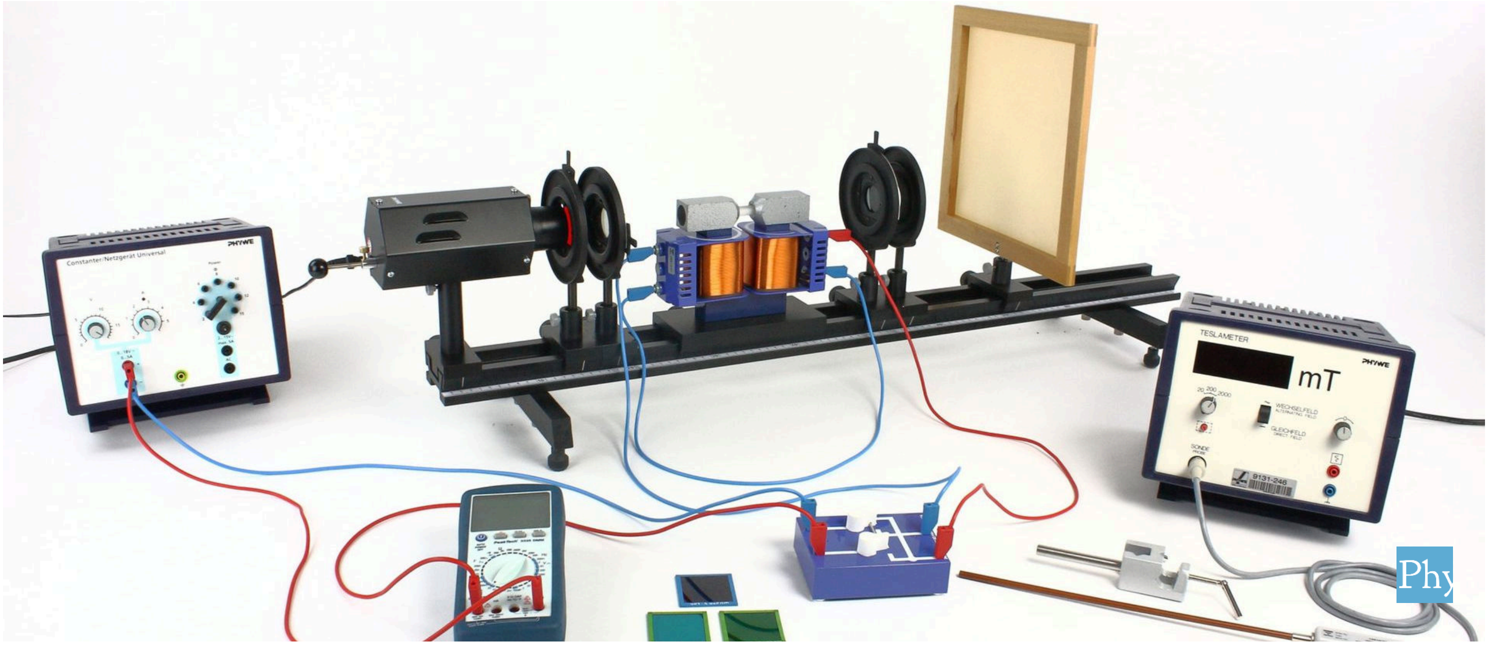
Faraday effect



Physics | Light & Optics | Polarisation

Difficulty level	Group size	Preparation time	Execution time
-	-	-	-

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General information

Application

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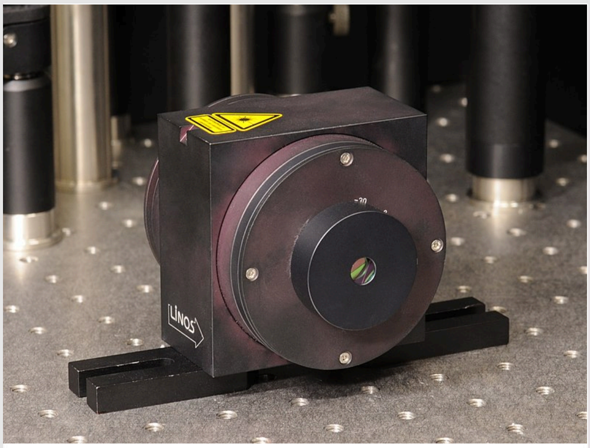

An optical isolator

The applications of Faraday effect can be found in:

- measuring instruments: to measure optical rotary power
- Faraday rotators: for amplitude modulation of light
- optical isolators and circulators: essential components in optical telecommunication

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Other information (1/3)

Prior knowledge

In a light wave, the electric field vector and the magnetic vector oscillate perpendicularly and in phase to each other. By convention, the polarization of electromagnetic waves refers to the direction of the electric field. Tthe fields oscillate in a single direction in linear polarisaion and rotate at a constant rate in a plane during the wave propagation in circular or elliptical polarisation.

Scientific principle

The angle of rotation of the polarisation-plane of plane polarized light through a flint glass rod is found to be a linear function of the product of the mean flux-density and the length of the optical medium. The factor of proportionally, called Verdet's constant, is investigated as a function of the wavelength and the optical medium.

Other information (2/3)

Learning objective

Understanding the principles of Faraday effect.

Tasks

1. To determine the magnetic flux-densitiy between the pole pieces using the axial Hall probe of the teslameter for different coil currents. The mean flux-density is calculated by numerical integration and the ratio maximum flux-density over mean flux-density established.

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Other information (3/3)

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Tasks

2. To measure the maximum flux-density as a function of the coil current and to establish the relationship between mean flux-density and coil current anticipating that the ratio found under 1. remains constant.

3. To determine the angle of rotation as a function of the mean flux-density using different colour filters. To calculate the corresponding Verdet's constant in each case.

4. To evaluate Verdet's constant as a function of the wavelength.

Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

Be certain that the power supply is zeroed and turned off before disconnecting the magnet in order to reverse current leads. Failure to observe this precaution may result in personal injury or damage to the equipment.

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Theory (1/3)

When a transparent medium is permeated by an external magnetic field, the plane of polarisation of a plane-polarized light beam passing through the medium is rotated if the direction of the incident light is parallel to the lines of force of the magnetic field. This is called the “Faraday effect”.

In oder to demonstrate the Faraday effect experimentally, plane-polarized light is passed through a flint-glass SF6 cylinder, supported between the drilled pole pieces of an electromagnet. An analyser arranged beyond the glass cylinder has its polarisation plane crossed in relation to that of the polariser, so that the field of view of the face of the glass cylinder projected on the translucent screen appears dark.

When current flows through the coils of the electromagnet, a magnetic field is produced, permeating the glass cylinder in the direction of irradiation. The rotation now occuring in the plane of oscillation of the light is indicated by resetting the analyser to maximum extinction of the translucent screen image.

After reversing the polarity of the coil current, the experiment is repeated with the opposite magnetic field direction.

Theory (2/3)

It can also be shown that the angle of rotation is proportional to the length of the test specimen (Here: l = 30 mm). Hence:

$$\Delta\phi \sim I \cdot \overline{B}$$

The proportionality factor V is called Verdet’s constant. V is a function of the wavelength λ and the refractive index $n(\lambda)$.

$$\Delta\phi = V(\lambda) \cdot I \cdot \overline{B} \qquad (1)$$

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Theory (3/3)

Verdet's constant as a function of the wavelength can be represented by the following empirical expression (Technical Information No. 17, Schott Company, Mainz,Germany.):

$$V(\lambda) = \frac{\pi}{\lambda} \cdot \left(\frac{n^2(\lambda) - 1}{n(\lambda)}\right) \left(A + \frac{B}{\lambda^2 - \lambda_0^2}\right) \qquad (2)$$

with: $A = 15.71 \cdot 10^{-7}\,\frac{rad}{T}$; $B = 6.34 \cdot 10^{-19}\,\frac{rad \cdot m^2}{T}$ and

$\lambda_0 = 156.6\,nm$

$n \sim 1.84(440 nm)$

$n \sim 1.80(660 nm)$

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Equipment

Position	Material	Item No.	Quantity
1	Glass rod for Faraday effect,	06496-00	1
2	Coil, 600 turns	06514-01	2
3	Pole pieces drilled, 1 pair, for iron core, U-shaped	06495-00	1
4	Iron core, U-shaped, laminated	06501-00	1
5	Experimental lamp LED HEX 1	08130-99	1
6	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C	07122-00	1
7	Commutator switch	06006-00	1
8	PHYWE Teslameter, digital	13610-93	1
9	Hall probe, axial	13610-01	1
10	Lens, mounted, f +150 mm	08022-01	1
11	Lens holder, beam height 120 mm	08012-01	1
12	Plateau slide mount for optical bench expert	08286-06	1
13	Universal Holder, rotational	08040-02	1
14	Colour filter, purple, 360...460 nm, 16% @ 440 nm	08411-00	1
15	Colour filter, blue-green, 400...560 nm, 63% @ 505 nm	08413-00	1
16	Colour filter, light green, 480...570 nm, 45% @ 525 nm	08414-00	1
17	Colour filter, light yellow, 560...630 nm, 19% @ 580 nm	08415-00	1
18	Colour filter, light red, >600 nm, 93% @ 595 nm	08416-00	1
19	Polarisation filter	08610-02	2
20	Screen, translucent, 250x250 mm	08064-00	1
21	Optical bench expert, l = 1000 mm	08282-00	1
22	Base for optical bench expert, adjustable	08284-00	2
23	Slide mount for optical bench expert, h = 30 mm	08286-01	5
24	Right angle clamp expert	02054-00	1
25	Connecting cord, 32 A, 750 mm, red	07362-01	3
26	Connecting cord, 32 A, 750 mm, blue	07362-04	3
27	Support rod,stainl.steel, 100mm	02030-00	1
28	Slide mount for optical bench expert, h = 80 mm	08286-02	1
29	PHYWE Power supply, universal DC: 0...18 V, 0...5 A / AC: 2/4/6/8/10/12/15 V, 5 A	13504-93	1
30	Post, L 50 mm, D 12 mm	08750-04	1
31	Setscrew for optics, set of 10 pieces	08750-13	1

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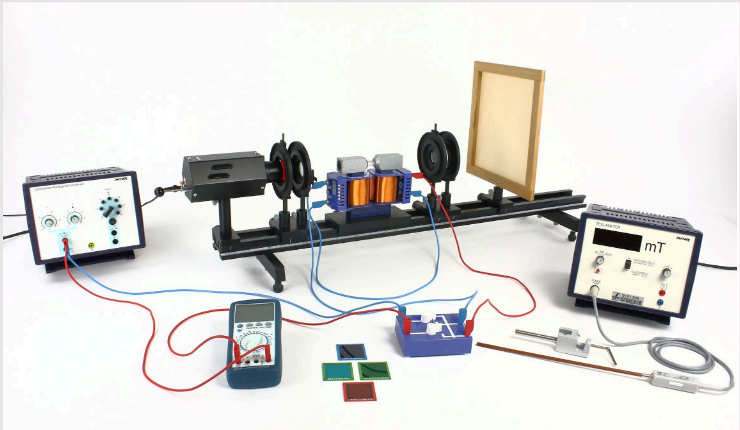
Setup and procedure

Setup (1/3)



Experimental setup

Set up the equipment as shown in the figure.

The experimental lamp, the object holder with the coloured glass, the polarizing filter, the electromagnet configuration on the plateau slide mount, the analyser, the lens holder with the lens of focal length 150 mm, and the translucent screen.

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Setup (2/3)

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Material	**Position** (cm)
Lamp LED	2
Coloured glass	15
Polarizing filter	19
Electromagnet	35
Polarizing filter (analyser)	52
Lens, f = 150 mm	56
Translucent screen	72

Positions on the optical bench.

Consult the operating instructions for the Experimental lamp LED HEX 1, power supply and the teslameter for proper handling and explanation of controls.

Setup (3/3)

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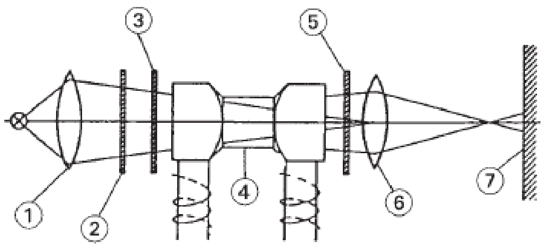
Fig. 2:
1. Condenser, f = 6 cm
2. Coloured glass
3. Polariser
4. Test specimen (flint glass SF6)
5. Analyser
6. Lens, f = 15 cm
7. Translucent screen.



Schematic diagram for the Faraday Effect optical axis with corresponding materials.

The electromagnet needed for the experiment is constructed from a laminaded U-shaped iron core, two 600-turn coils and the drilled pole pieces, the electromagnet then being arranged in a stable manner on the table on rod.

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Procedure (1/6)

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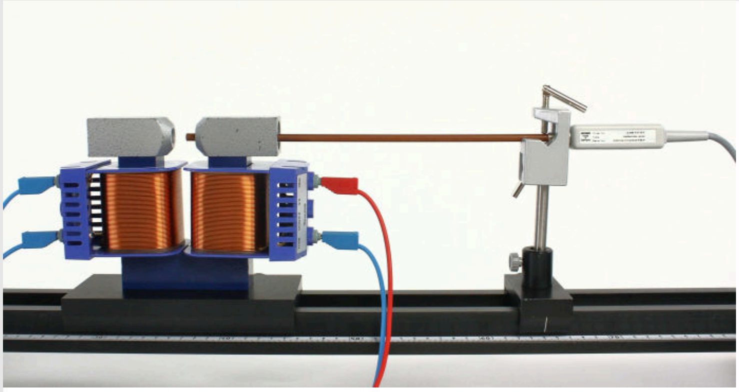

Determining magnetic flux-density set-up.

1) Determining magnetic flux-density

In the absence of the glass rod, the distribution of the magnetic flux-density is determined in the gap between the pole pieces. The set-up is shown in the figure. To perform this step, only the Teslameter, axial probe, right angle clamp with support rod (100 mm) on slide mount and the fully connected electromagnet on the plateau slide mount are required. First, connect the support rod to the right angle clamp and place it on the slide mount.

Procedure (2/6)

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Next, put the axial probe in the clamp and tighten the screw just enough to fix the probe in place. You do not want to tighten the screw too much. Have the slide mount slightly loose to allow for gradual movement along the optical bench. Center the electromagnet on the plateau slide mount so that the pole piece holes are directly aligned with the probe.

With the axial probe connected to the teslameter, the flux-density is measured along the pole pieces. From the central point of the gap, measure about 1.75 cm to both the left and right (which extends within the pole pieces). The entire 3.5 cm distance should be measured in steps of 5 mm. The procedure is repeated for different current intensities, from 0.5 to 4 A in increments of 0.5 A.

Before taking any measurement, the teslameter needs to first be zeroed. Once the axial probe is positioned in the center of the gap, use the "adjusting screw" and "adjusting knob" on the teslameter (described in the teslameter operating instructions) to zero the measurement before turning up the current intensity.

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Procedure (3/6)

Set the "stepping switch" to the lowest measuring range when zeroing. As the current intensity is increased up to 4 A during the experiment, change the measuring range to the higher settings when appropriate.

Plot the flux-density distribution for each current intensity along the gap length, and compare to Fig.1. Find the mean fluxdensity for each current intensity. Determine the ratio between the maximum flux density and mean flux-density in each case. Additionally, graph the mean flux-density between the pole pieces as a function of coil current, and compare to the magnet flux-density distributions.

Procedure (4/6)

2) Determining the angle of rotation of polarisation-plane and Verdet's constant as a function of wavelength

After the flux-density distribution has been measured, the 30 mm long glass rod is inserted in the pole piece holes, and the magnet is centered between the two polarisation filters. Straighten the glass rod as much as possible. The room should be darkened when carrying out the measurements. The planes of polarisation of the two polarisation filters are arranged in parallel.

The 3W LED experimental lamp should now be plugged in and the light refocused using the adjustment rod on the back of the lamp. The electromagnet is then moved into the path of the image rays and is positioned so that the pole piece holes with the inserted glass rod are aligned with the optical axis. By sliding the objective lens along the optical bench, the face of the glass rod is sharply projected onto the translucent screen. Adjustment is completed by inserting the coloured glass in the object holder.

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Procedure (5/6)

The polarizing filter should permanently have a position of $\pm 90^\circ$. In this case the analyser will have a position of $0^\circ \pm \Delta\phi$ for perfect extinction with $\Delta\phi$ being a function of the coil current, respectively of the mean flux-density.

Regarding the judgement about the complete extinction, it may eventually be better to remove the screen and to follow the adjustment of the analyser by eye-inspection. The maximum coils current under permanent use is 2 A. However, the current can be increased up to 4 A for a few minutes without risk of damage to the coils by overheating.

If the polariser and analyser are crossed, the translucent screen image appears dark. It brightens up when the coil current is switched on and a longitudinal magnetic field is generated between the pole pieces. Adjustment of the analyser through a certain angle $\Delta\phi$ produces maximum extinction of the light (Position 1).

Procedure (6/6)

If the direction of the magnetic field is reversed by changing the polarity of the coil current, the analyser must be adjusted in the opposite direction in order to darken the brightened field of view again (Position 2). The difference between position 2 and position 1 of the analyser is equal to $2 \cdot \Delta\phi$.

Plot the rotation of the polarisation-plane as a function of the mean flux-density for each coloured glass (wavelength), and compare the graphs. Calculate Verdet's constant and plot each as a function of the wavelength.

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Evaluation (1/8)

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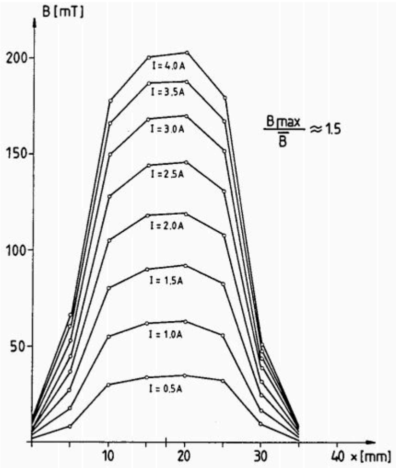

Flux-density distribution between the pole pieces for different coil currents.

Task 1:

The results for the magnet flux-density distributions are shown in the figure. The flux density increases strongly to the center of the gap and decreases to either side.

Whatever the coil current may be, the ratio maximum flux-density over mean flux-density (found by numerical integration) is in each case approximately equal to 1.5.

Evaluation (2/8)

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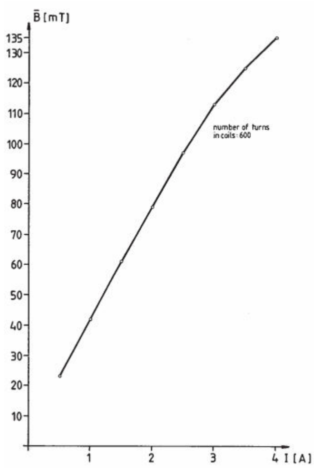

Mean flux-density between the pole pieces as a function of the coil current.

Task 2:

Starting from the maximum flux-density in the gap we can now easily attribute a mean flux-density to the test specimen for any coil current given. The corresponding graph has been plotted in the figure.

For all further considerations, it is anticipated that the test specimen is submítted to this mean flux-density.

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Evaluation (3/8)

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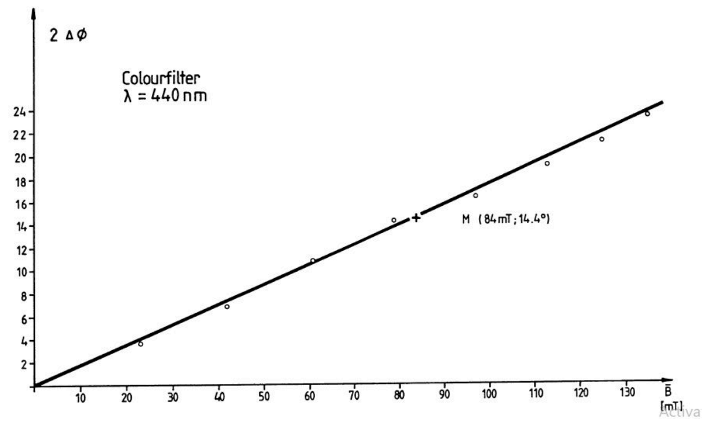

Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 440 nm.

Task 3

Figures show the angle $2 \cdot \Delta \phi$ as a function of the mean flux-density for the five different colour filters. It is observed that the plane of polarisation is rotated around the direction of propagation of the light which coincides with the direction of the magnetic flux-density vector. The angle of rotation becomes greater the higher the mean flux-density is.

For a particular wavelength we find a linear relationship between the angle of rotation $\Delta \phi$ and the mean flux-density $\overline{B}$.

Evaluation (4/8)

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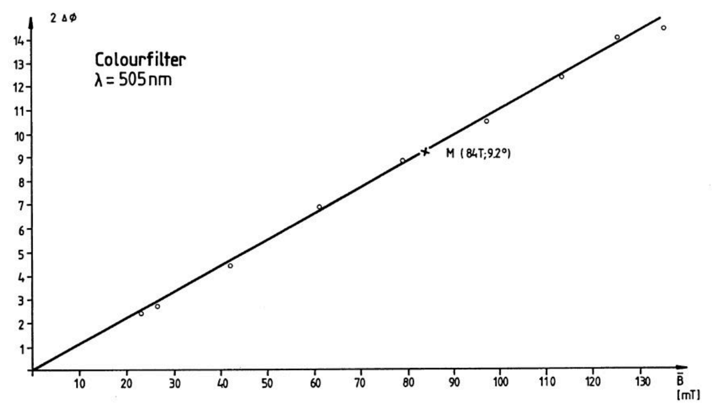
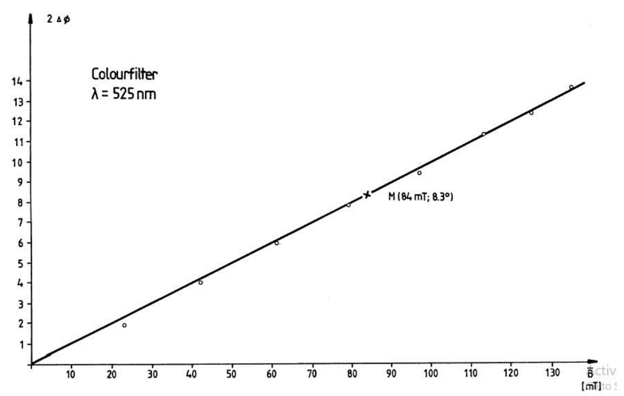


Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 505 nm.



Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 525 nm.

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Evaluation (5/8)

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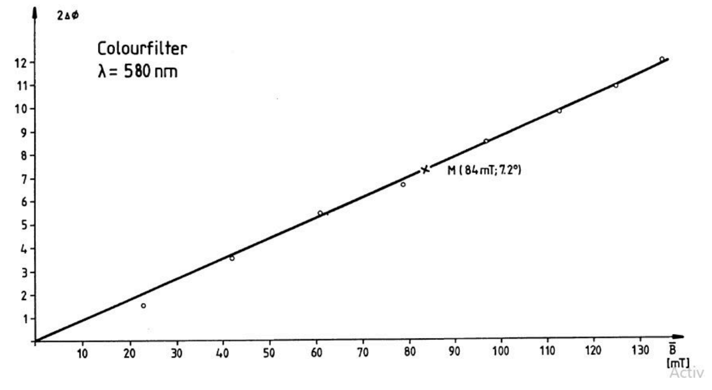
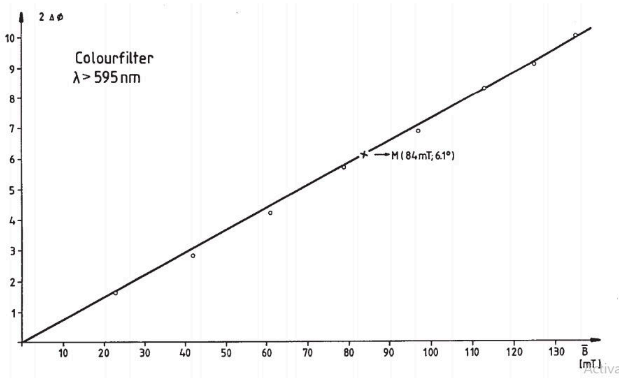


Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 580 nm.



Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 595 nm.

Evaluation (6/8)

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It can also be shown that the angle of rotation is proportional to the length of the test specimen (Here: l = 30 mm). Hence:

$$\Delta\phi \sim I \cdot \overline{B}$$

From the slopes of the graphs, we find the following values for V(λ):

	$V(\lambda)$ in [$\frac{\text{degree}}{\text{T}\cdot\text{m}}$]	$V(\lambda)$ in [$\frac{\text{radian}}{\text{T}\cdot\text{m}}$]
Colour filter λ = 440 nm	2857	49.8
Colour filter λ = 505 nm	1825	31.8
Colour filter λ = 525 nm	1647	28.7
Colour filter λ = 580 nm	1647	24.9
Colour filter λ = 595 nm	1210	21.1

$V(\lambda)$ for each wavelength

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Evaluation (7/8)

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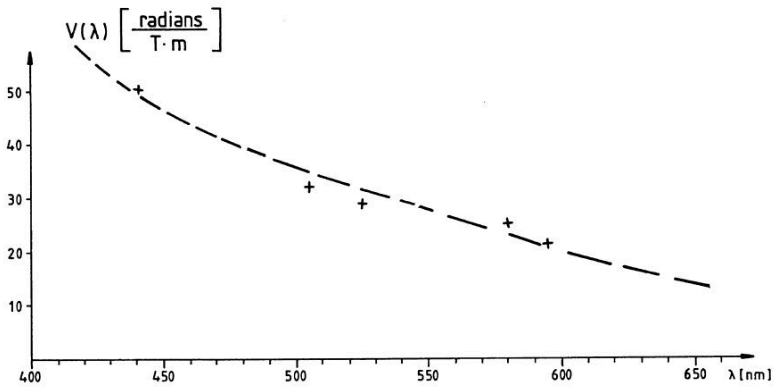
Task 4

A graphical representation of Verdet's constant as a function of the wavelength for glass SF6 is found in the figure. The cross-points represent the measured values (440 nm), (505 nm), (525 nm), (580 nm) and (595 nm).

They coincide reasonably well with the values predicted by Equation 2.

\+ measured values

--- theoretical values



Verdet's constant as a function of the wavelength

Evaluation (8/8)

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Verdet constant of a material :

- [ ] is polarisation angle dependent.
- [ ] is temperature dependant
- [ ] describes the strength of the Faraday effect
- [ ] is wavelength dependent.

Check

The magnitude of the rotation depends upon

- [ ] the properties of transmitting materials
- [ ] the strength of the magnetic field
- [ ] Verdet's constant

Check

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Slide	Score / Total
Slide 28: Multiple tasks	**0/6**

Total Score 0 / 6

Show solutions Retry

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