2.6.01-00 Faraday effect

What you can learn about …

- → Electromagnetic field interaction
- → Electron oscillation
- → Electromagnetism
- → Polarization
- → Verdet's constant
- → Hall effect

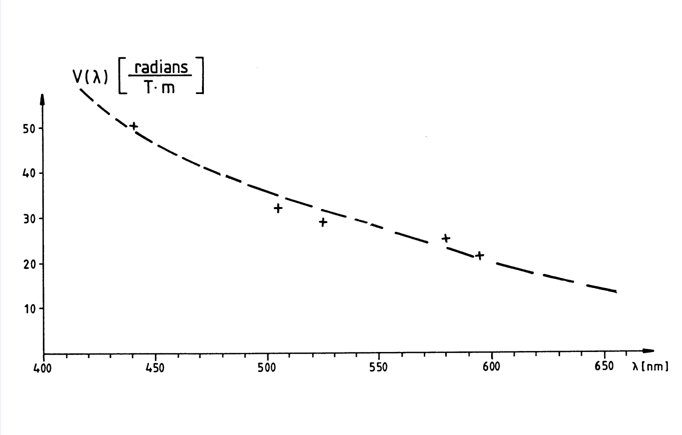
Principle:

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-densitiy 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.

What you need:

Glass rod for Faraday effect	06496.00	1
Coil, 600 turns	06514.01	2
Pole pieces, drilled, 1 pair	06495.00	1
Iron core, U-shaped, laminated	06501.00	1
Housing for experiment lamp	08129.01	1
Halogen lamp, 12 V/50 W	08129.06	1
Holder G 6.35 f. 50/100 W halo.lamp	08129.04	1
Double condenser, f = 60 mm	08137.00	1
Var. transformer, 25 VAC/20 VDC, 12 A	13531.93	1
Amperemeter	07036.00	1
Commutator switch	06034.03	1
Teslameter, digital	13610.93	1
Hall probe, axial	13610.01	1
Lens, mounted, f = +150 mm	08022.01	1
Lens holder	08012.00	1
Table top on rod, 18.5×11 cm	08060.00	1
Object holder, 5×5 cm	08041.00	1
Colour filter, 440 nm	08411.00	1
Colour filter, 505 nm	08413.00	1
Colour filter, 525 nm	08414.00	1
Colour filter, 580 nm	08415.00	1
Colour filter, 595 nm	08416.00	1
Polarizing filter with vernier	08611.00	2
Screen, translucent, 250×250 mm	08064.00	1
Optical profile-bench, l = 1000 mm	08282.00	1
Base f. opt. profile-bench, adjust.	08284.00	2
Slide mount f. opt. pr.-bench, h = 30 mm	08286.01	2
Slide mount f. opt. pr.-bench, h = 80 mm	08286.02	5
Universal clamp	37715.00	1
Connecting cord, l = 750 mm, red	07362.01	3
Connecting cord, l = 750 mm, blue	07362.04	3

Complete Equipment Set, Manual on CD-ROM included
Faraday effect P2260100



Verdet's constant as a function of the wavelength
+ measured values --- theoretical values.

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.
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.

Related topics

Electromagnetic field interaction, electron oscillation, electromagnetism, polarization, Verdet's constant, Hall effect.

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-densitiy 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.

Equipment

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Tasks

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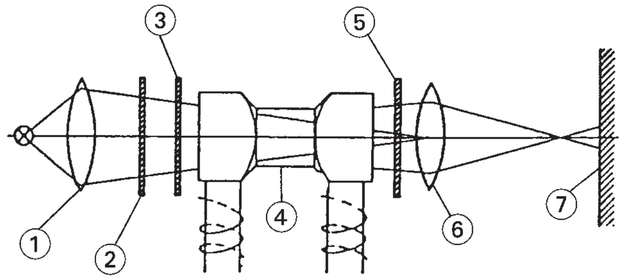
4. To evaluate Verdet's constant as a function of the wavelength.

Fig. 1: Experimental set-up for quantitative treatment of the Faraday effect.

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.



Set-up and procedure

Set up the equipment as shown in Fig. 1 and 2. The 50 W experimental lamp is supplied by the 12 V AC constant voltage source. The DC output of the power supply is variable between 0 and 20 VDC and is connected via an amperemeter to the coils of the electromagnet which are in series.

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.

After the flux-density distribution has been measured, the 30 mm long flint glass cylinder is inserted in the pole piece holes and the jack is raised so that the magnet is interpolated in the experimental set-up between the two polarisation filters.

First of all, the experiment lamp 2, fitted with a condensor having a focal length of 6 cm, is fixed on the optical bench. This is followed by the diaphragm holder with coloured glass, two polarisation filters and a lens holder with a mounted lens of f = 15 cm. The translucent screen is put in a slide mount at the end of the optical bench. The ray paths have been traced in Fig. 2.

The planes of polarisation of the two polarisation filters are arranged in parallel. The experiment lamp is switched on and the incandescent lamp moved into the housing until the image of the lamp filament is in the objective lens plane.

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 cylinder are aligned with the optical axis.

By sliding the objective lens along the optical bench, the face of the glass cylinder is sharply projected onto the translucent screen. Adjustment is completed by inserting the coloured glass in the diaphragm holder.

The polarizing filter should permanently have a position of +45°. In this case the analyser will have a position of -45° $\pm\Delta\phi$ 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.

Theory and evaluation

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.

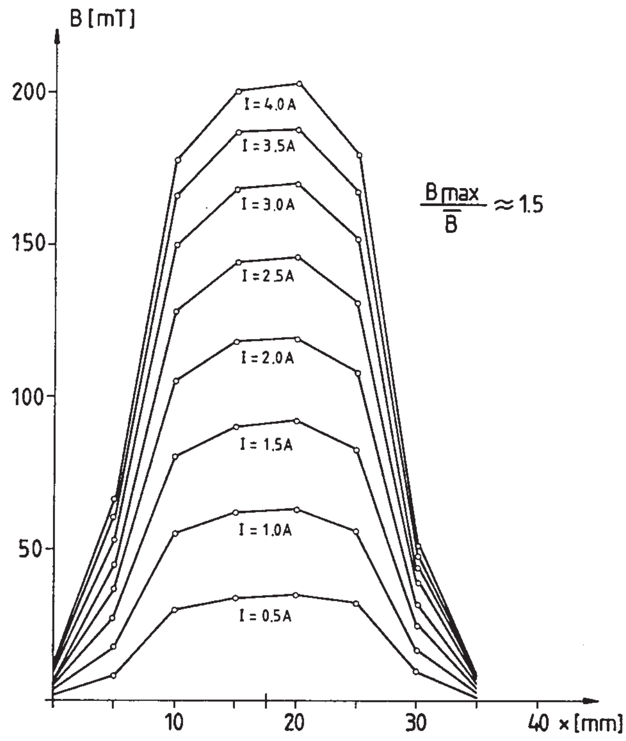


Fig. 3: Flux-density distribution between the pole pieces for different coil currents.

1. In the absence of the flint glass cylinder, the distribution of the magnetic flux-density is determined in the space between the pole pieces. Using the axial probe of the teslameter, which can easily be moved through one of the holes of the pole pieces when fixed in a universal clamp on a slide mount, the flux-density is measured anolg the whole gap in steps of 5 mm. The procedure is repeated for different current intensities. The results are shown in Fig. 3. 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.

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 Fig. 4. For all further considerations it is anticipated that the test specimen is submítted to this mean flux-density.

3. 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).

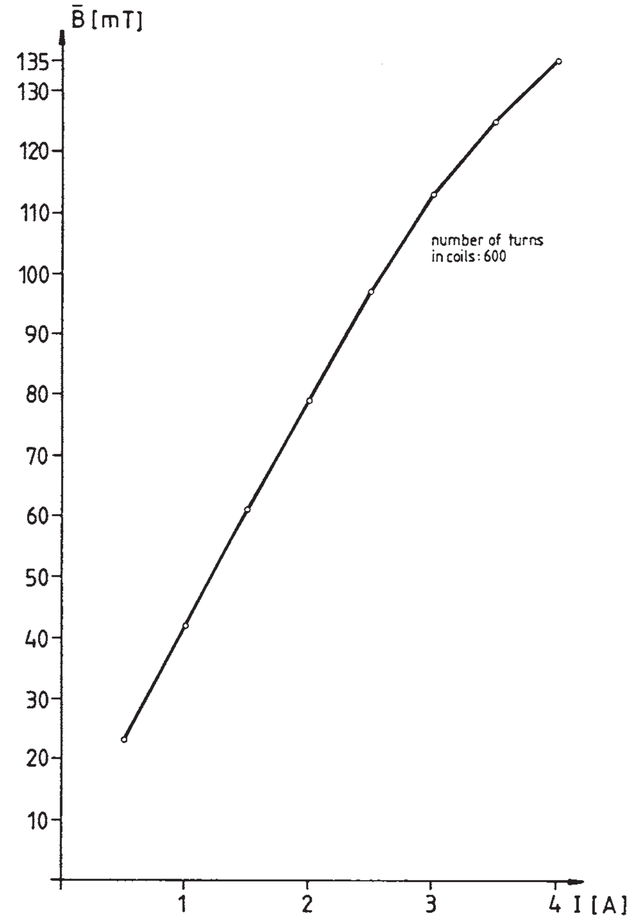


Fig. 4 : Mean flux-density between the pole pieces as a function of the coil current.

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 · $\Delta\phi$.

Fig. 5 to Fig. 9 show the angle 2 $\Delta\phi$ as a function of the mean flux-density for 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 $\overline{B}$

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

Hence:

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

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

$$\Delta\phi = V(\lambda) \cdot l \cdot \overline{B}$$

From the slopes of the graphs shown in Fig. 5 to Fig. 9 we find the following values for V(λ):

	$V(\lambda)$ in $\left[\frac{\text{degree}}{T \cdot m}\right]$	$V(\lambda)$ in $\left[\frac{\text{radians}}{T \cdot m}\right]$
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	1428	24.9
Colour filter λ = 595 nm	1210	21.1

The values shown in the table were calculated using the relation:

$$V(\lambda) = \frac{\overline{\Delta\phi}}{\overline{B} \cdot l}$$

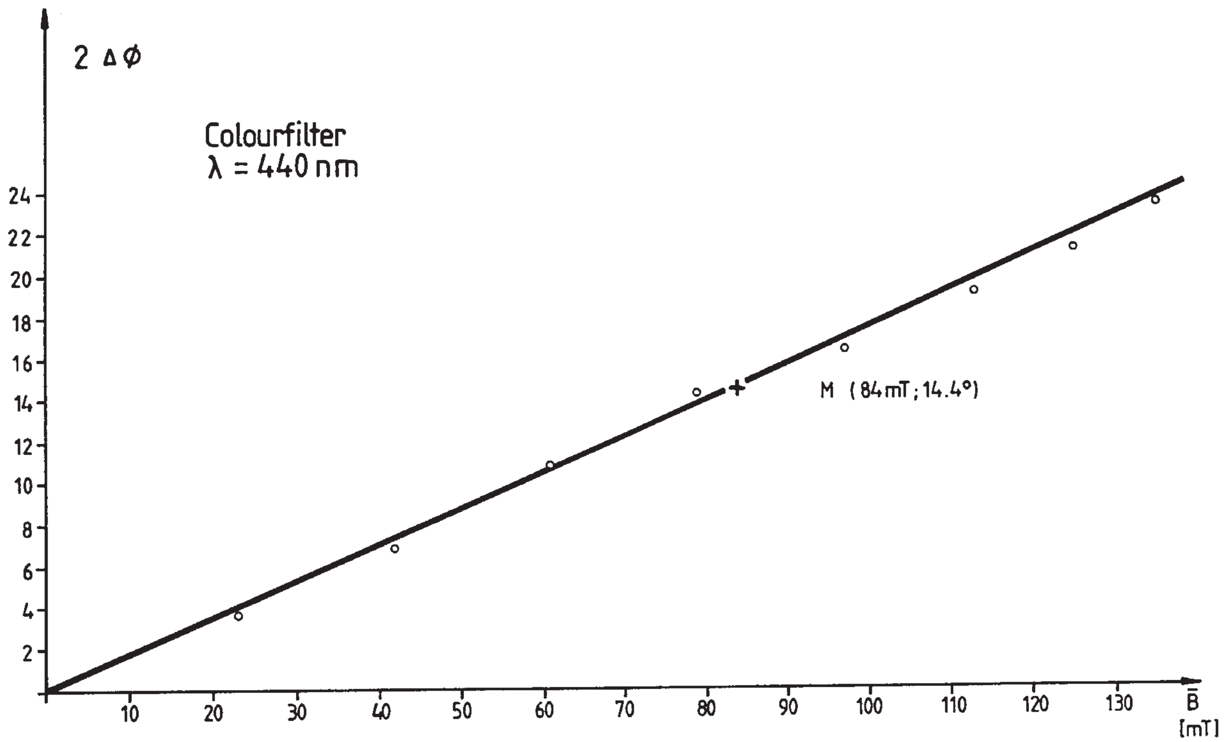
4. Verdet's constant as a function of the wavelength can be represented by the following empirical expression*:

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

with: $A = 15.71 \cdot 10^{-7}\ \frac{\text{rad}}{T}$; $B = 6.34 \cdot 10^{-19}\ \frac{\text{rad} \cdot \text{m}^2}{T}$
and
λ_0 = 156.4 [nm]
n ~ 1.84 (440 nm)
n ~ 1.80 (660 nm)

* Technical Information No. 17, Schott Company, Mainz, Germany.

Fig. 5: Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 440 nm.



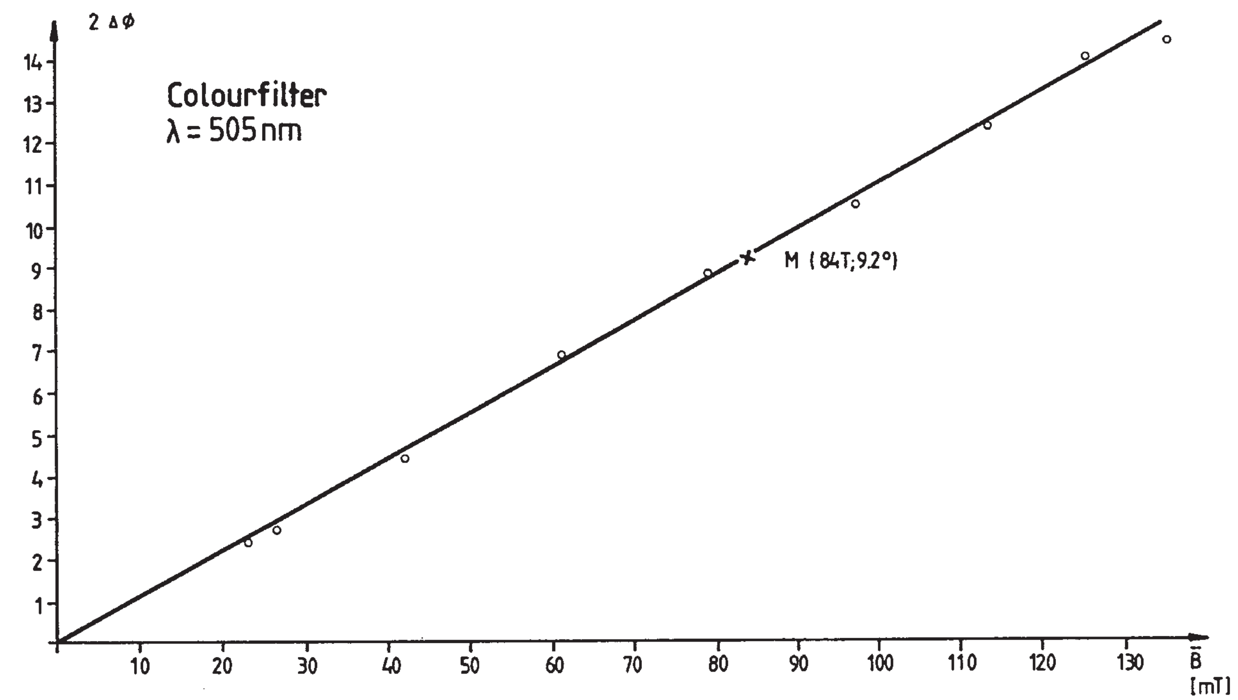
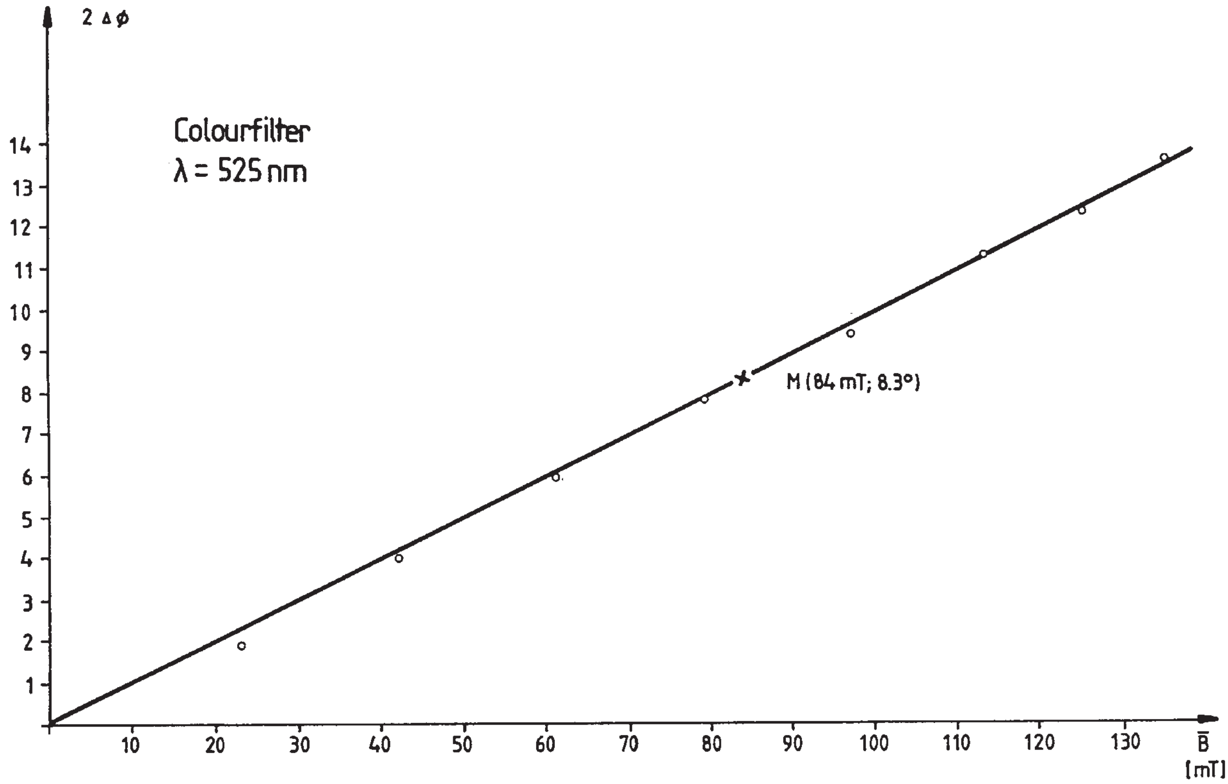


Fig. 6: Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 505 nm.

Fig. 7: Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 525 nm.



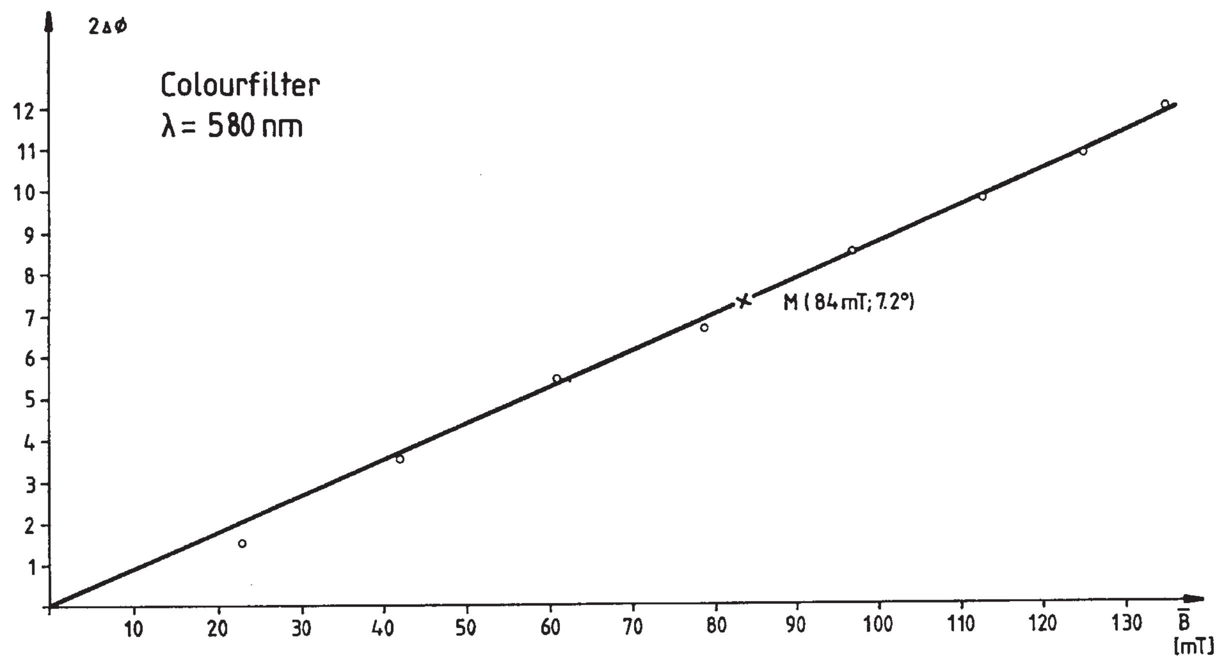
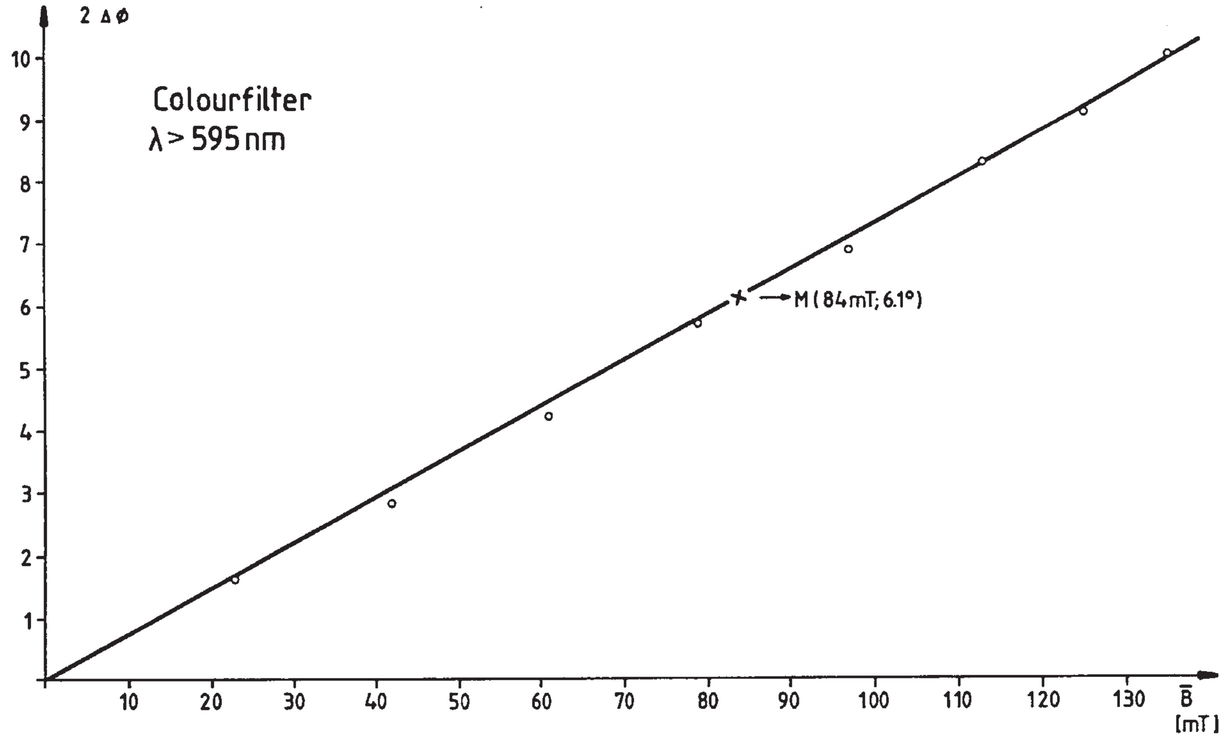


Fig. 8: Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ = 580 nm.

Fig. 9: Angle of rotation of the polarisation-plane as a function of the mean flux-density for λ > 595 nm.



as the mean wavelength for the UV resonances of flint glass SF6. A graphical representation of Verdet's constant as a function of the wavelength for flint glass SF6 is found in Fig. 10. The cross-points in Fig. 10 represent the measured values V(440 nm), V(505 nm), V(525 nm), V(580 nm) and V(595 nm). They coincide reasonably well with the values predicted by the above formula.

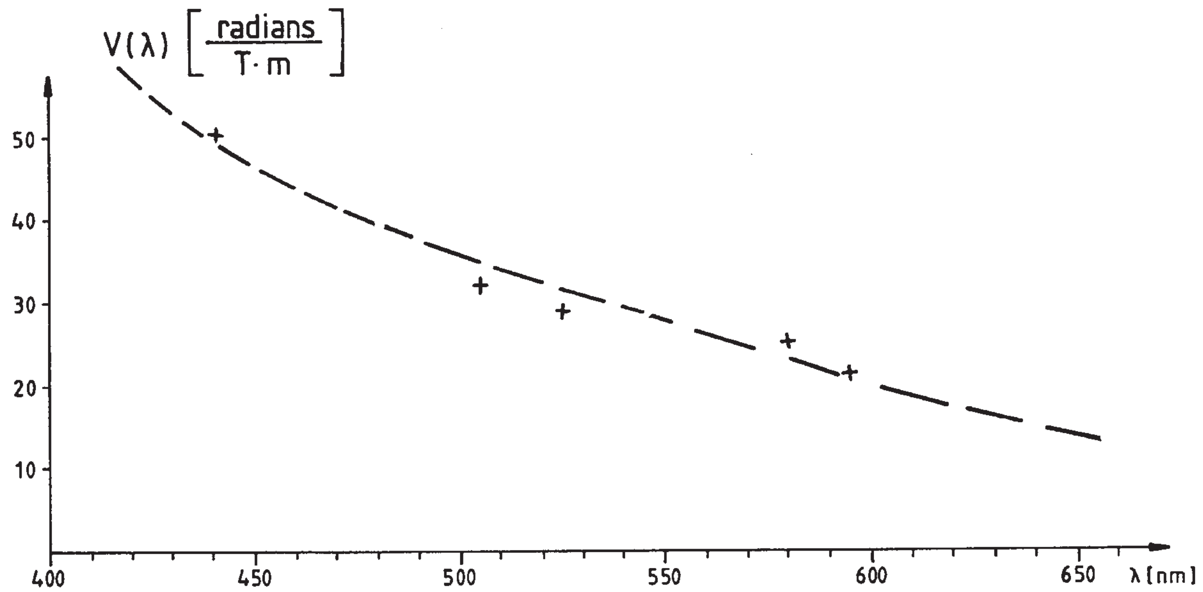


Fig. 10: Verdet's constant as a function of the wavelength + measured values --- theoretical values.