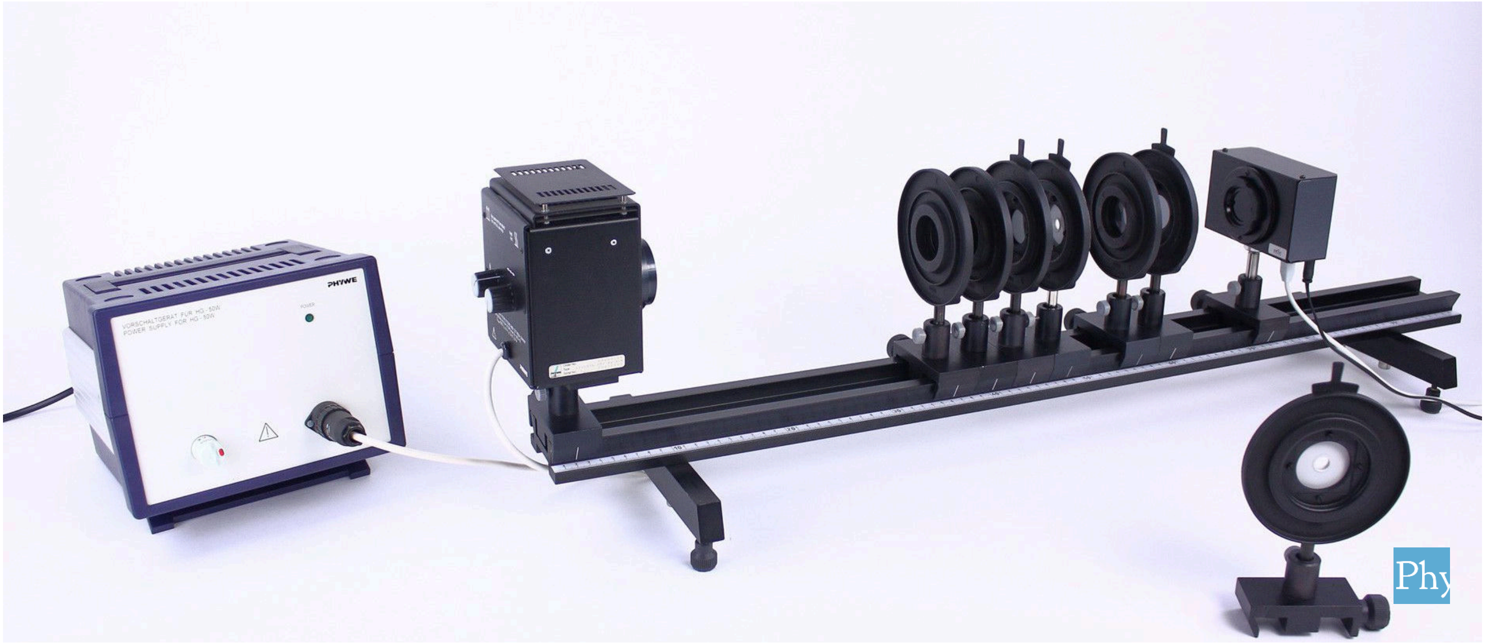
Polarisation through quarter-wave plates



Physics → Light & Optics → Polarisation

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

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General information

Application

Polarising filter

Polarisers are applied to eliminate glare from light scattering, increase contrast, and eliminate hot spots from reflective objects. This either brings out more intense color or contrast or helps to better identify surface defects or other otherwise hidden structures. Its application can be found in:

- photography
- polarised light microscope
- LCD screen
- 3D movies

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Other information (1/2)

Prior knowledge

Depending on how the electric field is oriented, polarized light can be classified into three types of polarizations, they are linear polarization, circular polarization and elliptical polarization.

Scientific principle

Monochromatic light falls on a mica plate perpendicular to its optic axis. At the appropriate plate thickness (λ/4, or quarterwave plate) there is a 90° phase shift between the ordinary and the extraordinary ray when the light emerges from the crystal. The polarisation of the emergent light is investigated at different angles between the optic axis of the λ/4 plate and the direction of polarisation of the incident light.

Other information (2/2)

Learning objective

Understanding the concept of light polarisation and the function of $\lambda/4$-plate.

Tasks

1. To measure the intensity of plane-polarised light as a function of the position of the analyser.
2. To measure the light intensity behind the analyser as a function of the angle between the optic axis of the λ/4 plate and that of the analyser.
3. To perform experiment 2. with two λ/4 plates one behind the other.

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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.

Theory (1/6)

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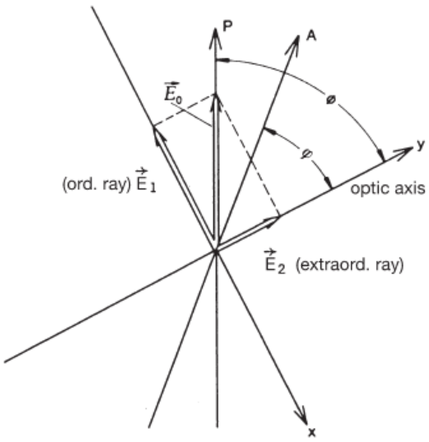

Splitting of polarised light in a double-refracting crystal

(P = polariser, A = analyser)

The velocity of the light travelling in the direction of the optic axis of a double-refracting crystal has the same value, c_o , whatever the direction of its plane of polarisation.

When travelling at right angles to the optic axis, polarised light has the same velocity c_o , when the electric vector is perpendicular to the optic axis (ordinary ray, see Fig.).

If the electric vector is parallel to the optic axis the light velocity $c \neq c_o$ (extraordinary ray).

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Theory (2/6)

E_0 is the amplitude of an electric field vector emerging from the polariser and ϕ the angle between the direction of polarisation P and the optic axis of a double-refracting crystal.

From previous Fig, we derive the following for the amplitudes of the ordinary and of the extraordinary ray:

$$E_1(t) = E_0(t) \cdot sin\,\phi \qquad (1)$$

$$E_2(t) = E_0(t) \cdot cos\,\phi$$

At time *t*, the state of vibration in the two rays at the crystal surface is described by:

$$E_1(t) = E_0(t) \cdot sin\,\phi \cdot sin\,\omega t \qquad (2)$$

$$E_2(t) = E_0(t) \cdot cos\,\phi \cdot sin\,\omega t$$

Theory (3/6)

In the case of double-refracting crystals (λ/4 plates), the thickness

$$d_{\lambda 4} = \frac{\lambda}{4} \cdot \frac{1}{n_0 - n_{ao}} \qquad (3)$$

where n_o is the refractive index of the ordinary ray and naonao that of the extraordinary ray in the crystal, causes a path difference of λ/4 (i.e. a phase difference of π/2) between the two rays when they combine to a resultant ray on emerging from the crystal. From (2) we obtain

$$E_x = E_1 = E_0(t) \cdot sin\,\phi \cdot sin\,\omega t \qquad (4)$$

$$E_y = E_2 = E_0(t) \cdot cos\,\phi \cdot sin\,\omega t$$

(4) is the parametric representation of an *E* vector rotating in the direction of propagation, i. e. perpendicular to the x and y axis, about a fixed axis.

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Theory (4/6)

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For angles of $\phi = 0^\circ$ and $\phi = 90^\circ$ we obtain plane polarised light of intensity

$$I = I_0 \sim E_0^2 \quad (5)$$

For an angle of 45°, $sin\,\phi = cos\,\phi = \frac{1}{\sqrt{2}}$, and the amount of the rotating E vector is

$$E = \sqrt{E_x^2 + E_y^2} = \frac{E_0}{\sqrt{2}} \quad (6)$$

The light is **circularly** polarised and of intensity

$$I = \frac{I_0}{2} \sim \frac{E_0^2}{2} \quad (7)$$

and is transmitted without loss of intensity in all analyser positions.

Theory (5/6)

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At all angles ϕ other than 0°, 45° and 90°, the transmitted light is elliptically polarised. The tip of the E vector rotating about the axis parallel to the direction of propagation describes an ellipse with the semi-axes.

$$E_a = E_0 \cdot sin\,\phi \text{ (x-direction)} \quad (8)$$

$$E_b = E_0 \cdot cos\,\phi \text{ (y-direction)}$$

For the intensity of the light transmitted by the analyser in the respective directions, we have:

$$I_a \sim E_a^2 = E_0^2\, sin^2\,\phi \quad (9)$$

$$I_b \sim E_b^2 = E_0^2\, cos^2\,\phi$$

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Theory (6/6)

By rotating the analyser we obtain the following for the ratio of the maximum to the minimum transmitted light intensity:

$$\frac{I_a}{I_b} = \frac{E_a^2}{E_b^2} = \frac{sin^2\,\phi}{cos^2\,\phi} = tan^2\varphi \qquad (10)$$

For any angular setting φ between the analyser and the optic axis of the λ/4 plate, we have:

$$I \sim E_0^2 \cdot cos^2\,\phi \cdot cos^2\,\varphi + E_0^2 \cdot sin^2\,\phi \cdot sin^2\,\varphi \qquad (11)$$

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Equipment

Position	Material	Item No.	Quantity
1	Digital array camera	35612-99	1
2	Lens holder, beam height 120 mm	08012-01	3
3	Lens, mounted, f +100 mm	08021-01	1
4	Universal Holder, rotational	08040-02	2
5	Iris diaphragm	08045-00	1
6	Double condenser, f = 6 cm	08137-00	1
7	High pressure Hg Lamp, 50 W	08144-00	1
8	PHYWE Power supply 230 V/ 50 Hz for 50 W-Hg-lamp	13661-97	1
9	Interference filter, yellow, 578 nm	08461-01	1
10	Polarisation filter	08610-02	2
11	Optical bench expert, l = 1000 mm	08282-00	1
12	Base for optical bench expert, adjustable	08284-00	2
13	Slide mount for optical bench expert, h = 30 mm	08286-01	9
14	Polarization specimen, mica	08664-00	2

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Setup and procedure

Setup (1/2)

Experimental setup

The experiment is set up as shown in the Figure.

The experiment lamp with the double condenser (focal length 60 mm) fitted, the lens holder with the iris diaphragm, the lens holder with the interference filter, the polarising filter, the holder with the λ/4 plate, the lens holder with the lens of focal length 100 mm, the analyser, and the digital array camera.

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Setup (2/2)

Material	Position (cm)
Hg Lamp	2
Iris diaphragm	36
Interference filter	40
Polarising filter	44
Polarization specimen, mica	48
*Polarization specimen, mica	52
Lens, f +100 mm	56
Polarising filter (analyser)	60
Camera	72

Positions on the optical bench

The second experiment uses an additonal λ/4 plate on a holder and placed directly behind the other plate. Make sure to connect the camera to the USB port of the PC, and the software should install automatically. For further information click the "Help" button in the bottom right.

The suggested optical bench positions are listed in Table.

* indicates the material is used only in the second experiment.

Procedure (1/2)

Darken the room as much as possible when performing the experiment. Ensure the Hg lamp is connected to the power supply before switching on, and wait several minutes for the lamp to warm up before carrying out the experiments. If necessary, the lamp may be adjusted vertically and horizontally by means of the adjusting knobs. Consult the operating instructions for the experimental lamp for proper handling and explanation of controls.

First, the path of the ray is adjusted so that the camera sensor is well illuminated (this is done without the λ/4 plate). Fine adjustment of the camera height may be needed in order to find the intensity distribution in the software. With the polariser on zero, the analyser is then rotated until the light which it transmitted is of minimum intensity. Measure the intensity over the range –90° to +90° in increments of 10°, and plot the intensity peak (maximum value) in a graph for each measured angle.

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Procedure (2/2)

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Next, the λ/4 plate is now clamped in the holder and rotated at various angles (here, at 0, 30, 45, 60, and 90°). For each λ/4 plate angle, measure the intensity over the range –90° to +90° in increments of 10° by rotating the analyser. Record the intensity peak for each of the measured angles, and plot the values in a graph.

For the second experiment, add the additional λ/4 plate and rotate both λ/4 plates at angles (e.g. 30, 45, and 60°). Again, for each of these angles, measure the intensity over the range –90° to +90° in increments of 10° by rotating the analyser. Record and plot the intensity peak value for each measured angle.

Results for all graphs should be comparable, although the intensity range may vary. The current intensity of the photo-cell is proportional to the intensity of the incident light.

Evaluation (1/4)

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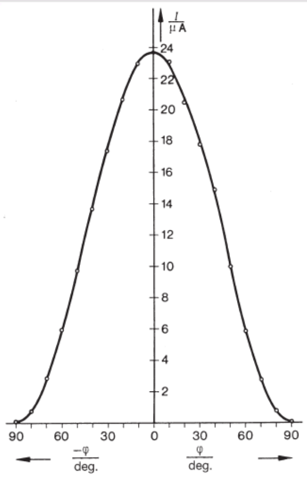

Without λ/4 plate

First of all the intensity distribution of plane-polarised light is measured as a function of the analyser position, without the λ/4 plate in the path of the rays .

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Evaluation (2/4)

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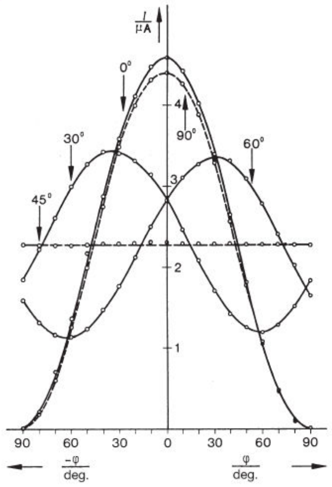

With λ/4 plate at various angular settings

The type of polarisation of the transmitted light is determined from the corresponding intensity distribution values, for various angles between the optic axis of the λ/4 plate and the direction of transmission of the analyser

Evaluation (3/4)

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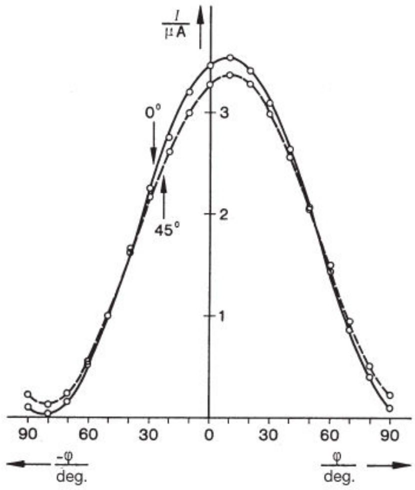

With λ/2 plate at various angular settings.

If two λ/4 plates are set one behind the other, plane-polarised light is produced whatever the direction of the optic axis of the λ/2 plate.

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Evaluation (4/4)

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Fill in the blank:

A quarter-wave plate converts ____ polarized light into ____ polarized light and vice versa. Meanwhile, a half-wave plate shifts the polarization direction of ____ polarized light.

linearly
linearly
circularly

Check

Slide	Score / Total
Slide 21: Wave plates	**0/3**

Total Score 0/3

Show solutions   Retry

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