10. Do you think that M is independent of the primary current?

Ans. If there is no iron in the primary coil, M is independent of primary current but when there is iron in the primary coil, M depends on the value of primary current, for the magnetic induction in iron does not vary linearly with the primary current.

11. What is electromagnetic induction?

Ans. When the magnetic flux linked with a circuit changes with time an e.m.f is induced in the circuit. This is known as electromagnetic induction.

12. What is self inductance?

Ans. When the current flowing through a coil changes with time, the magnetic flux linked with the coil also changes with time and an e.m.f is induced in it. This phenomenon is known as self inductance. The coefficient of self inductance L is defined as the induced e.m.f when current through it change at unit rate.

13. Why do you use the low resistance r?

Ans. To eliminate the galvanometer constant $K = C/n\ AB$.

14. Do you know any other method of measuring M?

Ans. Yes ; M can be measured by Carey Foster method.

15. The standard low resistance has four terminals—why?

Ans. See Oral Question 16 of Expt. 7.17.

[Also see Oral Questions on Ballistic Galvanometer in Expt. 8.2.]

CHAPTER 9

SOME MISCELLANEOUS EXPERIMENTS

9.1 Verification of Fresnel's laws of reflection of electromagnetic waves in case of a dielectric medium with the help of a spectrometer, a prism, a pair of polaroids and sodium light :

• **Theory :** According to the electromagnetic theory of light if the electric vector of an electromagnetic wave is parallel to the plane of incidence, then its amplitudes (E_0 and E_{10}) before and after reflection from a plane interface between two dielectric media, bears the ratio

$$\left.\frac{E_{10}}{E_0}\right/_{\parallel} = \frac{\tan(\theta - \theta_2)}{\tan(\theta + \theta_2)} \qquad \text{... (9.1-1)}$$

where θ is the angle of incidence and θ_2 is the angle of refraction.

If, however, the electric vector is perpendicular to the plane of incidence then the corresponding ratio is

$$\left.\frac{E_{10}}{E_0}\right/_{\perp} = -\frac{\sin(\theta - \theta_2)}{\sin(\theta + \theta_2)} \qquad \text{... (9.1-2)}$$

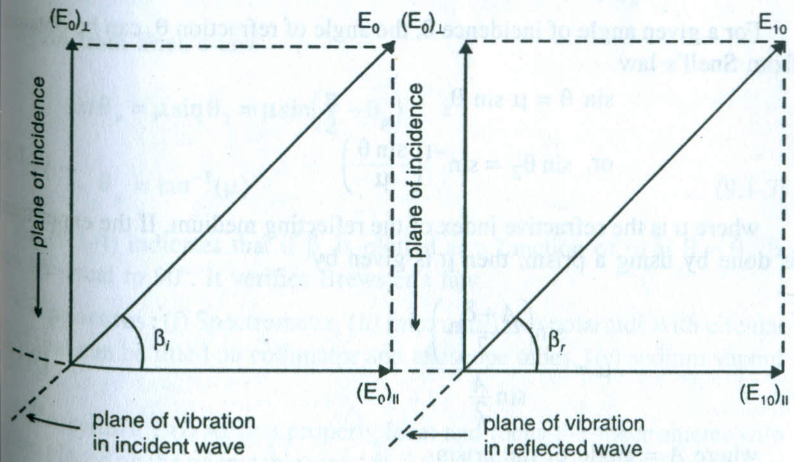

Fig. 9.1-1 : Pictorial representation of the angles β_i and β_r

The equations (9.1-1) and (9.1-2) relating the amplitude of the reflected wave with that of the incident wave are known as Fresnel's equation for reflection of electromagnetic waves from a plane boundary separating two dielectric media.

If β_i be the angle between the plane of vibration and the plane of incidence of the incident wave and if β_r be the corresponding angle for the reflected wave (Fig. 9.1-1) then

$$\tan\beta_i = \frac{(E_0)_\perp}{(E_0)_\parallel}$$

and $$\tan\beta_r = \frac{(E_{10})_\perp}{(E_{10})_\parallel}$$

Therefore, from Eqs. (9.1-1) and (9.1-2)

$$\tan\beta_r = -\frac{\cos(\theta-\theta_2)}{\cos(\theta+\theta_2)}\tan\beta_i \quad \text{... (9.1-3)}$$

If $\beta_i = 45°$ then

$$\tan\beta_r = -\frac{\cos(\theta-\theta_2)}{\cos(\theta+\theta_2)} \quad \text{... (9.1-4)}$$

For a given angle of incidence θ, the angle of refraction θ_2 can be obtained from Snell's law

$$\sin\theta = \mu\sin\theta_2$$

$$\text{or, } \sin\theta_2 = \sin^{-1}\left(\frac{\sin\theta}{\mu}\right) \quad \text{... (9.1-5)}$$

where μ is the refractive index of the reflecting medium. If the experiment is done by using a prism, then μ is given by

$$\mu = \frac{\sin\left(\dfrac{A+\delta_m}{2}\right)}{\sin\dfrac{A}{2}} \quad \text{... (9.1-6)}$$

where A = angle of the prism

δ_m = angle of minimum deviation.

Thus measuring the angles β_r, θ and θ_2 a graph may be plotted between

$-\dfrac{\cos(\theta-\theta_2)}{\cos(\theta+\theta_2)}$ and $\tan\beta_r$. For validity of the Fresnel's laws the graph must come out to be a straight line passing through the origin and inclined at an angle 45° to either of the axes as shown in Fig. 9.1-2.

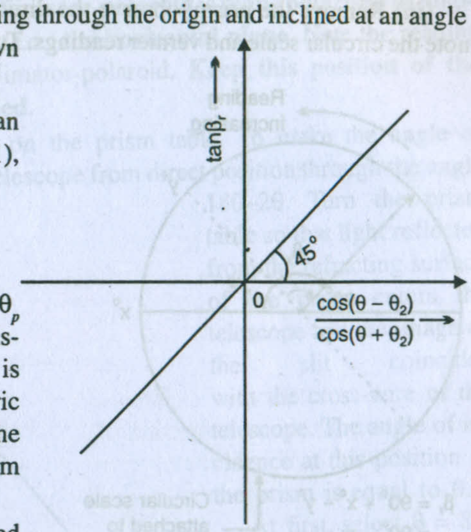

Fig. 9.1-2 : To verify Fresnel's laws

From Eq. (9.1-2), $(E_{10})_\perp$ can never be zero. But from Eq. (9.1-1), $(E_{10})_\parallel$ will be zero when

$$\theta + \theta_2 = \frac{\pi}{2}.$$

At this angle of incidence $\theta = \theta_p$ called Brewster's angle or polarising angle, the reflected light is plane polarised with its electric vector being perpendicular to the plane of incidence. Thus if from Eq. (9.1-1) $\left(\dfrac{E_{10}}{E_0}\right)_\parallel$ is plotted against the angle of incidence θ, the curve must show $\left(\dfrac{E_{10}}{E_0}\right)_\parallel = 0$ at $\theta = \theta_p$.

Again from Snell's law

$$\sin\theta_p = \mu\sin\theta_2 = \mu\sin\left(\frac{\pi}{2}-\theta_p\right)$$

$$\therefore\ \theta_p = \tan^{-1}(\mu) \quad \text{... (9.1-7)}$$

Eq. (9.1-4) indicates that if β_r is plotted as a function of θ, at $\theta = \theta_p$, β_r must be equal to 90°. It verifies Brewster's law.

- **Apparatus :** (*i*) Spectrometer, (*ii*) prism, (*iii*) two polaroids with circular scales that can be fitted on collimator and telescope tubes, (*iv*) sodium vapour lamp, etc.

- **Procedure :** (*i*) At first properly level and focus the spectrometer with prism placed on the prism table (see Art. 5.5). Determine the vernier constants of both the verniers attached to the circular scale of the spectrometer.

(*ii*) Determine the angle of the prism A and angle of minimum deviation

δ_m in the usual way. Calculate μ using the relation (9.1-6). Find θ_p using the relation (9.1-7). It comes out to be nearly 58°.

(*iii*) Remove the prism, observe the direct rays through the telescope and note the circular scale and vernier readings. Turn the telescope through an angle $180° - 2\theta_p$ and then clamp it. Place the prism again on the prism table so that a refracting surface passes along one central line. Turn the prism table so that light reflected from this refracting surface enters the telescope and the image of the slit coincides with the cross-wire of the telescope. The angle of incidence in this position of the prism is equal to θ_p. The reflected light is plane polarised with its electric vector being perpendicular to the (horizontal) plane of incidence, i.e., **the electric vector is in the vertical plane.**

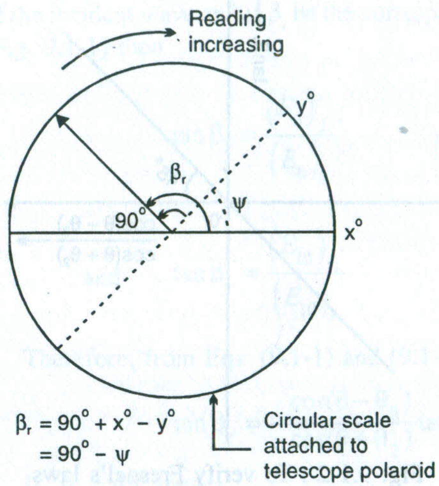

Fig. 9.1-3 : Illustrates how to measure β_r

(*iv*) Now, fit a polaroid on the telescope objective and rotate it so that the light is extinguished. Note the reading of the pointer (attached to the polaroid and moving over a circular scale).

Let it be X°. **At this position, the pass-axis of this telescope-polaroid is in the horizontal plane.**

(*v*) Remove the prism and observe direct rays through the telescope. Fit another polaroid on the collimator tube and rotate it to get the light extinguished. Note the reading of the polaroid pointer. In this setting the two polaroids are crossed; **the pass-axis of collimator-polaroid is vertical and that of the telescope-polaroid is horizontal.** Rotate the collimator-polaroid through an angle of 45°. In this position **light from the collimator-polaroid is plane polarised at angle 45° with** the plane of incidence, i.e., **the horizontal plane.** Note the reading of the pointer attached to collimator-polaroid. **Keep this position of the collimator-polaroid undisturbed.**

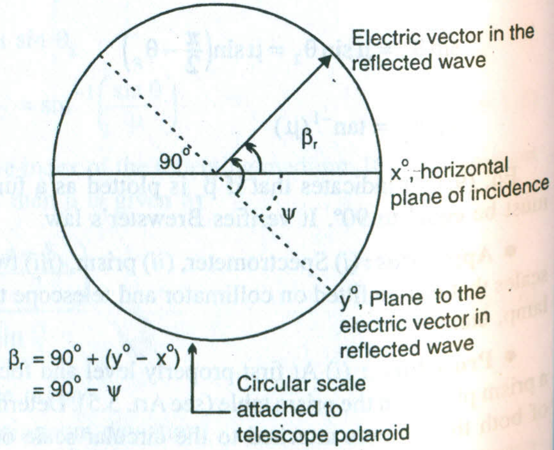

Fig. 9.1-3 : Illustrates how to measure β_r

(*vi*) Place the prism again on the prism table. To make the angle of incidence equal to θ rotate the telescope from direct position through the angle 180–2θ. Turn the prism table so that light reflected from the refracting surface of the prism enters the telescope and the image of the slit coincides with the cross-wire of the telescope. The angle of incidence at this position of the prism is equal to θ.

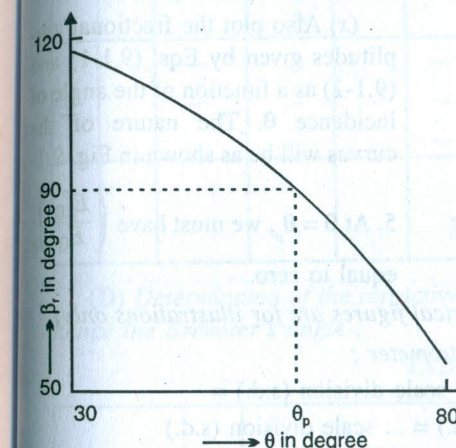

Fig. 9.1-4 : Verification of Brewster's law

At first, select θ = 80° (say). Turn the telescope from direct position through $180 - 2 \times 80 = 20°$ [i.e., set the telescope at direct reading ± 20°]. Rotate the telescope-polaroid to extinguish light. Let the reading of the polaroid pointer be *Y*°. The angle of rotation of the polaroid is $\psi = Y° - X°$. The inclination of the plane of vibration of the reflected light to the plane of incidence (horizontal plane) will be $\beta_r = 90 - \psi$. This is due to the fact that at the position *X*°, the pass-axis of the telescope-polaroid is in the horizontal (plane of incidence) and at the position *Y*° the pass-axis is perpendicular to the direction of electric vector in the reflected wave (see, Fig. 9.1-3). Find $\tan \beta_r$ and compare it with the value of $\tan \beta_r$ calculated from the Eq. (9.1-4). For a known θ, find θ_2 from Eq. (9.1-5) and calculate $\tan \beta_r$, from Eq. (9.1-4).

(*vii*) Repeat the operation (*vi*) for various other angles of incidence (say, 80° to 30° in steps of 5°).

(*viii*) Plot a graph between $-\dfrac{\cos(\theta - \theta_2)}{\cos(\theta + \theta_2)}$ and $\tan \beta_r$. It must be a straight line passing through the origin and making an angle 45° with the axes as shown in Fig. 9.1-2. It verifies Eq. (9.1-4) and hence Fresnel's laws of reflection.

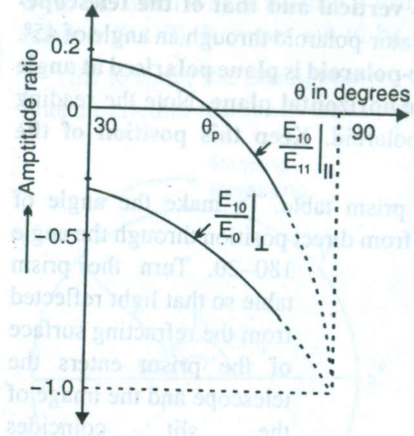

Fig. 9.1-5 : Fraction of incident amplitude reflected as a function of the angle of incidence

(*ix*) Plot a curve of θ versus β_r. The nature of the curve will be as shown in Fig. 9.1-4. At $\theta = \theta_p$, β_r must be equal to 90°. This verifies Brewster's law.

(*x*) Also plot the fractional amplitudes given by Eqs. (9.1-1) and (9.1-2) as a function of the angle of incidence θ. The nature of the curves will be as shown in Fig. 9.1-5. At $\theta = \theta_p$, we must have $\left(\frac{E_{10}}{E_0}\right)_{\parallel}$ equal to zero.

• **Experimental Data** : (*Numerical figures are for illustrations only*)

(A) *Vernier constant of the spectrometer* :

1 smallest circular scale division (s.d.) = ...

... vernier division (v.d.) = ... scale division (s.d.)

vernier constant (v.c.) = 1 v.d. − 1 s.d. = ... s.d. = ...

(B) *Determination of the angle of the prism (A)* :

TABLE I

Vernier No.	Readings for first image: Scale (s)	Venier read (v.r.)	Total $R_1 = s + v.r. \times v.c.$	Mean R_1	Readings for second image: Scale (s)	Venier read (v.r.)	Total $R_2 = s + v.r. \times v.c.$	Mean R_2	Difference $\theta = R_1 \sim R_2$	Mean θ	$A = \theta/2$
1st	...	...	...		...	...	...				
	...	...	...		...	...	...				
	...	...	...								
2nd											

(C) *Data for the angle of minimum deviation* :

TABLE II

Vernier No.	Readings for minimum deviation position: Scale (s)	Venier read (v.r.)	Total $R_1 = s + v.r. \times v.c.$	Mean R_1	Readings for direct rays: Scale (s)	Venier read (v.r.)	Total $R_2 = s + v.r. \times v.c.$	Mean R_2	Minimum $\delta_m = R_1 \sim R_2$	Mean δ_m
1st	...	...	...	...	...	...	...	...		
	...	...	...	...	...	...	...	...		
	...	...								
2nd										

(D) *Determinaton of the refractive index of the material of the prism and hence the Brewster's angle* :

TABLE III

Angle of the prism *A*	Angle of minimum deviation δ_m	$\mu = \dfrac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}}$	$\theta_p = \tan^{-1}\mu$
...	... ...	... ...	... ...

(E) *To set the prism at the angle of incidence* $\theta = \theta_p$:

TABLE IV

θ_p from TABLE III	Director reading (D.R.) from TABLE II	Telescope turned through $\phi = 180 - 2\theta_p$	Telescope set at D.R. ± φ
...	... ...	... ...	... ...

(F) *Initial adjustment of polaroids to polarise incident light at 45° to the plane of ineidence :*

(*i*) 1 smallest scale division of the circular scales attached to the polaroids = ...

... vernier division (v.d.) = ... scale division (s.d.)

∴ vernier constant (v.c.) = 1 v.d. –1 s.d. = ... s.d. = ...

(*ii*) Initial reading of the telescope-polaroid when light is extinguished = X^o = ...

(*iii*) Initial reading of the collimator-polaroid when light is extinguished = $(\theta_{cp})_i$ = ...

(*iv*) Collimator-polaroid turned through 45° and set at $(\theta_{cp})_i \pm 45°$ = ... This makes $\beta_i = 45°$.

(G) *Determination of β_r for different angle of incidence :*

TABLE V

X^o = ..., Reading for direct rays (D.R.) = ...

No. of obs.	Angle of incidence θ	Telescope turned through $\phi = 180° - 2\theta$	Telescope set at D.R. $\pm \phi$	Read of Tel. Pol. when light is extin-guished Y^o	Rotation $\psi = Y^o - X^o$	$\beta_r = 90° - \psi$
1.	75°	30°			29°30′	60°30′
2.	70°	40°			23°24′	66°36′
3.	65°	50°			12°12′	77°48′
4.	60°	60°			2°42′	87°18′
5.	55°	70°			–2°18′	92°18′
6.	50°	80°			–12°24′	102°24′
7.	45°	90°			–18°12′	108°12′
8.	40°	100°			–26°18′	116°18′
etc.	etc.	etc.			etc.	etc.

Brewster's angle θ_p from θ vs. β_r graph : θ_p = ...

(H) *Verification of Fresnel's equation :* $\beta_i = 45°$, μ = ...

TABLE VI

θ	$\theta_2 = \sin^{-1}\left(\dfrac{\sin\theta}{\mu}\right)$	$-\dfrac{\cos(\theta-\theta_2)}{\cos(\theta+\theta_2)}$	β_r from TABLE V	$\tan\beta_r$
75°				
70°				
65°				
60°				
55°				
50°				

(I) *Data for drawing fractional amplitudes as a function of θ :*

TABLE VII

θ	$\theta_2 = \sin^{-1}\left(\dfrac{\sin\theta}{\mu}\right)$	$\left(\dfrac{E_{10}}{E_0}\right)_{\parallel} = \dfrac{\tan(\theta-\theta_2)}{\tan(\theta+\theta_2)}$	$\left(\dfrac{E_{10}}{E_0}\right)_{\perp} = -\dfrac{\sin(\theta-\theta_2)}{\sin(\theta+\theta_2)}$
75°			
70°			
65°			
etc.			

• **Precautions and Discussions :** (*i*) The spectrometer should be properly evelled and focussed.

(*ii*) Sometimes the zero of the circular scale is crossed by the zero of the ernier when the telescope moves from one position to another. In this case he angle of rotation of the telescope is given by {360°– (difference of the eadings at two positions)}.

(*iii*) The polaroid readings for the position of minimum intensity or the osition where the light is extinguished should be carefully judged. To inimise the error of judgement the mean of three independent observations n be taken.