Exp. No.2.1

Spectrometer- i-d curve

Aim: To study the relationship between the angle of incidence 'i' and the angle of deviation 'd' of a glass prism and hence to determine the refractive index of the material of the prism by drawing the graph of 'i' and 'd'.

Apparatus: Spectrometer, sodium vapor lamp, prism, reading lens etc.

Theory: For a given prism, corresponding to a given angle of deviation there are two possible angles of incidence i_1 and i_2. These two angles are such that if one of the angles is the angle of incidence, the other angle will be the angle of emergence.

Let i_1 and i_2 be the two angles of incidence and r_1 and r_2 be the corresponding angles of refraction for the given angle of deviation d. Then,

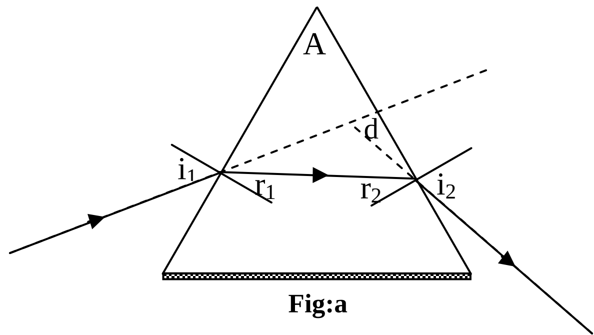


Fig:a

$$i_1 + i_2 = A + d \qquad (1)$$

$$r_1 + r_2 = A \qquad (2)$$

Fig.b gives the variation of angle of deviation d with angle of incidence i. When the angle of deviation is minimum, $i_1 = i_2 = i$, $r_1 = r_2 = r$ and $d = D$. Then, from eqn.1 we get,

$$2i = A + D \qquad (3)$$

$$i = \frac{A+D}{2} \qquad (4)$$

From eqn.2,

$$r = \frac{A}{2} \qquad (5)$$

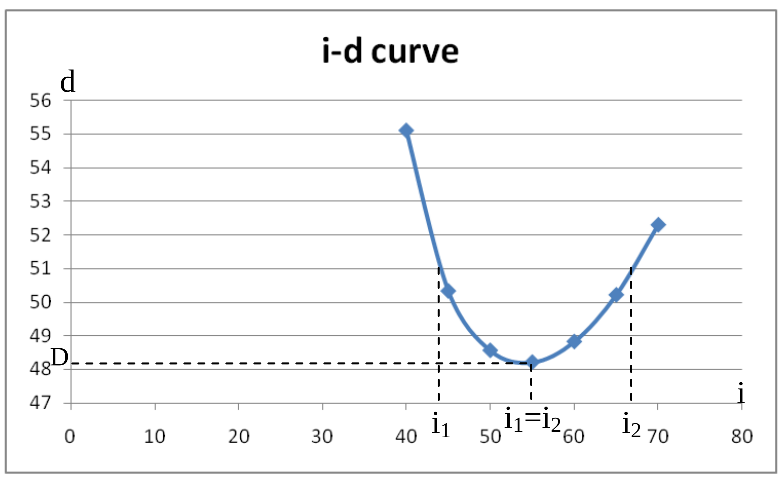


Fig.b : i-d curve for an equilateral prism of μ = 1.62

Refractive index of the material of the prism,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad (6)$$

Procedure: All the preliminary adjustments of the spectrometer are made (refer Exp. No. 1.11 practical-I). The prism is mounted on the prism table with its base is parallel and close to the clamp. The prism table is leveled either by observing the reflected images from both the sides of the prism or by using a spirit level. Then the prism is removed.

Adjustment to set the prism for a particular angle of incidence, say 'i' : Now the telescope is brought parallel to the collimator and the direct image of the slit is obtained at the vertical wire of the cross wire. The reading on one of the verniers is noted. Now the telescope is released and turned through an angle θ = 180–2i as shown in the fig.c (dashed arrow represents the motion of the telescope) and it is clamped there. Place the prism on the prism table with one of the faces, say AB, facing the collimator. Then the vernier table (or prism table) is rotated to and fro so that the image of the slit reflected from the face AB is obtained on the vertical cross wire. The vernier table is clamped there. Now the prism is set for the angle of incidence i. [It may be convenient to set the two verniers at 0-180 for the direct image. But in this case the prism table alone is rotated to find the reflected image.]

The telescope is then released, turned towards the refracted ray and the refracted image of the slit is obtained at the vertical cross wire. The readings on both the verniers are noted. Let it be ‘a’. Again the telescope is brought in a line with the collimator and direct image of the slit is obtained at the cross wire. The readings (b) on both the verniers are taken. The difference between ‘a’ and ‘b’ gives the angle of deviation. The angles of deviation for different angles of incident, say, i = 40°, 45°, 50° etc. [For prisms with μ ≈ 1.5 to 1.6, the range of i is 35° to 65° and for prisms with, μ ≈ 1.6 to 1.7, the range of i is 40° to 70°].

A graph is plotted with ‘i’ along the X-axis and ‘d’ along the Y-axis as shown in fig.b. The angle of incidence corresponding to the angle of minimum deviation can be determined from the graph. Then by using eqns.1 and 3 the angle of the prism can be calculated and the refractive index is calculated by using the eqn.6.

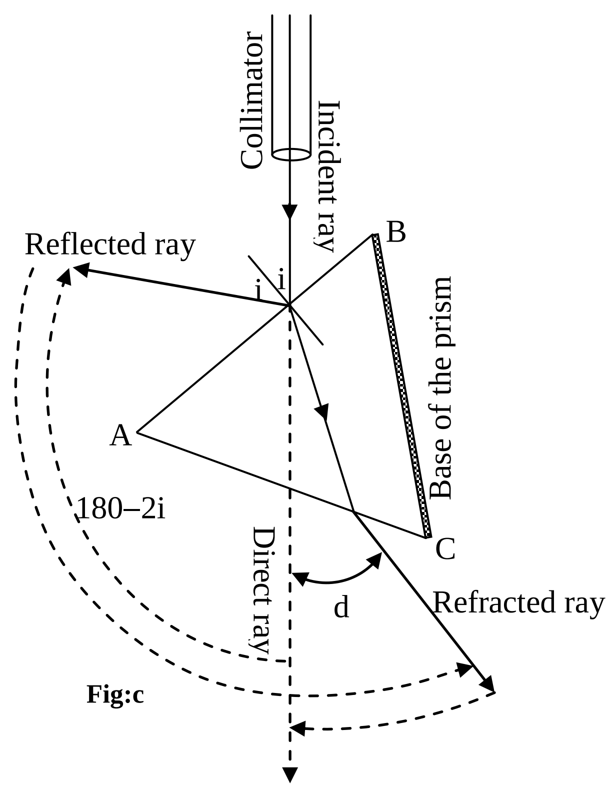


Fig:c

Precautions:

- The vernier table and the prism table are initially adjusted at the proper positions (both the verniers are in a line perpendicular to collimator) so that the readings on both the verniers are conveniently taken.
- To get the reflected and refracted ray simultaneously, the prism table must be set such that the reflected ray is on the side of the refracting edge (A) of the prism as shown in fig.c.
- Reading lens must be used to observe the vernier readings.
- If you are initially set the vernier table 0-180 for direct image, make sure that the final reading for direct image is still 0-180. If it is not 0-180, take the new direct reading.
- Don’t forget to clamp the vernier table and the telescope after each adjustment. For taking the direct reading, the prism must be removed carefully without any change in the vernier table.

Observation and Tabulation of data:

Value of one main scale division (1 m s d) = ……………

Number of divisions on the vernier n = ……………

Least count (L C) = $\frac{\text{Value of 1 m s d}}{n}$ = ……………

[One degree = 60 minute, (1° = 60′)]

Angle of incidence 'i'	Direct reading on any vernier	Angle through which telescope is to be turned θ = 180−2i	Reading corresponding to refracted ray 'a'						Reading corresponding to direct ray 'b'						Angle of deviation d = a~b		
			Ver 1			Ver II			Ver 1			Ver II					
			M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	Ver I	Ver II	Mean
35																	
40																	
45																	
50																	
55																	
60																	
65																	
70																	

Result

Angle of the prism A = ………….

Refractive index of the material of the prism, μ = ………….

Standard data*

Refractive index against air for mean sodium line (589.3 nm)

Crown glass 1.48 ~ 1.61

Flint glass 1.53 ~ 1.96

Exp.No.2.2

Spectrometer-i_1-i_2 curve

Aim: To study the relationship between the two angles of incidence (one is the angle of incidence i_1 and the other is the angle of emergence i_2) for a given angle of deviation. We also aim to study the variation of angle of emergence with angle of incidence and to draw the i_1-i_2 curve.

Apparatus: Spectrometer, sodium vapor lamp, prism, reading lens etc.

Theory:

Let i_1 and i_2, respectively, be the angle of incidence and the angle of emergence of a prism of angle A corresponding to the angle of deviation d. Then,

$$i_1 + i_2 = A + d \qquad (1)$$

$$r_1 + r_2 = A \qquad (2)$$

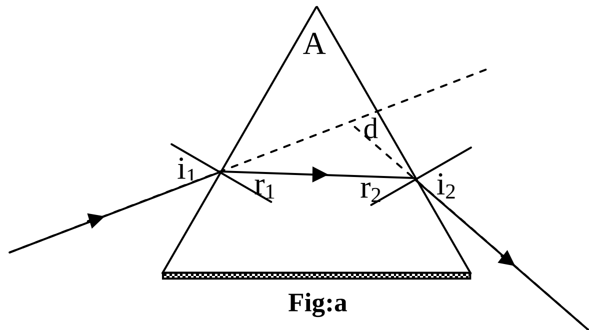


Fig:a

Fig.b gives the variation of angle of emergence i_2 with angle of incidence i_1. When the angle of deviation is minimum, $i_1 = i_2 = i$, $r_1 = r_2 = r$ and $d = D$. Then, from fig.b,

$$i = \frac{OB + OC}{2} \qquad (3)$$

By eqn.1,

$$2i = A + D \qquad (4)$$

$$D = 2i - A \qquad (5)$$

By eqn.4,

$$i = \frac{A + D}{2} \qquad (6)$$

From eqn.2,

$$r = \frac{A}{2} \qquad (7)$$

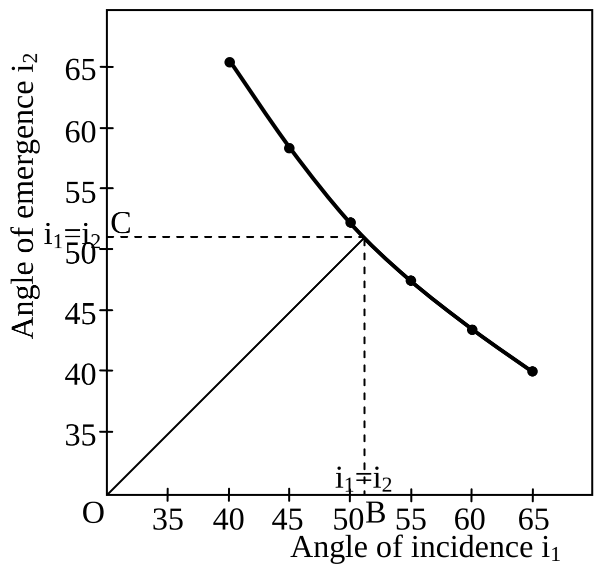


Fig.b: i_1-i_2 curve for an equilateral prism of $\mu = 1.56$
See that the scales are same for X and Y axes

Refractive index of the material of the prism, $$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad (8)$$

Procedure: Preliminary adjustments of the spectrometer are made (refer Exp. No. 1.11 of practical-I) and the prism is mounted on the prism table with its base is parallel and close to the clamp. The prism table is leveled either by observing the reflected images from both the sides of the prism or by using a spirit level.

The angle of the prism is found out either by the supplementary angle method (refer Exp. No. 2.6 of practical-II) or by observing the reflected rays from both sides of the prism.

Now the prism is set for a particular angle of incidence, say i_1 = 40° as in the i-d curve experiment. The telescope is then released and is brought in a line with the refracted ray. (The dashed curves indicate the motion of the telescope). The telescope is clamped there. By using the tangential screw of the telescope, the refracted image of the slit is made to coincide with the vertical wire.

Now looking through the telescope the vernier table is rotated in such a direction that the refracted image moves towards the minimum deviation position (the refracted image moves towards the direction of direct ray). Continue the rotation of the vernier table in the same direction till the refracted image is returned at the vertical wire of the telescope. The vernier table is then clamped and the tangential screw of it is adjusted to get the refracted image on the vertical cross wire.

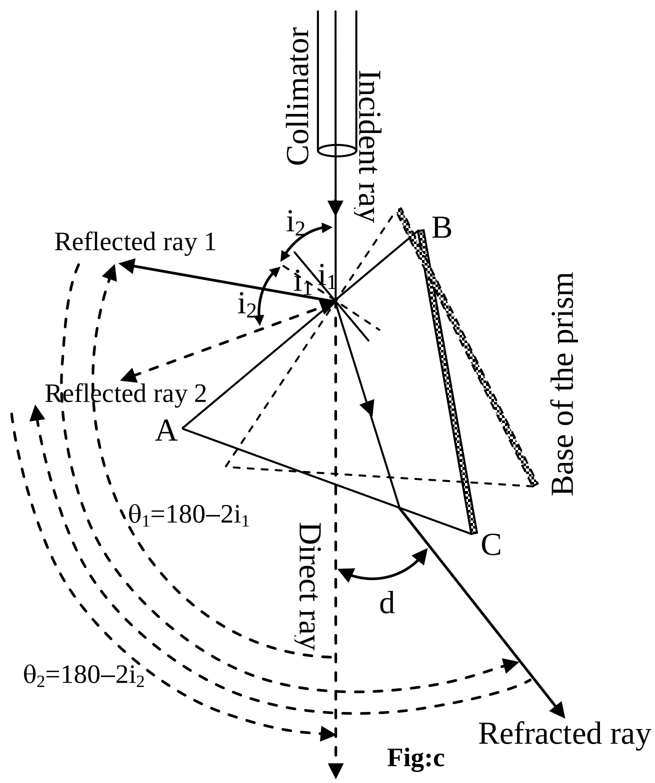


Fig:c

The telescope is released and is rotated towards the reflected ray. (Reflected ray 2 in the fig.c). By adjusting the tangential screw of the telescope, the reflected image of the slit is obtained exactly on the cross wire. The readings on both the verniers are noted. (Use the reading lens). Let it be ‘a’.

The telescope is again released. It is brought in the line of the collimator and the direct image of the slit is obtained on the cross wire. Again readings (b) on both the verniers are taken. The difference between the reading of the reflected image and the direct image gives $\theta_2=180-2i_2$. From that i_2 can be calculated.

The experiment is repeated for different values of i_1 = 45°, 50°, 55° etc. In each case i_2 is calculated. A graph is drawn between i_1 and i_2. From the graph, the angle of incidence ‘i’ corresponding to angle of minimum deviation D can be found by using eqn.3. Hence D can be calculated using the equation D = 2i − A.

Finally, the refractive index of the material of the prism is calculated using the eqn.8.

Precautions:

- See all the precautions given in the i-d curve experiment.
- Draw the i_1-i_2 curve with same scale in both the axes. Then it is easy to find out the $i = i_1 = i_2$ for minimum deviation from graph by simply drawing the bisector of the angle between X and Y axes (diagonal of squares on the graph).

Observation and tabulation

Value of one main scale division (1 m s d) = ……………

Number of divisions on the vernier n = ……………

Least count (L C) = $\dfrac{\text{Value of 1 m s d}}{n}$ = ……………

[One degree = 60 minute, $(1^\circ = 60')$]

Angle of the prism A

	Ver I			Ver II			Mean	
	M S R	V S R	Total	M S R	V S R	Total	2A	A
Reflected image from first face ‘a’								
Reflected image from second face ‘b’								
Difference between the above readings 2A = a~b				2A = a~b				

Determination of i_2

Angle of incidence ‘i_1’	Direct reading on any vernier	$\theta_1 = 180 - 2i_1$	Reading corresponding to reflected ray for second angle of incidence ‘a’						Reading corresponding to direct ray after the second reflection ‘b’						θ_2 = a~b			$i_2 = \frac{180-\theta_2}{2}$
			Ver 1			Ver II			Ver 1			Ver II						
			M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	Ver I	Ver II	Mean	
35																		
40																		
45																		
50																		
55																		
60																		
65																		
70																		

Result

Angle of the prism A = ……….

Angle of incidence corresponding to minimum deviation, i = ……….

Angle of minimum deviation D = ……….

Refractive index of the material of the prism μ = ……….

Standard data*: Same as in the experiment for i-d curve.

Exp.No.2.3

Spectrometer-Cauchy's constants

Aim: To determine the constants in the Cauchy's dispersion formula for the material of the prism.

Apparatus: Spectrometer, mercury vapor lamp, prism, reading lens etc.

Theory: Considering the microscopic properties of the bound charged particles of a transparent medium Cauchy developed a relation connecting the refractive index of the material and the wavelength of light passing through it. *Cauchy's relation* between the refractive index μ of the material and the wavelength λ of the light is given by,

$$\text{Refractive index,} \quad \mu = A + \frac{B}{\lambda^2} \tag{1}$$

where, A and B are constants for a transparent material and are called the Cauchy's constants. (Do not confuse with constant A and the angle of the prism A). These constants can be determined by a method as follows. Let μ_1 and μ_2 be the refractive indices corresponding to the wavelengths λ_1 and λ_2 respectively. Then, (if $\mu_1 > \mu_2$)

$$\mu_1 = A + \frac{B}{\lambda_1^2} \tag{2}$$

$$\mu_2 = A + \frac{B}{\lambda_2^2} \tag{3}$$

$$\mu_1 - \mu_2 = B\left(\frac{1}{\lambda_1^2} - \frac{1}{\lambda_2^2}\right) = B\left(\frac{\lambda_2^2 - \lambda_1^2}{\lambda_1^2\lambda_2^2}\right)$$

$$B = \frac{(\mu_1 - \mu_2)\lambda_1^2\lambda_2^2}{\lambda_2^2 - \lambda_1^2} \tag{4}$$

From eqn.2 and 3,

$$A = \mu_1 - \frac{B}{\lambda_1^2} \tag{5a}$$

Or,

$$A = \mu_2 - \frac{B}{\lambda_2^2} \tag{5b}$$

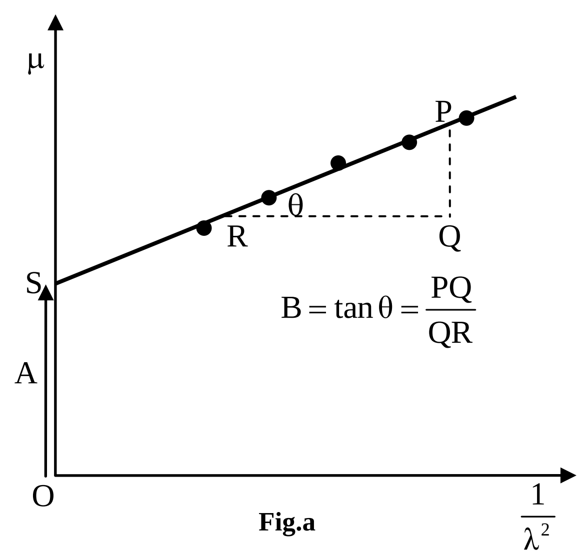


Fig.a

If D is the angle of minimum deviation for a wavelength λ when it passes through a prism of angle A', the refractive index μ is given by,

$$\mu = \frac{\sin\left(\frac{A'+D}{2}\right)}{\sin\left(\frac{A'}{2}\right)} \tag{6}$$

Cauchy's constants can also be determined graphically. A graph is drawn with $\frac{1}{\lambda^2}$ along the X axis and μ along the Y axis (fig.a). The graph will be a straight line. Its slope gives the constant B and the Y intercept gives the constant A.

Procedure: As usual, the preliminary adjustments, including the leveling of the prism table, of the spectrometer are made. The angle of the prism A' is determined as described in Exp.No.1. 11 of practical-I or Exp. No. 2.6 of practical-II.

The prism is then adjusted to obtain the refracted spectrum. It consists of different spectral lines with violet being deviated most and red the least. The prism is then adjusted to be in the minimum deviation position for the violet line as described in experiment number 11 and 12 of Part 1. Readings on both the verniers are taken. The prism is removed carefully and the readings on both the verniers for direct ray are noted. The difference between these readings gives the angle of minimum deviation for violet light. Similarly the angles of minimum deviation for the other colours are found out. Refractive indices of the material of the prism for various colours are calculated using eqn.6. The Cauchy's constants are determined by the calculation and graphical methods.

Precaution:

- See all the precautions given in the i-d curve experiment.
- The prism is set to the minimum deviation position for each spectral line and in each case the direct reading is to be taken.

Observation and tabulation

Value of one main scale division (1 m s d) = ...

Number of divisions on the vernier n = ...

Least count (L C) = $\frac{\text{Value of 1 m s d}}{\text{n}}$ = ...

[One degree = 60 minute, $(1^\circ = 60')$]

Angle of the prism A'

	Ver I			Ver II			Mean	
	M S R	V S R	Total	M S R	V S R	Total	$2A'$	A'
Reflected image from the first face 'a'								
Reflected image from the second face 'b'								
Difference between the above readings $2A' = a \sim b$				$2A' = a \sim b$				

Determination of refractive indices for various colours

Colours of spectral lines	Wavelength λ	Reading corresponding to the minimum deviation position of the refracted ray ‘a’						Reading corresponding to the direct ray ‘b’						Angle of minimum deviation D = a~b			μ	$\frac{10^{-12}}{\lambda^2}$
		Ver 1			Ver II			Ver 1			Ver II							
		M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	Ver I	Ver II	Mean		

Calculation of Cauchy’s constants

μ_1	μ_2	λ_1	λ_2	B	A
			Mean		

Cauchy’s constants from graph A = ……….. B = ………..

Result

Angle of the prism A′ = ………

Cauchy’s constants A = ………

B = ………..

Standard data*

Mercury spectral lines

Colour	Wavelength in nm
Yellow I	579.06
Yellow II	576.96
Green	546.07
Greenish blue	491.60
Blue	435.83
Violet I	407.78
Violet II	404.65

Exp.No.2.4

Spectrometer – Diffraction grating-normal incidence

Aim: To determine the grating element of the given diffraction grating by using the light of known wavelength (green) and hence to determine the wavelength of the prominent lines of mercury spectrum by normal incidence method.

Apparatus: Spectrometer, mercury vapor lamp, diffraction grating, reading lens etc.

Theory: An arrangement consisting of a large number of parallel slits of equal width and separated from one another by equal opaque spaces is called a *diffraction grating*. A grating is made by ruling a very large number (about 15000 lines per inch) of fine, equidistant and parallel lines with a diamond point on an optically plane glass plate. The ruled lines act as opaque region and the space between any two lines is transparent and it acts as slits. Such a grating is called a plane transmission grating.

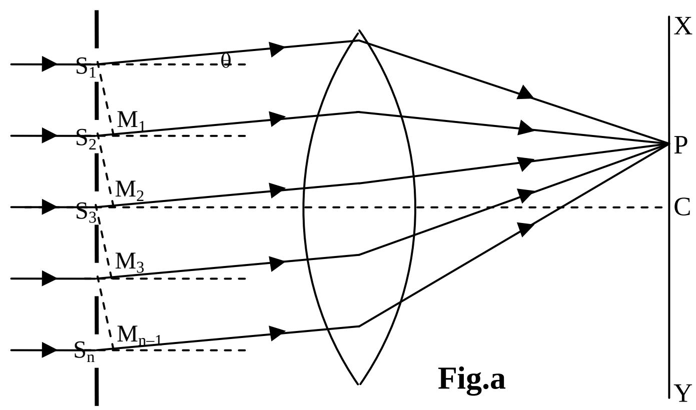


Fig.a

The directions of the principal maxima of a grating in normal incidence are given by,

$$(b+c)\sin\theta = n\lambda \quad ; n = 0, 1, 2\ldots. \quad (1)$$

where, 'b' is the width of a slit and 'c' is the width of the opaque region and $(b+c)$ is called the *grating element*. If there are N number of rulings per metre, $N(b+c) = 1$ and then,

$$\sin\theta = Nn\lambda \qquad (2)$$

where, n = 0, 1, 2…… is the order of the spectrum, θ is the angle of diffraction and λ is the wavelength of the light used.

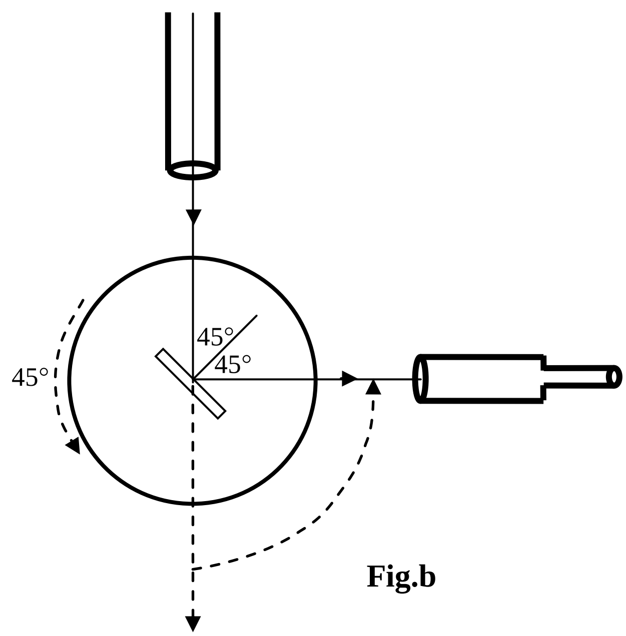


Fig.b

Procedure

Adjustments to set the grating for normal incidence: The telescope is turned towards the white wall and the eye- piece is focused on the cross wires. Then the telescope is adjusted to receive the parallel beam of light from a distant object. The telescope and the collimator are now brought in a line and the collimator is adjusted to produce parallel beam of light emanated from the given source so that a clear image of the slit falls on the cross wire. This position of the telescope is noted by taking reading on one of the verniers. The telescope is now turned 90° and is clamped.

Next the grating is mounted on the prism table with its ruled surface facing the collimator such that the rulings parallel to the slit and the prism table (or vernier table) is rotated till the reflected image from one face of the grating coincides with the vertical wire. If necessary, the leveling screws of the prism table are adjusted such that the reflected image is divided by the horizontal wire and again the vernier readings are noted. Then the vernier table is rotated exactly through 45°(or 135°) so that the ruled surface of the grating faces the incident light. In this position the grating is normal to the incident light.

Determination of grating element: The grating can be standardized as follows. Use the light of known wavelength (green of mercury spectrum) to illuminate the slit and find out the angle ‘θ’ for the corresponding spectral line. Then,

$$b+c = \frac{n\lambda}{\sin\theta} = \frac{1}{N} \qquad (3)$$

Or,

$$N = \frac{\sin\theta}{n\lambda} \qquad (4)$$

Determination of angle of diffraction for the unknown wavelength: The slit is illuminated with the light whose wavelength is to be determined. Now the telescope is rotated to the left of the direct image till the vertical wire coincides with the first order spectral line of the unknown wavelength and the readings of both the verniers are noted. Then rotate the telescope to the right side till the vertical wire coincides with the spectral line of the same order on the right side of the direct image and the vernier readings are again noted. The difference between the two readings of the same vernier gives 2θ for first order.

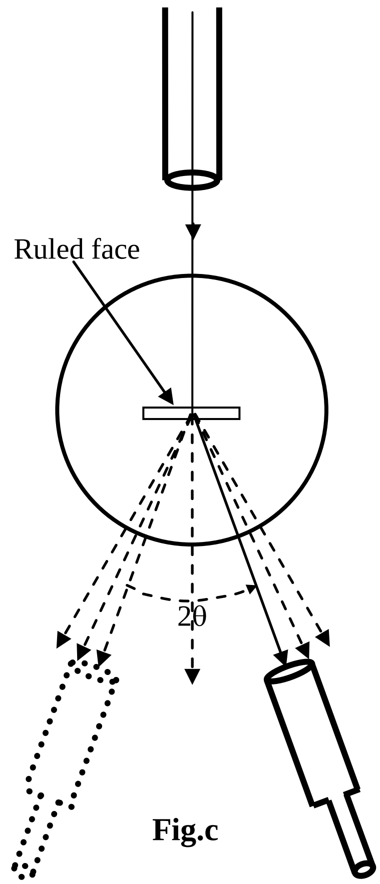


Fig.c

Wavelength λ can be calculated using $\lambda = (b+c)\sin\theta = \frac{\sin\theta}{Nn}$. While determining the wavelengths of spectral lines of mercury, take readings successively from the red line on one side to the red line on the other side. Experiment can be repeated for other orders of the spectrum.

Precautions

- See all the precautions given in the i-d curve experiment.
- If the spectral lines are not bright and sharp rotate slightly the slit in its plane so as to make the rulings parallel to the slit.

Observation and tabulation

Value of one main scale division (1 m s d) = ……………

Number of divisions on the vernier n = ……………

$$\text{Least count (L C)} = \frac{\text{Value of 1 m s d}}{n} = \ldots\ldots$$

[One degree = 60 minute, $(1^\circ = 60')$]

Order of the spectrum n	Colour of the spectral lines	Reading corresponding to the diffraction spectral lines on												Difference $2\theta = a \sim b$			θ	Wavelength λ
		left 'a'						right 'b'										
		Ver 1			Ver II			Ver 1			Ver II							
		M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	Ver I	Ver II	Mean		
	Yellow I																	
	Yellow II																	
	Blue-green																	
	Blue																	
	Violet I																	
	Violet II																	
	Green	Wavelength of green line of mercury = 546.07 nm																N
	Yellow I																	
	Yellow II																	
	Blue-green																	
	Blue																	
	Violet I																	
	Violet II																	
	Green	Wavelength of green line of mercury = 546.07 nm																N

Result

Number of lines per metre of the grating N = ………..

Grating element 1/N = ………..

The prominent lines of mercury spectrum are determined and are recorded in the tabular column.

Standard data*

Mercury spectral lines

Colour	Wavelength in nm
Yellow I	579.06
Yellow II	576.96
Green	546.07
Greenish blue	491.60
Blue	435.83
Violet I	407.78
Violet II	404.65

Exp. No. 2.5

Spectrometer-Grating-minimum deviation

Aim: To determine the grating element of the given diffraction grating by using the light of known wavelength (green) and hence to determine the wavelength of the prominent lines of mercury spectrum by minimum deviation method.

Apparatus: Spectrometer, mercury vapor lamp, diffraction grating, reading lens etc.

Theory: Let i be the angle of incidence and θ_n be the angle of diffraction corresponding to the n^{th} order spectrum. The path difference between the corresponding rays is

$$EF + FG = (b+c)\sin i + (b+c)\sin\theta_n \qquad (1)$$

For the n^{th} order primary maximum,

$$(b+c)\sin i + (b+c)\sin\theta_n = n\lambda \qquad (2)$$

$$2(b+c)\sin\left(\frac{\theta_n + i}{2}\right)\cos\left(\frac{\theta_n - i}{2}\right) = n\lambda$$

$$\sin\left(\frac{\theta_n + i}{2}\right) = \frac{n\lambda}{2(b+c)\cos\left(\frac{\theta_n - i}{2}\right)} \qquad (3)$$

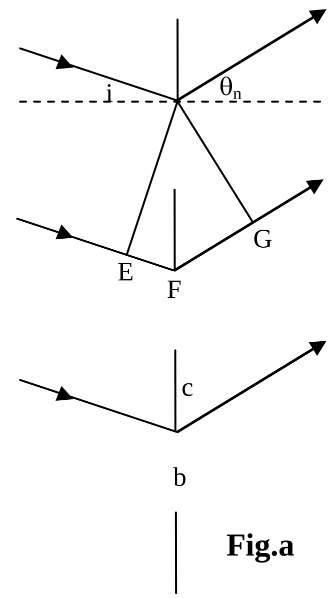


Fig.a

The angle of deviation of the diffraction beam is,

$$\theta_n + i = 2\sin^{-1}\left\{\frac{n\lambda}{2(b+c)\cos\left(\frac{\theta_n - i}{2}\right)}\right\} \qquad (4)$$

For minimum deviation, $\cos\left(\frac{\theta_n - i}{2}\right)$ must be maximum = 1. That is, $\frac{\theta_n - i}{2} = 0$, or, $\theta_n = i$.

Then, the angle of minimum deviation, $D = \theta_n + i = 2\theta_n \qquad (5)$

By eqn.2, $$(b+c)\left\{\sin\left(\frac{D}{2}\right) + \sin\left(\frac{D}{2}\right)\right\} = n\lambda$$

$$2\sin\left(\frac{D}{2}\right) = \frac{n\lambda}{(b+c)} = Nn\lambda \qquad (6)$$

where, $(b+c)$ is the *grating element* and N is the number of rulings per metre.

Procedure: The preliminary adjustments of the spectrometer are made. The grating is mounted vertically on the prism table with its ruled surface facing the collimator such that the rulings parallel to the slit. The prism table (vernier table) is rotated till the plane of the grating is approximately normal to the incident light. On either side of the direct ray the diffracted spectrum are formed.

Determination of grating element: The grating can be standardized as follows. The green line (known wavelength) of the first order diffracted spectrum on one side (say, the left side) is viewed through the telescope. The vernier table is slowly rotated so that the green line moves towards the position of direct image. The telescope also is moved in the direction of motion of the green line. The rotation of the vernier table and telescope are continued till at a particular position the green line is found to remain stationary for a moment and then begins to move in the opposite direction. By adjusting the vernier table very carefully the green line is kept at the position where it just turns back. Now the vernier table is clamped and the telescope is made to coincide with the green line. The readings on both the verniers are taken. The telescope is then released and is made to coincide with the direct image. The readings on both the verniers are again noted. The difference between these two readings gives the angle of minimum deviation for green line. Next the green line on the other side (right) of the direct image is viewed and its angle of minimum deviation is determined. Then the grating element and the number of lines per metre are calculated using the equations,

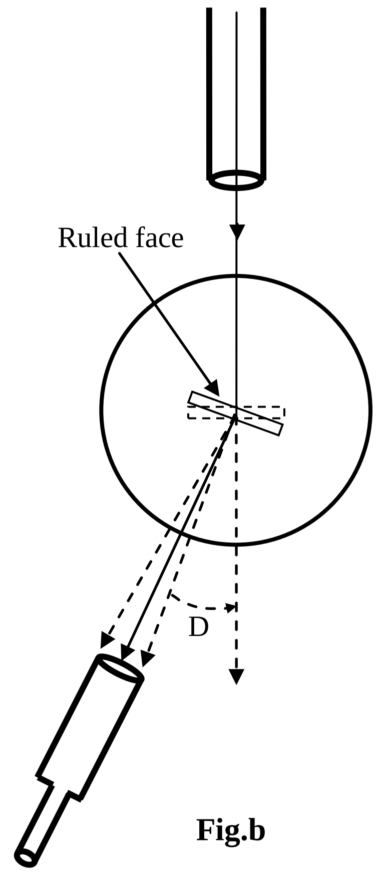


Fig.b

$$N = \frac{2\sin\left(\frac{D}{2}\right)}{n\lambda} \qquad (7)$$

$$b + c = \frac{1}{N} \qquad (8)$$

Determination of angle of diffraction for the unknown wavelength: Using the same method mentioned above, the angles of minimum deviation for other colours of the spectrum are determined and the wavelengths are calculated using the equation,

$$\lambda = \frac{2\sin\left(\frac{D}{2}\right)}{Nn}$$

Experiment can be repeated for other orders of the spectrum.

Precautions

- See all the precautions given in the exp.no.2.1.
- If the spectral lines are not bright and sharp rotate slightly the slit in its plane so as to make the rulings parallel to the slit.

Observation and tabulation

Value of one main scale division (1 m s d) = ……………

Number of divisions on the vernier n = ……………

$$\text{Least count (L C)} = \frac{\text{Value of 1 m s d}}{n} = \ldots\ldots$$

[One degree = 60 minute, $(1^\circ = 60')$]

Order of the spectrum, n = ………

	Colour of the spectral lines	Reading corresponding to the diffraction spectral lines 'a'						Reading corresponding to the direct image 'b'						Difference D = a~b			Mean D of left and right	Wavelength λ
		Ver 1			Ver II			Ver 1			Ver II							
		M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	M S R	V S R	Total	Ver I	Ver II	Mean		
Left side of direct image	Yellow I																	
	Yellow II																	
	Blue-green																	
	Blue																	
	Violet I																	
	Violet II																	
	Green																	
Right side of direct image	Yellow I																	
	Yellow II																	
	Blue-green																	
	Blue																	
	Violet I																	
	Violet II																	
	Green	Wavelength of green line of mercury = 546.07 nm																N

Draw another tabular column for second order.

Result

Number of lines per metre of the grating N = ………..

Grating element 1/N = ………..

The prominent lines of mercury spectrum are determined and are recorded in the tabular column.

Standard data*: Same as given for normal incidence method.

Exp.No.2.6

Small angled prism- normal incidence & normal emergence

Aim: To find the refractive index of the material of the given small angled prism by setting the prism for (1) normal incidence and (2) normal emergence.

Apparatus: Spectrometer, sodium vapor lamp, small angled prism, reading lens etc.

Theory: For a given prism, corresponding to a given angle of deviation there are two possible angles of incidence i_1 and i_2. These two angles are such that if one of the angles is the angle of incidence, the other angle will be the angle of emergence. So these two angles are interchangeable. In the following experiment we make use of this property.

Let i_1 and i_2 be the two angles of incidence and r_1 and r_2 be the corresponding angles of refraction for the given angle of deviation d. Then,

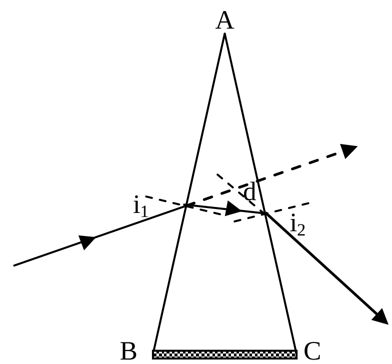


Fig.a

$$i_1 + i_2 = A + d \qquad (1)$$

$$r_1 + r_2 = A \qquad (2)$$

Normal incidence: In this case the incident ray is normal to one of the refracting faces (AB) of the prism. Then, $i_1 = 0$ and $r_1 = 0$. Thus, by eqn.1,

$$i_2 = A + d \qquad (3)$$

And by eqn.2,
$$r_2 = A \qquad (4)$$

$$\text{Refractive index,} \quad \mu = \frac{\sin i_2}{\sin r_2} = \frac{\sin(A+d)}{\sin A} \qquad (5)$$

Normal emergence: In this case the emergent ray is normal to the face (AC) of the prism. Then, $i_2 = r_2 = 0$. Hence, $i_1 = A + d$ and $r_1 = A$. Thus,

$$\text{Refractive index,} \quad \mu = \frac{\sin i_1}{\sin r_1} = \frac{\sin(A+d)}{\sin A} = \frac{\sin i_1}{\sin(i_1 - d)} \qquad (6)$$

Procedure: All the preliminary adjustments of the spectrometer are made. The small angled prism is then mounted on the prism table with its base parallel and close to the clamp.

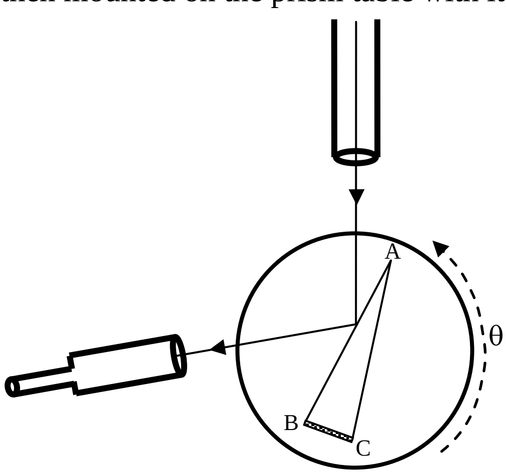


Fig.b

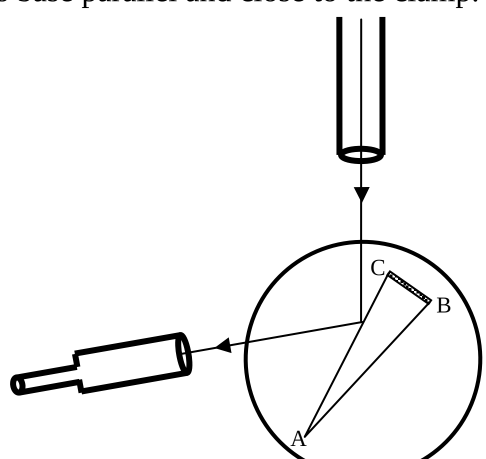


Fig.c

To find the angle of the prism by supplementary angle method: The telescope is clamped nearly normal to the collimator. The vernier table is slowly rotated until the reflected image of the slit from one of faces, say AB, is obtained on the cross wire of the telescope (fig.b). The vernier table is then clamped and using its tangential screw the image is made to coincide exactly with the vertical wire. The readings on both the verniers are noted. Then the vernier table is released and is rotated through an angle θ as shown in fig.b such that the reflected image from the other face (AC) is obtained on the cross wire of the telescope (fig.c). After making the fine adjustments of the vernier table, the readings on both the verniers are taken. The difference between the two readings gives θ and (180–θ) gives the angle of the prism.

To set the prism for normal incidence: (We follow the same method as in the case of grating normal incidence). The prism is removed from the prism table. The telescope is brought in a line with the collimator and the direct image is made to coincide with the vertical cross wire. This position of the telescope is noted by taking reading on one of the verniers. The telescope is now turned 90° and is clamped.

Next the prism is mounted on the prism table with one of its refracting surface facing the collimator and the prism table (vernier table) is rotated till the reflected image from that face of the prism coincides with the vertical wire (fig.d). If necessary the leveling screws of the prism table are adjusted such that the reflected image is divided by the horizontal wire and again the vernier readings are noted. Then the vernier table is rotated exactly through 45° in the proper direction so that the surface facing the collimator now becomes normal to the incident light (fig.e). The vernier table is clamped in this position.

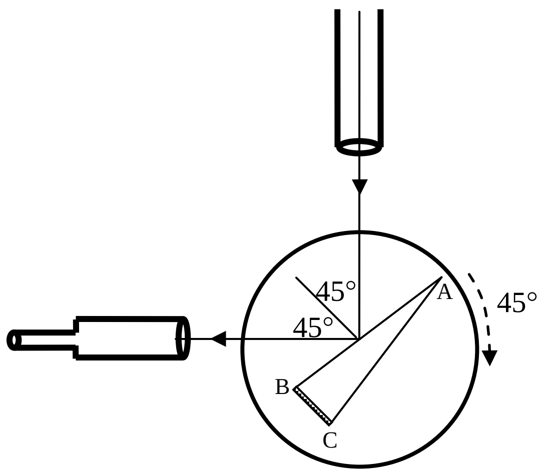


Fig.d

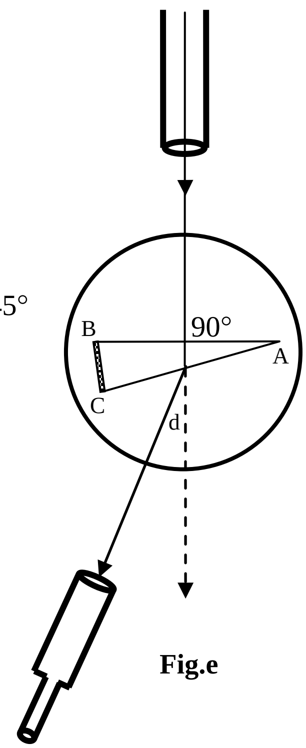


Fig.e

Determination of the angle of deviation in normal incidence: The telescope is released and is brought in the line of refracted ray (fig.e). By making the fine adjustments with the tangential screw of the telescope the refracted image is obtained exactly on the vertical cross wire. The readings on both the verniers are noted. The prism is then removed carefully without changing the vernier table. The telescope is released and is made to coincide with the direct image. The readings on both the verniers are again noted. The difference between these two readings gives the angle of deviation. The refractive index is calculated by the eqn.5.

Normal emergence: To find the angle of deviation and the angle of incidence at the first face when the ray undergoes normal emergence, we make use of the property of the prism that the incident and the emergent rays are interchangeable.

The prism is again set for normal incidence and the refracted image is made to coincide with the vertical cross wire. After clamping the telescope the vernier table is released and is rotated such a direction that the refracted image moves towards the minimum deviation position. The rotation of the vernier is continued in the same direction until the refracted image returns to the cross wire. The vernier table is then clamped at this position and the fine adjustment of the vernier is done if necessary. Now the prism is set for normal emergence at the second face (fig.f). The readings on both the verniers are taken. Let it be ‘a’.

The telescope is then released and is brought in the line of the reflected image from the first face. By making fine adjustments the reflected image is made to coincide with the vertical cross wire and readings on both the verniers are noted. Let it be ‘b’.

The prism is then removed carefully. The telescope is brought in the line of the direct ray and the readings on both verniers are noted (c). The difference between the refracted image readings and the direct image readings (a~c) gives the angle of deviation corresponding to the normal emergence. The difference in the readings between reflected image and the direct image (b~c) gives $\theta = 180 - 2i_1$, from which i_1 can be calculated. Finally the refractive index of the material of the prism is calculated using eqn.6.

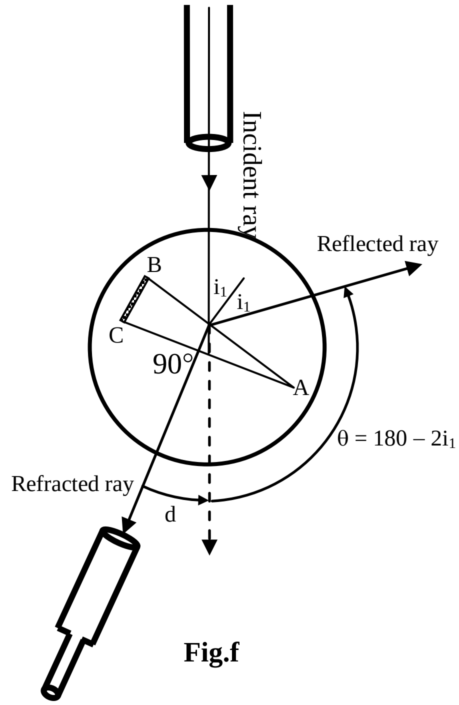


Fig.f

- If the image is not in field of view of the telescope make sure that the prism table is leveled. Looking through the prism with naked eye (without telescope) you can see the image and judge its direction which helps to know whether it passes through the field of view of the telescope and the leveling of vernier is needed.

Observation and tabulation

Value of one main scale division (1 m s d) = ……………

Number of divisions on the vernier n = ……………

$$\text{Least count (L C)} = \frac{\text{Value of 1 m s d}}{n} = \ldots\ldots\ldots\ldots$$

[One degree = 60 minute, $(1^\circ = 60')$]

Angle of the prism A (Supplementary angle method)

	Ver I			Ver II			Mean θ	A=180−θ
	M S R	V S R	Total	M S R	V S R	Total		
Reflected image from first face ‘a’								
Reflected image from second face ‘b’								
Difference between the above readings θ = a~b				θ = a~b				

To set prism for normal incidence

	Ver I	Ver II
Direct reading		
Reading at which telescope is to be set = Direct reading + 90° =		
Reading corresponding to the reflected image		
Reading at which vernier is to be set = Reflected reading ± 45° =		

To find angle of deviation 'd' for normal incidence

Reading corresponding to	Ver I			Ver II			Mean d
	M S R	V S R	Total	M S R	V S R	Total	
Refracted image 'a'							
Direct image 'b'							
Difference between the above readings d = a~b				d = a~b			

Refractive index of the material of the prism, $\mu = \dfrac{\sin(A+d)}{\sin A} = \ldots\ldots\ldots\ldots$

To set prism again for normal incidence (for normal emergence method)

	Ver I	Ver II
Direct reading		
Reading at which telescope is to be set = Direct reading + 90° =		
Reading corresponding to the reflected image		
Reading at which vernier is to be set = Reflected reading ± 45° =		

To find angle of deviation 'd' and angle of incidence i_1 for normal incidence

Reading corresponding to	Ver I			Ver II			Mean d	Mean θ
	M S R	V S R	Total	M S R	V S R	Total		
Refracted image 'a'								
Reflected image 'b'								
Direct image 'c'								
Difference between the readings a~c = d				a~c = d				
Difference between the readings b~c = θ				b~c = θ				

Angle of incidence at the first face for normal emergence, $i_1 = \dfrac{180-\theta}{2} = \ldots\ldots..$

Refractive index of the material of the prism $\mu = \dfrac{\sin i_1}{\sin(i_1 - d)} = \ldots\ldots..$

Result

Mean refractive of the material of the prism, $\mu = \ldots\ldots\ldots$

Standard data*: Same as given for normal incidence method.

Exp.No.2.7

Air Wedge-Diameter of a thin wire

Aim: To find the diameter of a thin wire by measuring the width of the interference band formed by an air wedge arrangement with this thin wire and two plane glass plates.

Apparatus: An air wedge, sodium vapour lamp, travelling microscope, reading lens etc.

Theory: An air wedge is produced by two optically plane rectangular glass plates in contact with one pair of the edges and a thin wire, whose diameter is to be determined, is kept in between the plates near the other end parallel to the line of contact of the two plates.

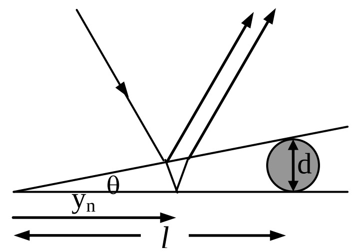


Fig.a

If the angle between the two glass plates is small and the ray incident normally, the approximate path difference between the two reflected rays from the upper and lower surfaces of the air film is given by,

$$\Delta = 2t_{\text{in medium}} - \frac{\lambda}{2} = 2\mu t_{\text{in air}} - \frac{\lambda}{2}$$

Since when the reflection takes place at the boundary of an optically denser medium (lower surface of the air film) the reflected ray undergoes a phase change π or an equivalent path difference $\lambda/2$. (μ is the refractive index of the thin wedge shaped film in between the glass plates. For air wedge $\mu = 1$). For constructive interference path difference 'Δ' is an even multiple of $\lambda/2$. Thus,

$$2\mu t - \frac{\lambda}{2} = 2n\frac{\lambda}{2} \text{ where, } n = 0, 1, 2, 3\ldots$$

i.e., $$2\mu t = (2n+1)\frac{\lambda}{2}, \text{ where, } n = 0, 1, 2, 3\ldots \qquad (1)$$

For destructive interference path difference 'Δ' is an odd multiple of $\lambda/2$. Thus,

$$2\mu t - \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2}$$

Or, $$2\mu t = 2n\frac{\lambda}{2} = n\lambda, \text{ where, } n = 0, 1, 2, 3\ldots \qquad (2)$$

If y_n is the distance of the n^{th} dark fringe from the line of contact of the two glass plates, $t = y_n\theta$. Then, eqn.2 becomes,

$$2\mu\, y_n\theta = n\lambda \qquad (3)$$

For $(n+1)^{th}$ dark fringe, $$2\mu\, y_{n+1}\theta = (n+1)\lambda \qquad (4)$$

Subtracting eqn.3 from eqn.4, we get,

$$2\mu(y_{n+1} - y_n)\theta = \lambda$$

Therefore, fringe width, $$\beta = y_{n+1} - y_n = \frac{\lambda}{2\mu\theta} \qquad (5)$$

From eqn.1 we can also show that the distance between two consecutive bright fringes $x_{n+1} - x_n = \dfrac{\lambda}{2\mu\theta}$. If an *air wedge* is formed by placing a thin wire of diameter 'd' in between the glass plates at a distance '*l*' from the line of contact of the two glass plates, the fringe width is given by,

$$\beta = \frac{\lambda}{2\theta} = \frac{\lambda l}{2d} \qquad (6)$$

Since $\theta = \dfrac{d}{l}$ and for air $\mu = 1$.

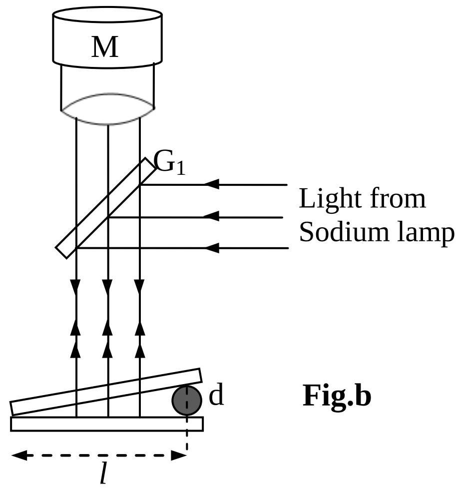


Fig.b

Procedure: Light from the sodium lamp is allowed to fall on the glass plate G_1 kept at 45° with the horizontal. The air wedge is placed such that the reflected light from the glass plate G_1 falls normally on it. The interference pattern is viewed from above by the travelling microscope as shown in fig.b. The pattern consists of large number of equally spaced alternate dark and bright bands as shown in fig.c. The microscope is moved towards one of the sides, say left, and one of the cross wires is made to coincide with any of the dark line, say n_0. The microscope is then moved in the opposite direction. (Remember now onwards the tangential screw is rotated only in one direction to avoid the backlash error). It is then made to coincide with the n^{th} dark line and the microscope reading on the horizontal scale corresponding to it is noted. Then the microscope is moved and the cross wire is made to coincide with the dark lines (n+3), (n+6), (n+9), ……….upto (n+27) and the corresponding readings are noted. From these observations find out mean band width β.

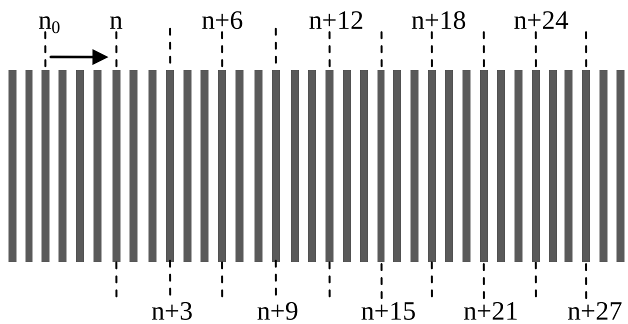


Fig.c

To find the distance *l* between wire and the line of contact of the glass plates take microscope readings corresponding to the line of contact and the wire. The difference between these readings gives '*l*'. (Microscope measurement is not essential).

Knowing the values of β and *l* and assuming the wavelength of sodium light (589.3 nm) the diameter of the wire can be calculated using the equation $d = \dfrac{\lambda l}{2\beta}$.

Precautions

- The glass plate G_1 should be 45° with the light from the sodium lamp.
- The glass plate G_1 should be oriented such that the light from the sodium lamp incident at the inner side of it. This helps the incident light to reflect towards the air wedge.
- To see the interference bands clearly focus the microscope. The objective lens of the microscope must be at a certain distance from the air wedge. This can be achieved by adjusting the main clamping screw and the rack and pinion arrangement of the microscope.

- In order to avoid the backlash error of the travelling microscope, initially the tangential screw of the microscope is rotated in a direction and the cross wire is moved from back of the n^{th} line and is then made to coincide with the n^{th} line. The tangential screw should not be rotated in the opposite direction (or to and fro) while coinciding with the first line and throughout the experiment. By mistake, if you have moved the microscope in the opposite direction while taking the reading give up all the readings taken and do the experiment from the beginning itself.
- Before starting to take readings ensure that we can move the microscope from the n_0^{th} line to more than n+30 lines. If it is not so loose the main screw of the vernier and loosen or tighten sufficiently the tangential screw and then tighten the main screw.

Observation and tabulation

Value of one main scale division (1 m s d) = ………. cm

Number of divisions on the vernier n = ……….

Least count $= \dfrac{1 \text{ m s d}}{n}$ = ……… cm

Determination of band width

Number of bands	Microscope readings			Width of 15 bands cm	Mean width of 15 bands w cm	Band width $\beta = w/15$ m
	M S R cm	V S R	Total cm			
n						
n+3						
n+6						
n+9						
n+12						
n+15						
n+18						
n+21						
n+24						
n+27						

Distance between the wire and the line of contact of the plates l = ………. m

Diameter of the wire, $d = \dfrac{\lambda l}{2\beta} =$ = …….. m

Angle of the wedge, $\theta = \dfrac{d}{l} = \dfrac{\lambda}{2\beta} =$ = ……… radian

Result

Diameter of the wire, d = ………. M

Angle of the wedge, θ = ………. radian

Standard data*

Wavelength of sodium light, λ = 589.3 nm.

Exp. No. 2.8

Newton's Rings by reflected light- wavelength of sodium light

Aim: To determine the wavelength of sodium light by forming Newton's rings due to reflected light.

Apparatus: Newton's rings arrangement, sodium vapour lamp, travelling microscope, reading lens etc.

Theory: The phenomenon of Newton's rings is a special case of interference in a thin film of air of slowly varying thickness. When a plano-convex lens (or convex lens) of large focal length is placed in contact with a plane glass plate such that an air film is enclosed in between the curved surface of the lens and the plane glass plate. When monochromatic light is allowed to fall normally on such a film we get a central dark spot surrounded by alternatively bright and dark circular rings when viewed the reflected light.

Theory of the wedge shaped film shows that the effective path difference of the rays reflected from the upper and lower surfaces of the thin film is,

$$\Delta = 2\mu t\cos(r'+\theta) - \frac{\lambda}{2} \qquad (1)$$

where, r' is the angle of refraction, θ is the angle of wedge and μ is the refractive index of the wedge shaped film (for air μ = 1). The additional path difference $\lambda/2$ is due to the phase change π occurs when the reflection takes place at the lower surface of the film. For normal incidence r' = 0, and if θ is small, the effective path difference,

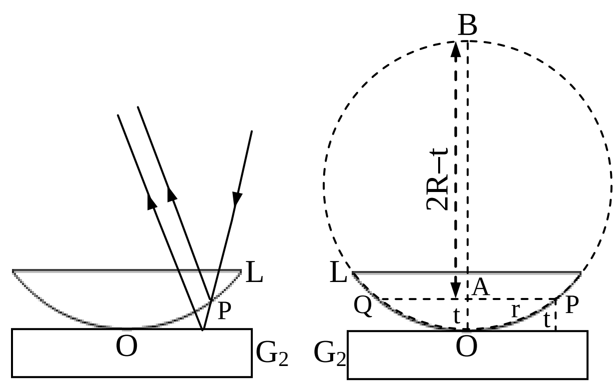


Fig.a **Fig.b**

$$\Delta = 2\mu t - \frac{\lambda}{2} \qquad (2)$$

Diameter of dark rings: The condition for dark ring is that the path difference is equal to odd multiple of $\frac{\lambda}{2}$

i.e. $\Delta = 2\mu t - \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2}$, where, n = 1, 2, 3…….

Or, $2\mu t = n\lambda$, where, n = 1, 2, 3…….

For air, $2t = n\lambda$, where, n = 1, 2, 3……. (3)

Let 'R' be the radius of curvature of the plano-convex lens. Consider a point 'P' where the thickness of the film is 't' and radius of the ring through 'P' is 'r'. Then from the property of the circle, (refer fig.b),

$$PA\times AQ = BA\times AO$$

i.e. $$r^2 = (2R-t)t = 2Rt - t^2$$

In actual practice t << R. Thus we can neglect t^2 in comparison with 2Rt.

$$\therefore \quad r^2 = 2Rt \quad (4)$$

Then by eqn.2, $r_n^2 = nR\lambda$

Or, $$D_n^2 = 4nR\lambda \quad (5)$$

For $(n+k)^{th}$ dark ring,

$$D_{n+k}^2 = 4(n+k)R\lambda = 4nR\lambda + 4kR\lambda$$

$$D_{n+k}^2 - D_n^2 = 4kR\lambda$$

$$\therefore \quad \lambda = \frac{D_{n+k}^2 - D_n^2}{4kR} \quad (6)$$

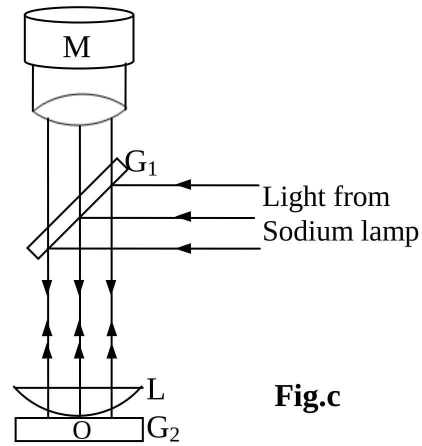


Fig.c

Procedure: The Newton's rings arrangement consists of a plano-convex lens or a biconvex lens 'L' of large focal length (~ 100 cm) placed over an optically plane glass plate G_2 as shown in fig.c. The light from sodium lamp is allowed to fall on the glass plate G_1 kept at 45° with the horizontal. The reflected light from the glass plate G_1 falls on the Newton's rings arrangement. The interference pattern is viewed from above by the travelling microscope as shown in fig.c. The pattern consists of large number of alternate dark and bright rings as shown in fig.d. The microscope is moved towards one of the sides, say left, and one of the cross wires is made to coincide with 25^{th} dark ring. The microscope is then moved in the opposite direction. (Remember now onwards the tangential screw is rotated only in one direction to avoid the backlash error). It is then made to coincide with the 20^{th} dark ring and the microscope reading on the horizontal scale corresponding to it is noted. Then the microscope is moved and the cross wire is made to coincide with the 18^{th}, 16^{th}, 14^{th}, …… up to 20^{th} dark ring on the other side and the corresponding readings are taken. The difference between the readings on the left and the right of any ring gives the diameter of that ring. The diameters of the 20^{th}, 18^{th}, ……., 2^{nd} rings are found. The square of the diameters and $D_{n+k}^2 - D_n^2$ are calculated for chosen 'n' and 'k' (say, n = 10, 8, 6, 4, 2 and k = 10).

The focal length 'f' of the lens can be determined by plane mirror method or u-v method. In plane mirror method the plane mirror is held behind the lens and the distance between the object and the lens is changed until a clear image of the object is seen side by side of the object as shown in fig.e. Then the distance between the object and the lens gives the focal length 'f'.

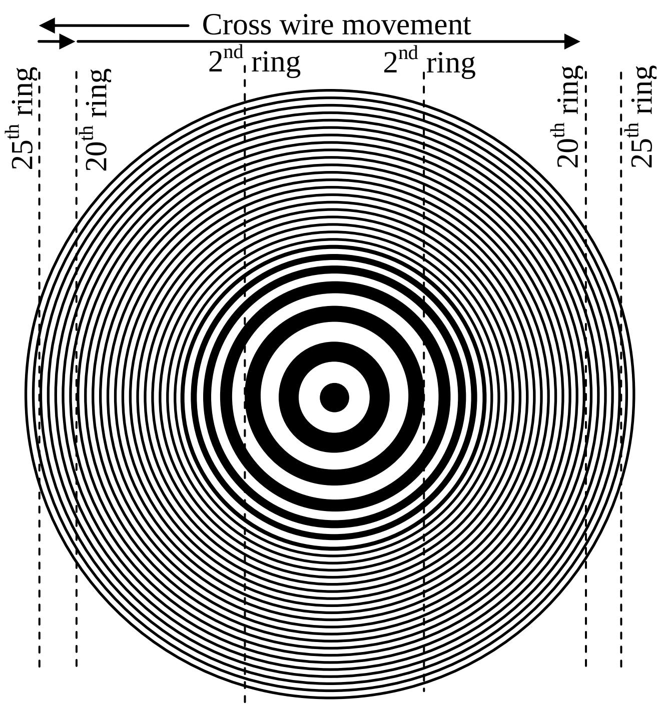


Fig.d: Newton's rings by reflected light

The radius of curvature of the lens is determined by Boy's method. In this method a dark screen (frame of the plane mirror) is held behind the lens and the side by side image is obtained by changing the distance between the lens and the object. The distance 'd' is measured and the radius of curvature is calculated using the formula $R = \frac{fd}{f - d}$. Finally, the wavelength is calculated using eqn.6.

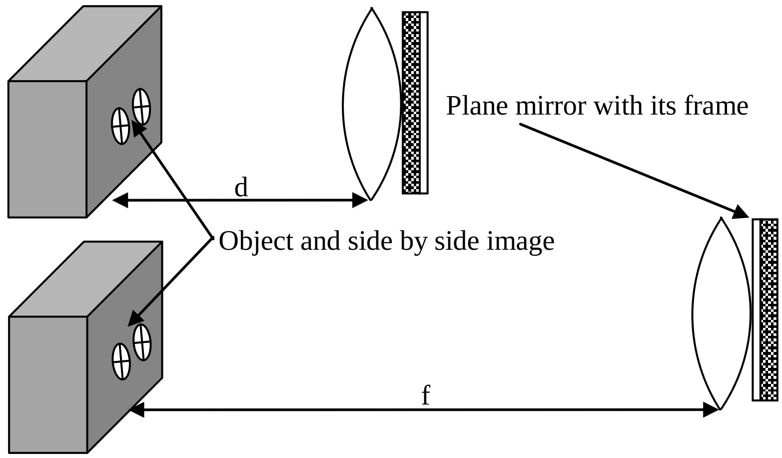


Fig.e

Precautions

- The glass plate G_1 should be 45° with the light (horizontal) from the sodium lamp.
- The glass plate G_1 should be oriented such that the light from the sodium lamp incident at the inner side of it. This helps the incident light to reflect towards the Newton's rings arrangement.
- Focus the microscope to see the interference bands clearly. The objective lens of the microscope must be at a certain distance from the air wedge. This can be achieved by adjusting the main clamping screw and the rack and pinion arrangement of the microscope.
- In order to avoid the backlash error of the travelling microscope, initially the tangential screw of the microscope is rotated in a direction and the cross wire is moved from back of the 20th ring (say, from 25th ring) and is then made to coincide with the 20th ring. The tangential screw should not be rotated in the opposite direction (or to and fro) while coinciding with the 20th ring on one side and throughout the experiment. By mistake, if you have moved the microscope in the opposite direction while taking the reading abandon all the readings taken and do the experiment from the beginning itself.
- Before starting to take readings ensure that we can move the microscope from the 25th ring on one side to more than 20th ring on the other side. If it is not so loose the main screw of the vernier and loosen or tighten sufficiently the tangential screw and then tighten the main screw.

Observation and tabulation

Value of one main scale division (1 m s d) = ………. cm

Number of divisions on the vernier n = ……….

Least count $= \frac{1 \text{ m s d}}{n}$ = ………

Determination of diameter D of the rings

Selected ‘k’ = 10

Number of the ring ‘n’	Microscope readings						Diameter D = a~b cm	D^2 cm^2	$D^2_{n+10} - D^2_n$ cm^2
	Left			Right					
	M S R cm	V S R	Total ‘a’ cm	M S R cm	V S R	Total ‘b’ cm			
20									
18									
16									
14									
12									
10									
8									
6									
4									
2									

Distance of the lens form the object when side by side image is formed with dark screen behind the lens, d = ……… cm

Distance of the lens form the object when side by side image is formed with plane mirror behind the lens, f = ……… cm

Radius of curvature of the lens, $R = \frac{fd}{f-d}$ = …….. m

Wavelength of sodium light $\lambda = \frac{D^2_{n+k} - D^2_n}{4kR}$ = ………..

= ……….. nm

Result

Wavelength of sodium light λ = ……….. nm

Standard data*

Wavelength of sodium light λ = 589.3 nm

Exp.No.2.9

Laser-Slit width from diffraction pattern

Aim: To find the width of a narrow slit by producing single slit diffraction pattern by laser source.

Apparatus: A laser source, single slit, a screen with a graph paper pasted on it, scale etc.

Theory: Parallel beam of light from a laser source is passed through a slit of width AB = b. Let XY be a screen at a distance D from the slit. The diffraction pattern of a single slit consists of a number of bright and dark spots as shown in fig.b. The theory of Fraunhofer diffraction by a single slit (since the theory is too long we avoid it here) shows that the condition for minimum intensity (or directions of minimum intensity) is

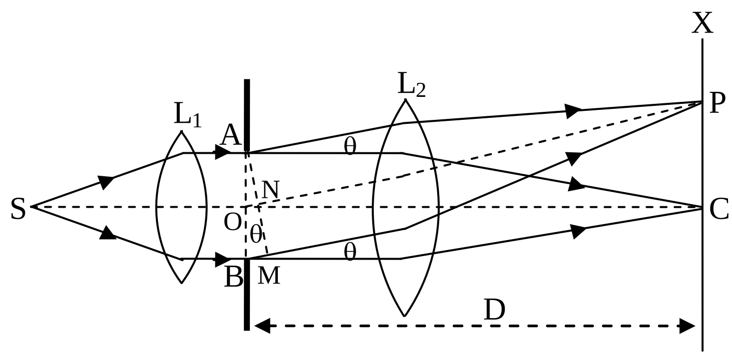


Fig.a: Diffraction by a single slit

$$b \sin\theta_n = \pm n\lambda, \text{ where, } n = 1, 2, 3\ldots\ldots \qquad (1)$$

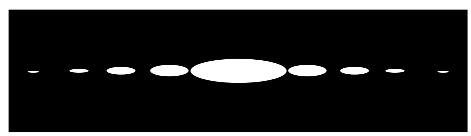


Fig.b: Single slit diffraction pattern corresponding to a slit of width of the order of 0.176mm

[The spread of the central diffraction maximum is between the first minima on either side of the central maximum (refer fig.b)]. By eqn.1,

$$\text{Slit width, } b = \frac{n\lambda}{\sin\theta_n}, \text{ where, } n = 1, 2, 3, \ldots.$$

Let $\pm x_1, \pm x_2, \pm x_3, \ldots\ldots$ are the distances of the *dark spots* from the centre of the central maximum. (Refer fig.c and fig.e). Then,

$$\sin\theta_n = \frac{x_n}{D}$$

$$\text{Thus,} \qquad b = \frac{n\lambda D}{x_n} = \frac{\lambda D}{\left(\frac{x_n}{n}\right)} \qquad (2)$$

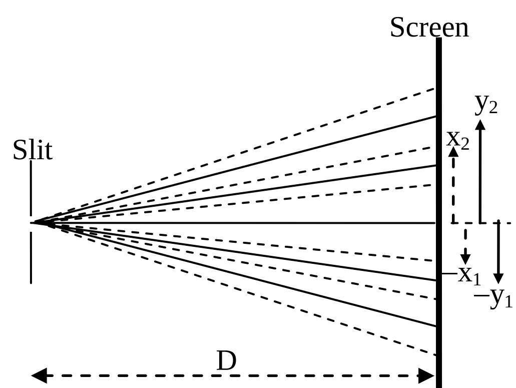


Fig.c

Since λ and D are constants $\frac{x_n}{n}$ is a constant. Thus x_n-n graph will be a straight line as shown in fig.d. The slope of the graph gives the mean value of $\frac{x_n}{n}$. Thus,

$$b = \frac{\lambda D}{\text{slope of } x_n - n \text{ graph}} \qquad (3)$$

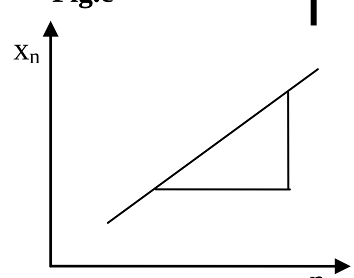


Fig.d

The directions of the secondary maxima (condition for secondary maxima) approximately are given by,

$$b \sin\theta_n = \pm(2n+1)\frac{\lambda}{2} \quad \text{where, } n = 1, 2, 3, \ldots.. \qquad (4)$$

Let $\pm y_1$, $\pm y_2$, $\pm y_3$, …… are the distances of the centres of the secondary maxima (bright spots) from the centre of the central maximum. (Refer fig.c and fig.e). Then,

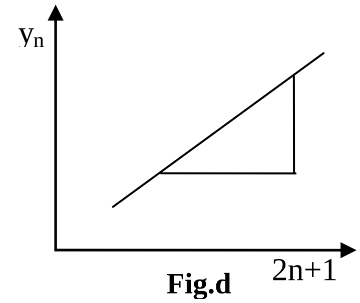


Fig.d

$$\sin\theta_n = \frac{y_n}{D}$$

Thus, $$b = \frac{(2n+1)\lambda D}{2y_n} = \frac{\lambda D}{2\left(\frac{y_n}{2n+1}\right)} \qquad (5)$$

Since λ and D are constants, $\frac{y_n}{2n+1}$ is a constant. Thus the graph between y_n and 2n+1 is a straight line. Its slope gives average $\frac{y_n}{2n+1}$. Then,

$$b = \frac{\lambda D}{\text{Twice the slope of } y_n\text{-}(2n+1) \text{ graph}} \qquad (6)$$

Procedure: The slit is mounted on the stand. Its width is made narrow. The laser beam is allowed to pass through the slit. Ensure that the slit is at the middle of the laser beam. A screen fixed with a graph paper is arranged at a large distance 'D'. The plane of the screen must be parallel to the plane of the slit. Adjust the width of the slit and its orientation to get well defined diffraction pattern consisting of a number of dark and bright spots on the screen. Since the length of the slit is large the diffraction effect (the dark and bright spots in the pattern) occurs only in the direction of the width of the slit. Using a pencil draw the outline of all bright spots on the graph paper and mark the centre of the spots. Also mark the midpoint of the dark region in between the bright spots. Measure the distance D between the slit and the screen. Determine the distances x_n from the centre of central bright spot to the midpoint of the dark regions in between the bright spots and draw a graph between x_n and n. Find out the slope of the graph and calculate the slit width 'b' by eqn.3. Also determine the distances y_n from the centre of the central bright spot to the centres of the other bright spots and draw a graph between y_n and 2n+1. Find out the slope and calculate 'b' by the eqn.6. The experiment may be repeated for different D. Similarly we can find out other slit widths.

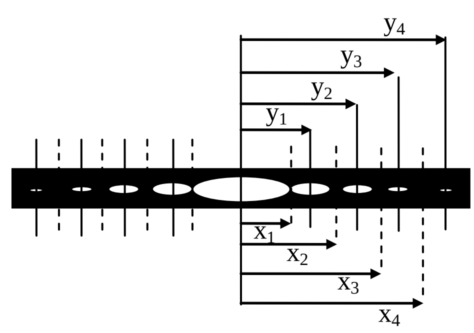


Fig.e

- The diffraction pattern will be well defined only when the slit width is small.
- Proper orientation of the slit is necessary. The slit must be adjusted so that it is at the middle of the laser beam.
- D must be sufficiently large.
- For accurate measurement of x_n and y_n travelling microscope may be used.

Observation and tabulation

Observation with dark spots

Distance of the screen from slit D cm	Order of dark spots ‘n’	Distance of the dark spots from the centre x_n mm	Slope = $\frac{x_n}{n}$ m	Slit width $b = \frac{\lambda D}{slope}$ m
	1			
	2			
	3			
	4			
	5			
	1			
	2			
	3			
	4			
	5			
	1			
	2			
	3			
	4			
	5			

Observation with bright spots

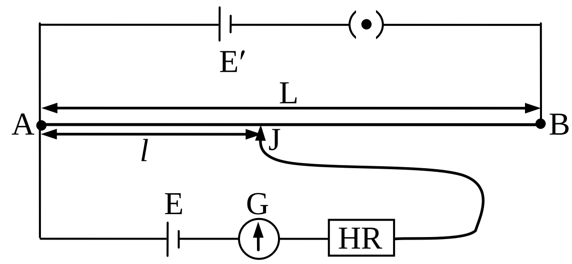
Distance of the screen from slit D cm	Order of bright spots ‘n’	Distance of the bright spots from the centre x_n mm	Slope = $\frac{y_n}{2n+1}$ m	Slit width $b = \frac{\lambda D}{2\times slope}$ m
	1			
	2			
	3			
	4			
	5			
	1			
	2			
	3			
	4			
	5			
	1			
	2			
	3			
	4			
	5			
			Mean	

Result

Width of the slit b = ………… m

Standard data*: Wavelength of laser light (Ruby-solid state), λ = 628 nm

Theory of potentiometer



Let a steady current I be passed through the wire AB with the help of a cell of e m f E′. Let ρ be the resistance per unit length of the potentiometer wire and J is a sliding contact. Let AB = L and AJ = l. Then,

Potential difference across AB = ILρ

Potential difference across AJ = Ilρ

$$\therefore \qquad \frac{\text{PD across AB}}{\text{PD across AJ}} = \frac{IL\rho}{Il\rho} = \frac{L}{l} \qquad (1)$$

$$\therefore \qquad \text{PD across AJ} = \left(\frac{\text{PD across AB}}{L}\right) l = \text{PD per unit length} \times \text{length of the wire} \qquad (2)$$

Thus, when a steady current is flowing through the potentiometer wire AB, the PD across any length of the wire is proportional to the length of the wire.

If a DC voltmeter is connected between A and the variable point J it can be seen that the voltmeter registers greater values as the contact maker J moves from A to B.

If another cell of e m f equal to PD across AJ is connected between A and J as shown in the figure, no current will flow in the secondary circuit and the galvanometer will show no deflection.

Exp.No.2.10

Potentiometer- Calibration of ammeter

Aim: To calibrate the given ammeter using a potentiometer.

Apparatus: A potentiometer, the given ammeter, rheostats, two accumulators (or power sources), a Daniel cell (or a power source of standard voltage), a standard resistance, six terminal key or a three terminal key, etc.

Theory

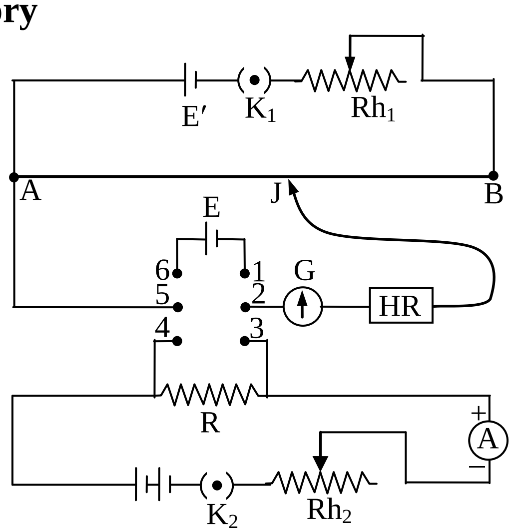


Fig.a: Six terminal key is used

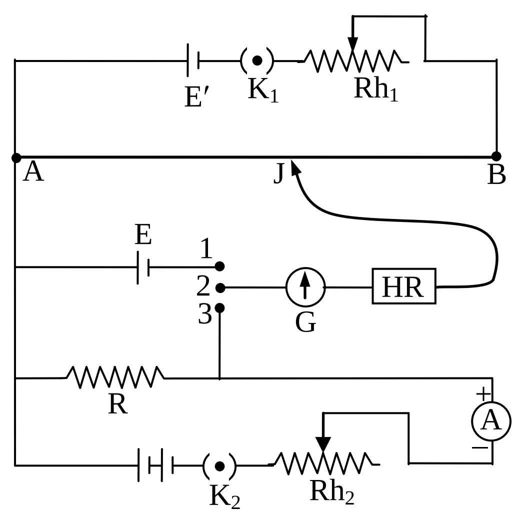


Fig.b: Three terminal key is used

Let L be the balancing length when a cell of standard e m f E (for Daniel cell E = 1.08 V) is connected in the secondary circuit. Then by the theory of potentiometer,

$$E \propto L \qquad (1)$$

The potential difference developed across the standard resistance when a current I flows through it is,

$$V = IR \qquad (2)$$

Let l be the balancing length when the potential difference across R is applied to the potentiometer. Then,

$$V \propto l$$

$$IR \propto l \qquad (3)$$

Dividing eqn.3 by eqn.1, we get,

$$\frac{IR}{E} = \frac{l}{L}$$

$$\therefore \qquad I = \frac{E}{LR}l \qquad (4)$$

If E = 1.08 volt,

$$I = \frac{1.08l}{LR} \qquad (4a)$$

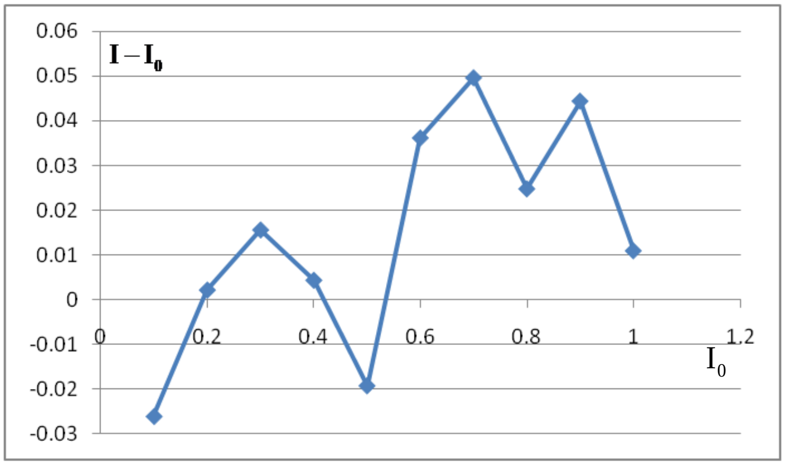


Fig.c

Correction to the ammeter reading $= I - I_0 = \frac{E}{LR}l - I_0 \qquad (5)$

The graph between the measured current I_0 in the X axis and the correction $I - I_0$ in the Y axis is called the calibration graph. A model of it is shown in the fig.c.

Procedure: The connections are made as shown in the fig.a or b. A steady current is allowed to flow through the wire AB by connecting the terminals of it to the cell of e m f E′ through the rheostat Rh_1 and key K_1. E is a standard cell (may be a Daniel cell). The ammeter to be calibrated is connected in the secondary circuit in series with the battery, key K_2, rheostat Rh_2 and a standard resistance R (1 or 2 ohms).

Now connect terminals 1 and 2 in fig.b (for fig.a insert keys in between 1 and 2 and 5 and 6). Adjust the sliding contact J till the galvanometer shows zero deflection and the balancing length L corresponding to e m f E is measured from the end A. Next disconnect 1 and 2 and connect terminals 2 and 3 (for fig.a unplug the keys in between 1 and 2 and 5 and 6 and insert in between 2 and 3 and 4 and 5) . Adjust the rheostat Rh_2 so that the ammeter reads a value I_0, say 0.1 A. Let I be the actual current flowing through the circuit. This current produces a potential difference IR across the resistance R. Again adjust the contact maker and find the balancing length l corresponding to this potential difference. Next the rheostat Rh_2 is adjusted successively for currents 0.2A, 0.3A, 0.4A,………., 1A and the corresponding balancing lengths are determined in each case. The current I and $I - I_0$ are calculated. Then the calibration graph is plotted with ammeter reading I_0 in the X axis and the correction $I - I_0$ in the Y axis. The different points obtained are joined by straight lines.

Precautions

- Clean the ends of the wires before the connecting.
- Ensure that the wires are not broken.
- In all the electricity experiments, it is advised to do the series connections first and then the parallel connections.
- If there is no deflection, check the voltages of the cells or power supplies used and also check the continuity of the circuit with a multimeter.
- Ensure that the secondary voltage applied to the potentiometer (in this case P D across the standard resistance R) should not exceed the P D across A B of the potentiometer wire. If the balancing length for 1.08 volt is about 920 cm and the standard resistance used is 1 Ω the current greater than 1A is not suitable.
- Ensure that all the positive potential sides are connected to the terminals 4, 5 and 6 and negative sides are connected to the terminals 1, 2 and 3.
- You can check the circuit by a method as follows. Unplug the key K_1 in the primary circuit. By inserting keys in the secondary circuit and the six terminal keys apply the secondary voltage to the potentiometer. Press the sliding contact J at the ends A and B. Make sure that the deflections in the galvanometer are in the same direction. If there is no deflection check the voltage and continuity of secondary circuit. Now insert the key K_1 in the primary circuit and check the deflections at A and B. If the deflections are in the opposite directions connections are correct. Otherwise, check the voltage and continuity of the primary circuit. This checking for opposite deflections must be done separately with standard voltage and P D across R.
- Ensure that the key of the high resistance is to be inserted during the determination of final balance point.
- Keep the potential difference in the primary circuit (p d across AB) undisturbed throughout the experiment.

Observation and tabulation

Standard resistance R = …………Ω

Standard voltage E = …………volts

Balancing length for standard e m f E = L = ……… cm

Ammeter reading I_0 A	Balancing length for PD across R l cm	Calculated current $I = \frac{E}{LR} l$ ampere	Correction $(I - I_0)$ ampere
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1			

Result

The given ammeter is calibrated and the calibration graph is drawn.

Exp.No.2.11

Potentiometer-Reduction factor of TG

Aim: To determine the reduction factor of a tangent galvanometer and hence to find out the horizontal component of earth's magnetic field.

Apparatus: A potentiometer, tangent galvanometer, rheostats, two accumulators (or power sources), a Daniel cell (or a power source of standard voltage), a standard resistance, six terminal key or a three terminal key, etc.

Theory

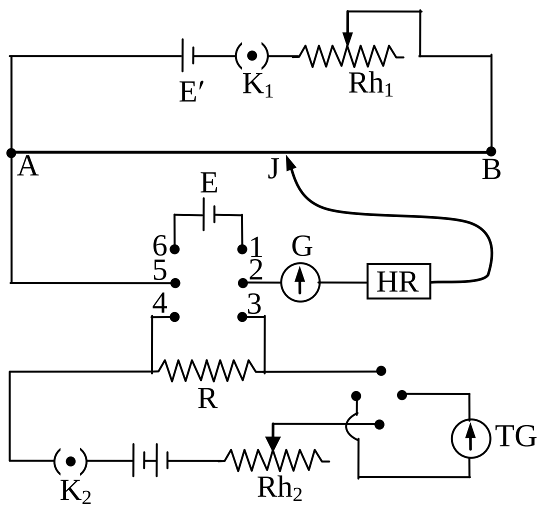


Fig.a: Six terminal key is used

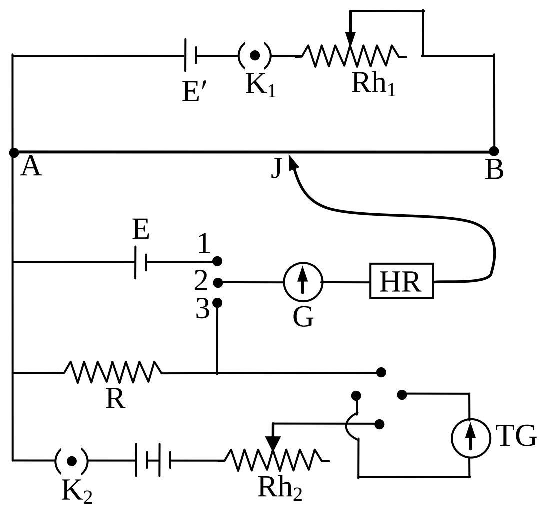


Fig.b: Three terminal key is used

A tangent galvanometer consists of a circular coil of radius 'a' and a compass box placed at the centre of the coil. The magnetic field produced at the centre of the coil when a current I flows through the coil is,

$$B = \frac{\mu_0 n I}{2a} \qquad (1)$$

If the plane of the coil is set along the north-south direction, the magnetic field will be in the east-west direction. Hence the resultant magnetic field at the centre of the coil makes an angle θ with the direction of earth's magnetic field and the magnetic needle in the compass box will be aligned itself in the direction of the resultant field. Then,

$$\frac{B}{B_h} = \tan\theta$$

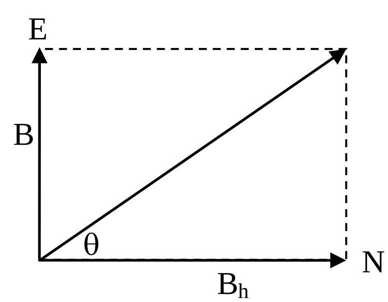
Or,

$$B = B_h \tan\theta \qquad (2)$$

i.e.

$$\frac{\mu_0 n I}{2a} = B_h \tan\theta$$

$$I = \left(\frac{2aB_h}{\mu_0 n}\right)\tan\theta = K\tan\theta \qquad (3)$$



where, $K = \frac{2aB_h}{\mu_0 n}$ is called the *reduction factor* of the T G. (4)

Let L be the balancing length when a cell of standard e m f E (for Daniel cell E = 1.08 V) is connected in the secondary circuit. Then by the theory of potentiometer,

$$E \propto L \tag{5}$$

The potential difference developed across the standard resistance when a current I flows through it is,

$$V = IR \tag{6}$$

Let l be the balancing length when the potential difference across R is applied to the potentiometer. Then,

$$V \propto l$$

$$IR \propto l \tag{7}$$

Dividing eqn.7 by eqn.5, we get,

$$\frac{IR}{E} = \frac{l}{L}$$

$$\therefore \qquad I = \frac{E}{LR} l \tag{8}$$

Using eqn.3, $K \tan\theta = \frac{E}{LR} l$

$$\therefore \qquad K = \frac{El}{LR \tan\theta} \tag{9}$$

If E = 1.08 volt, $K = \frac{1.08l}{LR \tan\theta}$ (9a)

By eqn.4, $B_h = \frac{\mu_0 nK}{2a}$ (10)

Procedure: The connections are made as shown in the fig.a or b. Before inserting the different keys do the initial adjustments of the TG. To set the TG in the magnetic meridian, rotate the compass box alone till the 90-90 mark line coincides with the vertical plane of the coil. Then the TG as a whole is rotated till the aluminum pointer reads 0-0. For leveling, if necessary, rotate the leveling screws provided at the base.

To standardize the potentiometer for a particular p d per unit length, connect the standard cell (Daniel cell or power source) to the potentiometer by inserting keys in the gap between 1 and 2 and 5 and 6. Also close key K_1. Keep the sliding contact J at some point, say 920 cm, and adjust rheostat Rh_1 for no deflection in the galvanometer. Then close the high resistance key and the exact balancing length L for the standard cell is determined.

Then unplug the keys in between 1 & 2 and 5 & 6 and close keys in between 2 & 3 and 4 & 5. Also close key K_2. Now the p d across R is applied to the potentiometer. The rheostat Rh_2 is adjusted for a suitable deflection in between 30° and 60°. The readings at the ends of the aluminum pointer are noted. Find the balancing length l. Repeat the experiment by interchanging the commutator keys. Repeat the experiment for different deflections and in each case the deflection and the corresponding balancing length are determined.

Using a piece of twine the circumference of the T G coil is determined and from which its radius is calculated. Finally, K and B_h are calculated using eqns.9 and 10.

Precautions

- Precautions given in exp.No.10 are applicable in this case also.
- Ensure that the 90-90 line is at the centre of the coil and parallel to plane of the coil. Place a small plastic scale close to the coil with its plane parallel to the coil plane and look through the gap in between the coil and the scale. While looking lean a little forward and close one of the eyes.
- Avoid the parallax error during measurement. For that set the TG at a convenient place.
- Keep TG away from galvanometer, ammeter, rheostat etc., since the magnetic fields due to them may affect the reading.
- Ensure that the current through the TG is such that the deflection in the TG is in between 30° and 60°.
- Before taking reading tap on the frame of TG.
- Checking for opposite deflection must be done for each current through R. This is to ensure that the p d across R is less than p d between A and B due to primary voltage.
- If an ammeter is connected in series with the T G circuit you can check whether there is any change in the current during the determination of balancing point and also after the interchange of commutator keys.

Observation and tabulation

Standard resistance, R = ……… Ω

Standard voltage, E = ……… volt

Balancing length for standard voltage, L = …….. cm

Sl.No	Reading against the pointer of the T G in degrees				Mean θ Degree	Balancing length in cm			K ampere
	Commutator position 1		Commutator position 2			Position 1	Position 2	Mean l cm	
	1	2	3	4					
								Mean K	

Number of turns of the coil n = ……..

Circumference of the T G coil C = ………. cm

Radius of the coil, $a = \frac{C}{2\pi}$ = ……… m

Horizontal component of earth's magnetic field $B_h = \frac{\mu_0 nK}{2a}$ = ……… tesla

Result

Reduction factor of T G, K = ………. ampere

Horizontal component of earth's magnetic field B_h = ……… tesla

Standard data*: Horizontal component of earth's magnetic field $B_h = 0.38\times10^{-4}$ tesla

Exp.No.2.12

Potentiometer-Calibration of high range voltmeter

Aim: To calibrate the given high range voltmeter using a potentiometer.

Apparatus: A potentiometer, the given high range voltmeter, rheostats, two accumulators (or power sources), a Daniel cell (or a power source of standard voltage), two resistance boxes, six terminal key or a three terminal key, etc.

Theory

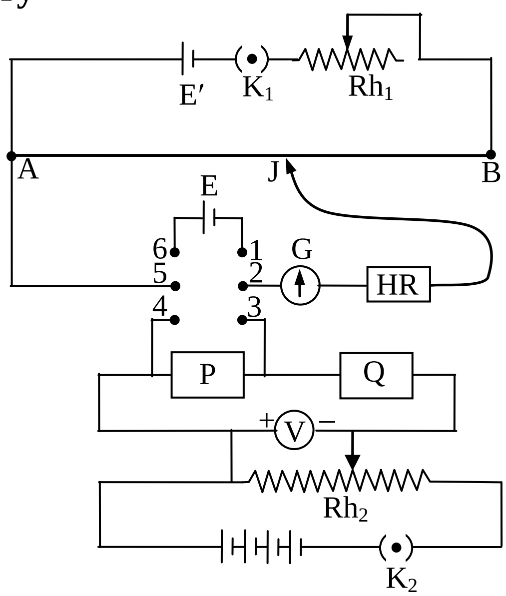


Fig.a: Six terminal key is used

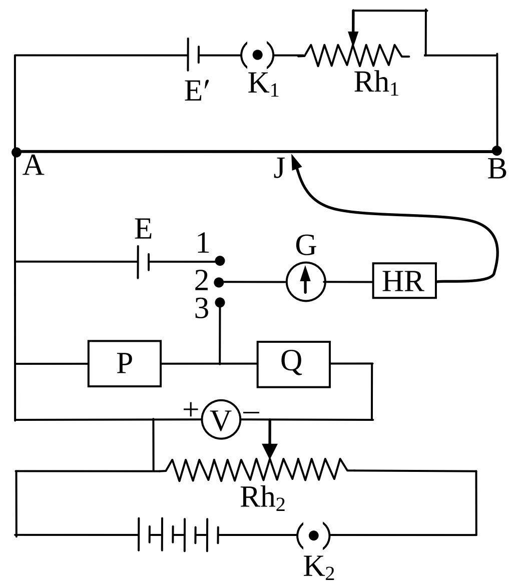


Fig.b: Three terminal key is used

Let L be the balancing length when a cell of standard e m f E (for Daniel cell E = 1.08 V) is connected in the secondary circuit. Then by the theory of potentiometer,

$$E \propto L \qquad (1)$$

Let V be the actual potential difference across P and Q. Then the current I through P and Q is given by,

$$I = \frac{V}{P+Q}$$

Potential difference across P, $$V_1 = IP = \frac{VP}{P+Q} \qquad (2)$$

If l is the balancing length for the p d developed across the resistance P, we can write,

$$V_1 \propto l$$

i.e. $$\frac{VP}{P+Q} \propto l \qquad (3)$$

Dividing eqn.3 by eqn.1, $$\frac{VP}{(P+Q)E} = \frac{l}{L}$$

$$\therefore \qquad V = \frac{E}{L}\left(\frac{P+Q}{P}\right)l \qquad (4)$$

$$= \frac{1.08}{L}\left(\frac{P+Q}{P}\right)l \qquad (4a)$$

$$\text{Voltmeter correction} = V - V_0$$

$$= \frac{E}{L}\left(\frac{P+Q}{P}\right)l - V_0 \qquad (5)$$

The graph plotted between the correction $V - V_0$ in the Y axis and V_0 in the X axis is the calibration graph of the given voltmeter. A model of the graph is shown in the fig.c.

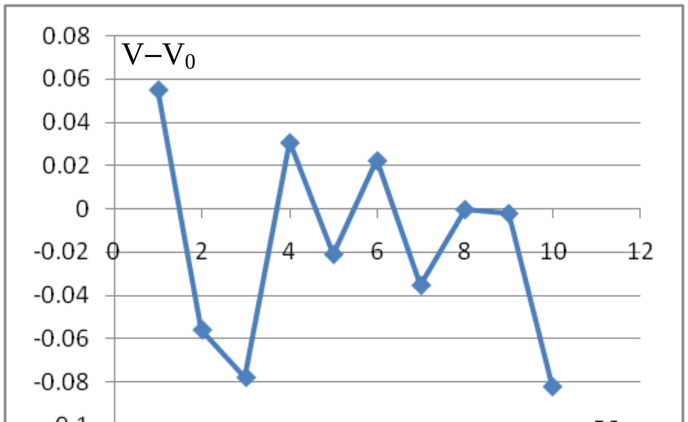


Fig.c

Procedure: Connections are made as shown in fig.a or fig.b. A two volt accumulator or a power supply E′ is connected in between A and B. The secondary circuit consists of a standard voltage power source and a high voltage power supply. In addition to the rheostat Rh_2, resistances P and Q also act as a potential divider arrangement. Take suitable resistances in P and Q, say 50 ohm in P and 450 ohm in Q (or, 100 ohm in P and 900 ohm in Q), such that the potential difference developed across P does not exceed the p d across A B.

The key K_1 is closed and check for opposite deflections with the standard voltage and the voltage across P. By inserting suitable keys, the standard voltage source is applied to the potentiometer and the balancing length L is determined. Then, take suitable resistances in P and Q. The keys in the six terminal key or three terminal key are changed such that the standard voltage is removed from the potentiometer circuit and the p d across P is applied to the potentiometer. The voltmeter reading is adjusted to, say 1 volt by adjusting the rheostat Rh_2. The balancing length l is determined. Then the rheostat Rh_2 is adjusted for voltmeter reading 2V, 3V, ………. etc. and in each case the balancing length is determined.

The voltages and corrections are calculated using eqns. 4 and 5. A calibration graph is plotted with the voltmeter readings V_0 in the X axis and the correction $V-V_0$ in the Y axis.

Precautions:

- Same as given in exp.No.10.
- Be careful that the voltage across P is less that the primary voltage across AB. That is, resistance P << Q.
- Tight all the plugged keys in all resistance boxes, since the loose keys create unwanted resistance in the circuit.

Observations and tabulations

Standard voltage E = …………volts

Balancing length for standard e m f E = L = ……… cm

Sl. No.	Voltmeter Reading V_0 volt	Resistance in ohm		Balancing length l cm	Calculated voltage $V = \frac{E}{L}\left(\frac{P+Q}{P}\right)l$ volt	Correction $V-V_0$ volt
		P	Q			
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Result

The given high range voltmeter is calibrated and the calibration graph is drawn.

Standard data*: Voltage of Daniel cell = 1.08 volt.

Exp.No.2.13

Circular coil- Determination of B_h and m

Aim: To determine the value of the horizontal component of earth's magnetic field and the dipole moment of a bar magnet using a circular coil.

Apparatus: Circular coil apparatus (fig.a), power supply, compass box, bar magnet, ammeter, rheostat, commutator key and another key.

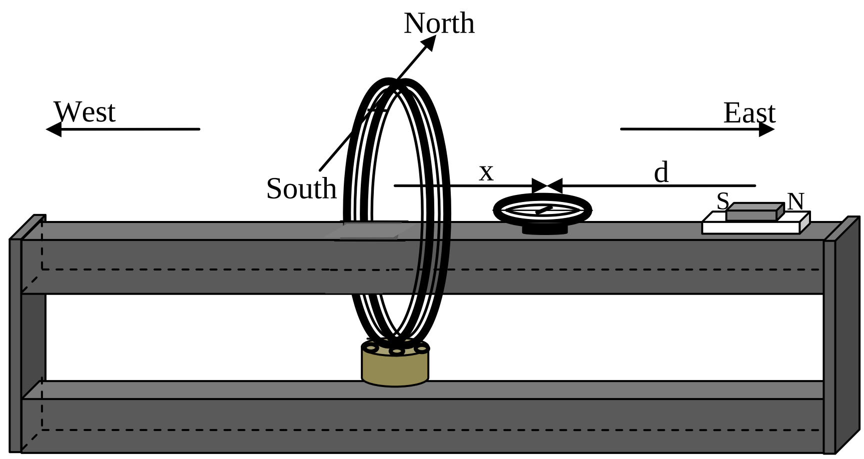


Fig.a

Theory: The magnetic field at a point on the axis at a distance 'x' from the centre of a current carrying circular coil of 'n' turns is given by,

$$B = \frac{\mu_0 n a^2 I}{2\left(a^2+x^2\right)^{3/2}} \qquad (1)$$

where, 'a' is the radius of the coil and 'I' is the current through it. Since, while doing the experiment the axis of the coil is set perpendicular to the magnetic meridian, the field due to the coil and the earth's horizontal field (directed from geographic south to geographic north) are mutually perpendicular, the resultant field is at an angle θ with the magnetic meridian. Then applying the tangent law, we get,

$$B = B_h \tan\theta \qquad (2)$$

From eqns.1 and 2, $B_h \tan\theta = \dfrac{\mu_0 n a^2 I}{2\left(a^2+x^2\right)^{3/2}}$

$$B_h = \frac{\mu_0 n a^2 I}{2\left(a^2+x^2\right)^{3/2}\tan\theta} \qquad (3)$$

If a magnet of half the length '*l*' and dipole moment 'm' is placed at a distance 'd' from the centre of the compass box such that the field due to the coil is exactly cancelled by the field due to the magnet, we can write,

$$\frac{\mu_0 n a^2 I}{2\left(a^2+x^2\right)^{3/2}} = \frac{\mu_0}{4\pi}\frac{2md}{\left(d^2-l^2\right)^2}$$

$$m = \frac{\pi n a^2 I\left(d^2-l^2\right)^2}{d\left(a^2+x^2\right)^{3/2}} \qquad (4)$$

Procedure: Connections are made as shown in the fig.b. Usually the coil consists of a set of coils of different number of turns. Select any one of them, say 5 turns. The initial adjustments to set the plane of the coil parallel to the magnetic meridian are made as follows. The compass box is placed at the centre of the coil. Rotate the compass box alone till the 90-90 mark line coincides with the vertical plane of the coil. Then the apparatus as a whole is rotated till the aluminum pointer reads 0-0. Now the plane of the coil is in the magnetic meridian and the platform is in the east-west direction as shown in the fig.a.

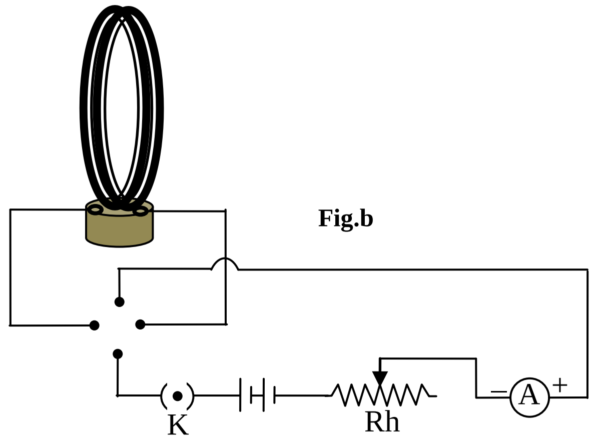


Fig.b

To find B_0: Now the compass box is kept at a distance 'x' from the centre of the coil, (say, 5 cm) on one side. The circuit is closed and the rheostat is adjusted for a current 'I'. The current is such that the deflection in the compass box is in between 30° and 60°. The ammeter reading and the readings corresponding to both ends of the pointer are noted. Then the current is reversed by changing the commutator keys and the pointer readings are again taken. Now the compass box is placed at the same distance on the other side of the coil and four more readings are taken. The average of these eight deflections is calculated. Let it be θ. The circumference of the coil is determined with a twine and from it the radius 'a' of the coil is calculated. B_h is calculated using eqn.3. The experiment is repeated for different values of distance x and current I. The average value of B_h is determined.

To find m: After making connections and the initial adjustments of the apparatus as discussed above, the compass box is placed at distance 'x' from the centre of the coil. The current is adjusted to get a deflection in between 30° and 60°. The given magnet is placed along the axis on one side of the compass box as shown in fig.a. The distance between the magnet and the compass box is adjusted so that the deflection in the compass box is reduced to zero. The current through the coil and the distance d_1 between the magnet and the compass box are measured. The current is reversed by changing the commutator keys. The magnet also must be reversed. The distance is adjusted for null deflection. The distance d_2 from the centre of the magnet and the centre of the compass box is again measured. Now the compass box and the magnet are placed on the other side of the coil and two more readings, d_3 and d_4, for null deflection are determined. The average distance 'd' of four distances is found.

The number of turns of the coil is noted. The radius of the coil 'a' is determined by measuring its circumference. The length of the magnet '2*l*' is also measured. Then using eqn.4 the dipole moment 'm' is calculated. The experiment is repeated for different values of distance x and current I. The average value of m is determined.

Precautions

- Ensure that the plane of the coil is set parallel to the magnetic meridian.
- The axis of the bar magnet should pass through the centre of the compass needle and the centre of the circular coil.
- The distances and the currents are such that the deflection is in between 30° and 60°.
- To get zero deflection with magnet, the field due to the coil and the field due to the magnet are in the opposite directions. If you are not getting a zero deflection reverse the magnet for changing the direction of field due to the magnet.

Observation and tabulation

To find B_h

Sl.No	Current I ampere	Distance 'x' cm	Deflections 'θ' in degree								Mean θ degree	B_h tesla
			One side				Other side					
			1	2	3	4	5	6	7	8		
1												
2												
3												
4												
5												
6												

Mean B_h = ……….. T

Number of turns of the coil, 'n' = ……….

Circumference of the coil 'L' = ………. cm

Radius of the coil, 'a' = $\frac{L}{2\pi}$ = ……… m

To find m

Sl.No	Current I ampere	Distance 'x' cm	Distance of magnet for null deflection				Mean d cm	moment **m** Am^2
			d_1 cm	d_2 cm	d_3 cm	d_4 cm		
1								
2								
3								
4								

Mean m = ……….. Am^2

Result

Horizontal component of earth's magnetic field, B_h = ……….. tesla

Dipole moment of the given bar magnet, m = ……….. ampere metre^2

Standard data*

Permeability of the free space, $\mu_0 = 4\pi\times10^{-7}$ henry/metre

Exp.No.2.14

Carey Fosters' Bridge-Temperature coefficient of resistance

Aim: To determine the temperature coefficient of the resistance of the material of the coil by measuring its resistance at different temperatures using Carey Foster's bridge.

Apparatus: Carey Foster's bridge, given coil of wire, a cell (power supply), standard resistances, a resistance box, key, galvanometer, high resistance, heating arrangement and a thermometer.

Theory: The temperature coefficient of resistance is defined by the change in resistance to its resistance at zero degree Celsius per unit resistance per unit degree rise of temperature.

$$\text{Temperature coefficient of resistance} \quad \alpha = \frac{X_t - X_0}{X_0 t} \tag{1}$$

$$X_t = X_0(1+\alpha t)$$

Let X_1 and X_2 be the resistances at temperatures t_1°C and t_2°C respectively. Then,

$$X_1 = X_0(1+\alpha t_1) \tag{2}$$

$$X_2 = X_0(1+\alpha t_2) \tag{3}$$

Dividing eqn.2 by eqn.3,

$$\frac{X_1}{X_2} = \frac{(1+\alpha t_1)}{(1+\alpha t_2)}$$

Cross multiplying and rearranging,

$$\alpha = \frac{X_2 - X_1}{X_1 t_2 - X_2 t_1} \tag{4}$$

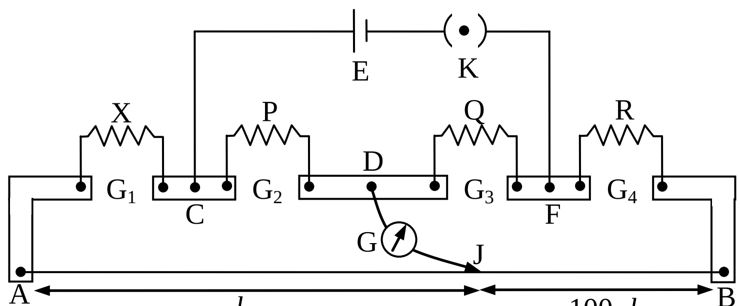


Fig.a

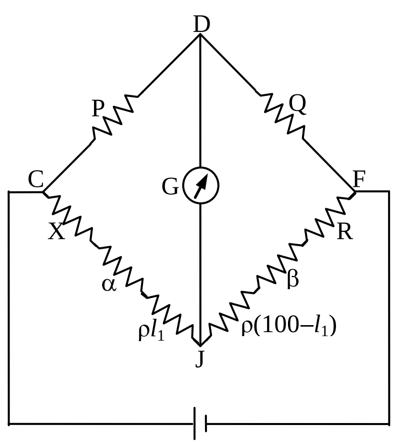


Fig.b

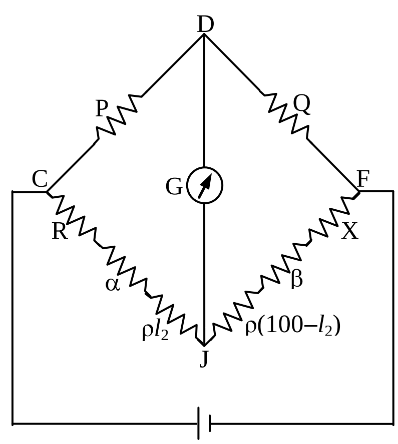


Fig.c

In this experiment we use Carey Foster Bridge to determine the unknown resistance X_1 and X_2. The basic principle of it is Wheatstone's principle. Carey Foster Bridge consists of a uniform wire AB of length 1 m stretched on a wooden board. Five metallic strips are fixed on the wooden board as shown the figure. G_1, G_2, G_3 and G_4 are gaps between the metal strips. Two equal resistances P and Q are connected in the gaps G_2 and G_3 respectively. The unknown resistance X is connected in the gap G_1. A standard resistance R is connected in the gap G_4. A standard cell is connected across the terminals C and F. A galvanometer G is connected between D and the contact maker J, that is able to slide along AB.

Theory*: The contact maker J is moved along the wire AB until the galvanometer shows no deflection. Then the bridge is said to be balanced. Let l_1 be the balancing length as measured from the end A. Let α and β, respectively, be the end resistances at A and B. Let ρ be the resistance per unit length of the wire AB. The above bridge is equivalent to a Wheatstone's bridge as shown fig.b.

Applying Wheatstone's principle we get,

$$\frac{P}{Q} = \frac{X+\alpha+\rho l_1}{R+\beta+\rho(100-l_1)} \tag{5}$$

The resistances R and X are interchanged and the bridge is again balanced. The balancing length l_2 is measured from the same end A. Then,

$$\frac{P}{Q} = \frac{R+\alpha+\rho l_2}{X+\beta+\rho(100-l_2)} \tag{6}$$

Equating the RHS of eqns.5 and 6 we get,

$$\frac{X+\alpha+\rho l_1}{R+\beta+\rho(100-l_1)} = \frac{R+\alpha+\rho l_2}{X+\beta+\rho(100-l_2)}$$

Adding 1 on both sides, we get,

$$\frac{X+\alpha+\rho l_1}{R+\beta+\rho(100-l_1)} + 1 = \frac{R+\alpha+\rho l_2}{X+\beta+\rho(100-l_2)} + 1$$

$$\frac{X+\alpha+\rho l_1+R+\beta+\rho(100-l_1)}{R+\beta+\rho(100-l_1)} = \frac{R+\alpha+\rho l_2+X+\beta+\rho(100-l_2)}{X+\beta+\rho(100-l_2)}$$

Since the numerators are equal, we can equate the denominators. Thus we get,

$$R+\beta+\rho(100-l_1) = X+\beta+\rho(100-l_2)$$

i.e. $$X-\rho l_2 = R-\rho l_1$$

i.e. $$X = R+\rho(l_2-l_1) \tag{7}$$

To find ρ: A thick copper strip is connected in the gap G_1 and a small resistance R′ of the order of 0.1 Ω is connected in the gap G_4 and the balancing length l_3 is determined. Now the copper strip and R′ are interchanged and the balancing length l_4 is determined. Then from eqn.7, since X = 0 and R = R′ in this case, we get,

$$0 = R' + \rho(l_4-l_3)$$

i.e. $$\rho = \frac{R'}{l_3-l_4} \tag{8}$$

Thus, by knowing R and ρ the unknown resistance X can be calculated using eqn.7.

Procedure

To find ρ

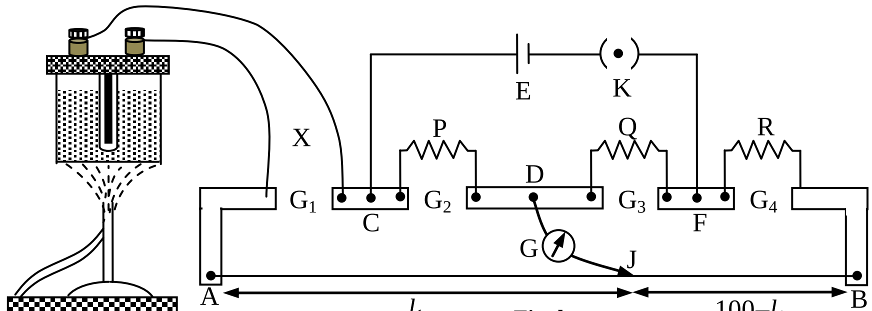


Fig.d

The connections are made as shown in the fig.d. Suitable standard resistances P and Q are connected in the gaps G_2 and G_3. Instead of X connect a thick copper strip in the gap G_1 and a resistance box with fractional resistance in the gap G_4. Take a resistance $R' = 0.2\ \Omega$ in the box. Find the balancing length l_3. It is measured from the end A. Then interchange the copper strip and the resistance box. The balancing length l_4 is determined. It is again measured from the end A. Calculate 'ρ' using eqn.8. The experiment is repeated for $R' = 0.3\ \Omega, 0.4\ \Omega$, ……….. The average of 'ρ' is calculated.

To find the resistance of the coil

Connections are made as shown in fig.d. The resistance coil is connected in the gap G_1 and a resistance box in the gap G_4. The coil is immersed in water taken in a vessel. The temperature t_1°C of the water bath is noted with a thermometer. Introduce a suitable resistance R in the box (read precautions) and the balancing length l_1 is determined. It is measured from the end A. Then interchange the coil and the resistance box and the balancing length l_2 is determined. It is again measured from the end A. Repeat the experiment for different values of R.

The water bath is then heated to the temperature t_2°C (= 100 °C if water boils). The new resistance is determined as discussed above.

The resistances X_1 and X_2 are calculated by eqn.7 and the temperature coefficient of resistance by eqn.4.

Precautions

- Ensure that the resistances X and R are not far different. If they are equal you will get the balance point at the middle of the wire AB. To find approximately equal resistance, the contact maker J is kept pressed at the middle of AB and find the resistance needed in R for no deflection in the galvanometer. Then take three readings with R less than and three more readings with R greater than this resistance. Increase or decrease the resistance in steps by 0.5 ohm (or 0.3 Ω).
- When copper strip is used, instead of X, take only the fractional resistance 0.2, 0.3, 0.4, …… Since ρ is the resistance per unit length sign of $l_3 - l_4$ is not considered.
- The sign of $l_2 - l_1$ is very important. Take positive as positive negative as negative.
- If you are not getting any deflection check the supply voltage and continuity of the circuit with a multimeter.
- Remember the balancing length is always measured from the end A.
- Tight all the plugged keys in all resistance boxes, since the loose keys create unwanted resistance in the circuit.

Observation and tabulation

To find ρ

Sl.No.	Resistance R' Ohms	Balancing length with R' in		$l_3 \sim l_4$ cm	$\rho = \frac{R'}{l_3 \sim l_4}\ \Omega$
		Right gap l_3 (cm)	Left gap l_4 (cm)		
1					
2					
3					
4					
5					

Mean ρ = ………… Ω

To find X_1 and X_2

Temperature	Sl.No.	Resistance R ohms	Balancing length with R in		$l_2 - l_1$ cm	$X = R + \rho(l_2 - l_1)$ ohm
			Right gap l_1 (cm)	Left gap l_2 (cm)		
t_1 = …….°C	1					
	2					
	3					
	4					
	5					
					Mean X_1	
t_2 = …….°C	1					
	2					
	3					
	4					
	5					
					Mean X_2	

$$\alpha = \frac{X_2 - X_1}{X_1 t_2 - X_2 t_1} = \text{………} = \text{………. Per °C}$$

Result

Temperature coefficient of resistance of the material of the coil, α = ………per °C

Standard data*

Temperature coefficient of resistance of copper, α = 0.0040±0.0002 per celsius

The accepted value is 0.0039 per celsius.

Exp.No.2.15

Conversion of a Galvanometer into voltmeter- calibration using potentiometer

Aim: To convert the given galvanometer into a voltmeter and calibrate it with a potentiometer.

Apparatus: The given pointer type galvanometer, potentiometer, resistance boxes, commutator key, accumulator, Daniel cell (or power supplies), etc.

Theory: A galvanometer can be converted into a voltmeter by connecting a high resistance in series with it. The range of the voltmeter (converted galvanometer) depends on this series resistance. Let the galvanometer is converted to a voltmeter to measure a voltage range 0-V. Let I_g be the full scale deflection current (current flowing through the galvanometer when it shows full scale deflection) of the galvanometer. For example, the given galvanometer is graduated such that the division at the centre is zero and on each side of the zero line there are 30 divisions. Then the full scale deflection current means the current required to produce a deflection of 30 divisions in the galvanometer. Suppose this galvanometer is converted into a voltmeter of range 0 to V volt. When the converted galvanometer reads a voltage V, the current trough it is I_g ampere. Let G be the resistance of the galvanometer. Then, from fig.a,

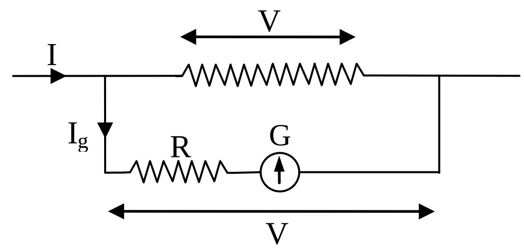


Fig.a

$$I_g(R+G) = V$$

$$R = \frac{V}{I_g} - G \qquad (1)$$

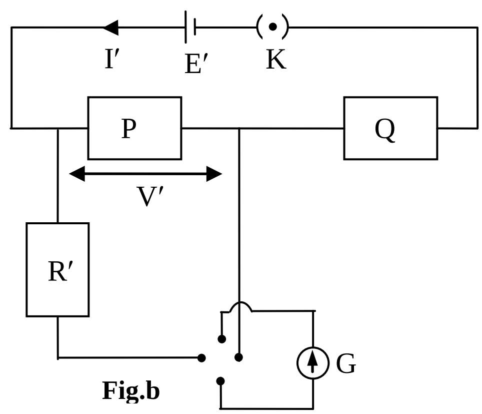


Fig.b

Let 'k' be the figure of merit (current sensitivity) of the galvanometer. It is the current required to produce a deflection of one division. If there are 'n' divisions on each side of the zero division,

$$I_g = kn \qquad (2)$$

To find out k and G we consider a circuit as shown in fig.b. Using Ohm's law, the current through P and Q is (since P << R′ + G),

$$I' = \frac{E'}{P+Q}$$

Potential difference across P is, $V' = \dfrac{E'P}{P+Q}$

Current through the galvanometer, $I_1 = \dfrac{V'}{R'+G} = \dfrac{E'P}{(P+Q)(R'+G)}$

If R′ = 0, $$I_1 = \frac{E'P}{(P+Q)G} \qquad (3)$$

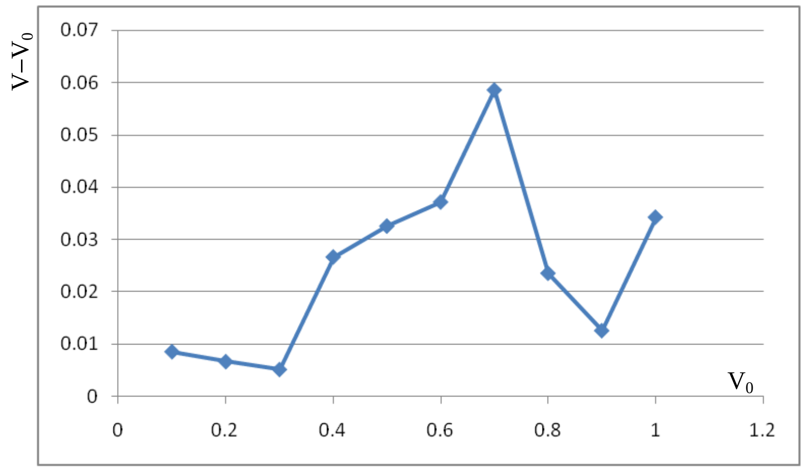
Due to this current the galvanometer shows a deflection of 'd' divisions. Then current sensitivity,

$$k = \frac{I_1}{d} = \frac{E'P}{(P+Q)Gd} = \frac{E'}{(P+Q)G}\left(\frac{P}{d}\right) \qquad (4)$$

When a resistance is introduced in R′, current I_1 decreases and hence the deflection in the galvanometer decreases. The current and hence the galvanometer deflection reduces to half when

$$R' \approx G + P. \qquad (5)$$

(See the appendix at the end). Using eqns.2, 4 and 5 in eqn.1 we get the resistance needed to convert a galvanometer to a voltmeter of range 0 to V volt. Its volt per division is V/n. Then convert the galvanometer into voltmeter and calibrate it. Draw the calibration graph as shown in the model.



Procedure

To find G and k: Connections are made as shown in the fig.b. Suitable resistances are introduced in P and Q with P << Q. For example, P = 10 Ω and Q = 990 Ω so that P + Q = 1000 Ω. The voltage across P (much smaller voltage) is applied to the galvanometer through the resistance box R′. All the keys in R′ are plugged and tightened so that R′ = 0. The deflection 'd' in the galvanometer is noted. Now increase the resistance in R′ and find out the resistance needed to reduce the deflection to half of its original value. This value of resistance is noted. The experiment is repeated after reversing the commutator. The entire experiment is repeated for different values of P and Q. In each case 'd' and 'G' are determined.

To convert galvanometer into voltmeter: Using eqns.2, 4 and 5 in eqn.1calculate the resistance R needed for the conversion of galvanometer to the voltmeter for the selected voltage range. For example, If there are 30 divisions in the galvanometer we can conveniently choose a range of 0 to 0.3, 0 to 3 or 0 to 30 volt. Connect the calculated resistance R in series with the galvanometer. Thus the galvanometer is converted to a voltmeter.

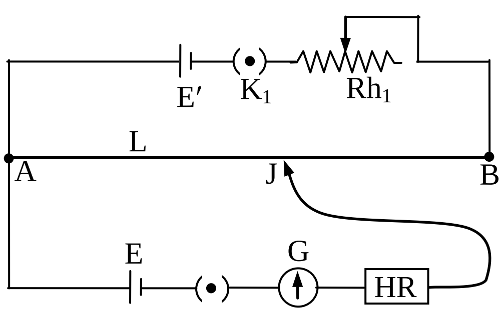


Fig.c

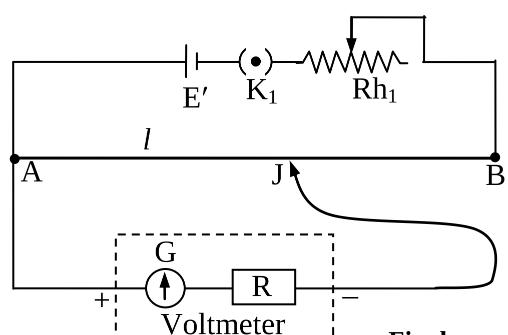


Fig.d

Calibration of the voltmeter: Depending upon the range of the voltmeter constructed, we can follow the method of calibration of low range voltmeter (Exp.No.1.20 of practical-I) or the method for high range voltmeter (Exp.No.2.12 of practical-II).

Here we use another simple method as follows. Standardise the potentiometer with a standard voltage using the diagram as shown in fig.c. The balancing length 'L' for the standard voltage (Daniel cell 1.08 V) is determined. Then the potential difference per unit length of the potentiometer wire $\frac{E}{L}$ is found out. Connect the newly constructed voltmeter as shown in fig.d. Move the contact maker J along the wire such that the voltmeter reads a particular value V_0, say, 0.1 volt. Measure the length 'l' corresponding to this voltage and calculate the voltage $V = \frac{El}{L} = \frac{1.08l}{L}$. Repeat the experiment for 0.2 volt, 0.3 volt, …………. A calibration graph is plotted with V_0 along the X axis and the correction along the Y axis.

- To make calculations easy choose P + Q as a multiple of 10 and keep it constant. For example If P = 10 and Q = 90, P +Q = 100 or, if P = 10, Q = 990, so that P + Q = 1000. If deflection is too large either reduce the voltage E or increase P + Q. Ensure P << Q. Also P << R′ + G.
- Tight all the plugged keys in all resistance boxes, since the loose keys create unwanted resistance in the circuit.
- It can be shown that the resistance needed for half deflection in the galvanometer is, (see the appendix at the end),

$$R' = G + \frac{P(Q+r)}{P+Q+r}$$, where 'r' is the internal resistance of the cell E′.

$$G = R' - \frac{P(Q+r)}{P+Q+r}$$

Since, r and P are much less than Q,

$$G \approx R' - P$$

Observation and tabulation

To find G, k and R

Voltage applied across P and Q = E′ = ……… volt

P + Q = ………. ohm

P Ohm	Q Ohm	Galvanometer deflection 'd'			$\frac{P}{d}$	Resistance for half deflection			G≈R′−P Ohm
		left	Right	Mean		Left Ω	Right Ω	Mean Ω	
				Mean				Mean G	

Current sensitivity (figure of merit) of the galvanometer,

$$k = \frac{E'}{(P+Q)G}\left(\frac{P}{d}\right) = \ldots\ldots \text{ ampere/division}$$

Number of divisions (one side of zero division) on the galvanometer, $n = \ldots\ldots\ldots$

Full scale deflection current, $I_g = nk = \ldots\ldots\ldots$ A

Range of voltage selected, 0 to V = 0 to ….. volt

Resistance, $R = \frac{V}{I_g} - G = \ldots\ldots$ ohm

To check the correctness of the voltmeter readings

Standard voltage $E = \ldots\ldots$ volt

Balancing length with standard voltage, $L = \ldots\ldots$ cm

Voltage per division of the constructed voltmeter, $v = \frac{V}{n} = \ldots\ldots$volt/division

Deflection in the converted galvanometer, 'd'	Measured voltage $V_0 = vd$ Volt	Length of the potentiometer wire corresponding to the measured voltage, l cm	Calculated voltage $= \frac{El}{L}$ volt	Error $= \frac{El}{L} - V_0$ Volt

Result

The given galvanometer is converted to a voltmeter to read a voltage range 0 to ….. volt. Its readings are checked with a potentiometer and a calibration graph is plotted.

Standard data*

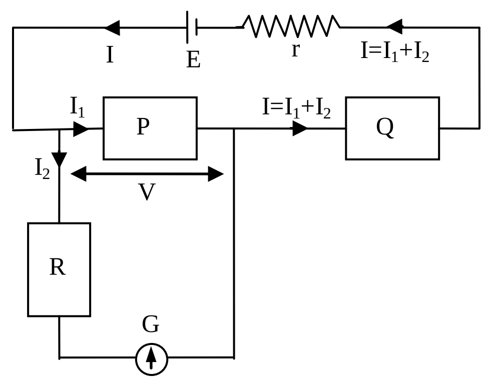
E m f of the Daniel cell, $E = 1.08$ volt

Appendix*

For the closed circuits we can write,

$$E = I_1P + (I_1 + I_2)Q + (I_1 + I_2)r \qquad (1)$$

$$I_1P = I_2(R + G) \qquad (2)$$



When R = 0, $I_1 = I_1'$ and $I_2 = I_g$, then the equations reduce to

$$E = I_1'P + (I_1' + I_g)Q + (I_1' + I_g)r \qquad (3)$$

$$I_1'P = I_gG \qquad (4)$$

$$I_1' = \frac{I_g}{P}G$$

$$E = I_gG + \left(\frac{I_g}{P}G + I_g\right)Q + \left(\frac{I_g}{P}G + I_g\right)r \qquad (5)$$

When R = R′, the deflection in the galvanometer is half, i.e. the $I_2 = \frac{I_g}{2}$ and $I_1 = I_1''$. Then the eqns. 1 and 2 become,

$$E = I_1''P + \left(I_1'' + \frac{I_g}{2}\right)Q + \left(I_1'' + \frac{I_g}{2}\right)r \qquad (6)$$

$$I_1''P = \frac{I_g}{2}(R' + G)$$

$$I_1'' = \frac{I_g}{2P}(R' + G)$$

$$E = \frac{I_g}{2}(R' + G) + \left(\frac{I_g}{2P}(R' + G) + \frac{I_g}{2}\right)Q + \left(\frac{I_g}{2P}(R' + G) + \frac{I_g}{2}\right)r \qquad (7)$$

Equating the R H Ss of eqns.5 and 7,

$$I_gG + \left(\frac{I_g}{P}G + I_g\right)Q + \left(\frac{I_g}{P}G + I_g\right)r = \frac{I_g}{2}(R' + G) + \left(\frac{I_g}{2P}(R' + G) + \frac{I_g}{2}\right)Q + \left(\frac{I_g}{2P}(R' + G) + \frac{I_g}{2}\right)r$$

Multiplying throughout by $\frac{2P}{I_g}$ and rearranging,

$$R'(P + Q + r) = G(P + Q + r) + P(Q + r)$$

$$R' = G + \frac{P(Q + r)}{(P + Q + r)}$$

$$G = R' - \frac{P(Q + r)}{(P + Q + r)} \qquad (8)$$

When P and r are much less than Q,

$$G \approx R' - P$$

If P << R', $\quad G \approx R'$

Exp.No.2.16

Conversion of Galvanometer into ammeter- calibration using potentiometer

Aim: To convert the given galvanometer into an ammeter and calibrate it using a potentiometer.

Apparatus: The given pointer type galvanometer, potentiometer, resistance boxes, standard resistance wire, commutator key, accumulator, Daniel cell (or power supplies), etc.

Theory: A galvanometer can be converted into an ammeter by connecting a small resistance (shunt resistance) in parallel with it. The range of the ammeter (converted galvanometer) depends on this parallel resistance. Let the galvanometer is converted to an ammeter to measure a current range 0 to I ampere. Let I_g be the full scale deflection current (current flowing through the galvanometer when it shows full scale deflection) of the galvanometer. Suppose this galvanometer is converted into an ammeter of range 0 to I ampere. When the converted galvanometer reads a current I ampere, the current trough it is only I_g ampere and the remaining current passes through the shunt resistance S. Let G be the resistance of the galvanometer. Then from fig.a,

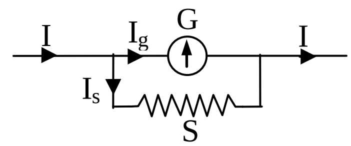


Fig.a

$$I_gG = I_sS = (I - I_g)S$$

$$S = \frac{I_gG}{I - I_g} \qquad (1)$$

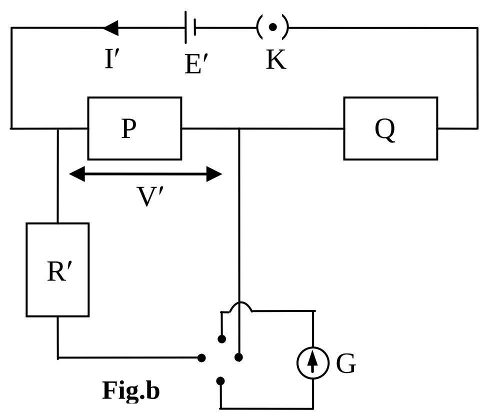


Fig.b

Let 'k' be the figure of merit (current sensitivity) of the galvanometer. It is the current required to produce a deflection of one division. If there are 'n' divisions on each side of the zero division,

$$I_g = kn \qquad (2)$$

To find out k and G we consider a circuit as shown in fig.b. Using Ohm's law, the current through P and Q is,

$$I' = \frac{E'}{P+Q}$$

Potential difference across P is, $V' = \dfrac{E'P}{P+Q}$

Current through the galvanometer, $I_1 = \dfrac{V'}{R'+G} = \dfrac{E'P}{(P+Q)(R'+G)}$

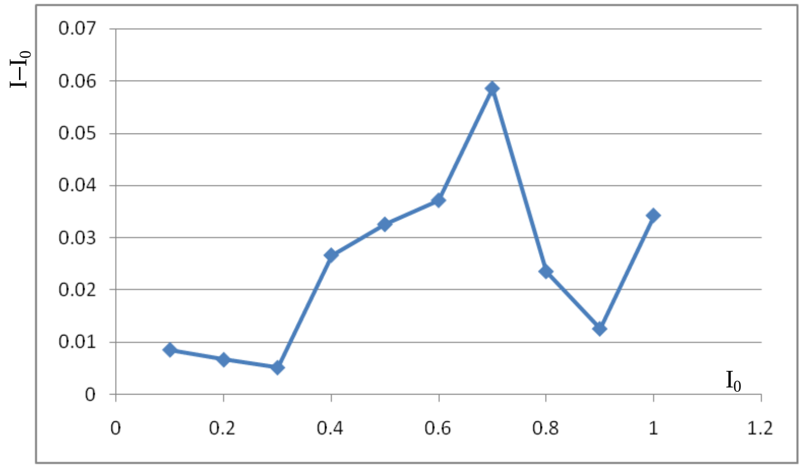
If $R' = 0$, $$I_1 = \frac{E'P}{(P+Q)G} \qquad (3)$$

Due to this current the galvanometer shows a deflection of 'd' divisions. Then current sensitivity,

$$k = \frac{I_1}{d} = \frac{E'P}{(P+Q)Gd} = \frac{E'}{(P+Q)G}\left(\frac{P}{d}\right) \qquad (4)$$

When a resistance is introduced in R′, current I_1 decreases and hence the deflection in the galvanometer decreases. The current and hence the galvanometer deflection reduces to half when

$$R' \approx G + P \qquad (5)$$



Using eqns.2, 4 and 5 in eqn.1 we get the resistance needed to convert a galvanometer into an ammeter of range 0 to I ampere. Its current per division is I/n.

Let ρ be the resistance per unit length of a standard resistance wire. Length of the wire needed for a resistance S is S/ρ.

Then convert the galvanometer into ammeter and calibrate it. Draw the calibration graph as shown in the model.

Procedure

To find G and k: Connections are made as shown in the fig.b. Suitable resistances are introduced in P and Q with P << Q. For example, P = 10 Ω and Q = 990 Ω so that P + Q = 1000 Ω. The voltage across P (much smaller voltage) is applied to the galvanometer through the resistance box R′. All the keys in R′ are plugged and tightened so that R′ = 0. The deflection ‘d’ in the galvanometer is noted. Now increase the resistance in R′ and find out the resistance needed to reduce the deflection to half of its original value. This value of resistance is noted. The experiment is repeated after reversing the commutator. The entire experiment is repeated for different values of P and Q. In each case ‘d’ and ‘G’ are determined.

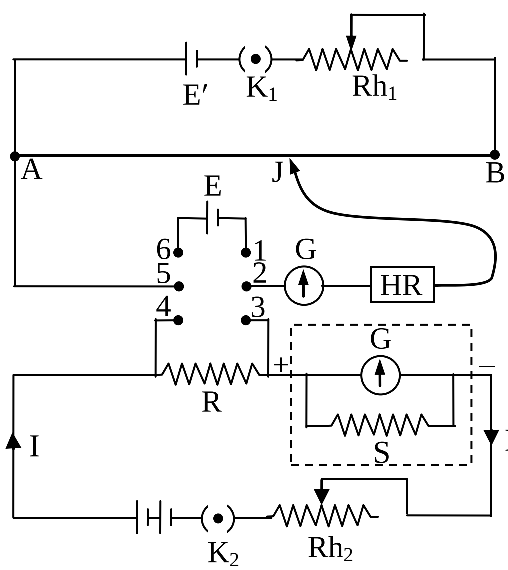


Fig.c

To convert galvanometer into ammeter: Using eqns.2, 4 and 5 in eqn.1, calculate the resistance S needed for the conversion of galvanometer to the ammeter for the selected current range. For example, If there are 30 divisions in the galvanometer we can conveniently choose a range of 0 to 0.3, 0 to 3 ampere. Connect the calculated resistance S in parallel with the galvanometer. Thus the galvanometer is converted to an ammeter.

Calibration of the ammeter: To calibrate the ammeter we follow the method described in exp.No.2.10. The balancing length L, corresponding to the standard voltage E and the balancing length l corresponding to the voltage across the standard resistance R for various currents are determined. The current and the error in the measurement of it are calculated as follows.

$$I = \frac{E}{LR}l$$

If E = 1.08 volt,

$$I = \frac{1.08l}{LR}$$

Correction to the ammeter reading $= I - I_0 = \frac{E}{LR}l - I_0$

The calibration graph between the measured current I_0 in the X axis and the correction $I - I_0$ in the Y axis is plotted.

Precautions

- All precautions given in exp.No.15 applicable in this experiment.
- Take an excess length (≈ 2 cm) of standard resistance wire required to connect at the two terminals of the galvanometer.

Observation and tabulation

To find G, k and R

Voltage applied across P and Q = E′ = ……… volt

P + Q = ………. ohm

P ohm	Q Ohm	Galvanometer deflection 'd'			$\frac{P}{d}$	Resistance for half deflection			G≈R′−P Ohm
		left	Right	Mean		Left Ω	Right Ω	Mean Ω	
				Mean				Mean G	

Current sensitivity (figure of merit) of the galvanometer,

$$k = \frac{E'}{(P+Q)G}\left(\frac{P}{d}\right) = \text{……. ampere/division}$$

Number of divisions (one side of zero division) on the galvanometer, n = ………

Full scale deflection current, $I_g = nk =$ ………. A

Range of current selected, 0 to I = 0 to ….. ampere

Resistance, $S = \frac{I_g G}{I - I_g}$ = ……. ohm

Resistance per unit length of the standard resistance wire, ρ = ……. ohm/metre

Length of the wire needed for the resistance S is $L' = \frac{S}{\rho}$ metre.

(Read the precautions given)

To check the correctness of the ammeter (converted voltmeter) readings

Standard voltage E = ……. volt

Balancing length with standard voltage, L = …….. cm

Current per division of the constructed ammeter, $i = \frac{I}{n}$ = ……ampere/division

Deflection in the converted galvanometer, 'd'	Measured current I_0 = id ampere	Length of the potentiometer wire corresponding to the measured current, l cm	Calculated current = $\frac{El}{LR}$ ampere	Error = $\frac{El}{RL} - I_0$ ampere

Result

The given galvanometer is converted to an ammeter to read a current range 0 to ….. A. Its readings are checked with a potentiometer and a calibration graph is plotted.

Standard data*

E m f of the Daniel cell, E = 1.08 volt

*Resistance per metre of copper wire of

Gauge number	Diameter in mm	Resistance per metre Ω/m
20	0.9144	0.0263
22	0.7112	0.0434
24	0.5588	0.0703
26	0.4572	0.105
28	0.3759	0.155
30	0.3150	0.221

Exp.No.2.17

Verification of Thevenin's and Norton's theorems

Aim: To verify the Thevenin's and Norton's network theorems.

Apparatus: Power supply, resistance box or standard resistances, voltmeter, ammeter etc.

Theory

Thevenin's theorem: It states that a two terminal network containing resistances (linear impedances) and voltage sources can be replaced by a single voltage source V_{Th}, in series with a single resistance R_{Th}, where, V_{Th}, called Thevenin voltage, is the open circuit voltage between the terminals and R_{Th}, called the Thevenin resistance, is the resistance that would be measured between the terminals with all the voltage sources are replaced by their internal resistances.

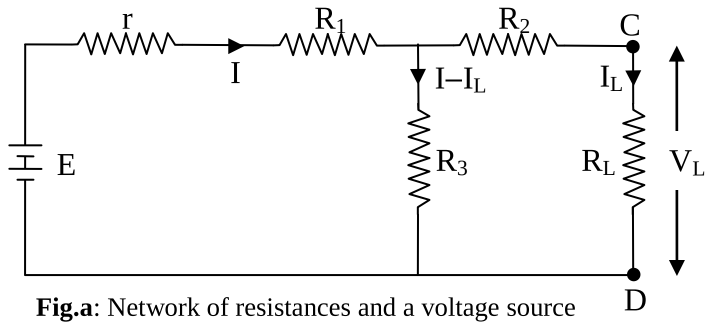


Fig.a: Network of resistances and a voltage source

Fig.a represents a circuit containing simple linear network of three resistances R_1, R_2 and R_3 with two terminals C and D. R_L is a load resistance connected between the two terminals C and D. E is the e m f of the voltage source and r is its internal resistance. Fig.b represents the Thevenin equivalent.

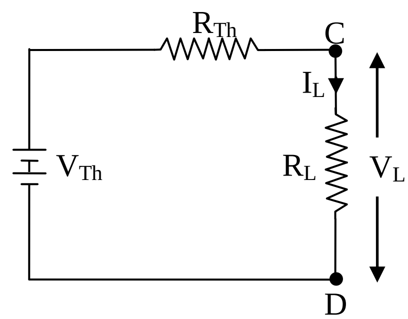


Fig.b: Thevenin equivalent

Theoretical calculation of Thevenin voltage and Thevenin resistance: From fig.a,

$$I(R_1+r)+I_L(R_2+R_L) = E \tag{1}$$

$$I_L(R_2+R_L)-(I-I_L)R_3 = 0 \tag{2}$$

$$IR_3 = I_L(R_2+R_3+R_L)$$

$$I = \frac{I_L}{R_3}(R_2+R_3+R_L) \tag{3}$$

Using eqn.3 in eqn.1,

$$\frac{I_L}{R_3}(R_2+R_3+R_L)(R_1+r)+I_L(R_2+R_L) = E$$

$$I_L = \frac{ER_3}{(R_2+R_3+R_L)(R_1+r)+R_3(R_2+R_L)} \tag{4}$$

$$V_L = \frac{ER_3R_L}{(R_2+R_3+R_L)(R_1+r)+R_3(R_2+R_L)} \tag{5}$$

Calculation of V_{Th}: Thevenin voltage is the open circuit voltage between the terminals C D. It is same as the voltage across R_3 in fig.c.

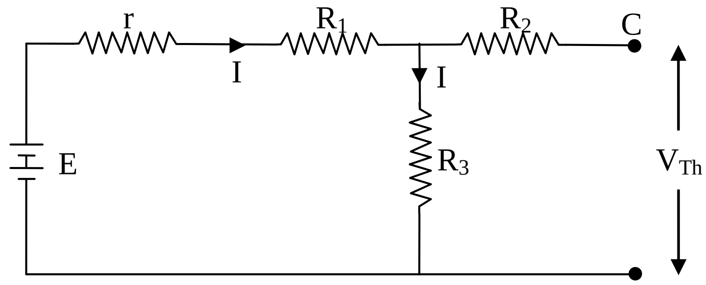


Fig.c: Calculation of V_{Th}

$$\text{Current} \quad I = \frac{E}{r + R_1 + R_3}$$

$$V_{Th} = IR_3 = \frac{ER_3}{r + R_1 + R_3} \qquad (6)$$

Calculation of R_{Th}: From the fig.d,

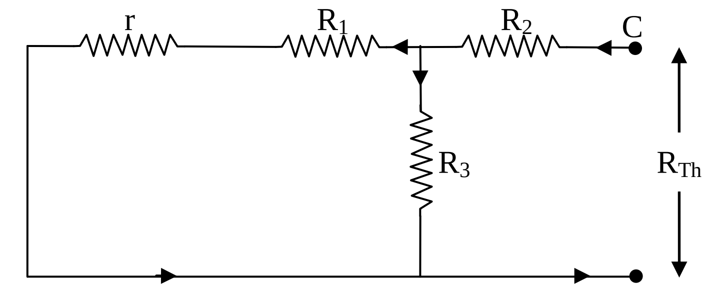


Fig.d: Calculation of R_{Th}

$$R_{Th} = R_2 + \frac{(R_1 + r)R_3}{r + R_1 + R_3} \qquad (7)$$

From fig.b,

$$I_L = \frac{V_{Th}}{R_{Th} + R_L}$$

Using eqns.6 and 7

$$= \frac{ER_3}{(R_2 + R_3 + R_L)(R_1 + r) + R_3(R_2 + R_L)} \qquad (4)$$

$$V_L = I_L R_L = \frac{ER_3 R_L}{(R_2 + R_3 + R_L)(R_1 + r) + R_3(R_2 + R_L)} \qquad (5)$$

Experimental verification: From the Thevenin equivalent circuit given in fig.b we can write,

$$V_{Th} = I_L R_{Th} + V_L$$

$$\text{Or,} \quad V_L = -I_L R_{Th} + V_{Th} \qquad (8)$$

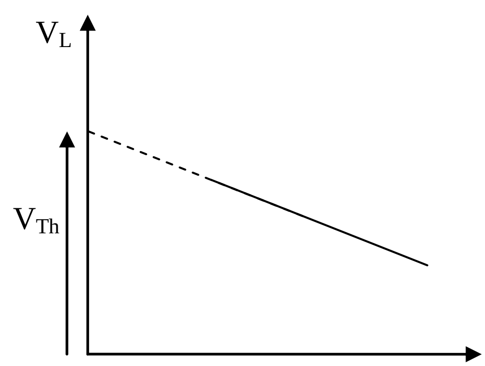


Fig.e

Eqn.8 represents a straight line. Thus the graph between I_L and V_L is a straight line with slope equal to $-R_{Th}$ and the Y intercept V_{Th}.

To verify the Thevenin's theorem we show that the value of V_{Th} and R_{Th} obtained by the calculation method and the graphical method are same as those obtained by the direct measurement.

Measurement of V_{Th}: Thevenin voltage V_{Th} can be measured directly from the open circuit shown in fig.c.

Measurement of R_{Th}: We use the circuit as shown in fig.f for the measurement of R_{Th}. The same power supply used in fig.a is used here. Send a current I through the circuit. Measure

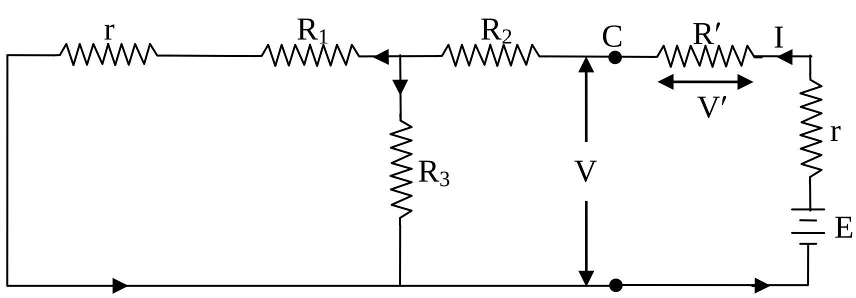


Fig.f: Determination of R_{Th}

the voltages V' and V, respectively, across R' and CD. Then,

$$V = IR_{Th}$$
$$V' = IR'$$
$$\frac{V}{V'} = \frac{IR_{Th}}{IR'} = \frac{R_{Th}}{R'}$$
$$\therefore \quad R_{Th} = \frac{VR'}{V'} \qquad (9)$$

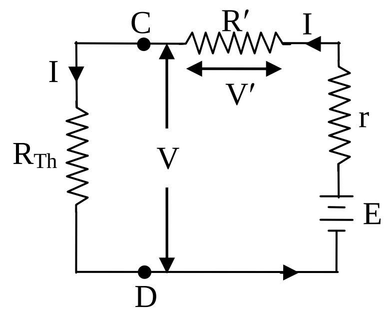


Fig.g: Equivalent circuit of fig.f

Norton's theorem: It states that a two terminal network containing resistances (linear impedances) and voltage sources can be replaced by a single current source I_S, in parallel with a single resistance R_S, where, I_S is the short circuit current between the terminals and R_S is the resistance that would be measured between the terminals with all the voltage sources are replaced by their internal resistances.

The network is shown in the fig.a. Its Norton's equivalent is shown in the fig.i.

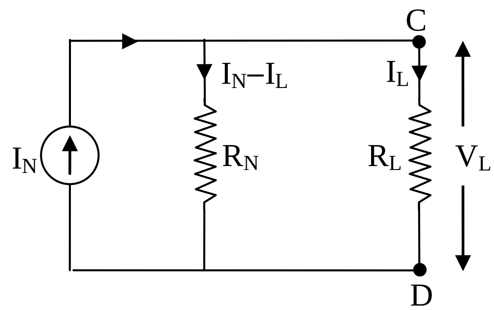


Fig.i: Norton's equivalent circuit

$$\text{Current through } R_N = \frac{V_L}{R_N}$$

From the fig.i,

$$I_L = I_N - \frac{V_L}{R_N} \qquad (10)$$

Thus the graph between V_L and I_L is a straight line with slope equal to $-\frac{1}{R_N}$ and the Y intercept I_N. By eqn.7

$$R_N = R_{Th} = R_2 + \frac{(R_1 + r)R_3}{r + R_1 + R_3}$$

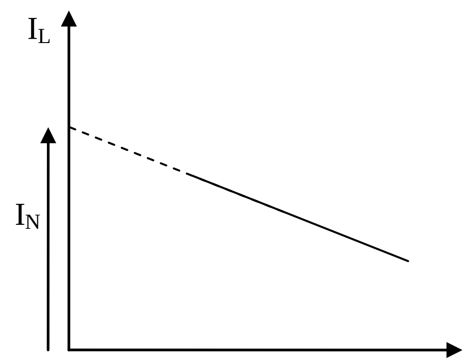


Fig.j

Calculation of I_N: Let I be the main current in the circuit with the terminals short circuited as shown in fig.k. From the fig.k,

$$(I - I_N)R_3 = I_N R_2$$
$$I = \frac{I_N(R_2 + R_3)}{R_3}$$

Also, $$E = I(r + R_1) + I_N R_2$$
$$= \frac{I_N(R_2 + R_3)(r + R_1)}{R_3} + I_N R_2$$

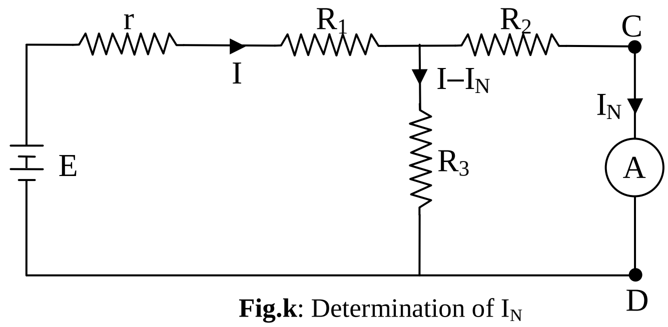


Fig.k: Determination of I_N

$$\therefore \qquad I_N = \frac{ER_3}{(R_1+r)(R_2+R_3)+R_2R_3} \qquad (11)$$

To verify the Norton's theorem we show that the value of I_N and R_N obtained by the calculation method and the graphical method are same as those obtained by the direct measurement. (*Remember R_N is same as R_{Th}*)

Procedure:

Step 1: *Determination of internal resistance 'r' of power supply*

Measure the open circuit voltage E (=10~15 volt) of the power supply. Connect a suitable resistance R, say 10 Ω as shown in fig.m and measure the terminal voltage V_t.

$$I = \frac{E}{R+r} = \frac{V_t}{R}$$

$$r = \frac{(E-V_t)R}{V_t}$$

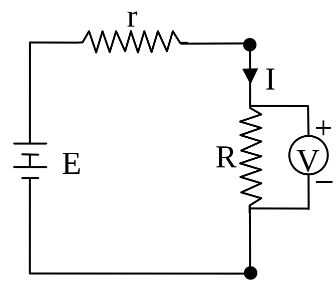


Fig.m

Step 2: Theoretical calculation of V_{Th}, R_{Th} and I_N

Step 3: Experimental verification - by graphical method

The connections are made as shown in fig.a. (Do not connect 'r', since it is the internal resistance of the power supply). Take suitable resistances in the boxes R_1, R_2, R_3 and R_L. Measure the load voltage and current. Change the load resistance and in each case the V_L and I_L are noted.

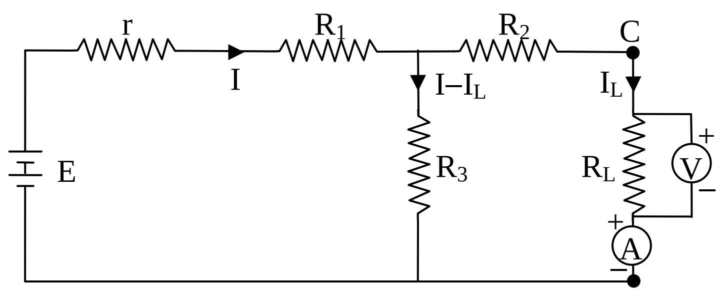


Fig.a: Network of resistances and a voltage source

For the verification of Thevenin's theorem draw a graph between V_L and the calculated (or measured) current I_L. Find out V_{Th} and R_{Th} from graph and compare it with the calculated values.

To verify the Norton's theorem draw another graph between the measured current I_L and the load voltage V_L (calculated or measured). Find out I_N and R_N (= R_{Th}) from the graph. Compare it with the calculated values.

Step 4: Experimental verification - by direct measurement method

Now the two terminals C and D are made open as shown in fig.c and the voltage across it is measured. This open circuit voltage directly gives the Thevenin voltage V_{Th}. Compare it with the previous results (calculation and graphical).

Then connect an ammeter in between C and D as shown in fig.k and measure the short circuited current. (Remember 'r' is the internal resistance not an externally connected one). This directly gives the Norton's current. Compare it with the previous results.

To measure directly R_{Th} or R_N, connections are made as shown in fig.f. In this case 'r' should be connected. Measure the voltage V between C D and voltage V′ across R′. Calculate R_{Th} using eqn.9. Compare the result with the previous results.

- Power supply voltage E must be kept constant throughout the experiment. So use regulated power supply
- Ensure that all the unplugged keys of the resistance boxes are tightened.
- Formula for theoretical calculation is applicable only for the 'T' type network given in the figure. It is different for different networks.

Observation and Tabulation

Measurement of internal resistance of the power supply

Open circuit voltage of the power supply, E = ……..volt

Value of resistance connected to the power supply, R = ……. Ohm

Terminal voltage (voltage across R), V_t = ……. Volt

Internal resistance, $r = \dfrac{(E-V_t)R}{V_t}$ = …….. ohm

Theoretical calculation of V_{Th}, $R_{Th} = R_N$ and I_N

$R_1 \Omega$	$R_2\ \Omega$	$R_3 \Omega$	$V_{Th} = \dfrac{ER_3}{r+R_1+R_3}$ volt	$R_{Th} = R_2 + \dfrac{(R_1+r)R_3}{r+R_1+R_3}$ Ω	$I_N = \dfrac{ER_3}{(R_1+r)(R_2+R_3)+R_2R_3}$ Ampere

Measurement of load voltage and load current

Sl.No.	Load resistance $R_L\ \Omega$	For verification of Thevenin' theorem				For Norton's theorem		
		Load voltage volt		Mean V_L volt	Calculated current I_L ampere	Load current ampere		Mean I_L ampere
		1	2			1	2	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Graphical verification

Thevenin voltage, V_{Th} = Y intercept of V_L-I_L graph = ……… volt

Thevenin resistance, R_{Th} = Slope of the V_L-I_L graph = ……… ohm

Norton's current, I_N = Y intercept of I_L-V_L graph = ……… ampere

Experimental verification - by direct measurement method

Thevenin voltage, V_{Th} = Open circuit voltage = ……… volt

Norton's current, I_N = Short circuited current = ……… ampere

Determination of R_{Th}

Sl.No.	R'	Voltage across the terminals C D, V volt	Voltage across R' V' volt	$R_{Th} = \frac{VR'}{V'}$ Ω
1				
2				
3				
4				
5				

Result

Thevenin voltage, V_{Th}

By calculation = ……… volt

By graphical method = ……… volt

By direct measurement = ………. volt

Thevenin resistance, R_{Th}

By calculation = ……… ohm

By graphical method = ……… ohm

By direct measurement = ……… ohm

Norton current, I_N

By calculation = ……… ampere

By graphical method = ……… ampere

By direct measurement = ……… ampere

Since the values obtained for V_{Th}, R_{Th} and I_N by different methods are nearly equal Thevenin's and Norton's theorem are verified.