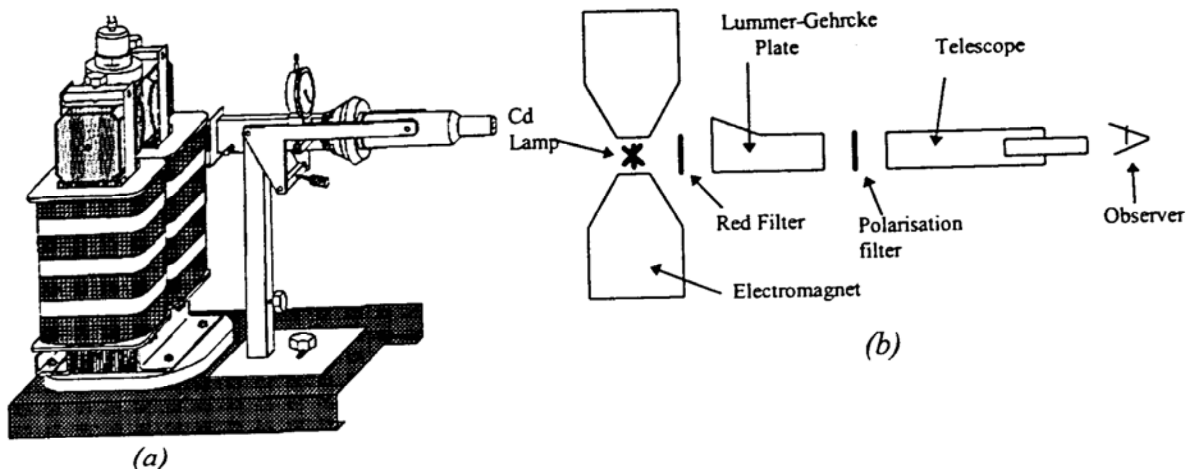

Figure: (a) Picture of the setup and (b) the schematic diagram of the Zeeman Effect experiment

26.4 Formula

Then e/m ratio can be calculated by using the following formula

$$e/m = \frac{4\pi c\delta a(\mu^2 - 1)^{\frac{1}{2}}}{2tB \ \Delta a(\mu^2 - 1)}$$

where

δa = distance of one of the split lines from the original position of the interference lines (without magnetic field)

Δa = distance between two adjacent interference lines without magnetic field

μ = refractive index of the Lummer-Gehrcke quartz glass = 1.4567

t = the thickness of the Lummer-Gehrcke plate = 4.04 mm

B = magnetic flux density (Teslas)

c= velocity of light

26.5 Model Graph

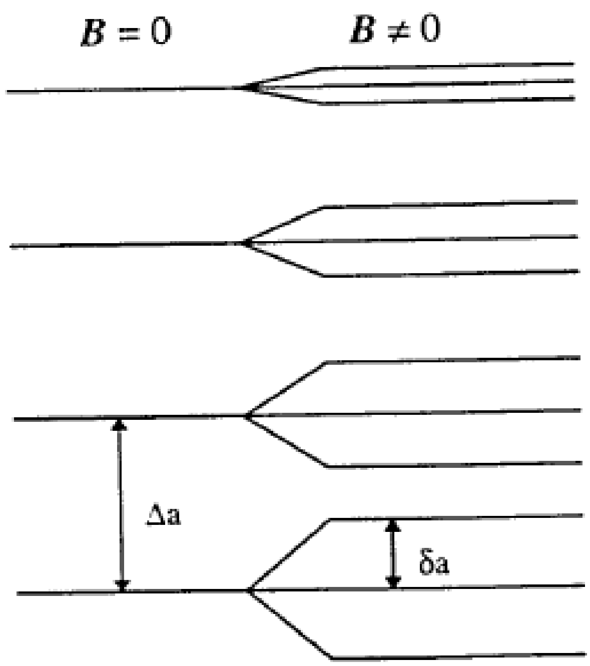

Figure: Interference lines observed in the presence of a magnetic field and without a magnetic field.

26.6 Theory and description

The experimental observation of the quantisation of orbital angular momentum in a uniform magnetic field is called the normal Zeeman effect. The total angular momentum J of an atom is given by

$$J = L + S$$

where L and S are the total orbital and spin angular momentum, respectively. For a single electron atom, the magnitude of L is associated with the orbital angular momentum quantum number l as

$$L = \sqrt{l(l + 1)}\hbar$$

Assume that, the spin angular momentum of the electron is neglected, or that the total net spins is zero. Thus, the total angular momentum is due to the orbital angular momentum of the atom. The magnetic moment of a single orbital electron of the atom is given by

$$\mu_l = -eL/2m$$

Here, μ_l is quantised since L is quantised. The magnetic potential energy of an atom in a magnetic field is; therefore,

$$V_m = -\mu_l . B$$

Then

$$V_m = \frac{e(L.B)}{2m}$$

$L.B = LB\cos\theta$ and $L\cos\theta = L_z$, the magnetic potential energy becomes

$$V_m = \left(\frac{e}{2m}\right) L_z B$$

since $L_z = m_l \hbar$, hence we get

$$V_m = m_l \left(\frac{e\hbar}{2m}\right) B$$

The quantity, $\frac{e\hbar}{2m}$ is called Bohr magneton, μ_b. Since L has $(2l + 1)$-fold degeneracy, i.e., for a given value of l, m_l can take $(2l + 1)$ different values: $-l, -(l-1), \ldots, -2, -1, 0, 1, 2, \ldots, (l-1), l,$ therefore, from above equation, V_m can also take $(2l + 1)$ values. Thus, a state that is in a quantum state l with energy E_0 when placed in a magnetic field, will split into $(2l + 1)$ substates with their energies given by the expression

$$E = E_0 + V_m = E_0 + m_l \mu_b B$$

When $l = 2, m_l = -2,-1,0,1,2$; E will take the following values

$$E = E_0 - 2\mu_b B$$

$$E = E_0 - \mu_b B$$

$$E = E_0$$

$$E = E_0 + \mu_b B$$

$$E = E_0 + 2\mu_b B$$

Here, it may be noted that the levels are equally spaced.

In actual practice one cannot observe the resulting new levels. The only way to get information about the levels is to observe the transitions between the levels. In the absence of the magnetic field, the photon energy $h\nu_0$ is

$$h\nu_0 = E_0^i - E_0^f$$

In a magnetic field, B, the expressions for the energies take the form

$$E^i = E_0^i + V_m^i + m^i l \mu_b B$$

$$E^f = E_0^f + V_m^f + m^f l \mu_b B$$

Therefore, the photon energy $h\nu$ of the transition between the initial and the final states in a magnetic field can be found by subtracting above equations as

$$\begin{aligned} h\nu &= E^i - E^f \\ &= E_0^i + V_m^i + + m^i l \mu_b B - (E_0^f + V_m^f \\ &+ m^f l \mu_b B) \end{aligned}$$

$$h\nu = E_0^i - E_0^f + \Delta m_l \mu_b B)$$

where $\Delta m_l = m_l^i - m_l^f$. Thus, the frequency of the transition is,

$$\nu = \nu 0 + \Delta m_l \frac{eB}{4\pi m}$$

Due to the selection rule, only those for which the change in magnetic quantum number is 0 or ±1, i.e.,

$$\Delta m_l = 0, \pm 1$$

Combining Equations will show that the original transition frequency ν_0 is replaced by these transitions with the following frequencies,

$$\nu = \nu_0 - \frac{eB}{4\pi m}$$

$$\nu = \nu 0$$

$$\nu = \nu_0 + \frac{eB}{4\pi m}$$

As an example, the normal Zeeman effect for the transition between the 5^1D2 state and 5^1P1 state of Cadmium (Cd) is shown in Figure

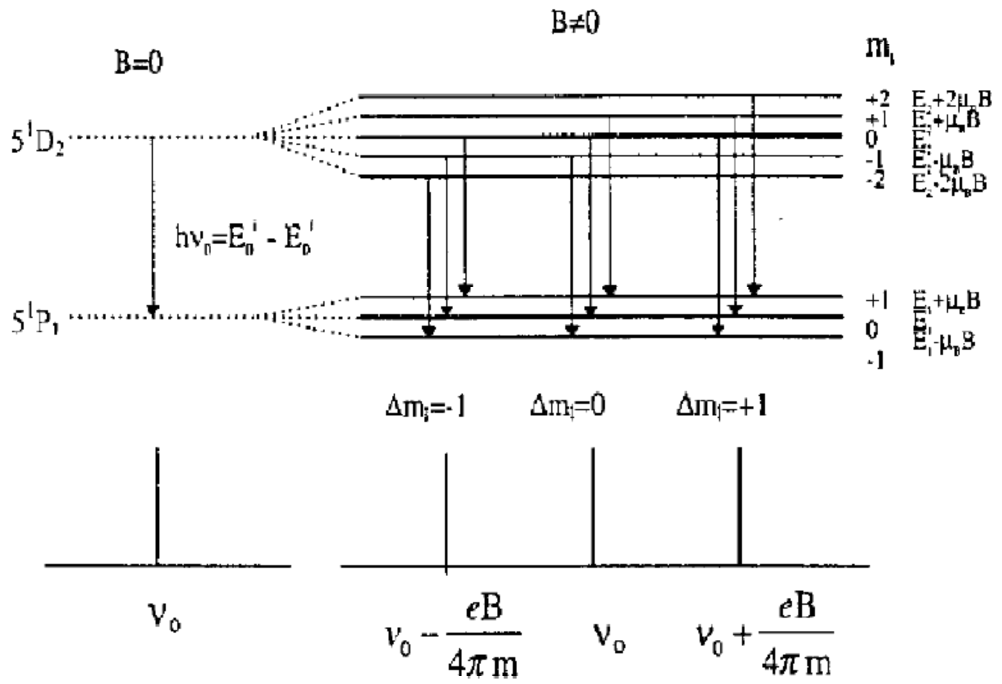

Figure 11.1: Normal Zeeman Effect of a transition between 5^1D2 and 5^1P1

This specific transition gives off a red line with a wavelength of 6438 °A, which is studied in our experiment. Here, it may be seen from the term symbol of these states that the total spin angular momentum is zero in both levels; therefore, the total angular momentum is purely orbital angular momentum so the transition is studied under the normal Zeeman effect.

Although there are nine transitions, the magnitudes of the separations are such that show up as only three groups of different frequencies, each containing a group of three lines. However, a doublet or a triplet is observed when the transitions are viewed in the direction parallel or perpendicular to the direction of the magnetic field.

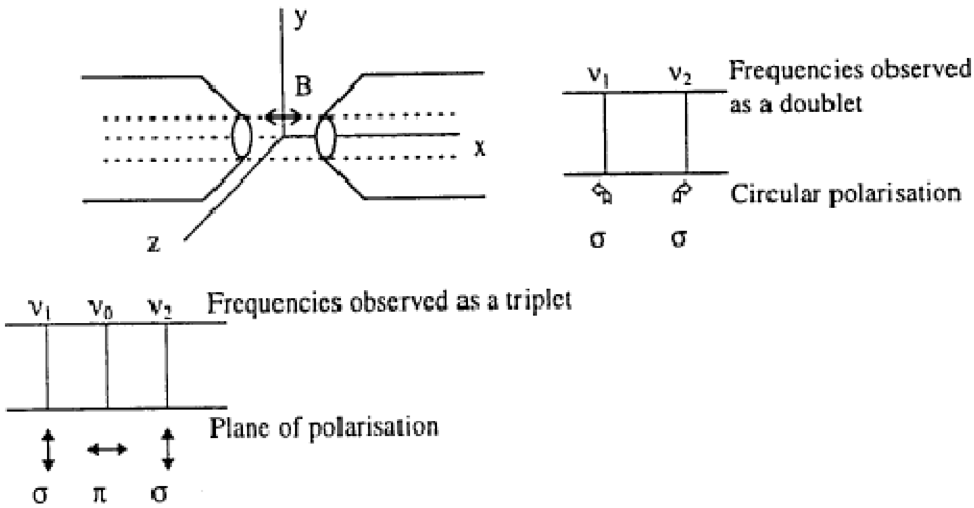

Figure: Zeeman splitting of a line when viewed in the direction parallel and perpendicular to the direction of an external magnetic field

In above figure the abbreviation π represents the vibrations parallel to the external field B and σ represents the vibrations perpendicular to.

The nature of the light emitted in these transitions are described as follows:

1. When the Zeeman Effect is viewed along the direction of the magnetic field B, only a doublet is observed. The view can be obtained through a hole in the pole face and only the two components corresponding to right-handed and left-handed circularly polarised light are observed. The right-handed components correspond to the transition $\Delta m_l = 1$ while the left-handed component correspond to $\Delta m_l = -1$. This is because, light is transverse in nature and the electromagnetic field must always have the field vectors *E* and *B* normal to the direction of propagation, thus, according to Figure no light will be emitted in the x-direction parallel to the direction of field *B*.

2. When the Zeeman Effect is viewed in a direction perpendicular to the direction of the magnetic field B, a triplet is observed. Meanwhile, the other two lines are observed as plane polarised light with the electric field vector, which is perpendicular to the direction of the external magnetic field. Meanwhile, the third line is observed in the same position of field free line and it is the same as plane polarised light with the electric field vector of the electromagnetic wave parallel to the direction of the external magnetic field.

The polarisation values may be summarised as follows:

Viewed $\perp$ to B

$\Delta m_l = \pm 1$; plane polarised $\perp$ to B; σ components

$\Delta m_l = 0$; plane polarised $\perp$ to B; π components

Viewed $\parallel$ to B

$\Delta m_l = \pm 1$; circularly polarised ; σ components

$\Delta m_l = 0$; forbidden ; π components

The two σ-components, or outer secondaries of the triplet, or the two lines of the doublets are shifted as

$$\Delta \nu = \pm \mu_b B = \pm \frac{eB}{4\pi m}$$

$\Delta \nu$ may be derived from the resolution of the Lummer-Gehrcke plate as follows:

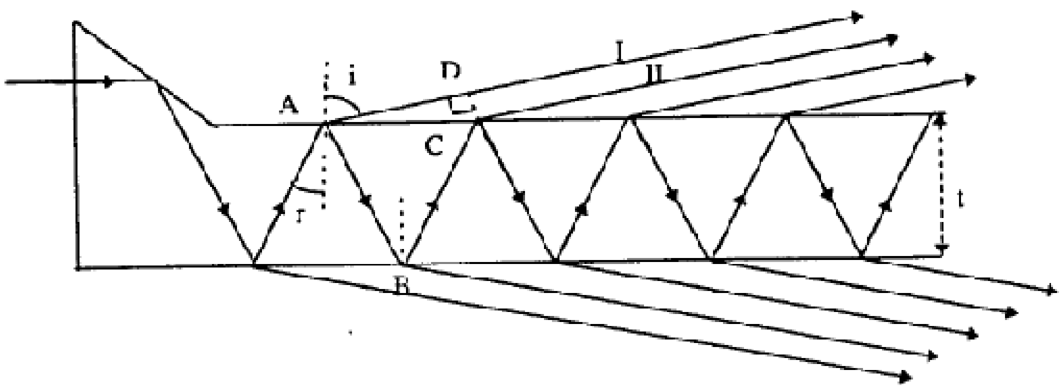

Figure: Lummer-Gehrcke Plate

The Lummer-Gehrcke plate is a kind of interferometer with high resolving power $(R = \frac{\lambda}{\Delta\lambda} \approx 50000)$. As a result, $\Delta\lambda = 0.01\,\mathring{A}$ is measurable from the visible displacement of a spectral line. It is a parallel plate of quartz, provided with the prism, at the left end as shown in Figure, for introducing the light. The incident light is multiply reflected internally at the plate surfaces, since both sides of the plate are coated with a thin metal providing high reflectivity, but low transmission for light. At each reflection, which is arranged to be near the critical angle, a beam emerges from the surface of the plate at an almost grazing angle. If the emerging beams are collected by a lens, the fringes are formed at the lens focus. For constructive interference, the path difference between beam I and II in the figure will be

$$\delta = \mu(AB + BC) - AD = n\lambda$$
$$AB = BC; AD = AC\,cos(90 - i)$$
$$AC = 2AB\,sin\,r$$
$$AD = 2AB\,sin\,r\,sin\,i$$

and

$$t = AB\,cos\,r$$

where μ: refractive index of the quartz plate (=1.457)

n: order number

t : thickness of the plate (= 4.04mm)

i : emerging angle of the beam

r: the reflection angle

Since the relationship between i and r is:

$$sin\,i = \mu\,sin\,r$$

Then

$$2\mu AB - 2AB\,sin\,r\,sin\,i = n\lambda$$
$$2AB(\mu - \mu \sin^2 r) = n\lambda$$
$$2AB\mu(\cos^2 r) = n\lambda$$

$$2\mu t\, cos\, r \;=\; n\lambda$$

or in terms of the angle i:

$$2t(\mu^2 - \sin^2 i)^{\frac{1}{2}} \;=\; n\lambda$$

taking the square of both sides:

$$4t^2(\mu^2 - \sin^2 i) \;=\; n^2\lambda^2$$

Differentiating with respect to i gives:

$$\delta i \;=\; -\frac{n\lambda^2}{2t^2\, sin\, 2i}\delta n$$

The change in angle $\Delta\, i$ corresponding to a change of a single order ($\delta n \;=\; 1$) is given by

$$\Delta\, i \;=\; -n\lambda^2/(2t^2\, sin\, 2i) = -\frac{\lambda(\mu^2 - \sin^2 i)^{\frac{1}{2}}}{2t\, sin\, 2i}$$

since $\sin^2 i \approx\; 1$, then,

$$\Delta\, i = -\frac{\lambda(\mu^2 \;-\; 1)^{\frac{1}{2}}}{t\, sin\, 2i}$$

The dispersion, which is the rate of i with λ is found by differentiating with respect to λ;

$$n^2\lambda \;=\; 2t^2\left[2\mu\left(\frac{d\mu}{d\lambda}\right) - sin\, 2i\frac{di}{d\lambda}\right]$$

$$\frac{di}{d\lambda} = \frac{\left(2\lambda\mu\left(\frac{d\mu}{d\lambda}\right) \;-\; 2(\mu^2 - \sin^2 i)\right)}{\lambda\, sin\, 2i}$$

The wavelength range between the successive orders is given by equating δi with $\Delta\, i$ which gives $\Delta\, \lambda$, the order separation as:

$$\Delta \lambda = \frac{\lambda^2(\mu^2 - 1)^{\frac{1}{2}}}{2t\left[\mu^2 - 1 - \frac{\mu\lambda d\mu}{d\lambda}\right]}$$

by ignoring the $\frac{d\mu}{d\lambda}$, Equation becomes;

$$\Delta \lambda = \frac{\lambda^2(\mu^2 - 1)^{\frac{1}{2}}}{2t(\mu^2 - 1)}$$

In the experiment, spectral lines are always observed in several interference levels at the same time. Instead of one line, a whole system of lines appears.

From the above figure, the distance, δa, of the splitted line from the original interference line is proportional to Δa, which is the distance between two interference lines without a magnetic field. If the change in λ is small (e.g. $\Delta \lambda$), the corresponding displacement also decreases:

$$\Delta \lambda = \frac{\delta a}{\Delta a} \Delta \lambda$$

$$\Delta \lambda = \frac{\delta a}{\Delta a} \frac{\lambda^2(\mu^2 - 1)^{\frac{1}{2}}}{2t(\mu^2 - 1)}$$

Since $\nu = \frac{c}{\lambda}$, the frequency shift is $\Delta \nu = \pm \frac{c}{\lambda^2} \Delta \lambda$, the frequency shift turns out to be

$$\Delta \nu = \frac{c\delta a}{\Delta a} \frac{(\mu^2 - 1)^{\frac{1}{2}}}{(\mu^2 - 1)}$$

Then e/m value can be found as

$$e/m = \frac{4\pi c\delta a(\mu^2 - 1)^{\frac{1}{2}}}{2tB \Delta a(\mu^2 - 1)}$$

The picture and schematic diagram of the Zeeman Effect experiment are shown in Figure. The necessary magnetic field is produced by an electromagnet. For the fixed spacing, between the poles of the magnet, the magnetic field strengths associated with the currents passing through the coils are given in Table.

Table 1: Magnetic field strength associated with a current passing through the coils.

I [A]	B [T]
2.0	0.050
4.0	0.105
6.0	0.163
8.0	0.223
10.0	0.279
12.0	0.336
14.0	0.421
16.0	0.445
18.0	0.494

Although the information given above describes the Zeeman splitting in both cases; when viewed parallel and perpendicular to the direction of the external magnetic field, you will carry out the experiment only by viewing the spectra in the direction perpendicular to the direction of the magnetic field.

26.7 Self Learning Exercise-I

Q.1 For a single electron atom, relate orbital angular momentum with the orbital angular momentum quantum number.

Q.2 Define the magnetic moment of a single orbital electron of the atom.

Q.3 When $l = 2$ calculate m_l and E.

Q.4 Show the normal Zeeman effect for the transition between the 5^1D2 state and 5^1P1 state of Cadmium (Cd).

26.8 Procedure

1. Turn the cadmium lamp on. It takes about 5 minutes for the red Cd line to be emitted sufficiently strong.
2. For pre-adjustment, remove the eyepiece. Turn the whole optical system in a clock-wise direction until a fine straight pattern can be seen on the Lummer-Gehrcke plate.
3. Adjust the height of the Lummer-Gehrcke plate until it reaches the Cd lamp (screw it to the base of the column of the optical system).
4. Set the position of the incident window relative to the Lummer-Gehrcke plate; to do this, loosen the covering cup, either lift or lower these and then tighten the knurled screws again.
5. Repeat steps 3 to 5 until a bright and clear line pattern is seen above and underneath the Lummer-Gehrcke plate.
6. Put the eyepiece back in, and by moving the eyepiece, focus the spectral line. Focus the graticule by turning the eyepiece.
7. To measure the line pattern and the distance, Δa, between them in the absence of a magnetic field, align the cross-hair in the eyepiece with any line you have chosen, and set the micrometer clockwork to an initial reference value.
8. By turning the screw at the bottom of the clockwork, align the cross in the eyepiece with the next line and then read the distance, Δa, on the micrometer clockwork relative to the reference value. Record it in Table 9. Turn on the power supply unit of the electromagnet in order to observe the Zeeman splitting of the lines. Set the coil current of the magnet to 19A, observe the splitting of the lines into three components.

Note: Before turning on the magnetic current, make sure that the poles of the magnet are firmly screwed on. When the magnetic field is turned on, do not come close to the spectral lamp with ferromagnetic objects. Treat the Lummer-Gehrcke plate very carefully so that the smooth surface of 1/100 mm remains intact.

10. Take one triplet that you can see clearly, but do not lose the position of that triplet until the experiment is over.

Note: Since the lines generated by the Lummer-Gehrcke plate are not equidistant, Δa and δa distances must be measured on the same triplet.

11. Align the cross in the eyepiece with the lower component of the triplet, and then take the micrometer clockwork position as a reference point. By going through the upper component of the triplet, measure the distance $2\delta a$ relative to the reference point obtained before. Record it in Table.

12. Repeat step 11 to obtain, $2\delta a$, for lower values of the current passing through the coil. And then, tabulate your data on Table. It will be necessary to observe the decrease in splitting, since the magnetic field strength is directly proportional to the splitting distance, or in other words, to the frequency shift.

13. Plot a graph of $\delta a / \Delta a$ vs B. Obtain the worst and best lines for this plot, and then find the slopes of these lines. Show your calculations and report them in the space below Table..

14. Using the slope of the best line, find the ratio. Show your calculations and record them in the space below Table.

15. Using the slopes of the worst and best lines, calculate your error in (*e/m*). Record it in the space below Table.

16. Obtain the magnetic field strengths from the corresponding currents passing through the magnet by interpolating the data in above Table. Record them in Table 6.2.

26.9 Observation

Spacing between successive lines without a magnetic field $\Delta\ a = \cdots$mm.

I(A)	B(T)	$2\delta a\ [\times 10^{-2}]$ mm	$\delta a\ [\times 10^{-2}]$mm	$\delta a/\Delta\ a$
19				
18				
17				
16				
15				
14				
13				
12				
11				
10				

I Magnet Current

B Magnetic Field Strength

$2\delta a$ Spacing between 2 extreme lines

δa Spacing between successive lines

26.10 Graph

Plot the required graph on graph paper.

26.11 Calculations

26.12 Result

The slope of the best line = ...

The slope of the worst line =...................

$\frac{e}{m} =$……………………………………………………………………………………
………………………………………………………………………

$\Delta\left(\frac{e}{m}\right)$=……………………………………………………………………………
…………………………………………………………………………………

26.13 Discussion

26.14 Precautions and Sources of error

1. The Zeeman effect apparatus should be used in a dry room with a good ventilation. Cover the unit when it is not in use.

2. Lubricate the surface of the optical bench periodically to prevent it from rusting.
3. When not in use, the fabry perreault at tom should be stored in a sealed container with a desiccators.
4. Do not touch any optical part with your hand. To remove dust or dirt, use a photographic lens brush, or blow the dust off with canned air.
5. To prolong the life to the mercury lamp avoid turning it on and off frequently.
6. When applying the magnetic field, increase the current slowly and avoid leaving the potentiometer in the zone marked by yellow dots for long period. This will avoid excessive heat generation in the magnetic coils.

26.15 Self Learning Exercise-II

Q.1 Why one should increase the current slowly.

Q.2 How to calculate error?

Q.3 In the measurement of the splitting, you measured $2\delta a$ instead of δa. Does this make any sense?

Q.4 Define Zeeman Effect.

26.16 Glossary

Electromagnet - A magnet consisting of a solenoid with an iron core, which has a magnetic field only during the time of current flow through the solenoid.

Magnet - A magnet is an object made of certain materials which create a magnetic field. Every magnet has at least one north pole and one south pole. By convention, we say that the magnetic field lines leave the North end of a magnet and enter the South end of a magnet. This is an example of a magnetic dipole ("di" means two, thus two poles).

Magnetic Field (B) - When specified on our site, the surface field or magnetic field refers to the strength in Gauss. For axially magnetized discs and cylinders, it is specified on the surface of the magnet, along the center axis of magnetization. For blocks, it is specified on the surface of the magnet, also along the center axis of magnetization. For rings, you may see two values. $B_{y,center}$ specifies the vertical component of the magnetic field in the air at the center of the ring. $B_{y,ring}$ specifies the vertical component of the magnetic field on the surface of the magnet, mid-way between the inner and outer diameters.

Magnetic quantum number. *(m_ℓ)*

Quantum number that labels different orbitals within a subshell. m_l can take on values from $-\ell$ to $+\ell$. The number of orbitals in a subshell is the same as the number of possible m_ℓ values.

Orbital.

A wavefunction that describes what an electron with a given energy is doing inside an atom or molecule.

26.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: $L = \sqrt{l(l+1)}\hbar$

Ans.2: $\mu_l = -eL/2m$

Ans.3: $m_l = -2, -1, 0, 1, 2$

$$E = E_0 - 2\mu_b B$$
$$E = E_0 - \mu_b B$$
$$E = E_0$$
$$E = E_0 + \mu_b B$$
$$E = E_0 + 2\mu_b B$$

Answers to Self Learning Exercise-II

Ans.1: This will avoid excessive heat generation in the magnetic coils.

Ans.2: The slopes of the worst and best lines, calculate error in (*e/m*).

Ans.3: Yes

Ans.4: The Zeeman effect is the name for the splitting of atomic energy levels or spectral lines due to the action of an external magnetic field. The effect was first predicted by H. A. Lorenz in 1895 as part of his classic theory of the electron, and experimentally confirmed some years later by P. Zeeman.

26.18 Viva Questions

Q.1 Explain the Zeeman effect and its experimental detection. What means "transverse" and "longitudinal" Zeeman effect?

Q.2 Why does the magnetic field force the magnetic dipoles of atoms to precess, instead of aligning with the field?

Q.3 Why do completely filled shells not contribute to the total angular momentum J of an atom?

Q.4 Why is a normal Zeeman effect expected for the transition 3^1D_2 to 2^1P_1.

Q.5 What implies setting Land´e factor to unity?

Q.6 Why is the general Zeeman effect also known as"anomalous" Zeeman effect?

Q.7 What is the most important general statement you can make after performing this experiment?

Q.8 What do you think the spectral lines may correspond to?

Q.9 In the measurement of the splitting, you measured $2\delta a$ instead of δa. Does this make any sense? Why?

References and Suggested Readings

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4. A.C. Melissinos & J. Napolitano, Experiments in Modern Physics, 2nd Edition, pp 172 – 177.
5. E. Hecht, Optics.
6. Jenkins and White, Fundamentals of Optics

UNIT-27
Logic Gates

Structure of the Unit

27.1 Aim

(I) Verify the truth tables of AND, OR, NOT, NAND, NOR gates.

(II) Implement the logic functions AND, OR, NOT using NAND gates only

(III) Implement the logic functions AND, OR, NOT using NOR gates only

(IV) Verify the truth table of X-OR gate. Construct and realize the logic function X-OR using different logic combinations of AND, OR, NOT gates.

27.2 Apparatus

Power supply, Digital logic trainer, connecting leads.[or Breadboard, DC supply 5 volt, connecting wires, LED, IC 7400 (NAND), IC 7402 (NOR) IC 7404 (NOT), IC 7408 (AND), IC 7432 (OR), IC 7486 (XOR), as required]

27.3 Diagram

Logic Diagrams :

Part (I)(a)

AND Gate:

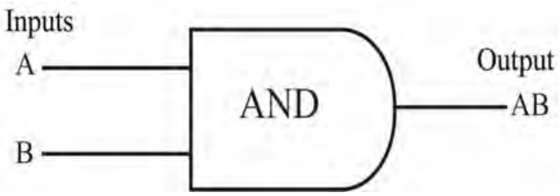


Figure 27.1

AND Gate:

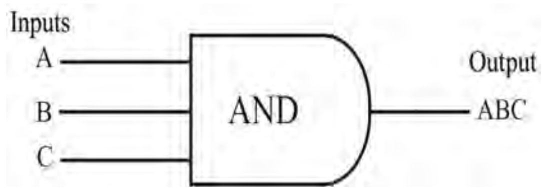


Figure 27.2

AND Gate:

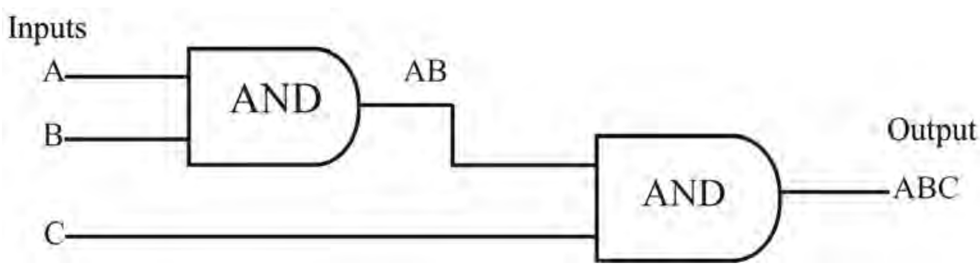


Figure 27.3

(b) OR Gate:

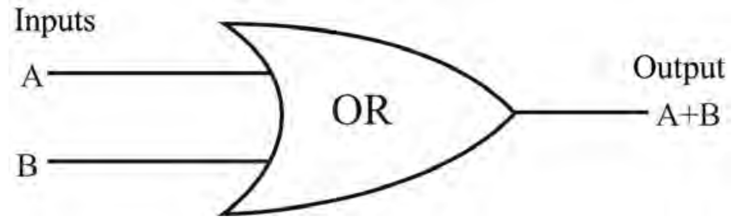


Figure 27.4

OR Gate:

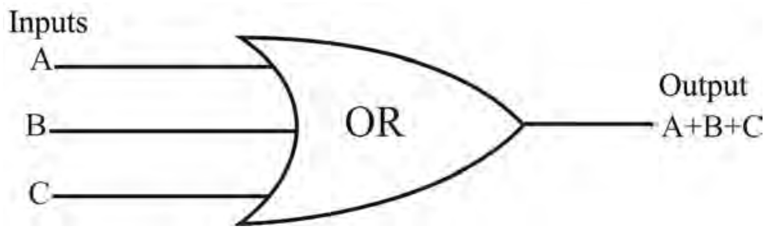


Figure 27.5

OR Gate:

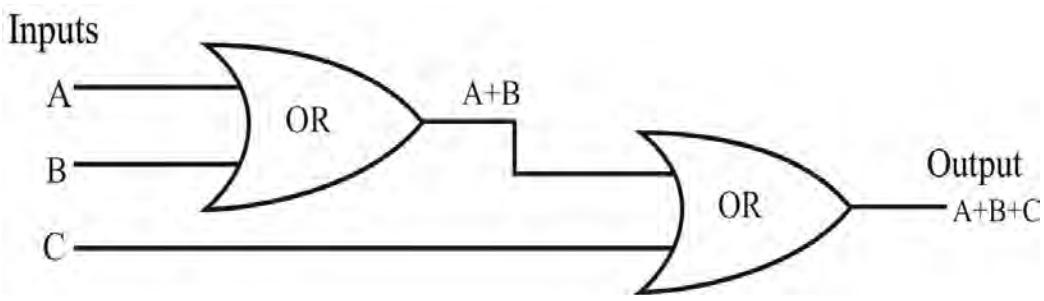


Figure 27.6

(c)NOT Gate

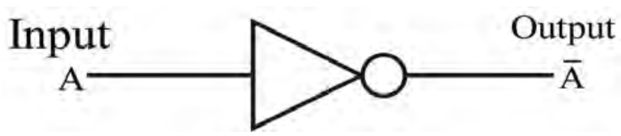


Figure 27.7

(d)NAND Gate

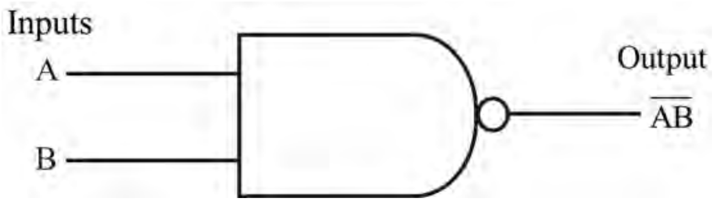


Figure 27.8

(e)NOR Gate

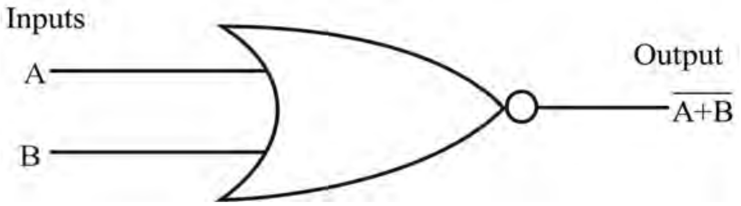


Figure 27.9

Part (II)

(a) Implementation of AND Gate using NAND Gates

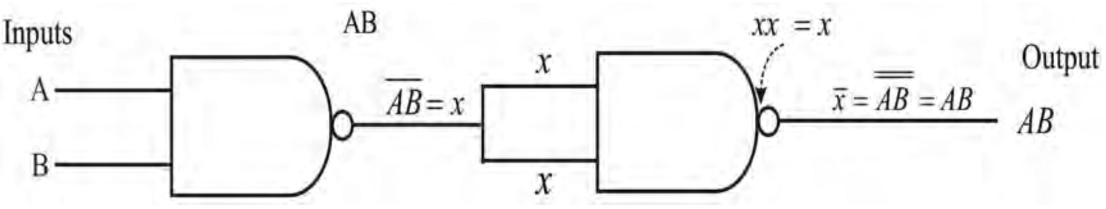


Figure 27.10

(b) Implementation of OR Gate using NAND Gates

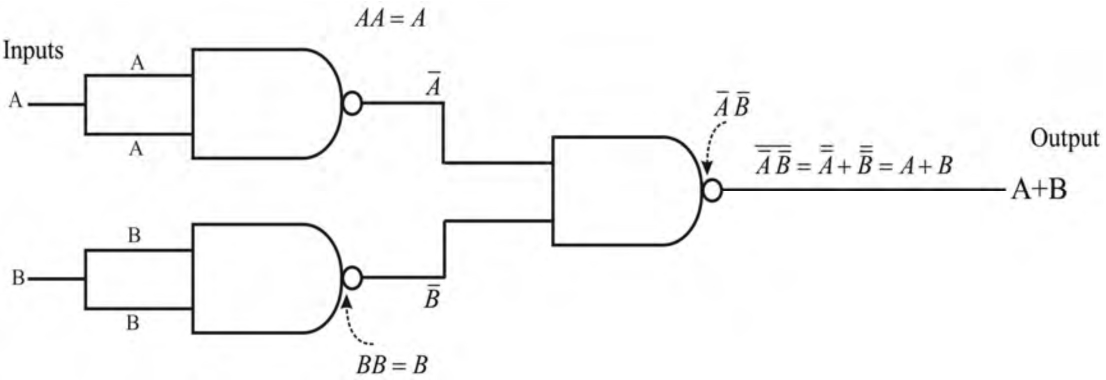


Figure 27.11

(c) Implementation of NOT Gate using NAND Gate

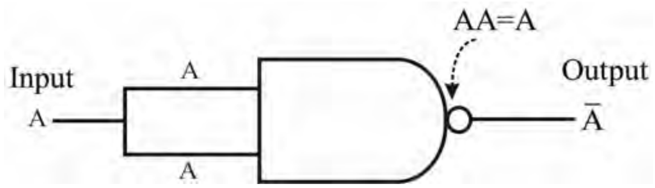


Figure 27.12

Part (III)

(a) Implementation of AND Gate using NOR Gates

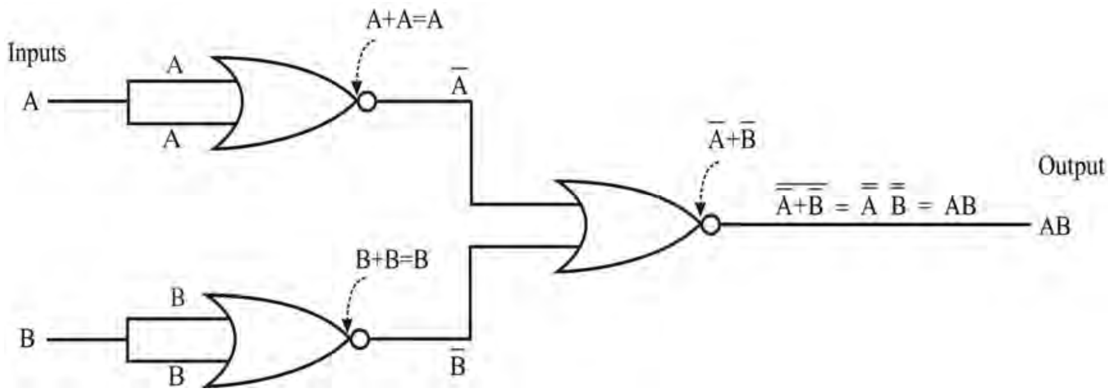


Figure 27.13

(b) Implementation of OR Gate using NOR Gates

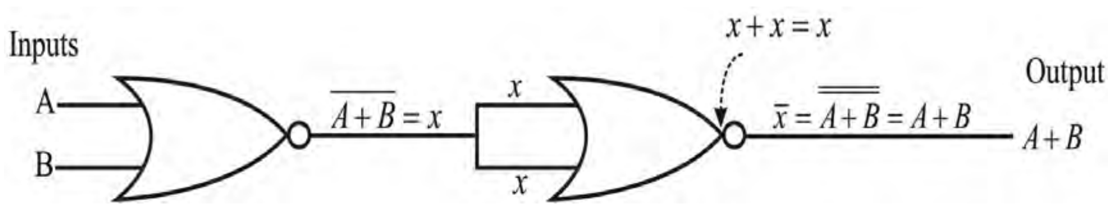


Figure 27.14

(c) Implementation of NOT Gate using NOR Gate

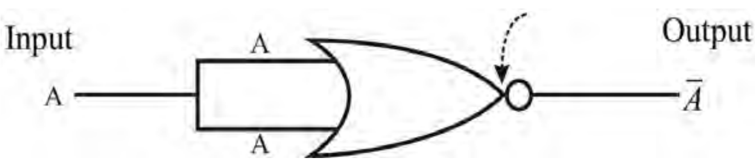


Figure 27.15

Part (IV)

(a) XOR Gate

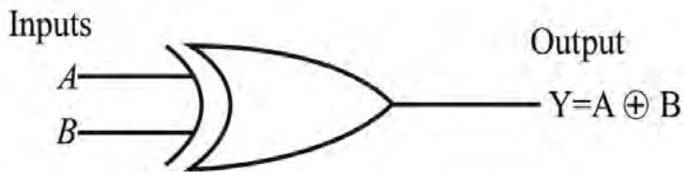


Figure 27.16

(b) Logic diagram for Y = $A \oplus B = A\overline{B} + B\overline{A}$

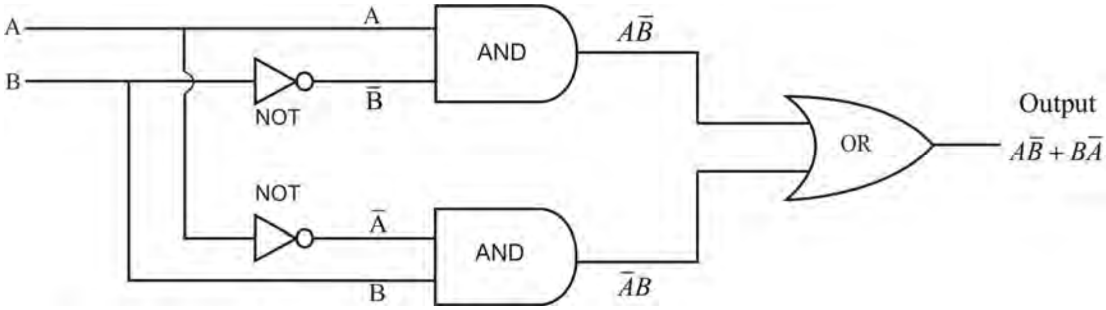


Figure 27.17

(c)Logic diagram for Y = $A \oplus B = (A+B)\,(\overline{AB})$

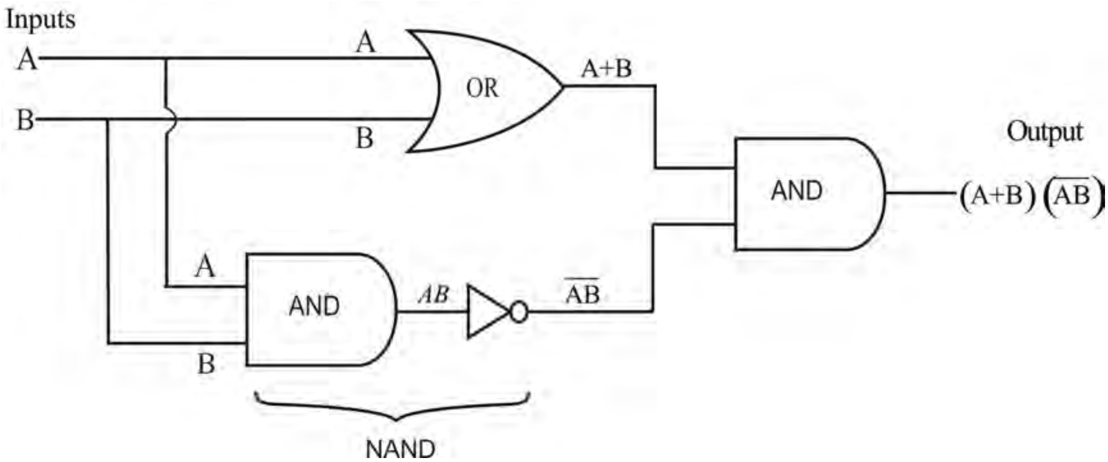


Figure 27.18

(d)Logic diagram for Y = $A \oplus B = \overline{AB + \overline{A}\overline{B}}$

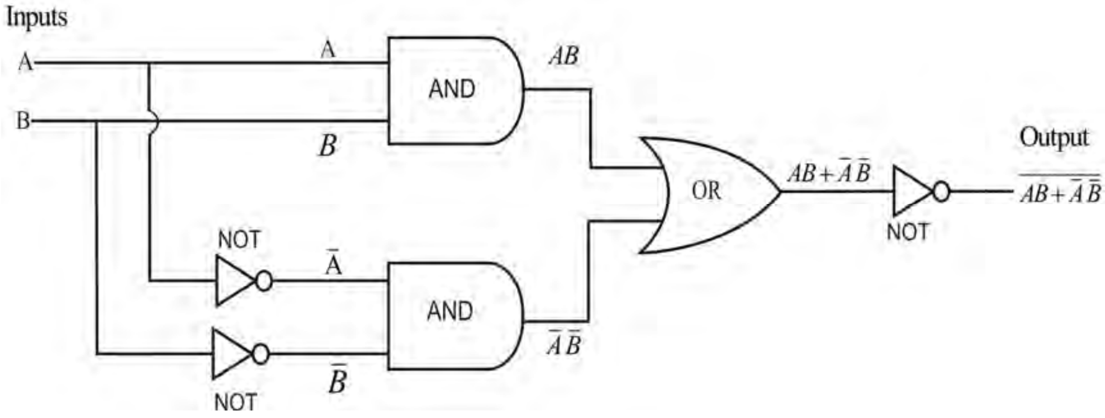


Figure 27.19

27.4 Formula (Truth Tables)

Formula (Truth Tables)

Part I, II, III

(a) AND Gate

output Y = AB

Truth Table of AND Gate

INPUTS		OUTPUT
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

For three input variables

Output Y = ABC

Truth Table of AND Gate

INPUTS			OUTPUT
A	B	C	Y
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

(b) OR Gate

Output Y = A+B

Truth Table of OR Gate

INPUTS		OUTPUT
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

For three input variables

Output Y = A+B+C

Truth Table of OR Gate

INPUTS			OUTPUT
A	B	C	Y
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

(c) NOT Gate (Inverter)

Output $Y = \overline{A}$

Truth Table of NOT Gate

INPUTS	OUTPUT
A	Y
0	1
1	0

(d) NAND Gate

Output $Y = \overline{AB}$

Truth Table of NAND Gate

INPUTS		OUTPUT
A	B	$\overline{AB}$
0	0	1
0	1	1

1	0	1
1	1	0

(e) NOR Gate

Output $Y = \overline{A+B}$

Truth Table of NOR Gate

INPUTS		OUTPUT
A	B	$\overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

<u>Part IV</u>

XOR Gate

Output $Y = A \oplus B$

We can write Y as

$Y = A\overline{B} + B\overline{A}$

$Y = (A+B)\overline{AB}$

$Y = \overline{AB + \overline{A}\overline{B}}$

INPUTS		OUTPUT
A	B	$A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

27.5 Theory and description

Logic Gates:

Gate is a digital circuit with one or more inputs (Voltages) but only one output voltage. The digital circuits use only two digits '0' and '1'.

George Boole developed Boolean Algebra .

AND Gate:

It has two or more inputs and only one output.

Y=A.B

This is read as " Y equals A AND B ".

OR Gate:

It has two or more inputs and only one output.

Y=A+B

This is read as " Y equals A OR B "

NOT Gate: (Inversion Gate)

It has one input and one output.

$$Y = \overline{A}$$

This can also be written as $Y = A'$

This is read as " Y equals compliment of A "

We can read as " Y equals NOT A "

De Morgan's Theorems

It consists two parts

(i) $\overline{A+B} = \overline{A}.\overline{B}$

The compliment of the sum of two variables is equal to the product of the complement of the variables.

(ii) $\overline{A.B} = \overline{A} + \overline{B}$

The complement of the product of two variables is equal to sum of complements of the variables.

For more than two variables De Morgan's theorems can be written as

$$\overline{A+B+C} = \overline{A}.\overline{B}.\overline{C}$$
$$\overline{ABC} = \overline{A} + \overline{B} + \overline{C}$$

Digital Integrated Circuits:

A digital integrated circuit(IC) is designed by an interconnection of resistors, transistors and small capacitors etc. that are formed on the surface of a semiconductor wafer. Various digital logic circuits are being fabricated using bipolar and unipolar technologies. Popular bipolar logic families are Resistor – transistor logic (RTL), Diode –Transistor logic (DTL), Transistor transistor logic (TTL),Direct coupled transistor logic (DCTL), Integrated –Injection logic (I^2L), High threshold logic (HTL), Emitter coupled logic(ECL).The unipolar logic families are PMOS,NMOS,CMOS.

Pinout diagram of Quad two input OR gate 7432 is shown in the diagram

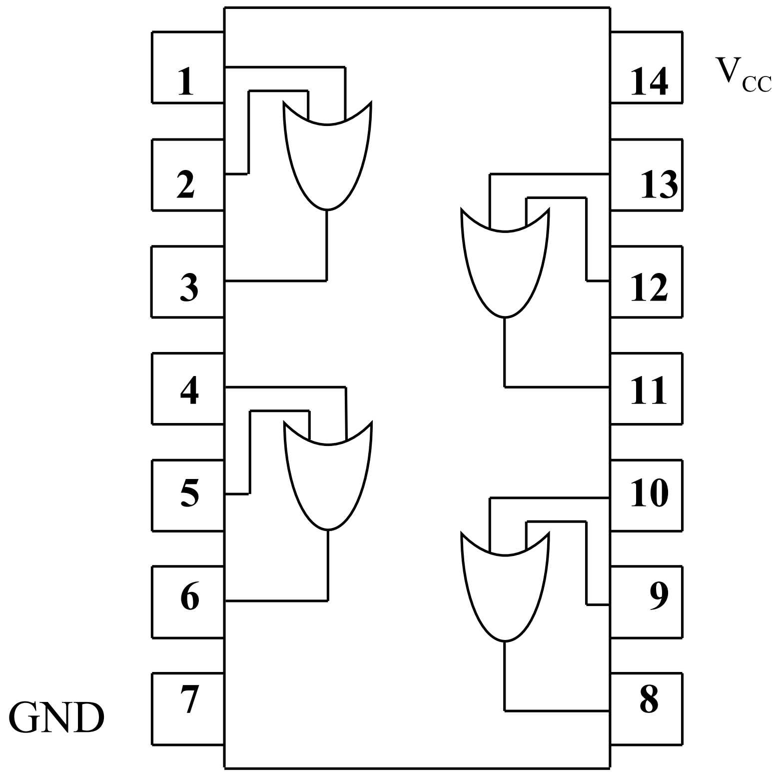


Figure 27.20: Pinout Diagram of OR Gate 7432

27.6 Self Learning Exercise-I

Q.1 What do you mean by 'bit'?

Q.2 What is the final value of following Boolean expressions

(i) A+1 (ii) A+0

Q.3 What do you mean by RTL.

Q.4 Prove the following $A \oplus B = \overline{A} \oplus \overline{B}$

27.7 Procedure

(a) For AND Gate (Fig. 27.1)

1. Make the connections as per the circuit diagram.
2. Connect the circuit to an appropriate power source and turn it on.
3. Observe the output on LED for each input combination.
4. Write down the corresponding logic level in the observation table.

For Breadboard Arrangement

(a) For AND Gate (Fig. 27.1)

1. Insert IC 7408 (AND Gate) in the breadboard
2. Before you wire the circuit for logic gate, we should label the associated Chip Pin Number on the circuit diagram.
3. Assemble the connection (using components, connecting wires etc.) to implement the circuit illustrated in figure 27.1
4. Connect output to LED with correct polarity and connect a series current limiting resistor (about 270Ω) to LED to limit the current and prevent burn out.
5. For IC 7408 (14 pin IC), connect Pin 7 to ground (0V) and Pin 14 to V_{cc} (+5V DC supply).
6. Turn on the power and observe output at LED indicator corresponding to all possible combinations of inputs (via input switches). Write down corresponding output in the observation table and verify the truth table.
7. If there is any mismatched result, troubleshoot result.
8. Turn off the power and disconnect the circuit connections.

For other parts of experiment, repeat the above steps using appropriate circuit diagrams (appropriate ICs, etc.) to demonstrate remaining experiments of this unit.

27.8 Observation

Part I

(a) Truth Table of AND Gate (Figure 27.1)

For two Inputs

INPUTS		OUTPUT
A	B	Y

Truth Table of AND Gate (Figure 27.2/27.3)

For three Inputs

INPUTS			OUTPUT
A	B	C	Y

(b) Truth Table of OR Gate (Figure 27.4)

For Two Inputs

INPUTS		OUTPUT
A	B	Y

Truth Table of OR Gate (Figure 27.5/27.6)

For three inputs

INPUTS			OUTPUT
A	B	C	Y

(c) Truth Table of NOT Gate (Figure 27.7)

INPUTS	OUTPUT
A	Y

(d) Truth Table of NAND Gate (Figure 27.8)

INPUTS		OUTPUT
A	B	Y

(e) Truth Table of NOR Gate (Figure 27.9)

INPUTS		OUTPUT
A	B	Y

Part II

(a) Implementation of AND Gate using NAND Gate

Truth Table (Figure 27.10)

INPUTS		OUTPUT
A	B	Y

(b) Implementation of OR Gate using NAND Gate

Truth Table (Figure 27.11)

INPUTS		OUTPUT
A	B	Y

(c) Implementation of NOT Gate using NAND Gate

Truth Table (Figure 27.12)

INPUTS	OUTPUT
A	Y

Part III

(a) Implementation of AND Gate using NOR Gate

Truth Table (Figure 27.13)

INPUTS		OUTPUT
A	B	Y

(b) Implementation of OR Gate using NOR Gate

Truth Table (Figure 27.14)

INPUTS		OUTPUT
A	B	Y

(c) Implementation of NOT Gate using NOR Gate

Truth Table (Figure 27.15)

INPUTS	OUTPUT
A	Y

Part IV

(a) Truth Table of XOR Gate (Figure 27.16)

INPUTS		OUTPUT
A	B	Y

(b) Implementation of logic function Y = $A \oplus B = A\overline{B} + B\overline{A}$

Truth Table (Figure 27.17)

INPUTS		OUTPUT
A	B	Y

(c) Implementation of logic function Y = $A \oplus B = (A+B)(\overline{AB})$

Truth Table (Figure 27.18)

INPUTS		OUTPUT
A	B	Y

(d) Implementation of logic function Y = $A \oplus B = \overline{AB + \bar{A}\bar{B}}$

Truth Table (Figure 27.19)

INPUTS		OUTPUT
A	B	Y

27.9 Result

(I) Demonstration of logic functions AND, OR, NOT, NAND, NOR were done and their truth tables were verified.

(II) --

(III) --

(IV) --

27.10 Discussion

27.11 Precautions and Sources of error

1. Circuit components (LED etc.), power supply must be connected with correct polarity.
2. DC supply voltage must not exceed the value of 5 Volt otherwise it will damage the ICs used during the experiment.
3. LED indicator should be used with series current limiting resistor.
4. Arrangement of IC chips on the breadboard should be such that short wire connections are needed.
5. Power supply should be turned off when connecting or disconnecting the components, wires etc.
6. Circuit should be assembled in systematic and organized fashion because improper connections cause overheating of ICs due to short circuit.
7. Jumper wires used for experiment should not be in broken state.
8. Insertion and removal of the ICs should be done gently to avoid the bending of the pins of ICs

27.12 Self Learning Exercise-II

Q.1 Show that

(i) $A + AB = A$

(ii) $A\left(B + \overline{B}\right) = A$

Q.2 Prove the following using De Morgan's theorem.

$$AB + CD = \overline{\overline{AB}\,.\overline{CD}}$$

Q.3: What are the main properties of ECL ?

Q.4 Draw logic symbol of NAND gate and give its Truth table.

27.13 Glossary

IC **:** Integrated Circuits

LED : Light Emitting Diode

27.14 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: A binary digit (1 or 0) is called bit.

Ans.2: (i) A+1=1 , (ii) A+0=A

Ans.3: Resistor Transistor logic

Ans.4: $\overline{A}\oplus\overline{B} = \overline{A}\overline{\overline{B}} + \overline{B}\overline{\overline{A}} = \overline{A}B + \overline{B}A = A\oplus B$

Answers to Self Learning Exercise-II

Ans.2: $\overline{\overline{AB}.\overline{CD}} = \overline{\overline{AB}} + \overline{\overline{CD}} = AB + CD$

Ans.3: Emitter coupled logic(ECL) has considerably faster speed in the TTL families, but power consumption is higher for each gate.

Ans.4: Refer section 27.3 & 27.4

27.15 Viva Questions

Q.1 What is dc positive logic?

Q.2 What do you mean by logical variables?

Q.3 Evaluate the following functions

(i) $A\overline{A}+1$

(ii) $A+\overline{A}+B$

Q.4 Prove that

$$\overline{\overline{\overline{A}\overline{B}+\overline{A}+\overline{A}\overline{B}}} = \overline{A}$$

Q.5 What do you mean SSI,MSI &VLSI?

Q.6 What do mean by figure of Merit?

Q.7 What do you mean by DTL &TTL.

Q.8 What is MOS logic?

Q.9 Give function of EX-NOR.

Q.10 Give the truth table of EXNOR

27.16 Answers to Viva Questions

Ans.1: If more positive voltage is the 1 level and the other is the 0 level then it is called dc positive logic. In dc negative logic binary 0 stands for high voltage and binary 1 for low voltage.

Ans.2: The binary variables are referred as logical variables.

Ans.3: (i) $A\overline{A}+1=0+1=1$

(ii) $A+\overline{A}+B=1+B=1$

Ans.4: $\overline{\overline{\overline{A}\overline{B}+\overline{A}+\overline{A}\overline{B}}}=\overline{\overline{\overline{A}\left(\overline{B}+1\right)+\overline{A}\overline{B}}}$

$$=\overline{\overline{\overline{A}(1)+\overline{A}\overline{B}}}$$

$$=\overline{\overline{\overline{A}\left(1+\overline{B}\right)}}$$

$$=\overline{\overline{\overline{A}(1)}}$$

$$=\overline{\overline{\overline{A}}}=\overline{A}$$

Ans.5: SSI: Small Scale Integration(No. of components on chip up to 99)

MSI: Medium Scale Integration(No. of components on chip 100 to 999)

VLSI: Very Large Scale Integration(No. of components on chip 10,000 to 99,999)

Ans.6: Figure of merit = Propagation delay time(ns)×Power(mW)

A low value of figure of merit is required.

Ans.7: DTL: Diode Transistor Logic

TTL: Transistor Transistor Logic

Ans.8: MOSFETs are used in logic circuits due to high density of fabrication and low power dissipation.

Ans.9: $Y=\overline{A\ \text{EX-OR}\ B}$

$$A\odot B=\overline{A\overline{B}+B\overline{A}}$$

$$A\odot B=AB+\overline{A}\overline{B}$$

Ans.10: A EXNOR B

Inputs		Output
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

References and Suggested Readings

1. R.P. Jain, Modern Digital Electronics(Second edition2002),Tata McGraw Hill.
2. Donald P. Leach &Albert Paul Malvino, Digital Principles and Applications(Fifth Edition),2003,Tata McGraw Hill.
3. Jacob Millman Christos C. Halkias ,Integrated Electronics(1999) ,Tata McGraw Hill.
4. D. Chatopadhyay, P.C.Rakshit ,B.Saha ,N.N. Purkait, Foundation of Electronics ,Second Edition(1995),New Age International Publishers Limited, Wiley Eastern Limited .

UNIT-28
Hall Effect

Structure of the Unit

28.1 Aim

To study the Hall Effect and to calculate:-

1) The Hall coefficient (R_H) and

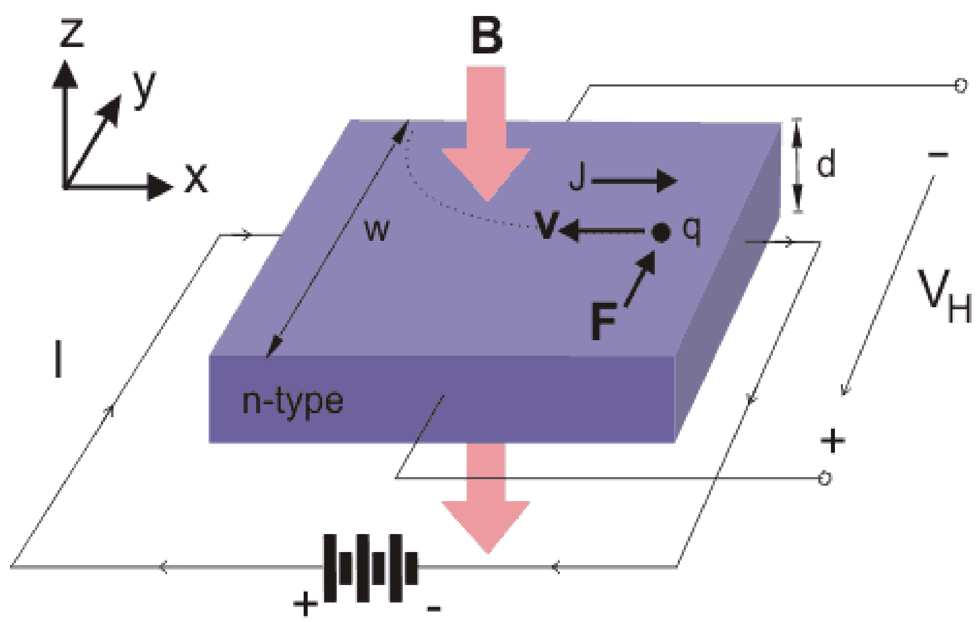
2) To measure the unknown magnetic field (B_{Y1}) and to compare it with that measured by the Gaussmeter (B_{Y2}).

28.2 Apparatus

- Gauss meter with probe,
- Electromagnet,
- Constant current source to Pass current through electromagnet,
- Specimen of semi-conducting material with connecting terminals to Pass current (I_X) through it and to measure the Hall voltage (V_H)
- Constant current source to Pass current (I_X) through semiconductor specimen,
- Milli-ammeter to measure I_X,
- Voltmeter to measure Hall voltage (V_H)

  Connecting terminals.

28.3 Diagram



BLOCK DIAGRAM OF EXPERIMENTAL SET-UP

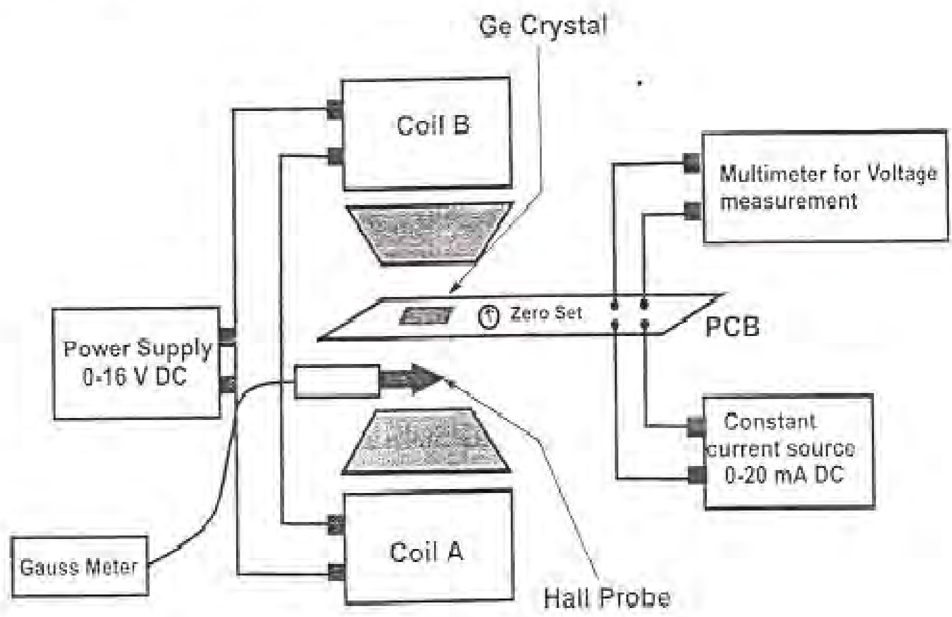


Fig. 2

28.4 Formula

1) Hall coefficient

$$R_H = \frac{V_H t}{I_x B_y} \frac{cm^3}{C}$$

2) Magnetic induction

$$I_R = V_H \frac{t}{I_x R_H} \; Gauss$$

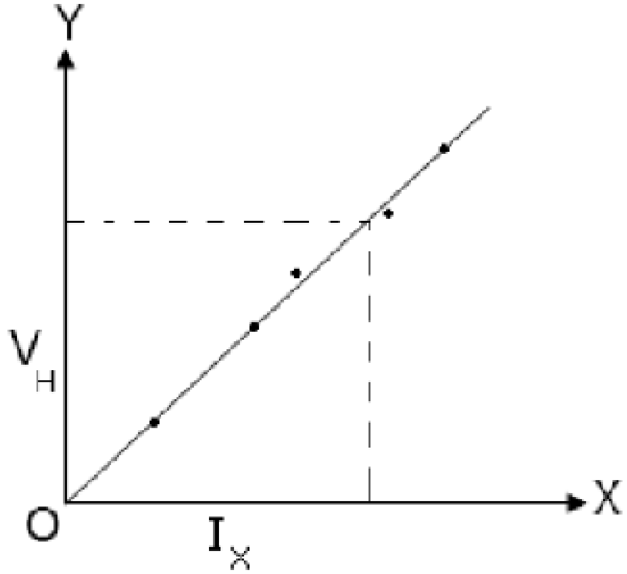
where

V_H = Hall voltage developed between the upper and lower faces of the specimen (V)

I_X = Current sent through the specimen (A)

t = Thickness of the specimen (Distance between the side faces) (cm)

28.5 Model Graph



Graph

28.6 Theory and description

Hall effect is a phenomenon that occurs when a conductor or semiconductor is placed in the magnetic field and a voltage (i.e. the electric field in the above definition) is applied through the material perpendicular to the magnetic field. While this voltage induces current flow along the electric field direction, the charge carriers also experience a magnetic deflection from their path. This results a separation of positive and negative carriers, and thus the generation of an electric field perpendicular to the direction of current flow. Note that, at sufficient temperature, the net current in a semiconductor is made up of counteracting currents of p-type and n-type carriers.

Consider a uniform thick semiconductor (or) metal strip (specimen) placed with its length parallel to X-axis. A current I_X is passed through the conductor along X-axis. A magnetic field B_Y is applied along Y – axis, then the charge carriers experience a force (F) perpendicular to X-Y plane i.e. along Z- axis as per the Fleming's Left Hand rule as shown in the figure. If electrons are the charge carriers, they accumulate at the upper surface. This surface acquires negative charge while the lower surface gets positive charge and some potential difference is developed between these two surfaces. This is electrostatic field. This voltage is called Hall Voltage (V_H) and the Electric field is called Hall electric field (E_H). (In this case the Hall voltage V_H is negative, this –ve sign indicates the charge carriers are negatively charged i.e. electrons. If it is +ve the charge carriers are holes.

These F and E_H act in opposite directions. i.e. The forces due to magnetic field and electrostatic field on charge carrier act in opposite direction.

Ultimately, the net force on the charge carrier becomes zero.

$$\therefore\ q\,(V_d \times B_Y) + q\,E_H = 0$$

$$\text{(or)}$$

$$(V_d \times B_Y) + E_H = 0$$

Here

V_d is the drift velocity of the charge carrier = J/nq.

J = Current density

q = Charge of the carrier

n = No. of charge carriers/cm3

Here is another physical quantity called Hall coefficient which is equal to the reciprocal of the amount of charge per unit volume.

Hall coefficient

Hall coefficient is a parameter that measures the magnitude of the Hall Effect in the sample. It has units of Ωm/Tesla. (Contrast this with ***resistivity***, which has units of Ωm.) The Hall coefficient is defined as

$$R_H = \frac{1}{nq} = \frac{E_H}{JB_Y}$$

$$\Rightarrow R_H = \frac{\left(\frac{V_H}{d}\right)1}{\left(\frac{I_X}{A}\right)B_Y}$$

$$\Rightarrow R_H = \frac{\left(\frac{V_H}{d}\right)1}{\left(\frac{I_X}{td}\right)B_Y}$$

$$\Rightarrow R_H = \frac{V_H t}{I_x\, B_y}\frac{cm^3}{C}$$

Where

E, J, and B are the magnitudes of the electric field, the current density, and the magnetic field, respectively. (In the experimental setup to determine the Hall coefficient, these three vectors are mutually perpendicular.)

t = Thickness of the specimen

d = Height

A = Area of cross-section

This experiment can be used to find

1) the nature of the charge carrier

2) the Hall voltage

3) current through the specimen

4) applied magnetic field

5) Conductivity of the conductor etc.

But for the present it is confined to measure the unknown magnetic field.

Description of the experimental set-up:-

The experimental set-up consists of 3 main instrumental parts.

(1)Digital Gaussmeter with Hall probe:-

Hall probe cable is to be plugged-in to the socket of the digital gaussmeter and the power should be given to the gaussmeter. This probe also operates basing on the principle of Hall effect. A small current sent through the Hall probe develops a small Hall voltage when it is placed in a magnetic field and the Hall voltage is amplified by an amplifier whose output is calibrated in Gauss which directly gives the magnetic induction (B) value in the gaussmeter.

(2)Electromagnet with constant current supply:-

Two insulated Copper wires are wound on two soft iron bars whose faces are facing each other. When a D.C. current (in amperes) from a constant current source is sent through the coils, the faces of the iron bars acts as the two poles of a magnet (electromagnet) creating a magnetic field in between them. The gap between poles can be varied, in general, the gap should be 1 cm.

(3)Hall effect board with Hall probe semi-conductor specimen mounted on sun mica PCB:-

A specimen of rectangular semi-conductor slab in which Hall effect is to be studied is fixed to a printed circuit board (PCB) with the help of 4 supporting terminals. Out of 4 terminals, 2 terminals are along the length and these (Middle & green) terminals are connected to the current source of the Hall effect board. The other 2 terminals are along the width and these (Red) terminals are connected to the Voltmeter of the Hall effect board.

The Hall effect board has 2 uses.

1. To pass current (I_X) through the specimen & to measure that current.
2. To measure the Hall voltage (V_H) developed across the specimen.

To meet these two purposes a two mode switch is arranged to the digital meter of the board. First mode is to measure the current (I_X), sent through the specimen and the second mode is to measure the Hall voltage (V_H) developed across the specimen.

28.7 Self Learning Exercise-I

Q.1 Define Hall Effect?

Q.2 What causes Hall Effect?

Q.3 What is Lorentz force?

Q.4 What is Hall Coefficient?

28.8 Procedure

This experiment comprises of two parts

1) Measurement of Hall coefficient (R_H)

2) Measurement of applied magnetic field (B_Y) by using Hall effect.

Measurement of Hall coefficient (R_H)

1. In the 1st part give the power supply to the gaussmeter. Keep the range switch of the gaussmeter in minimum range and adjust the zero adjustment such that the reading in the gaussmeter shows zero. If the gaussmeter does not come to zero, then keep its value at minimum and take it as zero error. This zero error is to be corrected while taking the final reading of magnetic induction (B_Y).
2. Now adjust the distance between the poles of the electromagnet equal to 1cm & pass 1A current through the electromagnet from its constant current source, then some magnetic field (B_Y) is created between the poles of electromagnet.
3. The magnetic field or magnetic induction (B_Y) is measured by the gaussmeter by keeping its probe between the poles of the electromagnet. The position of the probe is adjusted such that the flat faces of the probe are perfectly vertical and perpendicular to the magnetic field. Then the gaussmeter shows maximum value.
4. Keep the mode switch of the current source of the semiconductor specimen in the current mode (Here also the zero error and zero correction are to be made) and pass 0.5 mA (or) 1 mA current (I_X) through the specimen. Place this specimen between the poles of the electromagnet such that the faces of the specimen are perfectly vertical and note the voltage (V_1) developed between the upper and lower faces of the specimen after turning the mode switch of the current source of the specimen in to voltage mode.
5. Now reverse the position of the specimen (up side down and vice versa) and keep it between the poles once again and measure the voltage (V_2) developed between the upper and lower faces of the specimen.
6. Now calculate the Hall voltage

$$V_H = \frac{V_2 \sim V_1}{2}$$

   Note the values of I_X, V_1, V_2 in the table 1 and calculate V_H.

7. Repeat the experiment for different values of I_X by increasing its value in equal intervals of 0.25 mA.

Measurement of applied magnetic field (By)

1. In the 2nd part of the experiment keep the current through the semi-conductor specimen (I_X) at constant value of 1 mA and pass 1A current through the electromagnet and measure the voltages V_1 and V_2 by placing the specimen between the poles of the electromagnet & from that calculate the Hall voltage V_H (as measured in the 1st part).
2. Also measure the magnetic induction (B_{Y1}) with gaussmeter by placing its probe between the poles of electromagnet.
3. Substitute the values of I_X, V_H, t and Hall coefficient R_H (as calculated in 1st part) in the formula – 2 and calculate value of applied magnetic field (B_{Y2}).
4. The experiment is repeated by increasing the current through the electromagnet (it means by changing the magnetic field B_Y) in equal intervals of 0.5 A. Note the values in the table 2.

   In the 2nd part the experiment the magnetic field B_Y is measured with gaussmeter as B_{Y1} and also measured by using the Hall effect as B_{Y2}. These two are compared in the table 2.

28.9 Observation

Thickness of the semi-conductor specimen t = ……cm.

Current through the Electromagnet = 1 A

Applied magnetic field measured with gaussmeter B_Y =……

Table I

S.No.	Current through the specimen I_X (mA)	Measurement of Hall Voltage V_H (V)		
		V_1	V_2	$V_H = \frac{V_2 \sim V_1}{2}$
1.				
2.				

3.				
4.				
5.				
6.				

Current through the semi-conductor specimen I_X = 1 mA

Table 2

S.No.	Current through the specimen I_X (A)	Measurement of Hall Voltage V_H (V)			Magnetic induction measured with Hall effect $B_{Y2} = V_H \frac{t}{I_x R_H}$ $(Gauss)$	Magnetic induction measured with gaussmeter (B_{Y1}) (Gauss)
		V_1	V_2	$V_H = \frac{V_2 \sim V_1}{2}$		
1.						
2.						
3.						
4.						
5.						
6.						
7.						

More accurate method to measure V_H

In the above two parts of the experiment i.e. while measuring R_H and B_Y the Hall voltage (V_H) shall be measured first. In measuring V_H, the following is the accurate method.

1. First some current (1A) is sent through the electromagnet to create the magnetic field between the poles of the magnet.
2. Now the current I_X (1mA) is sent through the semiconductor specimen and put the specimen between the poles and measure the voltage (V_1) developed across the specimen (after switch over the mode switch in to voltage mode) as said above.
3. Now the current in the specimen is reversed by interchanging the current leads of the specimen and measure the voltage (V_2).
4. Then Hall voltage V_{H1} = (V1~V2)/2.
5. Now reverse the current direction in the electromagnet by interchanging its current leads.
6. Once again measure the voltages (V3 & V4) developed across the specimen by placing the specimen between the two poles, before and after reversing the current direction in the specimen by inter changing its current leads.
7. Now the Hall voltage $V_{H2} = (V_3 \sim V_4)/2$.
8. Then the Hall voltage

$$V_H = \frac{V_{H1} + V_{H2}}{2}$$

The above method is to be adopted while measuring V_H

28.10 Graph

Draw the graph by taking the current through the specimen I_X on X- axis and Hall voltage V_H on Y- axis. This gives a straight line passing through the origin. Take a particular value of I_X and note its corresponding value of V_H Note the thickness (t) of the specimen which was noted on the board of the specimen. Substitute the values of I_X, V_H, t and B_Y in the formula – 1 and calculate Hall coefficient (R_H)

28.11 Calculations

A graph is plotted in V_H and I_x. From its slope

$tan\theta = V_H / I_x$

Then Hall coefficient is

$$R_H = tan\theta \frac{t}{B_y} \frac{cm^3}{C}$$

Mean R_H=………

The number of charge carriers per unit volume

$$n = -\frac{1}{R_H e} = \cdots$$

28.12 Result

Then Hall coefficient is R_H=………

The number of charge carriers per unit volume n=……

28.13 Discussion

28.14 Precautions and Sources of error

1. Before starting the experiment, check the gaussmeter is showing zero value.
2. Ensure that the specimen is located at the centre between the pole faces and is exactly perpendicular to the magnetic field.
3. To measure the magnetic flux the hall probe should placed at the center the pole faces, parallel to the crystal.

4. Check the direction of electromagnet coils so that it generates the maximum magnetic field, this can be check by placing the soft iron near the generated magnetic field, if soft iron attracts forcefully the magnetic field produced is strong, otherwise magnetic field is weak.
5. Electromagnet power supply should be connected to a 3 pin main socket having good earth connection.
6. Switch "ON" or "OFF" the power supply at zero current position.
7. Adjust the distance between the poles of the magnet nearly 1 cm, then only the gaussmeter shows correct reading.
8. Hall voltage developed is very small and should be measured accurately with the help of a millivoltmeter of potentiometer.

28.15 Self Learning Exercise-II

Q.1 Define Charge carrier concentration.

Q.2 Why Hall voltage differ for different type of charge carrier?

Q.3 What is unit of Hall coefficient?

28.16 Glossary

***Conductor*:**

Conductor is a type of material in which charge carriers (effectively electrons or holes) can be made to flow with arbitrarily small voltages. A conductor is distinguished by having a partially filled conduction band, and, hence, no gaps between the highest occupied and the lowest unoccupied electronic states. Common examples of conductors are copper and iron.

***Electron Concentration* :**

Electron Concentration is the number of electrons per unit volume in the conduction band of the material.

***Extrinsic material* :**

Extrinsic material is a material whose number of free electrons is not equal to the number of free holes (positive carriers).

***Hall field*:**

Hall field is an electric field perpendicular to the direction of current flow generated by the Hall effect.

***Hall voltage* :**

Hall voltage is the potential difference across the semiconductor that is produced by the Hall field. This is the voltage which is exactly enough to compensate for the deflection of charge carriers by the magnetic field, so that the net current perpendicular to the applied voltage is zero.

***Hole* :**

Hole is an effective positively charged "empty state." The description of current in terms of the motion of positively charged holes rather than negatively charged electrons is convenient and accurate when describing a material with an almost filled conduction band.

***Hole concentration*:**

Hole concentration is the number of holes (positive carriers) per unit volume in the conduction band of the material.

***Intrinsic material*:**

Intrinsic material is a material in which the number of negative carriers (electrons) is the same as the number of positive carriers (holes).

***Insulator* :** It is a material in which electrons cannot be made to flow with low voltages. Using the quantum mechanical description of periodic solids, insulators are characterized by having completely filled valence bands, and large energy gaps to the lowest-lying unoccupied conduction bands.

***Drift mobility*:** It is the drift velocity per unit applied electric field,

$$\mu_d = \frac{v_d}{E}$$

***Drift velocity* :** It is the average velocity in the direction of an applied electric field of the all conducting charge carriers in the sample.

***Lorentz force*:**

$$F = q(v \times B)$$

Lorentz force is the force, which a moving charge experiences when subjected to a magnetic field. Here, B is the magnetic field, v is the velocity of the carrier, and *q* its charge.

N-*type material* **:**is a material in which the negatively (n) charged carriers are mostly responsible for the conduction.

P-*type material* **:**is a material in which the positively (p) charged carriers are mostly responsible for the conduction.

Resistivity **:**is a material parameter that is a measure of the resistance to current. The resistivity is defined as the resistance of the sample times the cross sectional area of the sample divided by the length of the sample,

$$\rho = \frac{RA}{l}$$

The resistivity has units of Ωm and it is inversely proportional to the conductivity of the sample,

$$\sigma = \frac{1}{\rho}$$

Semiconductor **:**is a material which is, intrinsically, barely insulating in that the filled conduction band lies very close to the valence band. Semiconductors can be deliberately modified through patterned doping to produce complex, compact, and reliable electronic devices.

28.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise-I

Ans.1: When a current carrying specimen is placed in a transverse magnetic field then a voltage is developed which is perpendicular to both, direction of current and magnetic field. This phenomenon is known Hall Effect.

Ans.2: Whenever a charge moves in a mutually perpendicular electric and magnetic field it experiences Lorentz force due to which it deflects from its path and Hall voltage is developed.

Ans.3: If charge ‘q’ moves in a magnetic and electric field ‘B’ &’E’ respectively with velocity v then force on it is given by

$F = qE + Bqv.\sin\theta$

Ans.4: It is the electric field developed per unit current density per unit magnetic field

Answers to Self Learning Exercise-II

Ans.1: No. of charge carriers per unit volume.

Ans.2: Because direction of Lorentz force is different for different type of charge carrier.

Ans.3: Ohm-meter/Tesla.

28.18 Viva Questions

Q.1 What is Hall Effect?

Q.2 What are n-type and p-type semiconductors?

Q.3 What is the effect of temperature on Hall coefficient of a lightly doped semiconductor?

Q.4 Do the holes actually move?

Q.5 Why the resistance of the sample increases with the increase of magnetic field?

Q.6 Why a high input impedance device is generally needed to measure the Hall voltage?

Q.7 Why the Hall voltage should be measured for both the directions of current as well as of magnetic field?

Q.8 On what factors the sign of Hall potential depends?

Q.9 How do you define Hall coefficient?

Q.10 What is mobility?

Q.11 If hall-coefficient is negative what does it indicate?

Q.12 Significance of hall coefficient. What information do we get?

Q.13 Hall effect?

Q.14 n- and p- type impurities?

Q.15 Define specific resistance.

Q.16 What is meant by conductivity?

Q.17 What are the applications of Hall effect?

Q.18 Give the expression for the Hall coefficient.

Q.19 What are the dimensions of Hall probe in your experiment?

Q.20 Give the value of those physical quantities determined in this experiment.

Q.21 Write down the uses of Hall Effect?

Q.22 Which type of magnet is used in the experiment, temporary or permanent?

Q.23 What is the unit of charge carrier concentration?

28.19 Answers to Viva Questions

Ans.21: To determine the sign of charge carrier and charge carrier concentration

Ans.22: Temporary.

Ans.23: Per Cubic-centimeter.

References and Suggested Readings

1. D. K. Schroder, "Semiconductor Material and Device Characterization", John Willey & Sons Inc. 1990.
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UNIT-29
Young Modulus of the Glass by Newton's Ring Method

Structure of the Unit

29.1 Aim

To determine the Young modulus of the glass (taken in the form of the bar) by Newton's Ring Method.

29.2 Apparatus

Sodium vapour lamp, glass beam, convex lens, travelling microscope, two knife edges, vernier calipers, screw gauge, a set of weights, weight hanger.

29.3 Diagram

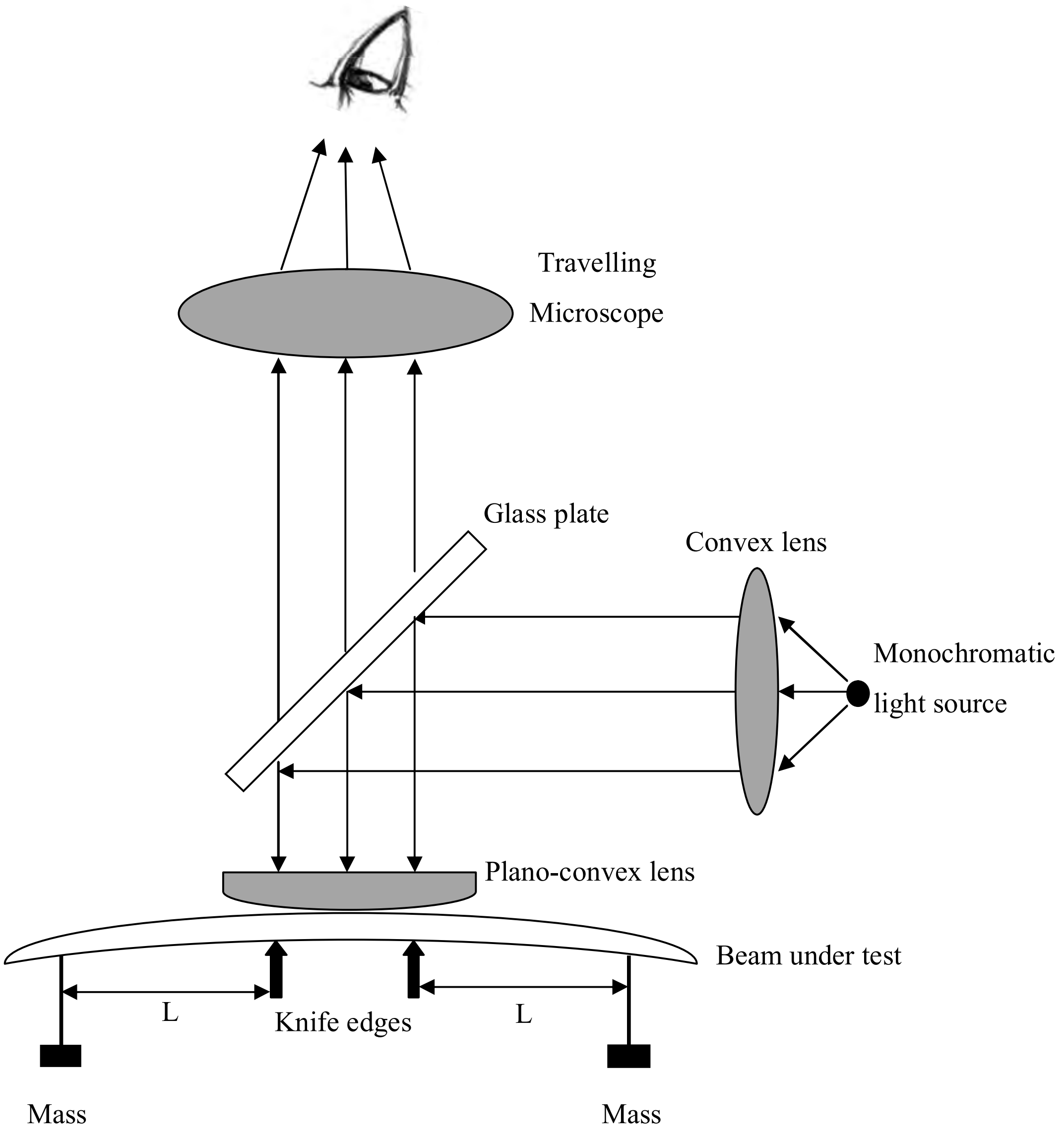

Fig. 1: *The arrangement of Cornus method.*

29.4 Formula

Young modulus by Cornu's method

$$Y = \frac{12mgLR}{bd^3}$$

And longitudinal radius of curvature R is given by

$$R = \frac{1}{4n\lambda}\frac{(D_n^0)^2 \times (D_n^1)^2}{(D_n^0)^2 - (D_n^1)^2}$$

Here:

m = mass suspended on the beam (kg)

g = acceleration due to gravitation (9.8 m/s^2)

L = length of the section of beam under test (in between knife edge and hanger).

b = breadth of Glass beam (meter)

d = Thickness of beam under test (meter)

λ = wavelength of sodium light source (5892 Å or 5892 x 10^{-10} m)

n = order of fringe.

D_n^0 = Diameter of n^{th} order fringe without mass (meter).

D_n^1= Diameter of n^{th} order fringe with mass m (meter).

29.5 Theory and description

Cornus method is particularly used to determine the elastic constant such as Young's modulus of given material in the shape of beam. This method includes Newton's ring experiment partially to determine the bending of beam optically with high accuracy.

(i) **Elasticity:** elasticity is property of material by which it opposes to change of its shape and return to their original shape after being deformed.

(ii) **Stress:** in the object reaction force per unit area due the strain is known as stress in the equilibrium stress is given in the term of the external force

$$Stress = \frac{Force}{Area} \quad \frac{N}{m^2}$$

(iii) **Strain:** The strain is a ratio of change in dimension with original dimension, according to the deformation there are three types of strain

1. Longitudinal strain
2. Volume strain
3. Sharing strain

(iv) **Hook's law:** according to hooks law in the limit of elasticity stress is directly proportional to strain

$$Stress \ \alpha \ Strain$$

$$Stress = E \times Strain$$

Here: E is elasticity constant

(v) **Elasticity constants:** There are three types of elasticity constant according to strain

1. *Young's modulus of elasticity (Y):* Young's modulus is ratio of longitudinal stress with longitudinal strain in the limit of elasticity

$$Y = \frac{Longitudinal\ Stress}{Longitudinal\ Strain} \quad \frac{N}{m^2}$$

2. *Bulk Modulus of elasticity (K):* It is ratio of normal stress to volume stress in the limit of elasticity

$$K = \frac{Normal\ Stress}{Volume\ Strain} \quad \frac{N}{m^2}$$

3. *Modulus of rigidity (η):* It is ratio of tangential stress to shearing strain in the limit of elasticity:

$$\eta = \frac{\text{Tangential}\ Stress}{Shearing\ Strain} \quad \frac{N}{m^2}$$

Table 1: *Young's modulus for some material*

S. No.	Material	Young's Modulus (N/m^2)
1.	Aluminium	7×10^{10}
3.	Iron	9×10^{10}
4.	Steel	21×10^{10}
5.	Glass	~6 x10^{10}

6.	Rubber	$\sim 10^7$

(vi) **Bending of Beam:** A beam is considered as made up of number of planes which are parallel to each other when uniform beam is loaded by mass on end in the result of it all planes beam are bent into shape of arc. Planes inward of arc get compressed and planes outward side of arc get elongated in between these two portion there is layer neither elongated nor the shorten such a surface s called neutral surface or neutral plane. Expending and compressed layers form a bending couple. Moment of bending couple is known as bending moment. Internal Bending moment of beam (G) is given as:

$$G = \frac{Ybd^3}{12R} \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Here,

b = breadth of the beam an

d = thickness (depth) of beam

R = radius of curvature of glass of beam.

Bending moment due to mass attached to its ends

$$G = mgL \ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Here,

g = gravitational acceleration

m = mass loaded by ends

L = length of beam

Under the mechanical equilibrium the equation 1 and 2 should be equal

$$G = \frac{Ybd^3}{12R} = mgl$$

$$Y = \frac{12mgLR}{bd^3}$$

(vii) **Interference:** When two coherent light waves travel in the same direction and superimposed at a point in space as a result the intensity of light is redistributed and the resultant light is maximum at some points and minimum on others, this phenomenon is known as interference of light. We can infer from Fig. (2) and (3), that the superposition of two trains of sine waves of the same frequency and travelling along the same line is to produce another sine wave of that frequency but having a new amplitude which is determined for given values their amplitudes by relative the phase difference between these two waves.

If the phase difference between the waves is $2n\pi$ (here n = 0, 1, 2, 3….) or in phase, it will give maximum resultant intensity (Solid line) and it known as constructive interference.

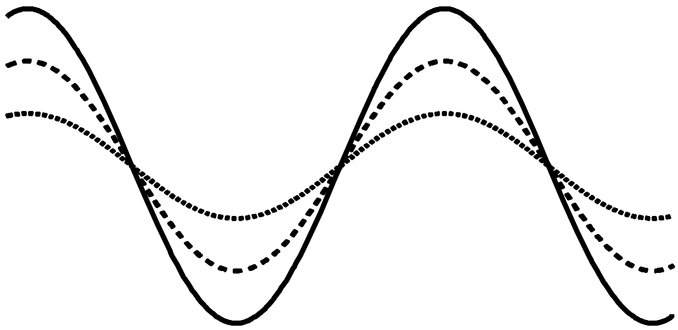

Fig. 2*: Constructive interference*

For those points where the waves meet in the phase difference of $(2n+1)\ \pi$ or opposite phase, the resultant intensity will be minimum (Solid line) i.e. destructive interference.

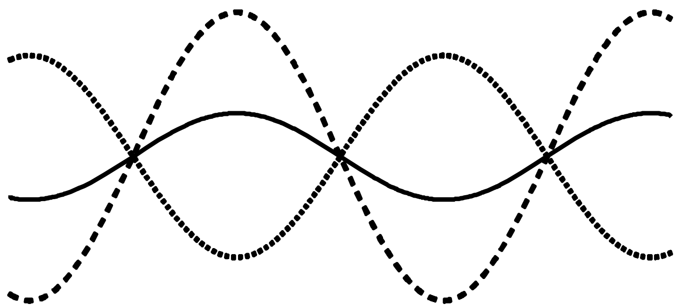

Fig. 3: *Destructive interference.*

(viii) **Newton ring:** In Newton's ring experiment setup(see Fig.1), rays from sodium lamp are reflected from a transparent glass plate inclined at 45° to the vertically and fall normally on the air gap between a plano-convex lens and a plane glass surface the rays reflected from the upper and lower surfaces of air gap are transmitted through the inclined glass plate and an received by travelling microscope. Interference between these two reflected gives a pattern in which alternate bright and dark concentric circular rings with their dark centre is occurred. These circular fringes are called as Newton's ring. Where diameter of n^{th} ring is given as

$$D_n = \sqrt{8Rt_n}$$

Here, t_n is the thickness of the air film for n^{th} order of fringe.

The travelling microscope can be moved along horizontal rails and can be locked at any position. Now read the main scale reading and vernier scale reading of the travelling microscope and use it for calculation of diameter of Newton's rings.

Cornu's method: This is an extension of Newton's ring experiment with the help of Cornu's experiment elastic constant can be calculated as shown experimental set up in the figure 4. We use glass beam instead of plane glass plate below the convex lens. When mass is loaded on the beam it get circular in result of Newton's rings change into elliptical shape due to the bending. The new Newton's rings get shrinks along the length of beam. Let D_n^0 is the diameter of n^{th} circular ring in the absence of bending and D_n^1 indicates the diameter of nth ring after bending of beam (see Fig 5.). Longitudinal bending also causes small lateral bending so the Newton rings get small extension in the lateral direction. Let the diameter of n^{th} ring in lateral direction is D_n^2. Due to small extension in lateral direction considered as $D_n^2 = D_n^0$.

Fig. 4: *Cornu's Method.*

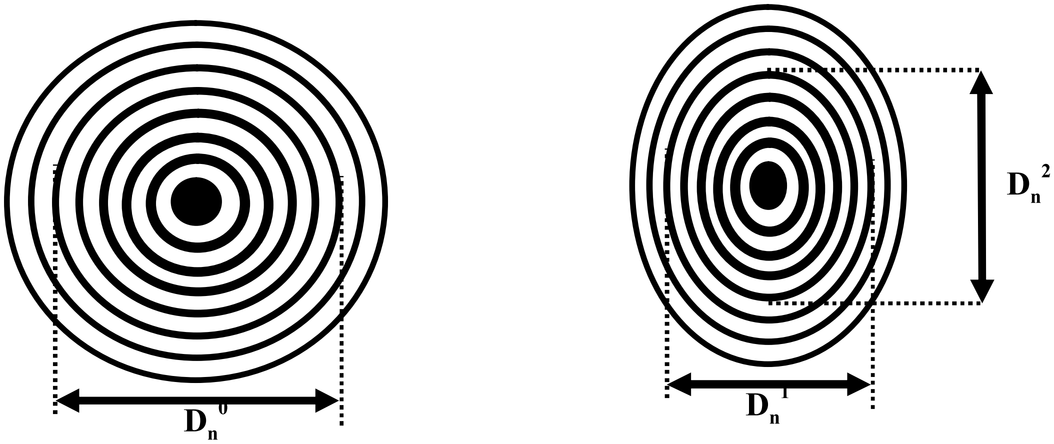

Fig. 5: *Newton's Rings in Cornu's Method.*

For the Young's modulus longitudinal strain is only to be considered so we count only D_n^1. The longitudinal radius of curvature of beam can be calculated as:

$$\frac{1}{R} = 4n\lambda\left[\frac{1}{(D_n^1)^2} - \frac{1}{(D_n^0)^2}\right]$$

(ix) **Vernier calipers:** A vernier caliper (see Fig. 6) consists of a metal ruler (called main Scale) with a vernier scale attached. A Vernier scale is a small, moveable scale placed next to the main scale of a measuring instrument (see Fig. 7). Using vernier scale with main scale we can made a measurement of distance (or length) to an accuracy of a tenth of a millimeter or better. For measurement of distance, use either the inside edges of the jaws, or the outside edges of the two prongs at the top of the caliper (see Fig. 6).

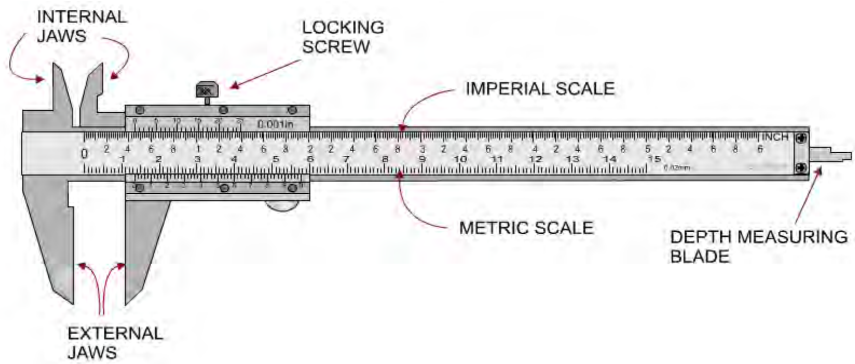

Fig. 6: Vernier caliper.

To read the caliper, the main metric scale is read first and record the numbers of line on main scale correspond to the last line on the rule just before the index line on the vernier scale (In Fig.7 this number is 13). Next find out the number of a vernier line which lines up with a line on the rule . In figure we can see this number is 21. Here we can see that the least count of main scale is 1 mm and 1 mm further divided into 50 division of variner scale, hence list count of this variner caliper is 1mm/50=0.02mm.

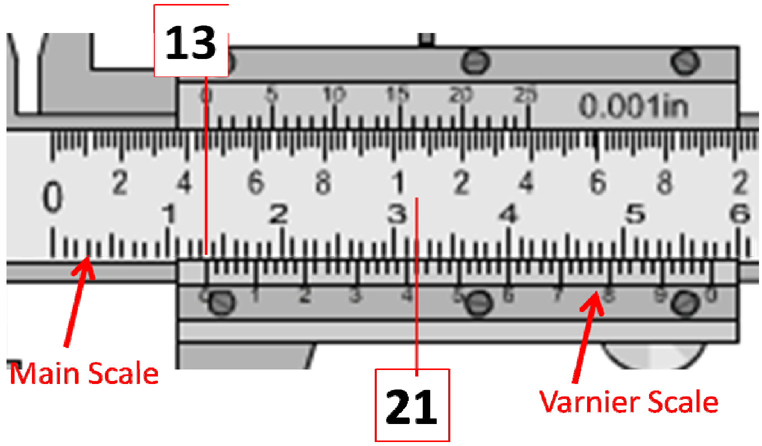

Fig. 7: *Vernier caliper (enlarged view of vernier and main scale).*

Thus, the reading of variner caliper in figure 7, can be calculated as following:

Main scale reading + Variner scale reading X least count

or

13 mm+21 X 0.02 mm=13.42 mm.

(xi) **Screw Gauge:** Micrometer screw gauge is a small metallic device whose working principle based on the "screw" principle (See Fig. 8). A screw gauge having a U shaped metallic frame.This instrument generally used to measure the diameter or thickness of any object like thin wire with very good accuracy.

(xii) A micrometer screw gauge also carries two scales similar to vernier caliper - a main scale and a circular scale (see Fig. 9). Generally the main scale is a millimeter scale and circular scale divided into 100 equal divisions. In order to measure the small length with a screw gauge, the object like thin wire is placed between the jaws which are moved by the thimble. The main scale reading is considered as the number of last visible line on main scale just to the left of the thimble (see fig.9). From figure 9, we can infer that the last line number 9 is visible; hence main scale reading is 9 mm. The circular scale reading read as the number of divisions on the thimble scale matches with the main scale (in Fig 9, this reading is 40).

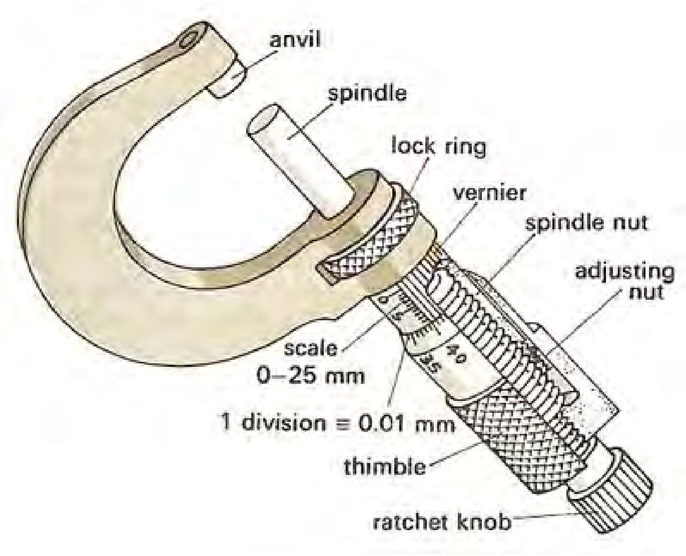

Fig. 8: *Screw Gauge.*

Furthermore, in one complete revolutions of the thimble the main scale reading change by 1mm. Hence the least count of circular scale is 1mm divided by number of divisions on the circular scale (n=100) or *least count of screw gauge = 1mm/100=0.01mm.*

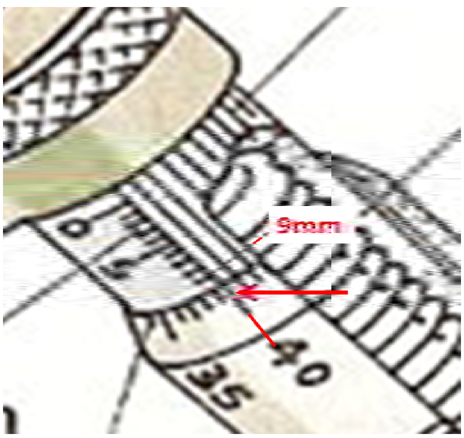

Fig. 9: Enlarged view of scales of the *Screw Gauge.*

So reading of screw gauge in figure 9 will be:

Main scale reading + circular scale reading X least count

or

= 9 mm+40 X 0.01 mm=9.40 mm.

(xiii) Travelling Microscope: It is an optical instrument used for measuring the length order of 0.01 mm. it consist of a microscope mounted on two rails. Position of the microscope can be varied by sliding it on the rails. It has two scales (main scale and vernier scale) and main scales attached with moving direction. For the measurement of Newton's ring diameter, the travelling microscope is moved along horizontal rails and locked at any position. Now read the main scale reading and vernier scale reading of the travelling microscope and use it for calculation of diameter of Newton's rings. The reading is read as similarly to vernier calipers.

Fig. 10: *Travelling microscope.*

Sodium Lamp: A sodium vapour lamp is a gas discharge lamp. The sodium lamp contains a double-walled envelope having a special glass that is resistant to blackening by hot sodium vapour. The inner envelope contains inert gases (argon or neon at low pressure) and a small amount of metallic sodium. Initially the discharge is started in the rare gas due to electrons emitted by the coiled filament ***F***. A relatively small positive potential is applied to the anode to sustained discharge. Since the space between the double walls is highly evacuated to prevent heat loss so that the temperature inside the lamp increases rapidly to the point where the sodium melts and vaporizes into the arc. So, due to vaporizations of sodium, the rare-gas spectrum disappear gradually, a yellow colour due to radiation from the more easily ionized atoms of sodium appears. After few minutes, we got almost yellow colour due to the sodium doublet. These radiations can be use as monochromatic light without the use of filters. The doublet is so narrow (separation 5.97 Å) that for our interference measurements with small path difference it may be assumed to be a single line (monochromatic) with the average wavelength 5892 Å.

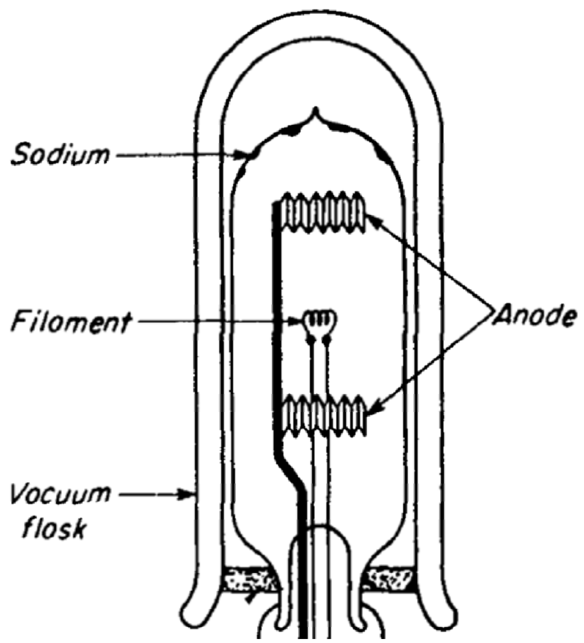

Fig. 7: *Sodium lamp.*

29.6 Self Learning Exercise-I

Q.1 What is SI unit of Young's modulus?

Q.2 Why you use sodium light in the experiment?

Q.3 What is the beam?

Q.4 What do you mean by elastic deformation?

Q.5 What is the stress?

29.7 Procedure

(i) To determine the breadth of glass beam

1. Adjust breadth of Glass beam in external jaw of vernier caliper and note the main scale reading and vernier scale reading and calculate total reading.
2. Repeat same process for other two any position along the length of beam and the note down the measurements.
3. Take the average breadth of beam.

(ii) To determine the thickness of glass beam

1. Adjust thickness of glass beam in the Anvil and Spindle of screw gauge by rotating the knob.
2. Note down the main scale reading and vernier scale reading of screw gauge.
3. Repeat the above process for different position, taking the thickness of glass beam.
4. Take the average breadth of beam.

(iii) To find the diameter of rings without mass

1. Put the given glass beam symmetrically over the two knife edges.
2. A convex lens is placed over the beam.
3. It must be ensure that the light should be fall normally on the air film with the help of glass plate on inclination of 45°.
4. The interference fringes are clearly viewed by means of travelling microscope.
5. Fix the cross wire on any of the n^{th} bright ring (or dark) on one side (left or right) using the knob and the reading by micrometer of travelling microscope is observed
6. Further move the cross wire to the $(n-1)^{th}$ bright ring (or dark) on the same

side and note down reading of micrometer.

7. In similar way observe the readings of the rings on either side of the centre position.

(iv) Diameter of rings with mass

2. Adjust the distance between the weight hanger and the knife edges.
3. Add mass on the weight hanger.
4. Repeat steps 5 to 7 to measure the horizontal and vertical position of rings.

29.8 Observation

For travelling Microscope:

Main scale least count (S) = ……. .meter

No. of verniers scale division N =………

Least count (S/N) =………meter

To find the breadth of glass beam using Vernier calipers:

Least count of vernier calipers = …………… meter

S. No.	**Main scale reading (meter)**	**Vernier scale reading**	**Total Reading=** ***Main scale reading*** **+** ***Variner scale reading X least count*** **(meter)**
1			
2			
3			
4			

Breadth of plate, b = ………… meter.

To find the thickness of glass beam using screw gauge:

Least count of screw guage = …………… meter

S. No.	Main scale reading (meter)	Circular scale reading	Total Reading Total Reading= Main scale reading + circular scale reading X least count (meter)
1			
2			
3			
4			

Thickness of glass beam, d = ……….. meter

To find the diameter of rings in horizontal direction:

λ = ………………. meter; L =………………. meter

Table: to measure the diameters of Newton's Rings without loading of the beam

S. No.	Order (n)	Microscope reading						D_n^0 =(b-a) (meter)
		Left			Right			
		Main scale reading	Vernier scale reading	a Total Reading (meter)	Main scale reading	Vernier scale reading	b Total Reading (meter)	
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								

Table: to measure the diameters of Newton's Rings when the beam is loaded.

S. No.	Order (n)	Microscope reading						D_n^1 =(b-a) (meter)
		Left			Right			
		Main scale reading	Vernier scale reading	a Total Reading (meter)	Main scale reading	Vernier scale reading	b Total Reading (meter)	
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								

Table: To measure the average R the beam is loaded

S. No.	$(D_n^0)^2$ (meter^2)	$(D_n^1)^2$ (meter^2)	$(D_n^0)^2 \times (D_n^1)^2$ (meter^2)	$(D_n^0)^2 - (D_n^1)^2$ (meter^2)	R (meter)	Average of R (meter)
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						

29.9 Calculations

Model Calculations:

m = mass suspended on the beam =100g = 0.1Kg

g = gravitation acceleration=9.8m/sec^2

L= Length of the beam = 10cm=0.1m

b = breadth of glass beam =3cm=.03m

d = Thickness of beam under test=1mm=.001m

λ = wavelength of light source =5892 x10^{-10}m

n = order of fringe = 6

D_n^0 = Diameter of nth order fringe without mass. = 0.345cm=.00345m

D_n^1= Diameter of nth order fringe with mass m= 0.281cm=0.00281 m

$$R = \frac{1}{4n\lambda}\frac{(D_n^0)^2 \times (D_n^1)^2}{(D_n^0)^2 - (D_n^1)^2}$$

$$R = \frac{1}{4 \times 6 \times 5892 \times 10^{-10}}\left\{\frac{(0.00345)^2 \times (0.00281)^2}{(0.00345)^2 - (0.00281)^2}\right\}$$

$$R = 1.659 \text{ meter}$$

$$Y = \frac{12mgLR}{bd^3} = \frac{12 \times 0.1 \times 9.80 \times 0.1 \times 1.659}{0.03 \times (.001)^3}$$

$$Y \approx 6.5 \times 10^{10}\frac{N}{m^2}$$

29.10 Result

For a given beam Young's modulus, Y=………………N/m^2.

29.11 Discussion

29.12 Precautions and Sources of error

1. Weight load on hanger slowly and carefully
2. Wait for taking the measurements for after loading of weight on hanger.
3. Position of glass beam should be remaining same for whole experiment.
4. The measurement of thicknesses of glass beam, should be made carefully because of Young's modulus depends upon cube of thicknesses of beam.
5. The experiment should be performed in a dark room, to achieve better contrast of rings.
6. Move travelling microscope in unidirectional during the measurements.

29.13 Self Learning Exercise-II

Q.1 What is the unit of strain?

Q.2 What is Young's modulus?

Q.3 What do you mean by neutral layer of bent beam?

Q.4 Why the centre of Newton's rings is dark?

Q.5 What is the purpose of the glass plate which is inclined at 45° in the experiment?

29.14 Glossary

Collimator: A device for producing a parallel beam of rays.

Elongation: Be long or stretched out.

Beam: A rod which having small cross section in compare to length.

Quasi: Partly similar

29.15 Answers to Self Learning Exercises

Answers to Self Learning Exercise -I

Ans.1: Nm^{-2}

Ans.2: Because sodium is quasi monochromatic light source.

Ans.3: A rod of uniform cross section and having very low thickness compared to its length known as a beam.

Ans.4: Elastic deformation is described as the change in the geometry of a body under the action of external forces.

Ans.5: Force per unit area.

Answers to Self Learning Exercise -II

Ans.1: Unit less

Ans.2: Longitudinal stress/ Longitudinal strain.

Ans.3: A layer between compressed plane and elongated plane.

Ans.4: Due to contact plano-convex lens and glass beam.

Ans.5: For the normal incidence of light on plano-convex lens.

29.16 Viva Questions

Q.1 What is Young's modulus of elasticity?

Q.2 What is longitudinal strain?

Q.3 What do you understand by elastic constants?

Q.4 What is the elastic limit?

Q.5 How the Young's modulus depends upon the temperature?

Q.6 Which property of material is indicated by the higher value of Young's modulus?

Q.7 What are the factors that are affecting the elasticity of material?

Q.8 What is the order of Young's modulus for metals?

Q.9 Why the Newton's rings are circular?

Q.10 Why should the light to falls the normally on Plano-convex lens?

Q.11 What is the basic principle of Newton's rings experiments?

Q.12 What will happen with Newton's ring pattern after loading the beam?

Q.13 What will happen with Young's modulus, if the thickness of beam is doubled?

Q.14 What will happen with Young's modulus, if the loading mass is doubled?

Q.15 What are coherence light sources?

Q.16 What is the relation between path difference and phase difference?

Q.17 What is the condition for constructive interference?

Q.18 What is the condition for destructive interference?

Q.19 If the yellow is replaced by green light source, how will it affect the experiment?

Q.20 What will happen if the sodium lamp is replaced by mercury lamp?

29.17 Answers to Viva Questions

Ans.1: Ratio of longitudinal stress to longitudinal strain in the limit of elasticity.

Ans.2: It is the ratio of the change in length of object to original length of object.

Ans.3: Elastic constant is ratio of stress to strain in the elastic limit.

Ans.4: Elastic limit is maximum limit of stress in which object returned to its original shape after removing deforming force.

Ans.5: Young's modulus decrease with incensement in the temperature.

Ans.6: Higher the Young's modulus indicated higher stiffness.

Ans.7: Temperature, impurity, a effect of hammering, crystalline structure.

Ans.8: $\sim 10^{10}$ NM^{-2}

Ans.9: Due to the circular geometry of plano-convex lens the locus of the points satisfying the condition for dark or bright fringes is circular.

Ans.10: The normal incidence of light in Newton ring experiment makes convenient the calculation. For normal incidence of light the angle of refraction can be taken zero.

Ans.11: Interference phenomena (division of amplitude).

Ans.12: Newton's rings become elliptical.

Ans.13: Young's modulus decrease by a factor of one by eight.

Ans.14: The value of Young's modulus will be remaining unchanged.

Ans.15: The light sources having same frequency (monochromatic) and their relatively phase difference should be zero or remain constant with time.

Ans.16: Phase difference = $(2\pi/\lambda)$ path difference.

Ans.17: Phase difference = $2n\pi$

Ans.18: Phase difference = $(2n+1)\,\pi$

Ans.19: The Newton's ring diameter and their thicknesses altered.

Ans.20: Newton's ring will be colourful.

References and Suggested Readings

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UNIT-30
Bipolar Junction Transistor

Structure of the Unit

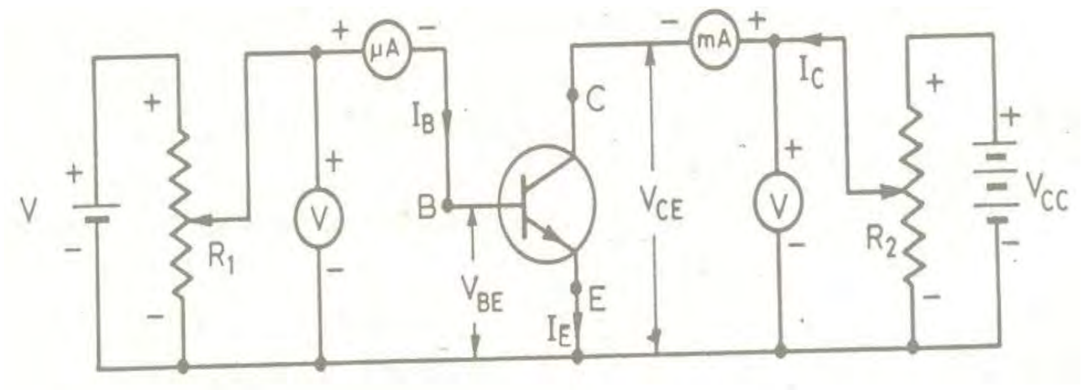
30.1 Aim

To study the input and output characteristics of a NPN transistor in a common emitter configuration.

30.2 Apparatus

Transistor, Voltmeter, ammeter, resistor, regulated power supply.

30.3 Diagram



30.4 Formula

From the input characteristics

$r_i = \Delta V_{BE} / \Delta I_B$ at V_{CE} =constant

(volts / A or Ω)

From the output characteristics

$r_o = \Delta V_{CE} / \Delta I_C$ at I_B =constant

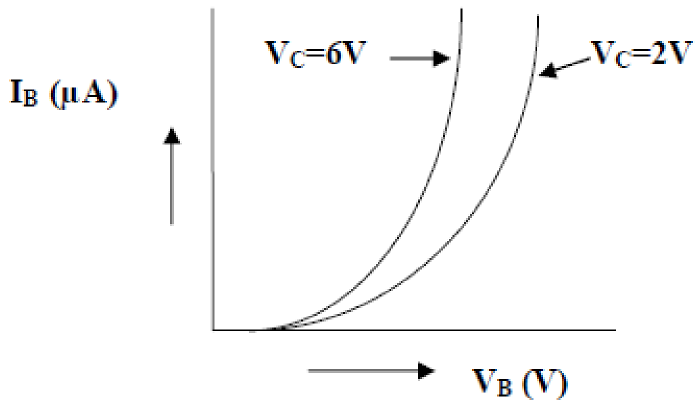
(volts / A or Ω)

From the transfer characteristics

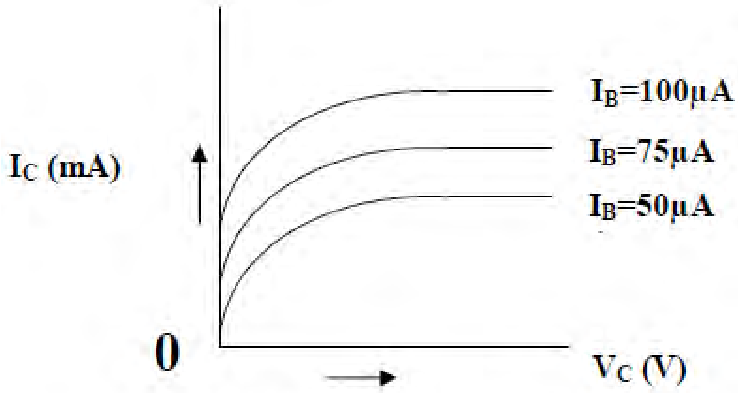
$\beta = \Delta I_C / \Delta I_B$ at V_{CE} =constant

30.5 Model Graph

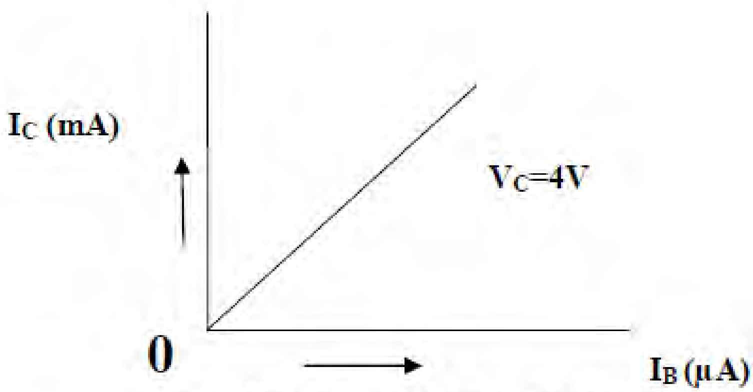
Model graphs for input characteristic, output characteristics and transfer characteristics are shown in following figures



INPUT CHARACTERSTIC



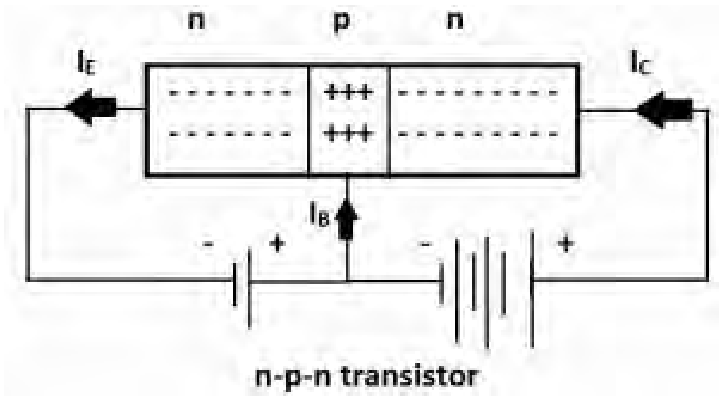
OUTPUT CHARACTERSTIC

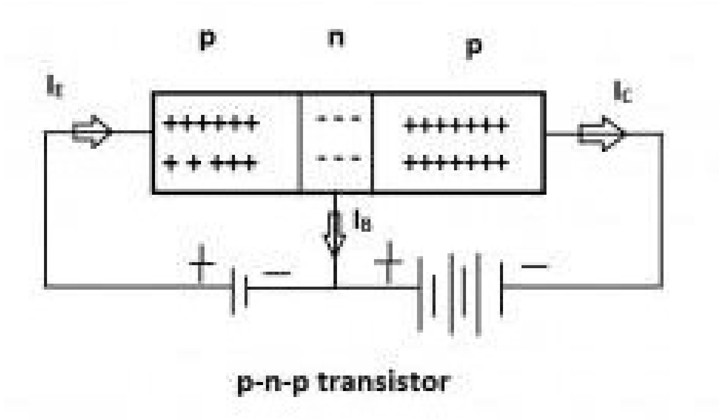


TRANSFER CHARACTERISTIC

30.6 Theory and Description

A BJT (Bipolar Junction Transistor) transistor has two similar semiconductor materials, and between them there is a third semi-conductive material of different type. So, if the two similar materials are P and the middle one is N, then we have a P-N-P transistor. Similarly, if the two materials are N and the middle one is P, then we have a N-P-N transistor.





Working principle of n-p-n and p-n-p transistor:-

In upper figure a n-p-n transistor is shown. In the left side, the emitter base junction is forward biased. P region is more positive than n-region. So electrons from n region can move easily towards the p region. It is meant that electrons come to the base from the emitter. On the right side collector-base junction is reverse biased so the collector region is more positive. Hence electrons travelling from the emitter towards the base are attracted strongly by the collector i.e. collector collects those electrons. While coming through the base some electrons and holes recombine in the base but about 95% electrons are speeded towards the collector and current flows from base to collector. Base is made very thin and lightly doped so that only a few number of electrons recombine with holes in the base and passes quickly through the base region.

For p-n-p transistor the biasing is done in a different way. Holes from the p-region enter into the base region and since collector is more negatively biased these holes speedily move towards the collector. In this way a strong current is produced.

Current flowing in the emitter region due to the flow of charges is called emitter current (I_E), current produced for the recombination of electrons and holes is called base current (I_B) and the current generated in the collector region due to the flow of charges is called collector current (I_C). The base current does not flow in the collector region. This current comes out through the base terminal. So it is seen that total emitter current does not flow to the collector region, i.e. the collector current is less than the emitter current. The relation between I_E, I_B and I_C is

$$I_E = I_B + I_C$$

The three parts of a BJT are collector, emitter and base. Before knowing about the bipolar junction transistor characteristics, we have to know about the modes of operation for this type of transistors. The modes are

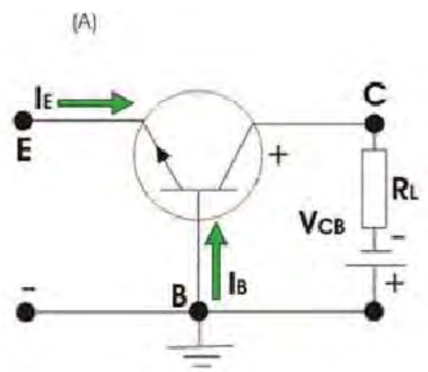
i) Common Base (CB) mode

ii) Common Emitter (CE) mode

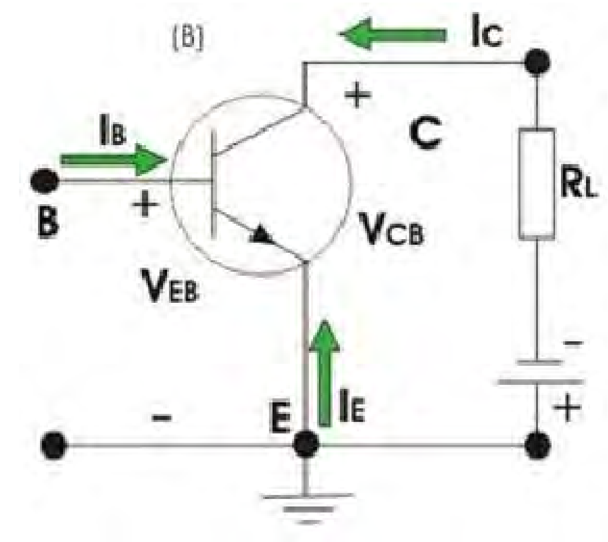
iii) Common Collector (CC) mode

All three types of modes are shown below

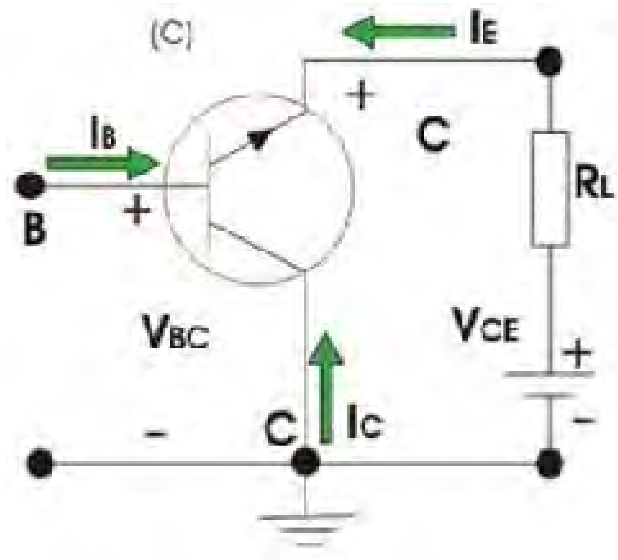
(A) Common base (CB) mode



(B) Common emitter (CE) mode



(C) Common collector (CC) mode

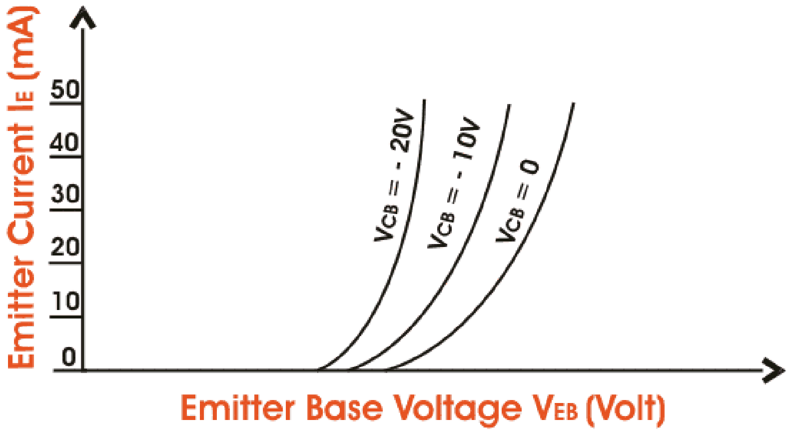


Characteristics of BJT

There are different characteristics for different modes of operation. Characteristics is nothing but the graphical forms of relationships among different current and voltage variables of the transistor. The characteristics for pnp transistors are given for different modes and different parameters.

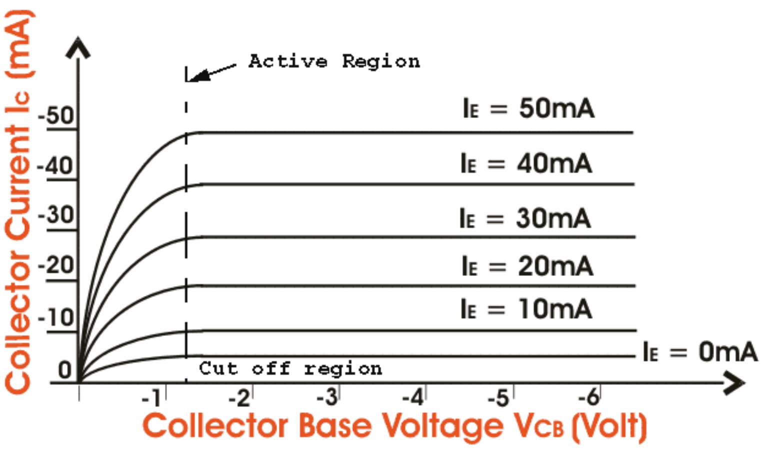
(A) Common Base Characteristics

Input Characteristics:- For pnp transistor, the input current is the emitter current (I_E) and the input voltage is the collector base voltage (V_{CB}).



As the emitter-base junction is forward biased, therefore the graph of I_E Vs V_{EB} is similar to the forward characteristics of a p-n diode. I_E increases for fixed V_{EB} when V_{CB} increases.

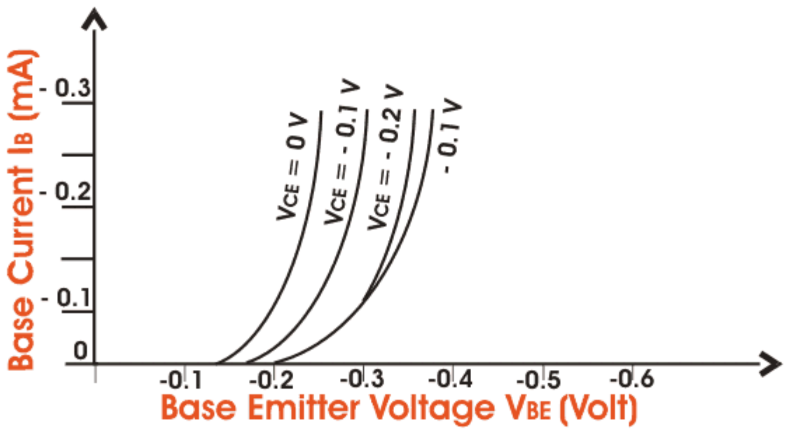
Output Characteristics:- The output characteristics shows the relation between output voltage and output current I_C is the output current and collector–base voltage and the emitter current I_E is the input current and works as the parameters. The figure below shows the output characteristics for a pnp transistor in CB mode.



As we know for pnp transistors I_E and V_{EB} are positive and I_C, I_B, V_{CB} are negative. These are three regions in the curve, active region ,saturation region and the cut off region. The active region is the region where the transistor operates normally. Here the emitter junction is reverse biased. Now the saturation region is the region where both the emitter collector junctions are forward biased. And finally the cut off region is the region where both emitter and the collector junctions are reverse biased.

(B) Common Emitter Characteristics

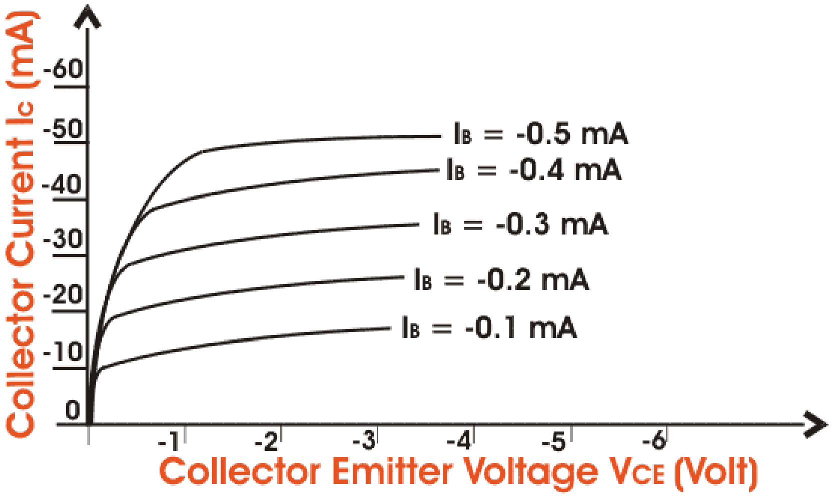
Input characteristics:-I_B (Base Current) is the input current, V_{BE} (Base-Emitter Voltage) is the input voltage for CE (Common Emitter) mode. So, the input characteristics for CE mode will be the relation between I_B and V_{BE} with V_{CE} as parameter. The characteristics are shown below



The typical CE input characteristics are similar to that of a forward biased of p-n diode. But as V_{CB} increases the base width decreases.

Output characteristics:- Output characteristics for CE mode is the curve or graph between collector current (I_C) and collector – emitter voltage (V_{CE}) when the base current I_B is the parameter. The characteristics is shown below in the figure.

Like the output characteristics of common-base transistor CE mode has also three regions named (i) Active region, (ii) cut-off regions, (iii) saturation region. The active region has collector region reverse biased and the emitter junction forward biased.



For cut-off region the emitter junction is slightly reverse biased and the collector current is not totally cut-off. And finally for saturation region both the collector and the emitter junction are forward biased.

Application of BJT

BJT's are used in discrete circuit designed due to availability of many types, and obviously because of its high transconductance and output resistance which is better than MOSFET. BJT's are suitable for high frequency application also. That's why they are used in radio frequency for wireless systems. Another application of BJT can be stated as small signal amplifier, metal proximity photocell, etc.

30.7 Self Learning Exercise-I

Q.1 Define BJT transistor.

Q.2 Write down different types of BJT transistor.

Q.3 Explain working principle of n-p-n and p-n-p transistor.

Q.4 Define

(a)Emitter current

(b)Base current

(c)Collector current

Q.5 What is Characteristics of the transistor.

Q.6 Explain application of BJT

30.8 Procedure

The scheme of connections is shown below in the figure

Input characteristics of a transistor:-

1. Adjust collector to emitter voltage at any suitable value (5 volts) and keep it constant.
2. Set the base current to a suitable value (10μA or 20μA) and note the corresponding base emitter voltage
3. Increase i_B and note the corresponding base emitter voltage $V_{BE.}$
4. Repeat steps '2' &'3' for different constant values of V_{CE}. Take at least three sets of observations at three different values of $V_{CE.}$
5. Plot the graph between base current (i_B) and base emitter (V_{BE}) with collector emitter (V_{CE}) voltage to be constant.
6. Plot at least three curves by choosing three different values of $V_{CB.}$
7. Draw a tangent to $V_{BE} – I_B$ curve & determine its slope .The reciprocal of the slope gives the value of input resistance of transistor.

Output characteristics of a transistor:-

1. Adjust base current i_B to 10μA by the base power supply and rheostat.
2. Adjust the collector emitter voltage V_{CE} is -5V and note the collector current i_C.
3. Reduce the collector emitter voltage V_{CE} and note the collector I_C every time corresponding to every V_{CE} keeping base current constant.
4. Repeat steps '2' and '3' for different constant values of base currents.
5. Draw a graph between collector currents (i_C) and collector emitter voltage V_{CE} with constant base current.
6. Take at-least three observation sets.
7. Draw a tangent on a V_{CE}-I_C curve and determine its slope. Reciprocal of the slope gives the value of output resistance of transistor.

Transfer characteristics of a transistor:-

1. Adjust collector voltage at suitable value and maintain it constant.
2. Adjust base current I_B to a suitable small but measurable value and

note down the corresponding collector current I_c. Increase I_B in small steps and note down the collector current I_c each time.

3. Plot a graph by taking base current I_B along x-axis and collector current I_C along y- axis as shown in fig. The slope of the graph gives the value of current gain β

30.9 Observation

1. **Input characteristics**

S.No.	Emitter base voltage V_{BE} (Volts)	Base current i_B (μA)		
		V_{CE}=...volts	V_{CE}=...volts	V_{CE}=...volts

2. **Output Characteristics**

S.No.	Collector base Voltage V_{CE}(volts)	Collector current i_C(mA)		
		I_B =…μA	I_B =…μA	I_B =…μA

3. **Transfer Characteristics**

Constant value of Collector Emitter voltage V_{CE} (Volts)

S.No.	Base current	Collector current

30.10 Graph

Plot the input characteristics, output characteristics and transfer characteristics of NPN transistor in CE configuration.

30.11 Calculations

30.12 Result

1. Plot of input characteristics, output characteristics and transfer characteristics of NPN transistor in CE configuration, is shown on the graph paper.
2. Transistor parameters are :

   Common emitter configuration:

   r_i =………Ohm

   r_o =………Ohm

   β =……….

30.13 Discussion

30.14 Precautions and Sources of error

4. Connections should be tight.
5. The voltage should be less than the breakdown voltage.
6. While doing the experiment the base end must be connected first and also while disconnecting base end should be disconnected first.
7. While performing the experiment do not exceed the ratings of the transistor. This may lead to damage the transistor.
8. Connect voltmeter and ammeter incorrect polarities as shown in the circuit diagram.
9. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.

10. Make sure while selecting the emitter, base and collector terminals of the transistor.

30.15 Self Learning Exercise-II

Q.1 Explain the various ways in which a transistor can be connected?

Q.2 Plot input, Output, and transfer characteristics?

Q.3 Define current gain of Common emitter transistor.

Q.4 What are input characteristics?

Q.5 What are output characteristics?

30.16 Glossary

Bipolar transistor, BJT **:** Bipolar Junction Transistor; a transistor consisting of three semiconductor regions (emitter, base, and collector) with alternating conductivity type (i.e. n-p-n or p-n-p); current flow comprises both majority and minority carriers (hence, "bipolar"), is controlled by vertical dimensions; current controlled device; key transistor structure in semiconductor electronics.

Base : Base region in bipolar transistor sandwiched between emitter and collector; typically n-type so that highly mobile electrons act as minority carriers in the base; should be very thin to allow rapid transfer of minority carriers from emitter to collector; electric field is created in the base by nonuniform doping to accelerate minority carriers moving from emitter to collector.

Collector **:** Collector region in bipolar transistor collecting carriers from the base; should be lightly doped to assure proper transistor operation.

Emitter **:** Emitter very high conductivity region in semiconductor devices acting as a source of free majority carriers typically injected into the adjacent region (for instance into base in the bipolar transistor)

HBT **:** Heterojunction Bipolar Transistor; very high-performance transistor structure; unlike conventional bipolar transistor built using more than one semiconductor material, hence "heterojunction"; takes advantage of different bandgap of semiconductors used to form emitter, base and collector; e.g. n-AlGaAs/p-GaAs/n-GaAs, or SiGe in combination with Si; formed using high precision epitaxy such as MBE or MOCVD.

Diode Rectifier : An electronic device with two wires or terminals. A rectifier allows electrical current to flow through in only one direction and is used for converting alternating current into direct current. Rectifiers were important for use in radios, which required direct current to power the amplifiers driving speakers or headphones.

Direct Current (DC) : Current which moves in a single direction in a steady flow. Normal household electricity is alternating current (AC) which repeatedly reverses its direction. However, many electronics devices require DC, and therefore must convert the current into DC before using it. Diodes are used to convert AC to DC.

Holes : When an array of atoms in a crystal is missing a conducting electron, it's said to have a "hole." Since conducting electrons are negative, holes are positive. Even though holes are an absence of a conducting electron, scientists often talk about holes flowing as if they were real particles.

N-type semiconductor : A semiconductor which has an excess of conduction electrons. A semiconductor can be made into N-type by adding trace amounts of another element to the original semiconductor crystal. Today's transistors all require sections of both N-type and P-type semiconductors.

P-type semiconductor : A semiconductor which has an excess of conducting holes. It is created by adding trace amounts of other elements to the original pure semiconductor crystal. Today's transistors all require sections of both N- type and P-type semiconductors.

Semiconductor : A material that conducts more than an insulator but less than a conductor. Some semiconductors conduct at some times but not at others. Some common semiconductors are silicon and germanium. Transistors are made out of semiconductor crystals.

30.17 Answers to Self Learning Exercises

Answers to Self Learning Exercise -I

Ans.1: A BJT (Bipolar Junction Transistor) transistor has two similar semiconductor materials, and between them there is a third semi-conductive material of different type. So, if the two similar materials are P and the middle one is N, then we have a P-N-P transistor. Similarly, if the two materials are N and the middle one is P, then we have a N-P-N transistor.

Ans.2: PNP and NPN

Ans.4: answers for part (a),(b),(c)are

a. Current flowing in the emitter region due to the flow of charges is called emitter current (I_E)
b. Current produced for the recombination of electrons and holes is called base current (I_B) and
c. The current generated in the collector region due to the flow of charges is called collector current (I_C).

Ans.5: Characteristics is nothing but the graphical forms of relationships among different current and voltage variables of the transistor.

Answers to Self Learning Exercise -II

Ans.1: CE, CB, CC configuration.

Ans.3: $\beta = \Delta I_C / \Delta I_B$ at V_{CE} =constant

Ans.4: These curves relate input current and input voltage for a given value of output voltage.

Ans.5: These curves relate output voltage and output current for a given value of input current.

30.18 Viva Questions

Q.1 What is a transistor?

Q.2 Write the relation between α and β?

Q.3 What is the range of α?

Q.4 Why α is less than unity?

Q.5 Input and output impedance equations for CB configuration?

Q.6 What do you mean by biasing of transistor?

Q.7 What is DC current gain in common base configuration?

Q.8 What is the typical value for DC current?

Q.9 What is AC current gain in CB configuration?

Q.10 Which configuration has highest voltage gain?

Q.11 Which configuration is most widely used?

Q.12 What is operating point?

Q.13 Which region is heavily doped in transistor?

Q.14 Which region is lightly doped in transistor?

30.19 Answers to Viva Questions

Ans.1: A transistor is a semiconductor device used to amplify and switch electronic signals and electrical power. It is composed of semiconductor material with at least three terminals for connection to an external circuit. The term transistor was coined by John R. Pierce as a portmanteau of the term "transfer resistor".

Ans.2:

$$\beta = \frac{\alpha}{1-\alpha} \leftrightarrow \alpha = \frac{\beta}{\beta+1}$$

Ans.3: The important parameter is the common-base current gain, α. The common-base current gain is approximately the gain of current from emitter to collector in the forward-active region. This ratio usually has a value close to unity; between 0.98 and 0.998.

Ans.4: It is less than unity due to recombination of charge carriers as they cross the base region.

Ans.5: $h_{ib}=V_{BE}/I_E, 1/h_{oe}=V_{CE}/I_C$

Ans.6: When DC voltages are applied across the different terminals of the transistor, it is called biasing.

Ans.7: It is the ratio of collector current I_c to emitter current I_E.

Ans.8: 0.99

Ans.9: It is the ratio of charge in collector current to change in emitter current.

Ans.10: Common emitter.

Ans.11: Common emitter.

Ans.12: The zero signal values of I_c and $V_{cc.}$

Ans.13: Emitter

Ans.14: Base

References and Suggested Readings

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