FARADAY EFFECT

Faraday observed that when a transparent medium is subjected to an external field, the plane of polarization of a plane-polarised light beam through the medium get rotated, if the direction of incident light is parallel to the line of magnetic field.

The angle of rotation $\emptyset$ is proportional to the magnetic flux density B and length L of the medium through which plane polarized light is transmitted:

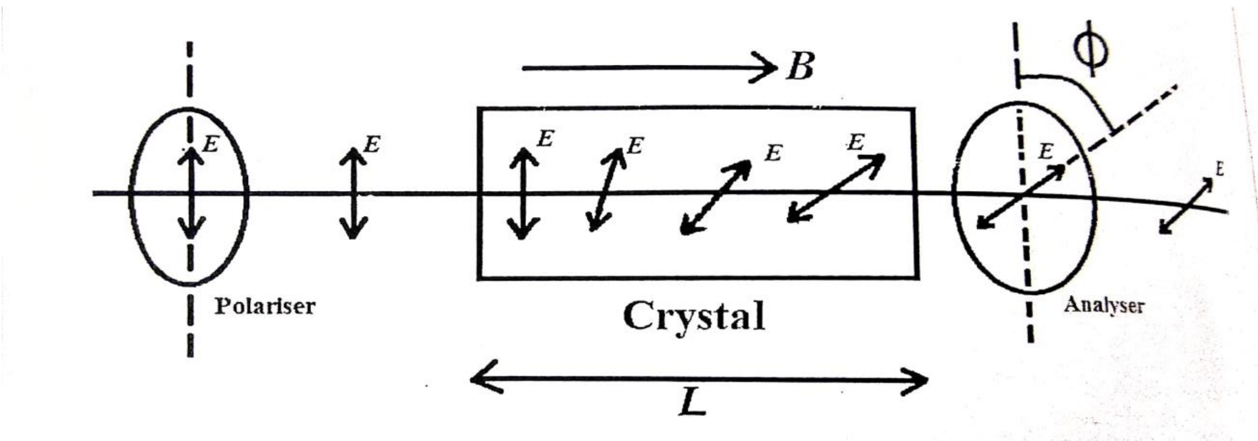
$$\emptyset \propto LB \text{.......................................(1)}$$

The proportionality constant V is called as Verdet Constant and depend upon wavelength λ and refractive index μ,

$$\emptyset = \text{VLB} \text{.......................................(2)}$$

Or, $$V = \frac{\Phi}{LB} \text{.......................................(3)}$$

From the graph at a particular wavelength, we find the slope and put in equation (3) to find V at that wavelength.



B is the Magnetic Field.
L is the Length of isotropic material.
E is the Electric Field.
SYSTEMIC ARRANGEMENTES OF ITEMS FOR DETERMINATION OF *V*.

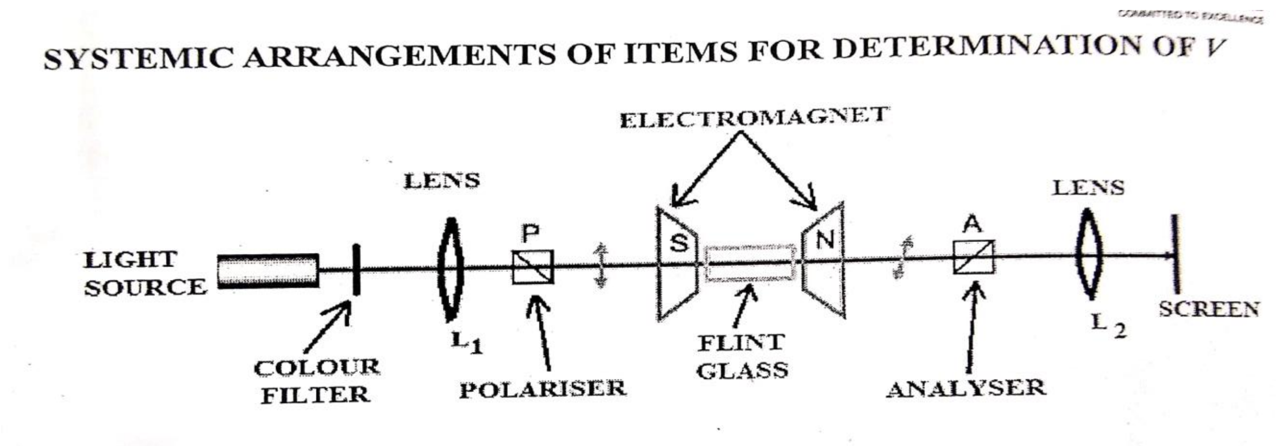


Fig 1: *Arrangements of Components in Optical Bench using Halogen lamp.*

NOTE:

1. Lens L_1 is not required with LASER source.
2. Colour Filter is not required for LASER source.

<u>OPTICAL BENCH SET-UP:</u>

1. Arrange the diode laser(or source) on the optical bench according to picture.
2. Position a polarizer close to the laser on the optical bench as shown.
3. Mount the Flint Glass Holder into the central slot of the 'U'- core.
4. Insert two coils of 500 turn in both arms of the 'U'- core.
5. Place the pole piece on the U core in such a manner that the flint glass rod can be placed on the holder as depicted.
6. Mount the Flint Glass into the upper platform of the Flint Glass Holder.
7. Push the pole piece right up to the flint glass square but without damaging it.
8. Use the clamps and pins to fix the bored pole piece on the U-core.
9. Position the analyzer (another polarizing filter) close to the U-core on the optical bench
10. Position the screen opposite to the analyzer.

NOTE: While doing the above steps, please ensure that the source light passes through the central portion of all the optical components. You may need to switch on the laser and do the necessary adjustment of all the optical components. The Laser light should be sharply focused at the screen.

<u>ELECTRICAL SETUP:</u>

1. Connect the coil in series to the variable power supply 30V, 10Amp at DC socket.
2. Connect the laser to main 230V AC.

NOTE: The maximum coil current under permanent use is 6 Amp. However the current can be increased up to 8A for a few minutes without risk of damage to the coils by overheating.

<u>CALIBRATION OF THE MAGNETIC FIELD:</u>

1. Remove the flint glass square.
2. Connect the digital gauss meter to main switch.
3. Place the hall probe between the pole piece. Use the stand material to hold the magnetic probe between the bored pole pieces.
4. Record the magnetic field B as function of the current I through the coils.

PRECAUTIOINS:

1. By sliding the lens L_2 along the optical bench, the face of flint glass square, should be projected in sharp focus on translucent screen.
2. The electromagnet must be positioned such that path of pole pieces and optical flint square are aligned with the optical axis.

ROTATION OF THE POLARIZATION PLANE ϕ AS A FUNCTION OF THE MAGNETIC FIELD

1. Arrange the apparatus as mentioned in previous section.
2. Place the flint glass square (15mm X 15mm X 15mm) on the support between the drilled pole piece of electromagnet.
3. Switch on the light source.
4. Rotate the analyser so that polarization plane is crossed in relation to that of polarizer. Make the field view of the face of flint square projected on the transluscent screen image appear dark.
5. Switch on the current through the coils of electromagnet. Due to the magnetic field produced the flint glass square get permeated in the direction of radiation. The image of spot due to the rotation of plane of polarization of polarized light brighten up due to the longitudinal magnetic field generated between the pole pieces.
6. Rotate the analyser till it produces maximum extinction of light (i.e, minimum intensity of image of spot). Note the reading (sayϕ_1).
7. Reverse the direction of magnetic field, by changing the polarity of the coil current.
8. Rotate the analyser in the opposite direction again in order to darken the brightness of field of view. Note the reading (sayϕ_2).
9. Record the difference between ($\phi_1$and ϕ_2), the position of analyser in step 6 and 8. This difference is equals to the rotation 2ϕ {= ϕ_1- ϕ_2 = ϕ - (-ϕ)} of plane of polarization of the light.
10. Vary the current and obtain different values of (2ϕ) for different values of magnetic field. Make the data in tabular form.
11. The magnetic field for different values of current can be found from the calibration data/ graph for the magnetic field.
12. Plot the rotation (2ϕ) as a function of the magnetic field and find the slope. Determine the Verdet's Constant (V) from the slope, by using equation (3).

ALITER

ROTATION OF THE POLARIZATION PLANE 2ϕ AS A FUNCTION OF THE MAGNETIC FIELD

1. Arrange the apparatus as mentioned in previous section.
2. Place the flint glass square (15mm X 15mm X 15mm) on the support between the drilled pole piece of electromagnet.
3. Switch on the light source.
4. Set the analyser to 0^0 position. (The pointer of the analyser will indicate 0^0 angle).
5. Switch on the current through the coils of electromagnet. Set the current to desired value I.
6. Rotate the polarizer to darken the light spot at the screen.
7. Rotate all the knobs of the power supply to bring them back to their initial position. The current will be reduced to zero value. Switch off the power supply.
8. Interchange the leads of the power supply. Now set the current to the initial value. (So, current will change from +I to –I. As a result, the direction of magnetic field will change. (Magnetic field changes from +B to –B.)
9. Rotate the analyser again in order to darken the light spot at the screen. Note down the angle as indicated by the pointer of the analyser. This angle denotes the rotation of the plane of polarization i.e. this angle = 2ϕ due to change in the magnetic field [+B – (-B) = 2B].
10. Vary the current and obtain different values of (2ϕ) for different values of magnetic field. Make the data in tabular form.
11. The magnetic field for different values of current can be found from the calibration date/graph for the magnetic field.
12. Plot the rotation (2ϕ) as a function of the magnetic field and find the slope. Determine the Verdet's Constant (V) from the slope.

OBSERTATION TABLES

TABLE – 1: CALIBRATION OF MAGNETIC FIELD

CURRENT, I (A)	MAGNETIC FIELD, B (GAUSS)
1.1	750
2.0	1300
3.0	1800
4.0	2400
5.0	3000
6.0	3600
7.0	3900
7.4	4000

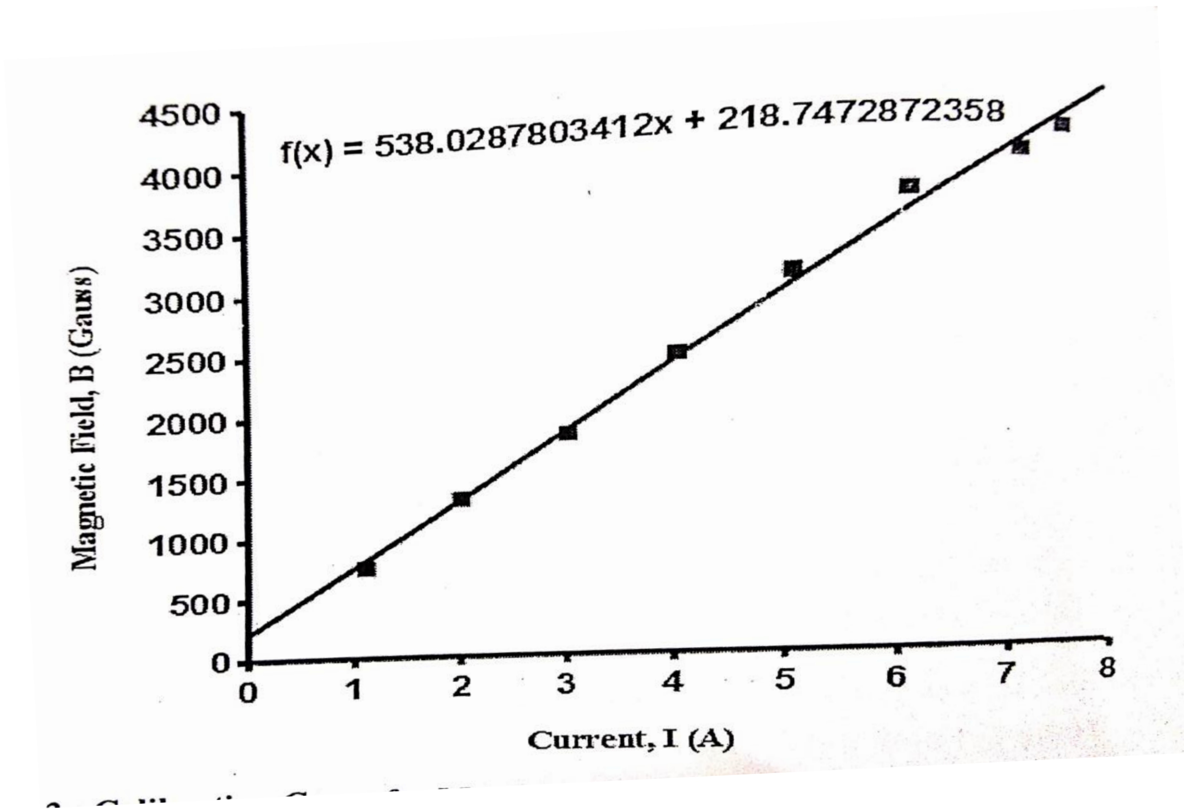


Fig. 2 *: Calibration Curve for Magnetic Field [Plot of Magnetic Field, B as a function of Current, I].*

The linear fit between I and B is given by, B = 538.029I + 218.747

<u>TABLE – 2 : ROTATION 2ϕ AS A FUNCTION OF THE MAGNETIC FIELD, B</u>

Wavelength of light used, λ = 632nm

Room Temperature = 22^0C

Current, I (A)	Magnetic Field, B (Gauss)	Rotation, 2ϕ (Degree)
8.3	4576.8	14
7.2	3984.9	12
6.2	3500.7	10
5.2	2962.7	10
4.1	2424.6	8
3.1	1886.6	6
2.1	1348.6	4
1.1	810.6	2

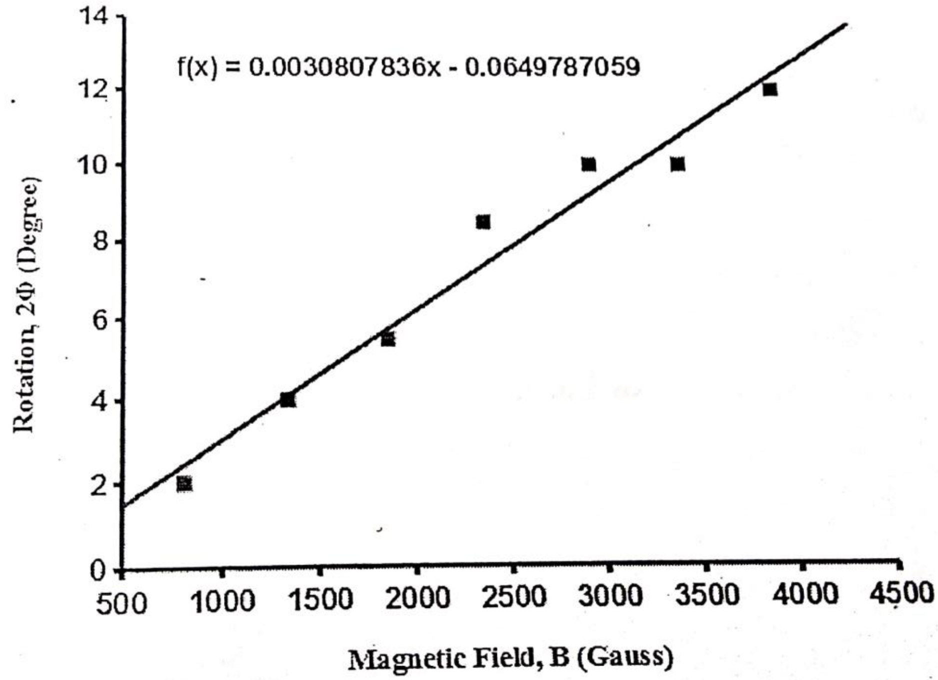


Fig. 3 : *Plot of Rotation, 2ϕ as a function of Current, I.*

Slope of the graph = 30.8 X 10^{-4} Degree/Gauss

Verdet's Constant, V = $\frac{Slope}{2I}$ = $\frac{30.8 \; X \; 10^{-4}}{2 \; X \; 1.5}$ Degree/Gauss/cm

= 10.3 X 10^{-4} Degree/Gauss/cm for 632nm wavelength

Where, I = Length of the crystal = 1.5cm

APPENDIX

CAUSE OF FARADAY EFFECT (OSCILLATION OF ELECTRONS IN MAGNETIC FIELD)

The angle of rotation of plane of polarized light when passes through a istropic transparent material, in the direction of field,

$$\phi \propto B$$
$$\phi \propto L$$
$$\phi = VBL$$

where V is called as Verdet Constant which depend upon temperature, refractive index and wavelength of light.

This can be explained by imaging the linearly polarized light as the superposition of two opposite components, α_+ and α_-. When an atom is subjected to magnetic field, the oscillating charges (i.e. electrons) acquire additional precession frequency equal to that of Larmour frequency.

$$\omega = \frac{e}{m} B \text{ ……………………………………………..(4)}$$

Now one component (α_+) has frequency $\omega_+ = \omega + \omega_L$ (say) and another $\omega_- = \omega - \omega_L$.

The referective index μ_+ and μ_- and phase velocities V_+ and V_- differ and are the measure of optical activity.

The angle of rotation of plane of polarization through length I., under influence of magnetic field is given by

$$\phi = \frac{\omega B}{2c} (\mu_+ - \mu_-) \quad \text{...(5)}$$

where, ω = frequency of transmitted light.

It can be proved that μ depend upon λ ($\mu = A + \frac{B}{\lambda^2}$)

And Verdet's Constant, $V = \frac{e\lambda}{2mc}\frac{d\mu}{d\lambda}$.

For the EXTRA – DENSE FLINT GLASS, we can use the following approximation,

$$\frac{d\mu}{d\lambda} = \frac{2.8 \, X \, 10^{-14}}{\lambda^3} \, m^{-3} \quad \text{................................(6)}$$

So,

$$V = \frac{e\lambda}{2mc} \, X \, \frac{2.8 \, X \, 10^{-14}}{\lambda^3} \quad \text{......................................(7)}$$

Or,

$$V = \frac{e}{2mc} \, X \, \frac{2.8 \, X \, 10^{-14}}{\lambda^3} \quad \text{......................................(8)}$$

The value of $\frac{e}{m}$ derived by using the above equation after putting the values of V as determined by Faraday Effect, agrees well with known standard value.

This justifies that natural oscillation of electrons are responsible for Faraday Effect.

So in this experiment we can verify.

1. The plane of polarization rotation $\phi \propto B$.
2. The verdect constant decreases with increasing λ as $\frac{1}{\lambda^2}$.

ADDITIONAL EXERCISE

VALUES OF VERDECT CONSTANT FOR VARIOUS WAVELENGTHS

By using different LASERS of different wavelengths, equation (8) can be verified.