EXPERIMENT 8

THE FARADAY EFFECT

AIM:

a) Verifying the proportionality between the rotation φ of the polarisation plane and the magnetic field B
b) Demonstration the decrease of the Verdet's constant V with increasing wavelengthλ .

APPARATUS:

1 Flint glass square with holder, 1 U-core with a pair of pole pieces, 1 Halogen lamp, 4 Filters, 1 Lens, 2 Polarisation filters, 1 Translucent screen, 1 Optical bench, 1 Teslameter, 1 Vraiable extra low-voltage transformer.

METHODOLOGY:

In 1845 Michael Faraday described the interaction between light and a magnetic field in optically transparent dielectric materials, including liquids. He concluded that such an interaction would result to a rotation of the plane of polarization of the light that would be proportional to the intensity of the component of the magnetic field in the direction of the beam of light.

This observation can be explained by imaging linearly polarised light as the coherent superposition of two opposite circularly polarised components $\sigma+$ and $\sigma-$.

In atomic physics the magnetic field influences the motion of the electrons in the atom. The magnetic field causes the oscillating charges to carry out an additional precession movement. The precession frequency is called the Larmor frequency, i.e.:

$$\omega_L = \frac{e}{m} B \qquad (8.1)$$

where e and m are the charge and mass of the oscillating particles, and B the magnetic flux density.

The components $\sigma+$ and $\sigma-$. of the polarised light have different frequencies relative to the charges performing the precession movement. One component has the frequency

$\omega + \omega_L$ and the other component has the frequency $\omega - \omega_L$. The refractive indices n_+, n_- and the phase velocities v_+, v_- differ, which is equivalent to optical activity.

Upon emergence from the medium, the rays can be considered to re-combine, however they suffer a phase shift of $\Delta\theta = 2\pi L\,(n^+ - n^-)/\lambda$., resulting in a rotation of the angle of linear polarization by φ. This process is shown explicitly in Figure 8.1.

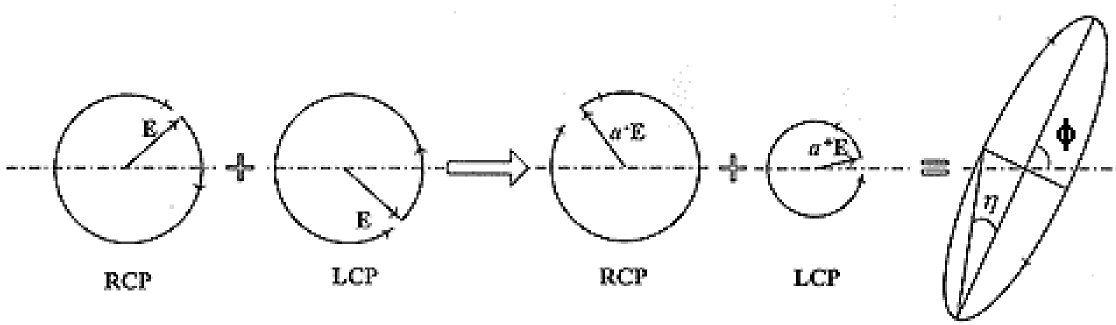

Figure 8. 1 A linearly-polarized beam of light may be considered as the superposition of equal amounts of right- and left-circularly polarized beams. In going through a perpendicularly magnetized slab of material at normal incidence, the two components of circular polarization experience different (complex) refractive indices and, therefore, each emerges from the medium with a different phase and amplitude. The amplitudes of the emergent beams may be denoted by a^+ and a^-, and their phase difference by $\Delta\phi$. The superposition of the emergent circular polarization states yields elliptical polarization. The angle of rotation of the major axis of the ellipse from the horizontal direction (which is the direction of the incident linear polarization) is given by $\varphi = \frac{1}{2}\Delta\theta$, and the ellipticity η is given by $\tan\eta = (a^+ - a^-)/(a^+ + a^-)$.

The relation between the angle of rotation of the polarization and the magnetic field in a diamagnetic material is:

$$\varphi = VBL \qquad (8.2)$$

where

φ is the angle of rotation (in radians)
B is the magnetic flux density in the direction of propagation (in teslas)
L is the length of the path (in metres) where the light and magnetic field interact

is the Verdet constant for the material. This empirical proportionality constant (in units of radians per tesla per metre) varies with wavelength and temperature.

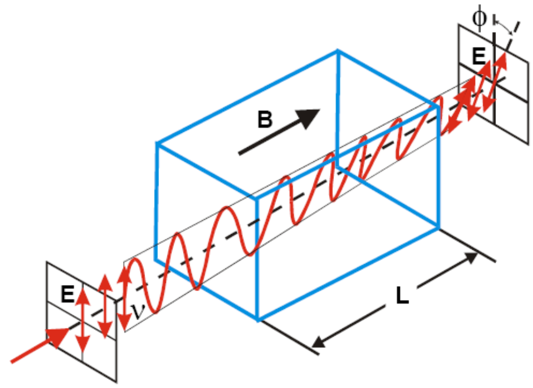

Figure 8.2 A schematic representation of the Faraday effect: B magnetic flux density parallel to the propagation direction of the polarised light. E: Electric field, L: length of isotropic material

A positive Verdet constant corresponds to L-rotation (anticlockwise) when the direction of propagation is parallel to the magnetic field and to R-rotation (clockwise) when the direction of propagation is anti-parallel. Thus, if a ray of light is passed through a material and reflected back through it, the rotation doubles. Finally note that Verdet's constant is inverse proportional to the wavelength of light λ, i.e.:

$$V = -\frac{e}{2mc^2}\frac{1.8\times10^{-14}}{\lambda^2}m^2 \qquad (8.2)$$

PROCEDURE:

Setup

- In this experiment a thread cross is attached to the analyzer and projected onto the translucent screen so that the angle of rotation $\Delta\varphi$ can be determined precisely.
- Equip one of the polarizing filters with a thread cross like depicted in Fig.(8.3) Make sure, that the cross is exactly at right angles and placed exactly in the center of the analyzer. Use the analyzer protractor scale to align it. The best material for this is silk thread.
- Arrange the halogen lamp on the optical bench according to Fig.(8.4). Mount the picture slider with heat insulation filter on the condenser.

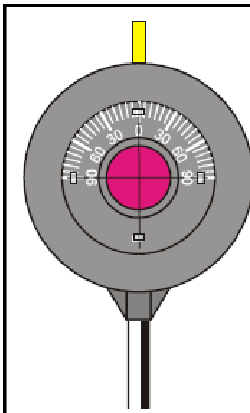

Fig. (8.3)

- Position a polarizer close the halogen lamp on the optical bench as shown in Fig.(8.4).
- Place the U-core of the demountable transformer with the two coils on the rider base with thread and fix it with the holder for the flint glass square.
- Place the bored pole pieces on the U-core in such a manner that the flint glass square can be placed on the holder as depicted in Fig.(8.4).
- Push the pole pieces right up to the flint glass square but without touching it.
- Use the clamps to fix the bored pole pieces on the U-core.
- Position the analyzer close the U-core on the optical bench as shown in Fig.(8.4).
- Position the translucent screen opposite to the analyzer.
- Place the lens f = +50 mm between the analyzer and the translucent screen.

<u>Electrical setup</u>

- Connect the coils to the power supply unit.

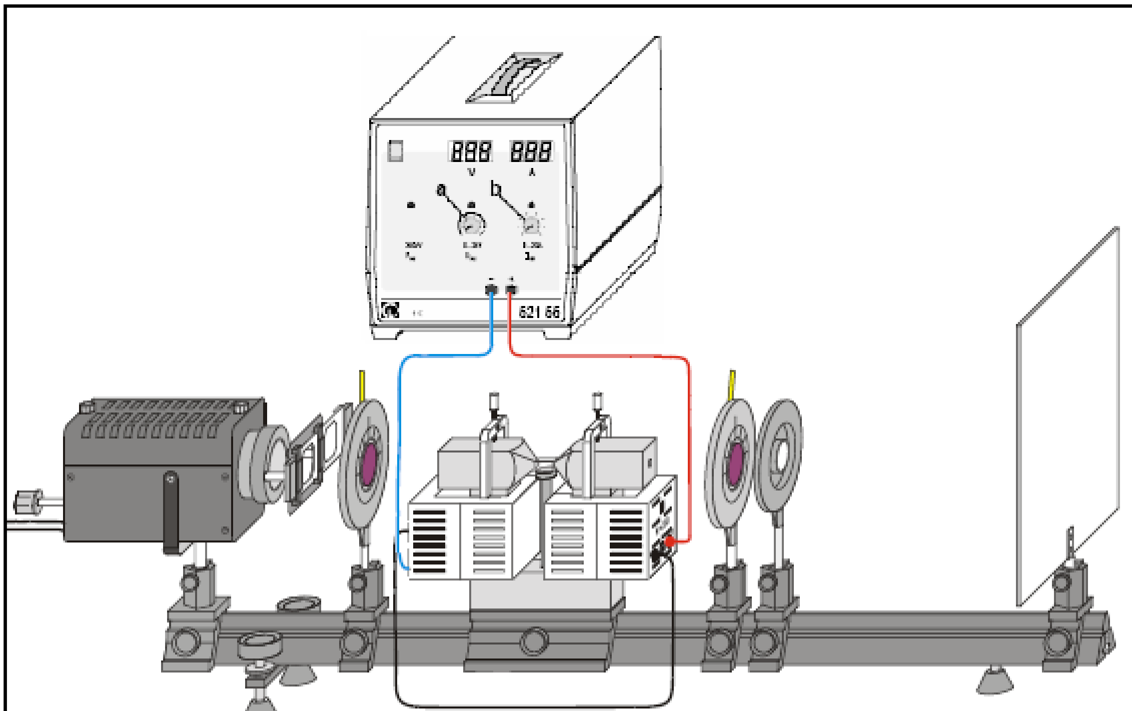

Fig (8.4)

- Connect the halogen lamp to 12 V sockets of the power supply unit.

<u>Optical adjustment</u>

- Use picture slider with the heat filter for absorbing the infrared component in halogen light.
- Switch on halogen lamp.
- Align the light source and the bored pole pieces in such a manner that light − as much as possible − passes through the bores in the pole pieces (with no flint glass square on the holder).
- To project an image of the thread cross on the analyzer onto the translucent screen shift the lens towards the analyzer until a sharp image is observed.

<u>Note</u>: The thread cross and protractor scale should be exactly concentric.

- Insert the polarizing filter.

Carrying out the experiment

a) Calibration of the magnetic field

1. Remove the flint glass square.
2. Place the tangential B probe of the Teslameter between the pole pieces. Use the stand material to hold the magnetic probe between the bored pole pieces.
3. Record the magnetic field B as function of the current I through the coils for currents from 0 to 10 A in steps of 1 A.
4. Plot I vs. B.

b) Rotation of the polarization plane φ as function of the magnetic field B

1. Insert the blue-with-violet filter that has λ = 450 nm (468 11) in the diagram slider.
2. Align the flint glass square between the bored pole pieces.
3. Set the desired magnetic field by means of the magnet current.
4. Set the analyzer to 0° position.
5. Find the intensity minimum by turning the polarizer.

Note: For a final minimum adjustment (almost dark) the minimum light intensity can be easily checked by looking directly into the light beam behind the imaging lens. The polarizer and analyzer are set to the intensity minimum as it can be easier accessed then the intensity maximum.

6. Reverse the polarity of the magnetic field without changing the magnet current. To do so, switch off magnetic field; reverse polarity of coil current; switch on magnetic field.

Note: When the direction of the field is reversed the doubled angle of rotation 2φ is measured as in Fig.(8.5).

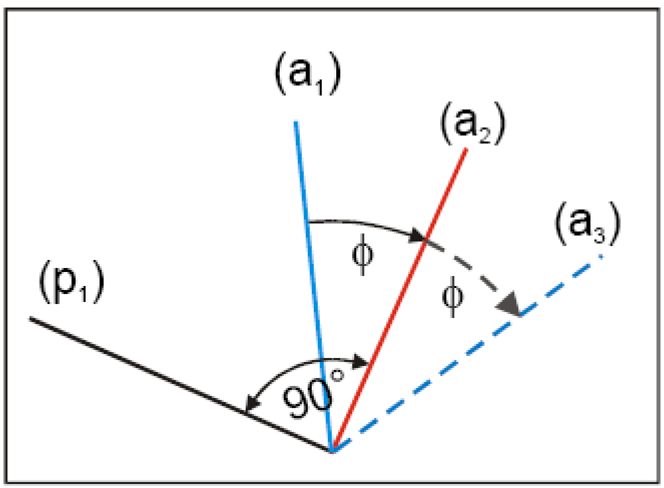

Fig.(8.5):Measuring the doubled angle of rotation 2φ by reversing the polarity of the magnetic field.
φ: angle of rotation of the polarization plane

(a1): analyzer position at the start
(a2): polarization plane of the light after passing through the flint glass square in both experiments.
(p1) polarizer position for the first magnetic field setting.
(a3): analyzer position after reversing the polarity of the magnetic field.

7. Find the intensity minimum by turning the analyzer.

8. Switch off the magnetic field and find the intensity maximum by turning the polarizer.
9. Remove the color filter from the beam path to enhance the contrast of the projected thread cross.
10. Read off the thread cross position.
11. Repeat this measurement steps for various magnetic fields by varying the magnetic current from 1 A to 10 A in steps of 1 A.
12. Plot B vs. $2\Delta\varphi$. Find Verdet constant for the used wavelength.

c) Verdet's constant as function of the wavelength λ

1. Place one of the color filters (Table. 8.1) in the picture slider of the halogen lamp fitting.
2. Set the thread cross to zero.
3. Place the filter in the beam path and apply a magnetic field of 135 mT.
4. Measure the rotation of the polarization plane 2φ as described in part b).
5. Remove the color filter from the beam path before reading off the thread cross position.
6. Repeat the measurement for the other filters.
7. Plot λ^{-2} vs. Verdet constant.

Filter	Transmitted Color	λ (nm)
468 05	Yellow	570
468 09	Blue Green	515
468 11	Blue with Violet	450
468 13	Violet	440

Table. (8.1)

Safety notes

When operating the halogenlamp.

- Operate with AC voltage only (i.e. 12 V AC)
- Do not cover the ventilation slits (danger of overheating).
- Do not touch the bulb of the halogen lamp with your fingers.
- Protect the heat filter of the picture slider from shocks, dropping or similar (the fragile material can break easily).