FARADAY EFFECT

EXPERIMENT PROCEDURE

- **Demonstrate the Faraday effect in flint glass.**
- **Measure the angle of rotation of the polarisation plane in the magnetic field.**
- **Determine the Verdet constant for red and green light.**
- **Determine the Cauchy coefficient *b* for the refractive index.**

OBJECTIVE

Demonstrate the Faraday effect and determine the Verdet constant for flint glass

SUMMARY

Optically isotropic, transparent, non-magnetic materials become optically active in a magnetic field. They rotate the plane of polarisation of linearly polarised light passing through them in the direction of the magnetic field because clockwise and anti-clockwise circularly polarised components of the light take differing amounts of time to pass through. This effect is known as the Faraday effect. In this ex-periment, the Faraday effect will be measured for flint glass. This particular type of glass exhibits a high degree of very uniform optical dispersion. The way that the frequency depends on the refractive index n is given to a good approximation by a Cauchy formula.

REQUIRED APPARATUS

Quantity	Description	Number
1	Optical Precision Bench D, 100 cm	**1002628**
4	Optical Rider D, 90/50	**1002635**
1	Optical Base D	**1009733**
1	Laser Diode, Red	**1003201**
1	Laser Module, Green	**1003202**
2	Polarisation Filter on Stem	**1008668**
1	Projection Screen	**1000608**
1	Transformer Core D	**1000976**
2	Pair of Pole Shoes	**1000978**
2	Coil D, 900 Turns	**1012859**
1	Flint Glass Block for Faraday Effect	**1012860**
1	Accessories for Faraday Effect	**1012861**
1	Teslameter E	**1008537**
1	Magnetic Field Sensor, Axial/Tangential	**1001040**
1	Barrel Foot, 1000 g	**1002834**
1	Universal Jaw Clamp	**1002833**
1	Set of 15 Experiment Leads, 75 cm 1 mm²	**1002840**
1	DC Power Supply, 1 – 32 V, 0 – 20 A (230 V, 50/60 Hz)	**1012857 or**
	DC Power Supply, 1 – 32 V, 0 – 20 A (115 V, 50/60 Hz)	**1012858**

BASIC PRINCIPLES

Optically isotropic, transparent, non-magnetic materials become optically active in a magnetic field. They rotate the plane of polarisation of linearly polarised light passing through them in the direction of the magnetic field because clockwise and anti-clockwise circularly polarised components of the light take differing amounts of time to pass through. This effect is known as the Faraday effect.

The difference in the time it takes the polarised light to pass can be explained in terms of the change in frequency experienced by the polarised light in the magnetic field using a simple model. Light with a clockwise polarisation undergoes a slight increase in frequency *f* by an amount called the Larmor frequency

(1) $$f_L = \frac{e}{4\pi \cdot m_e} \cdot B$$

e = 1.6021 . 10^{-19} As: Charge of an electron

m_e = 9.1 · 10^{-31} kg: Rest mass of an electron

The frequency of anti-clockwise polarised light decreases by the same amount, i.e.

(2) $$f_\pm = f \pm f_L$$

The differing frequencies can be attributed to differing refractive indices in the material. This means that the speed of propagation of waves inside the material differs as well.

These statements make it possible to determine the rotation of the plane of polarisation in optically active materials, as follows:

(3) $$\varphi = 2\pi \cdot f \cdot (t_+ - t_-) = 2\pi \cdot f \cdot \frac{d}{c} \cdot \left(n(f_+) - n(f_-)\right)$$

d: Length of sample,

$$c = 2{,}998 \cdot 10^8 \frac{\text{m}}{\text{s}}$$: Speed of light

Since the Larmor frequency f_L is much smaller than *f*, it follows that:

(4) $$\varphi = 2\pi \cdot f \cdot \frac{d}{c} \cdot \frac{\mathrm{d}n}{\mathrm{d}f} \cdot 2 \cdot f_L$$
$$= f \cdot \frac{\mathrm{d}n}{\mathrm{d}f} \cdot \frac{e}{m_e \cdot c} \cdot B \cdot d$$

The angle of rotation φ is also proportional to the magnetic field *B* and the length of material *d* through which the light passes:

(5) $$\varphi = V \cdot B \cdot d$$

The constant of proportionality

(6) $$V = \frac{e}{m_e \cdot c} \cdot f \cdot \frac{\mathrm{d}n}{\mathrm{d}f}$$

is called the Verdet constant and is dependent on the dispersion of the light in the material through which it passes and on the frequency *f* of that light. In this experiment, measurements are made of the Faraday effect in flint glass (F2). This particular type of glass exhibits a high degree of very uniform optical dispersion. The way that the frequency depends on the refractive index *n* is given to a good approximation by a Cauchy formula.

(7) $$n(f) = a + \frac{b}{c^2} \cdot f^2$$

where a = 1.62, b = 8920 nm²

To improve the accuracy of the measurement for small angles of rotation, this experiment is set up in such a way that when the magnetic field *B* is positive the polarisation of the light is such that the analyser filter causes the transmitted light to go dark at precisely 0°. When the magnetic field is switched to a negative one –*B*, the analyser must be rotated by an angle 2 φ in order to shut out the light again.

EVALUATION

From equations (6) and (7), the following can be derived:

$$V = \frac{2 \cdot e \cdot b \cdot f^2}{m_e \cdot c^3} = \frac{2 \cdot e \cdot b}{m_e \cdot c \cdot \lambda^2}$$

This means that it is possible to obtain the Cauchy coefficient *b* for the refractive index of the flint glass used here from the Verdet constant, as long as the wavelength λ of the light is known.

$$b = \frac{m_e \cdot c}{2 \cdot e} \cdot V \cdot \lambda^2$$

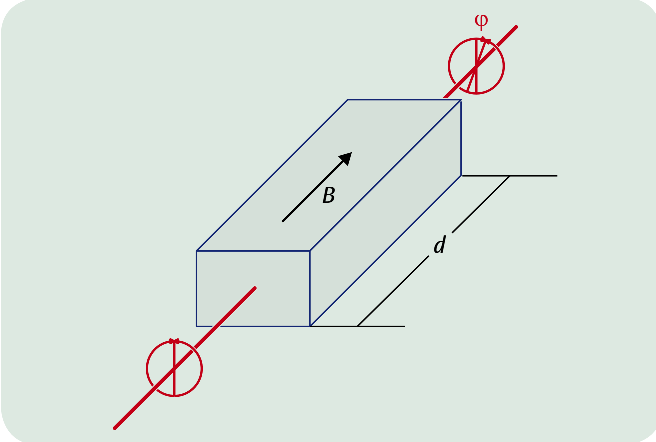

Fig. 1: Schematic diagram to illustrate the Faraday effect

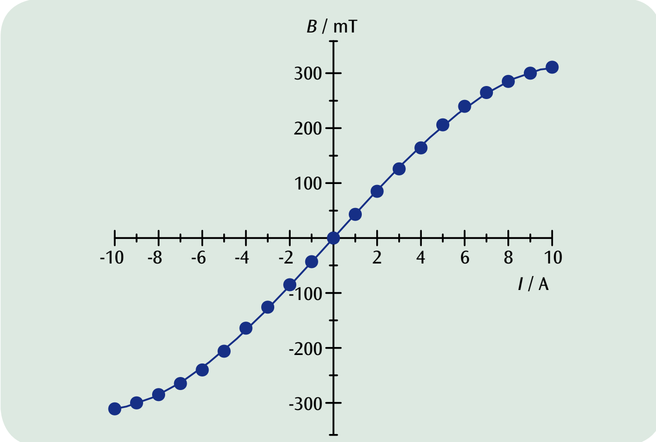

Fig. 2: Calibration curve for electromagnet

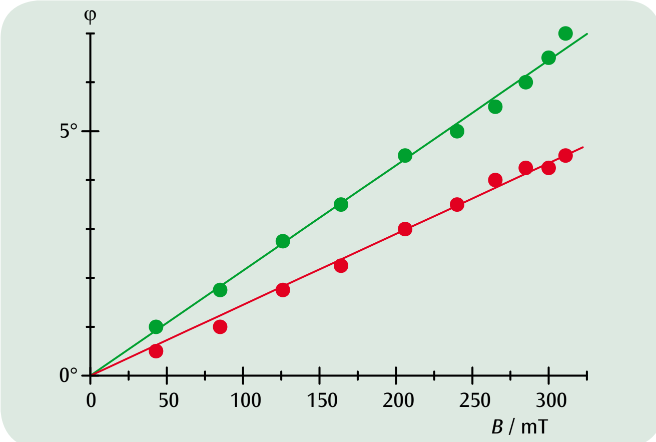

Fig. 3: Angle of rotation as a function of the magnetic field for red and green laser light