Instruction Sheet

Cadmium Lamp with Holder for Zeeman-Effect	Cat. No. 451 12
Optical Device for Lummer-Gehrcke-Plate	Cat. No. 471 20
Lummer-Gehrcke-Plate	Cat. No. 471 21
Electromagnet for Zeeman Effect	Cat. No. 514 50

1. Zeeman Effect, Principles, Examples of Calculation

A magnetic field changes the spectrum lines of a light source. The splitting up of the spectrum lines in several sharply separated components is called "Zeeman Effect". i. e. the splitting up in three components (Lorentz triplet) "**normal** Zeeman effect" and the splitting up in more than three components "**anomalous** Zeeman effect".

Elements the luminous electrons of which have paired antiparallel spin angular momentums exhibit the normal Zeeman effect, e. g. cadmium. The resultant spin quantum S is then $S = 0$ and the total angular momentum only consists of the orbital angular momentum. An externally applied magnetic field induces the spinning electrons to carry out precessional motions having the frequency

$$\nu = \frac{1}{4\pi} \frac{e}{m} B$$

ν = Larmor frequency

The precessional motion in the magnetic field causes the splitting up of the spectrum lines, which can be rather clearly demonstrated in the case of cadmium.

For a long time the splitting up of the red cadmium lines was taken as a simple example of the normal Zeeman effect. It was assumed that only the transition $^1P_1 - {}^1D_2$ emits the red line, whereas today it is known that the red line also contains other transitions of nearly the same energy difference. The calculation of the specific electron mass derived from the displacement of the spectrum lines remains unchanged.

Fig. 2 shows in a simplified manner the term diagram and polarization diagram of the red cadmium line (λ = 643.8 nm).

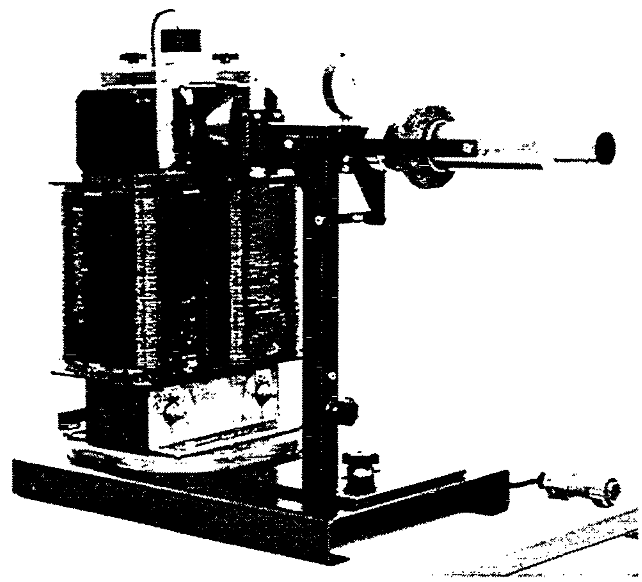
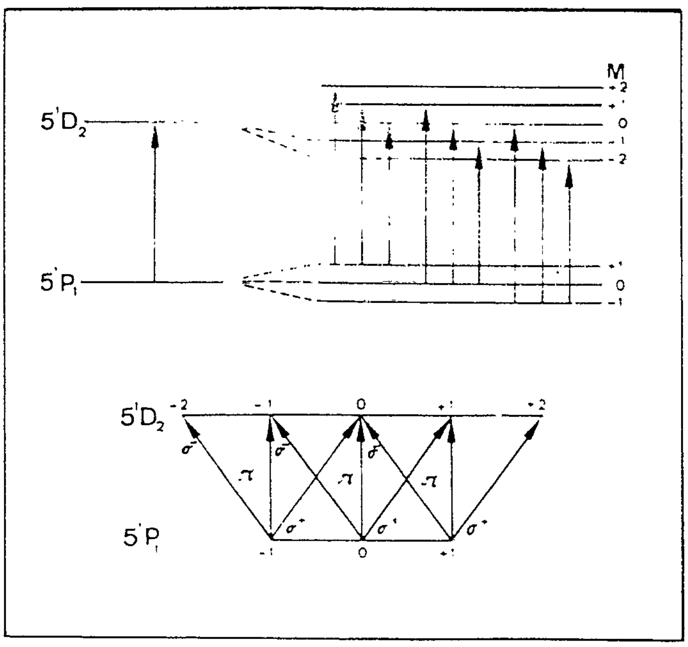


Fig. 1 Experimental assembly for observing the Zeeman effect

Fig. 2 Term diagram and polarization diagram



The red cadmium line is split up in the magnetic field in two outer σ-components and one inner π-component. This applies to transversal viewing, i. e. observation perpendicular to the direction of the magnetic field. All three visible lines of this Lorentz-triplet are linearly polarized, i. e. the central line, which corresponds to the spectrum line of the light source without external magnetic field, in direction of the magnetic field, and the two outer lines perpendicular to the direction of the magnetic field.

When viewing in longitudinal direction, i. e. in direction of the external magnetic field, a doublet is recognized. No central line is visible here. The two split-up lines are circularly polarized against each other.

To observe the splitting up of spectrum lines in the magnetic field, a spectroscope of high resolving power is required. In the described experimental assembly a Lummer-Gehrcke plate is used having a resolving power of

approx. $\frac{\lambda}{\Delta\lambda} = 500\,000$.

From the visible displacement of the spectrum lines results a measurable change of the wave length or frequency. The two σ-components or outer secondaries of the triplet or the two lines of the doublet are shifted, for example, to a frequency $\nu + \Delta\nu$ or $\nu - \Delta\nu$. For the displacement $\Delta\nu$ it applies, however:

$$\Delta\nu \pm \frac{1}{4\pi} \times \frac{e}{m} \times B.$$

from which e/m can be calculated:

$$\frac{e}{m} = \frac{4\pi}{B} \times \Delta\nu \qquad (1)$$

B = flux density in tesla $(\frac{Vs}{m^2})$
$\Delta\nu$ = frequency shift

$\Delta\nu$ must be derived from the resolution of the Lummer-Gehrcke-plate and from the wave-length displacement determined at a certain B.

According to Kohlrausch (Praktische Physik, volume III, page 385) for the differences of wavelength observable at a Lummer-Gehrcke-plate it applies

$$\Delta\lambda = \frac{\delta a}{\Delta a} \times \frac{\lambda^2 \sqrt{n^2 - 1}}{2\,d\,(n^2 - 1 - n \times \lambda \frac{\delta n}{\delta\lambda}} \qquad (2)$$

In the calculation the term $\frac{n^{\lambda}\,\delta\,n}{\delta\,\lambda}$ can be neglected.

It follows $\Delta\lambda = \frac{\delta a}{\Delta a} \times \frac{\lambda^2 \sqrt{n^2 - 1}}{2\,d\,(n^2 - 1)}$

δa = distance of one of the split-off lines from the original position of the interference lines (without magnetic field)

Δa = distance between two interference lines (without magnetic field)

Using a suitable method, the proportion $\frac{\delta a}{\Delta a}$ can be adjusted so that a simple fraction, e. g. 1/4, is obtained.

λ = wavelength of the red cadmium line = 643.8 nm

n = refractive index for the quartz glass of the Lummer-Gehrcke-plate = 1.4567

d = Thickness of the Lummer-Gehrcke-plate = 4.04 mm

c = velocity of light

To determine the specific charge of the luminous electron, the frequency shift must be calculated from the wavelength displacement. Calculation is made via the relationship between wavelength, frequency and velocity of light.

$$c = \lambda\,\nu$$

When forming the total differential

$$\frac{\delta\,c^2}{\delta\lambda \times \delta\nu} = \lambda d\nu + \nu d\lambda$$

it follows for c const.

$$0 = \lambda d\nu + \nu d\lambda.$$

The transition $d \rightarrow \Delta$ and entering $\nu = \frac{c}{\lambda}$ results in

$$\Delta\nu = -\frac{c\Delta\lambda}{\lambda^2}$$

$$\Delta\nu = -\frac{c}{\lambda^2} \text{ corresponds to } \Delta\nu = \frac{c}{\lambda^2}\Delta\lambda \quad (3)$$

The frequency shift may be negative or positive.

Using the equipment for observing the Zeemann effect, the following values were measured with longitudinal viewing:

d = 4.04 mm

$\frac{\delta a}{\Delta a} = \frac{1}{4}$ at a field strength of 0.7 tesla.

When observing the doublet the field strength of the magnet was increased until from the system of interference lines (prior to switching on the magnetic field) a new system was formed having double the number of uniformly distributed lines. Δa is the spacing of the interference lines prior to switching on the magnetic field, and δa is the deviation of one of the two lines of the doublet from the initial position.

It can be read from Fig. 3 that $\frac{\delta a}{\Delta a} = \frac{1}{2}$ when the lines of the doublet are adjusted so that their spacing from each other is uniform.

Entering $\lambda = 6.438 \times 10^{-5}$ cm, d = 0.404 cm and n = 1.4567 in formula (2) gives

$$\Delta\lambda = \frac{1}{4}\sqrt{\frac{1.4567^2 - 1}{2 \times 0.404\,(1.4567^2 - 1)}} \times \lambda^2$$

$$\Delta\lambda = 0.31\,\lambda^2$$

$$\Delta\lambda = 12.8 \times 10^{-8} \text{ cm}$$

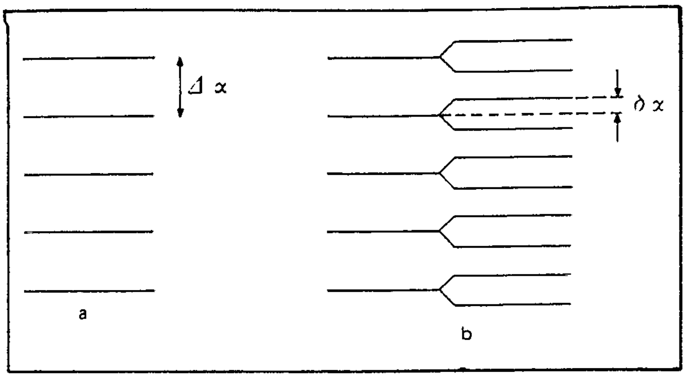


Fig. 3 Splitting up while observing the doublet, $\delta\alpha = \frac{1}{4}\Delta\alpha$
a) before switching on the magnetic field
b) after switching on the magnetic field

When entering the term $\Delta\lambda = 0.31\ \lambda^2$ in equation (3) it follows

$$\Delta\nu = c \times 0.31 \frac{\text{cm}}{\text{cm}^2}$$

and with the velocity of light

$c = 3 \times 10^{10} \frac{\text{cm}}{\text{s}}$ there results

$$\Delta\nu = 0.31 \times 3 \times 10^{10} \frac{1}{s'} \cdot \frac{\text{cm cm}}{\text{s cm}^2} = \frac{1}{\text{s}} = \text{Hz}$$

$\Delta\nu = 9.3 \times 10^9$ Hz.

With $B = 0.7$ Tesla it follows according to equation (1):

$$\frac{e}{m} = \frac{4\pi}{0.7} \times 9.3 \times 10^9$$

$$\frac{e}{m} = 1.67 \times 10^{11} \frac{m^2}{V\,s^2} =$$

$$1.67 \times 10^{11} \frac{A\,s}{\text{kg}}.$$

In the literature the value for $\frac{e}{m}$ is indicated from observation of the Zeeman effect with

$$\frac{e}{m} = 1.76 \times 10^{11} \frac{As}{\text{kg}}$$

2. Description of the Apparatus

2.1. A spectrum lamp without outer protective bulb is to be used. The diameter of the quartz burner of the spectrum lamp without protective bulb is approx. 8 mm so that the distance of the pole pieces may be approx. 10 mm. The current-carrying lines of the burner are insulated with glass fibre tubing. The supply leads at the burner ends and the resistors of the ignition electrodes are freely exposed and must not be touched during operation. Furthermore, it should be avoided to touch the quartz bulb by hand. The spectrum lamp has a nine-pin base matching the socket. When inserting the lamp into the socket, only touch the metal base of the spectrum lamp and exert a pressure on the rim of the metal base by means of a screw driver.

The metal base has a catch fitting into the slit of the socket. Also when extracting the lamp from the socket place screw driver into the slit below the base to push the lamp out of the socket.

The socket of the spectrum lamp is rotatable and adjustable in height. In this way the spectrum lamp can be shifted until the burner is positioned in the middle between the pole pieces.

The socket is slipped into a bridge which is pressed against the pole pieces of the magnet by two tommy screws.

Caution! Make sure before switching on the magnet current that the two tommy screws are tightened. When the magnetic field builds up loosely fitted pole pieces may attract each other and destroy the spectrum lamp.

Two ball clamps and one guide pin are used to fix the socket of the spectrum lamp. The guide pin fits into a cutout of the bridge.

The lamp socket is equipped with a supply lead with special plug fitting into the coupler socket of the new-type universal choke (451 30). If the spectrum lamp is to be connected to the older-type universal choke (451 22), the special plug must be replaced by plugs of connecting leads. The green-yellow conductor is for safety earthing for which there is no connection on the older-type universal choke. A connection can be provided on the older-type universal choke using special coupling or adapter (451 20) and connecting cables and plugs.

Insert the spectrum lamp with bridge into the pole pieces in such a way that the opening of the bridge shows in direction of the electrical connections of the magnet. At the same time the lamp itself must be turned so that the seal-off tip of the quartz burner shows in the same direction.

2.2. Optical Viewing Device for the Zeeman Effect (Fig. 4)

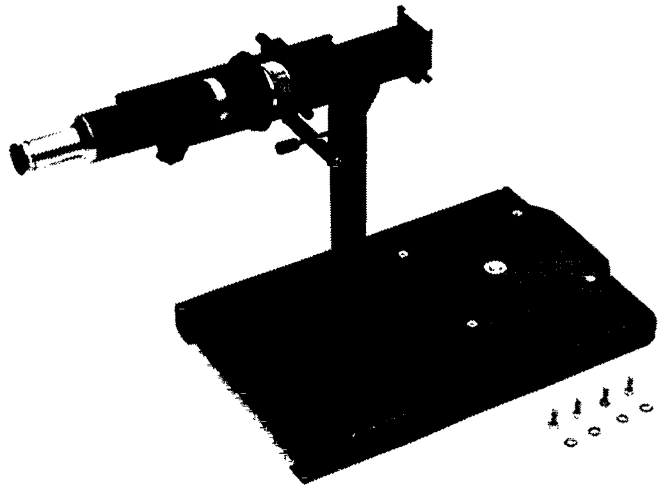


Fig. 4

Base plate for the electromagnet, column and holder for the Lummer-Gehrcke-plate and the telescope form one unit. The column base of the optical device is fixed to the base plate by one single tommy screw. The movable counterpart of this tommy screw is fitted in a slit below the base plate. Also the opening in the column base has the shape of a slit so that with loosened tommy screw the column base can be moved in all directions.

The column is adjustable in height for correct positioning of the inlet window of the Lummer-Gehrcke-plate.

The column carries the holder for the Lummer-Gehrcke-plate and the holding bracket for the observation telescope. The holder (a milled part) has an inside lining of velour foil for the Lummer-Gehrcke-plate and is closed on top by a cover. The cover, fixed to the holder by three small screws, is equipped at the light inlet with inlet diaphragm and a frame to insert a coloured filter and at its rear end with a cylindrical attachment onto which a rotatable holder with polarization foil can be fitted.

The two swivel arms for the telescope are inserted into pegs of the holding brackets. The telescope itself is held at the end of the two swivel arms. It can be turned on two pegs and locked by a tommy screw. The tommy screw in the bridge of the holding bracket supports the swivel arms against the column and is used to adjust inclination and height of the telescope.

A holder with polarization foil or retardation foil can be fitted on the light-admission side of the telescope.

There is furthermore a funnel-shaped light shield which can be attached either to the round filter holder of the polarization foil or to the filter holder of the retardation foil.

The observation telescope has a movable eyepiece for focusing the lines under observation.

2.3. Lummer-Gehrcke-Plate

The Lummer-Gehrcke-plate made of quartz fits into the velour-lined milled holder. The high-grade plane-parallel surface-ground plate has the dimensions 120 mm x 15 mm x 12 mm. A light-inlet prism is glued to one end of the plate.

The Lummer-Gehrcke-plate should be handled with great care. It should always be positioned so that it is uniformly supported over its whole length.

To observe the Zeeman effect, the front end of the plate and part of the light-inlet surface of the prism is covered.

When transporting the optical device, the Lummer-Gehrcke-plate should be removed from the holder and stored in a safe plate.

2.4. Electromagnet for the Zeeman Effect (Fig. 5)

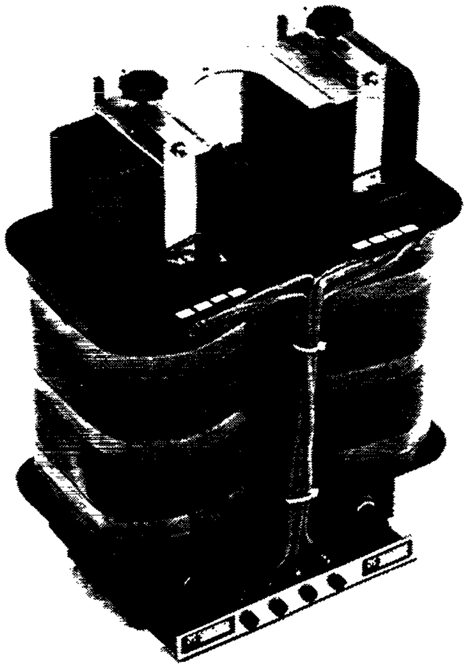


Fig. 5

The electromagnet for the Zeeman effect, consisting of U-core and coils, is mounted on a solid PVC plate. Pole pieces of special alloy are fitted to the ground ends of the U-core and secured by clamp straps and tommy screws.

Each of the two coils of the magnet has two windings the supply leads of which are connected to a socket terminal board.

These windings can be switched in series by connecting the supply leads to sockets 1 and 4, and socket 2 to socket 3.
The windings are switched in parallel by connecting the supply leads to sockets 1 and 2 or 3 and 4, socket 1 to socket 3 and socket 2 to socket 4.

For voltage, current and field strength between the pole pieces (spacing 10 mm) the following guide values can be assumed:

For connection in series

$\frac{U}{V}$	$\frac{I}{A}$	$\frac{B}{Tesla}$
17.5	15	0.87
12.0	10	0.70
6.0	5	0.4

For connection in parallel

$\frac{U}{V}$	$\frac{I}{A}$	$\frac{B}{Tesla}$
7	20	0.8
5	15	0.6
3.5	10	0.4
1.7	5	0.2

In the center of the PVC base plate a screw socket is inserted by means of which the electromagnet can be screwed to the base plate of the optical device. The fastening screw is introduced through the base plate from below and tightened.

Weights and dimensions:

1. Spectrum lamp with holder for Zeeman Effect:
   0.6 kg, 150 mm x 80 mm x 160 mm
2. Optical device for Zeeman Effect:
   2.7 kg, 160 mm x 410 mm x 360 mm
3. Base plate:
   3.7 kg, 270 mm x 410 mm x 35 mm
4. Lummer-Gehrcke plate:
   0.1 kg, 120 mm x 15 mm x 12 mm
5. Electromagnet for Zeeman Effect:
   42 kg, 260 mm x 220 mm x 420 mm.

3. Operating Instructions

3.1. Mounting the experimental assembly

Screw the electromagnet onto the base plate of the optical device (see Figs. 1 and 5). The magnet should be rotatable on the base plate by applying some force.

Screw the optical device onto the base plate. With the tommy screw not tightened the column of the optical device should be movable on the base plate.

Insert pole pieces and holder of the spectrum lamp. The pole pieces should be placed with their flat ends outwards so that they are approximately flush with the outer sides of the U-core in the coils, the blunted cones of the pole pieces showing inward. Spacing of the small inside surface of the pole pieces approx. 10 mm. The pole pieces should be aligned so as to give a straight view through the boreholes of the two pole pieces. The opening of the holder of the spectrum lamp when the spectrum lamp is inserted should show towards the side of the supply leads of the electromagnet.

Firmly tighten the tommy screws on lamp holder and pole pieces.

Introduce spectrum lamp, turning the lamp in its rotatable clamp fixture so that the sealed-off tip of the lamp bulb shows towards the side of the electrical connections of the magnet. Adjust seal-off tip and the two insulated connecting wires so that they are in angular position to the field direction. The insulated connecting wires may nearly touch the pole pieces. Adjust the spectrum lamp in height so that the lamp bulb is centered in the magnetic field. In transverse viewing direction (perpendicular to the magnetic field) the observation is only little disturbed by the visible connecting wire, and in longitudinal viewing direction (in direction of the magnetic field) the other connecting wire should not disturb the view at all.

Turn the magnet on the base plate so that the electrical connections are on the side opposite to the optical viewing device. The magnet is then so positioned that the longer axis of its base crosses the longer axis of the base plate.

Connect the spectrum lamp to the choke and start operation. If choke with five-pin plug is available, correct tapping is assured. If the lamp plug has to be connected via an adapter and banana plug to a choke with selectable connection, connection should be made in position Hg-Cd.

Cover both ends of the Lummer-Gehrcke-plate with adhesive tape, particularly on the side for light inlet, place the plate into the holder of the optical viewing device. Grip the Lummer-Gehrcke-plate only by its long sides. In no case should it be bent or exposed to any other form of mechanical strain. The Lummer-Gehrcke-plate should be placed with its prism towards the light inlet slit and the flat end side towards the observation telescope. The distance of the Lummer-Gehrcke-plate from the holder ends should be equal on both sides. The plate can be shifted a little to either side to bring the lines in focus.

Place holder with cover and inlet slit so that the cylindrical attachment shows toward the observation telescope. For fixation and height adjustment see "Directions to improve optical viewing".

Caution! Do not tilt the optical device after having inserted the Lummer-Gehrcke-plate which lies loosely on the holder. Therefore, the Lummer-Gehrcke-plate should not be inserted before the optical device has been connected to the base plate.

Place the diaphragm onto the cylindrical attachment of the cover. Align telescope. The telescope should allow glancing observation of the Lummer-Gehrcke-plate. Direct the optical viewing device towards the light source and carefully shift it in height until green-blue and red streaks become clearly visible in the telescope. At the same time the streaks of the intense green-blue mercury line, the blue mercury line and the red mercury line become visible.

Insert red filter and adjust position of Lummer-Gehrcke-plate and observation telescope until the system of red interference lines becomes clearly visible. Adjust eyepiece sharply. Precise focusing is only possible each time for a limited area of the band spectrum. When directing the telescope towards the rear end of the Lummer-Gehrcke-plate, the streaks appear symmetrically distributed upward and downward, over the surface of the plate. Observation can also be made from below as shown in Fig. 6.

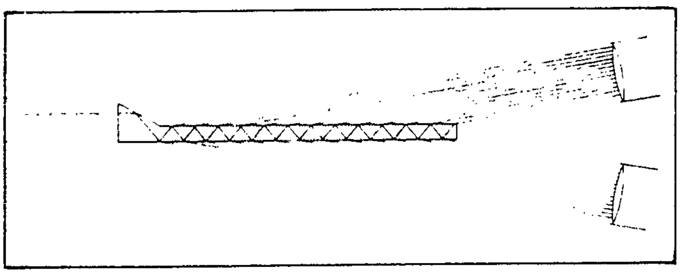


Fig. 6 Interference fringes issued in grazing beams from a Lummer-Gehrcke-plate

3.2. Observation of the fringe pattern of the red cadmium line

Insert polarization filter (the polarization-filter foil is slightly darker than the retardation foil). Turn the polarization filter (covered by diaphragm). The observed fringes do not change, they are not polarized.

Connect the magnet to a d.c. supply and slowly increase the current. Depending on the voltage source it may be preferable to switch the windings of the magnet either in series or in parallel. When viewed through the telescope, the splitting-up of the red interference lines starting at about 4 A becomes clearly visible. Make observation first without polarization filter only with the diaphragm. The splitting-up of the lines increases with increasing current. At approx. 9 A to 10 A the splitting-up of each interference line in three components is so far advanced (with transverse direction of view) that now again a pattern is resulting where the interference lines are uniformly distributed over the field of view (Fig. 7).

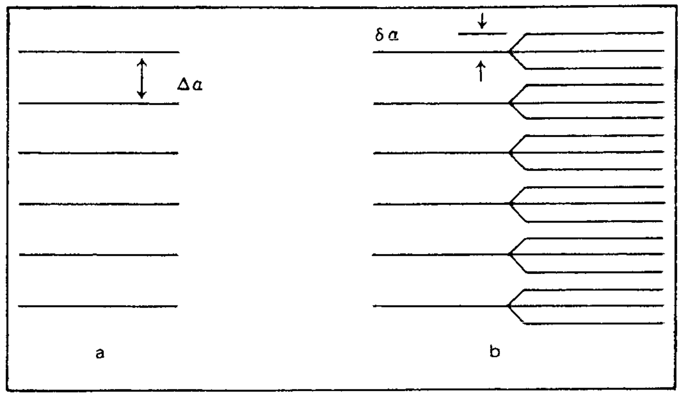


Fig. 7 Splitting-up while observing the triplet, $\delta\alpha = \frac{1}{3}\Delta\alpha$
a) before switching on the magnetic field
b) after switching on the magnetic field

As the human eye is well capable of recognizing small irregularities in a line pattern it is possible to adjust very accurately the current or field strength respectively to a value at which a new line pattern with uniform spacing is formed.

3.3. Polarization of the lines of the triplet

Insert polarization filter and observe the line splitting (triplet viewed in transverse direction) when turning the polarization filter. In one position the central line disappears while in the other position the two side lines are eliminated. Central line and secondary lines are well distinguished by reducing the magnetic field (3 to 5 A) so that the split-up interference lines are no longer uniformly distributed over the field of view. The central line and the two secondary lines are polarized perpendicular to each other.

The direction of polarization of the filter foil is checked by observing the light reflected at a glass plate. When light is incident on a glass plate at the Brewster angle (57°), the reflected light is polarized perpendicular to the plane of incidence. If the angle is not exactly maintained, e.g. due to stray light, the intensity change is still sufficient to determine the direction of polarization by turning the filter foil.

Observation of the fringe pattern using a polarization filter shows that the central line appears polarized in direction of the magnetic field while the secondary lines appear polarized perpendicular to the magnetic field. Observation in transverse direction shows the lines of the Lorentz triplet where the central line is called the π-line and the two other ones the σ-lines.

3.4. Observation of the doublet and determination of its direction of polarization

To observe the doublet, the magnet must be turned on the base plate after having moved back the optical device to the extreme outer position. Align the magnet so as to allow proper adjustment of the optical device in direction of the borehole in the pole piece of the magnet.

Switch on the Hg-Cd lamp and adjust the optical device vertically, horizontally and in viewing direction. The line pattern should appear as bright as possible. Due to their geometry and spacing, the interference fringes are weaker in longitudinal direction of view than in transverse direction of view.

Switch on the magnetic field and observe splitting-up of each line into a doublet without using a filter. Insert polarization filter and observe the splitting-up. When turning the polarization filter, the intensity of the two lines should not change. There is, however, a rather distinct change of intensity as the polarization filter foil used has polarizing as well as retarding properties (properties of a $\frac{\lambda}{4}$-plate.

Place holder with retardation foil on the telescope and repeat observation of the lines of the doublet. A polarization filter adjustment can be found at which the one or the other line can be eliminated by turning the retardation foil left or right. When the deflecting direction of the retardation foil is shifted by 45° to the left against the direction of polarization of the polarization-filter foil, one of the two circularly polarized σ-lines of the doublet is passed. When the retardation foil is turned by 45° to the right the oppositely directed polarized σ-line is passed (σ^+-line and σ^--line) (Fig. 8).

Bibliography: Physics Experiments, Volume 3 (599 942)
New Physics Leaflets for Colleges and Universities, Volume 1 (599 952)

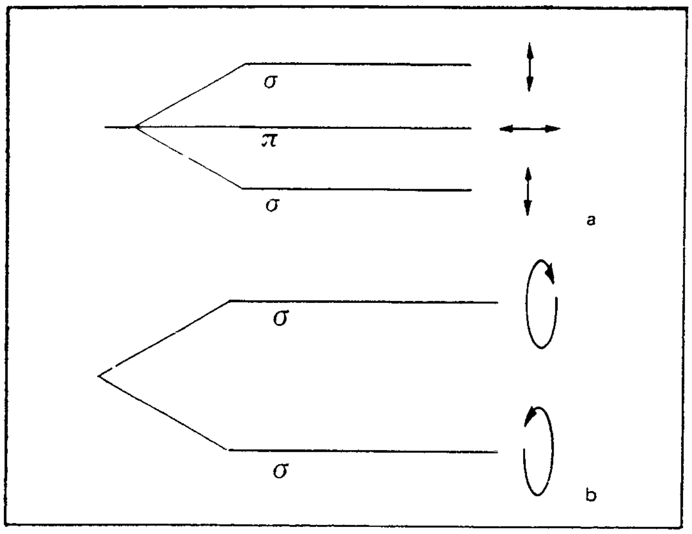


Fig. 8 Polarization of the triplet a and the doublet b

Directions to improve optical viewing

By vertical shifting of the cover the inlet opening as well as the outlet opening are displaced upward or downward. This allows to influence the brightness of the lines and the stray light. After adjustment of the cover the clamping screws must be tightened again. Disturbing stray light can be reduced by glueing foils onto the inlet prism. Then one specific line of the light inlet surface of the prism remains free. The most favourable light inlet opening is not the same for every Lummer-Gehrcke-plate and must, therefore, be determined by experiment.

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Gebrauchsanweisung 451 30*
Instruction Sheet

Universaldrossel in Gehäuse
Universal Choke in Housing

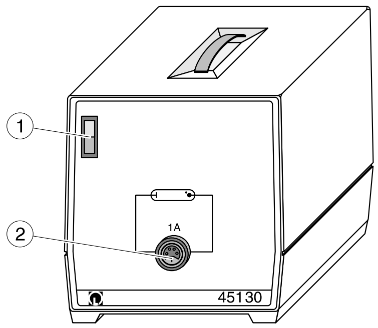

Fig. 1

Die zum Anschluß an 230 V /50 Hz bestimmte Universaldrossel dient zur Stromversorgung (1 A)

- der Quecksilber-Hochdrucklampe (451 15) in Fassung E 27 (451 19, ab Baureihe 3) oder in der Kompaktanordnung zur *h*-Bestimmung (558 79, ab Baureihe 2),
- der Cadmium-Lampe für den Zeemann-Effekt (451 12)
- sowie der Spektrallampen (451 011 - 451 111) in Gehäuse (451 16, ab Baureihe 2).

1 Sicherheitshinweise

- Gerät erst einschalten wenn die Verbindung zwischen der Vielfachbuchse ② und dem Spezialstecker der mit der Lampe bestückten Fassung ordnungsgemäß hergestellt ist (Verbindung mit der Überwurfmutter des Spezialsteckers sichern.)
- Geräte früherer Baureihen (als die oben angegebenen) müssen zur Anpassung an die Universaldrossel (451 30, Baureihe 4) bei Leybold-Didactic umgerüstet werden.

2 Beschreibung, technische Daten

① Netzschalter mit integrierter Betriebsanzeigeleuchte

② Vielfachsteckbuchse
Ausgangsstrom: 1 A

Auf der Geräterückseite

Wannenstecker für Netzanschlußkabel (im Lieferumfang enthalten)
Sicherungshalter, im Wannenstecker integriert, mit Betriebssicherung und Ersatzsicherung T 1,25 B

Netzanschlußspannung: 230 V/50 Hz
Abmessungen: 20 cm x 21 cm x 23 cm
Masse: 5 kg

*) Baureihe 4

The universal choke is designed for use with 230 V/50 Hz voltage for supplying (1 A) the apparatus:

- High-pressure mercury lamp (451 15) in lamp socket E 27 (451 19, series 3 on) or in the compact arrangement for determining Planck’s constant (558 79, series 2 on)
- Cadmium lamp for Zeemann effect (451 12), and
- Spectral lamps (451 011 - 451 111) in housing (451 16, series 2 on).

1 Safety notes

- Do not switch on the apparatus until the special plug of the socket in which the lamp is mounted has been correctly connected to the DIN socket ② (secure the connection using the union nut of the special plug).
- Apparatus from older series (than those specified above) must be returned to Leybold Didactic for conversion to match the universal choke (451 30, series 4).

2 Description, technical data

① Mains switch with integrated indicator lamp

② DIN socket
Output current: 1 A

On rear of housing:

Appliance plug connector for mains power lead (included in scope of supply)
Fuse holder, integrated in appliance plug, with operating and spare fuse T 1.25 B

Mains connection voltage: 230 V/50 Hz
Dimensions: 20 cm x 21 cm x 23 cm
Weight: 5 kg

*) Series 4

3 Sicherungsaustausch (s. Fig. 2.1/2)

- Einsatz ⓐ (mit Fassung für Primärschmelzsicherung ⓑ und Reservesicherung ⓒ) heraushebeln
- Defekte Sicherung ⓑ durch neue, auf richtigen Sicherungswert überprüfte Sicherung ⓒ ersetzen
- Reservesicherung ⓒ einsetzen und Einsatz ⓐ wieder einschieben (Bestell-Nr. für 10 Sicherungen T 1,25 B: 698 16)

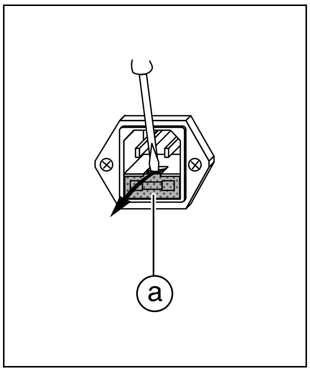

Fig. 2.1

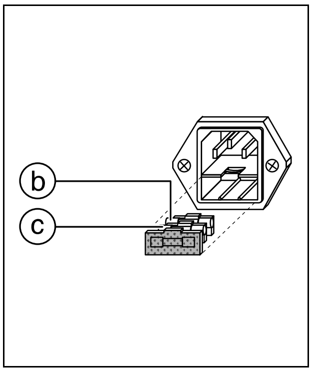

Fig. 2.2

3 Replacing the fuse (see Fig. 2.1/2)

- Pry out insert ⓐ (with holder for primary fuse ⓑ and reserve fuse ⓒ).
- Replace defective fuse ⓑ with a new one which has been checked for the correct rating ⓒ.
- Insert reserve fuse ⓒ and replace the insert ⓐ (Cat. No. for 10 fuses T 1,25 B: 698 16).

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Instruction sheet 460 32

Precision Optical Bench, Standardized Cross-Section, 1 m (460 32)
Precision Optical Bench, Standardized Cross-Section, 2 m (460 33)
Auxiliary Bench with Swivel Joint and Protractor (460 34)

These devices are designed for optical arrangements which require precise and stable axis adjustment of the ray path and an exact determination of distance.

Connecting the optical benches (460 32/33) with the auxiliary bench (460 34) creates an arrangement suitable for experiments with angled ray paths.

1 Description, scope of supply, technical data

1.1 Precision optical benches, standardized cross-section (460 32/33)

① Triangular aluminum rail, black anodized
Length: 1 m (Cat. No. 460 32)
2 m (Cat. No. 460 33)
② Millimeter scale
③ Double-sided groove for clamping of optic riders (460 351 ff.)
④ Groove for mounting support ⑤ and adjusting screw ⑧ in any position.
⑤ Bench support
⑥ Leveling feet (constitute three-point stand base for optical bench in conjunction with ⑧), height adjustment with screws (6.1), height fixed using lock washers (6.2)
⑦ Screw (7.1) and lock nut (7.2) for mounting the bench support ⑤ in groove ④
⑧, ⑨ Screw with leveling foot of three-point stand base, height adjustment of bench using knurled wheel (8.1); with screw with transverse hole (9.1) and lock nut (9.2) for attaching the leveling foot ⑧ in groove ④
⑩ Holes for screws with transverse hole ⑭ for connecting the optical benches (460 32/34) to the auxiliary bench (460 34); see section 2.1.2

Weight: approx. 2.5 kg (Cat. No. 460 32)
approx. 7.2 kg (Cat. No. 460 33)

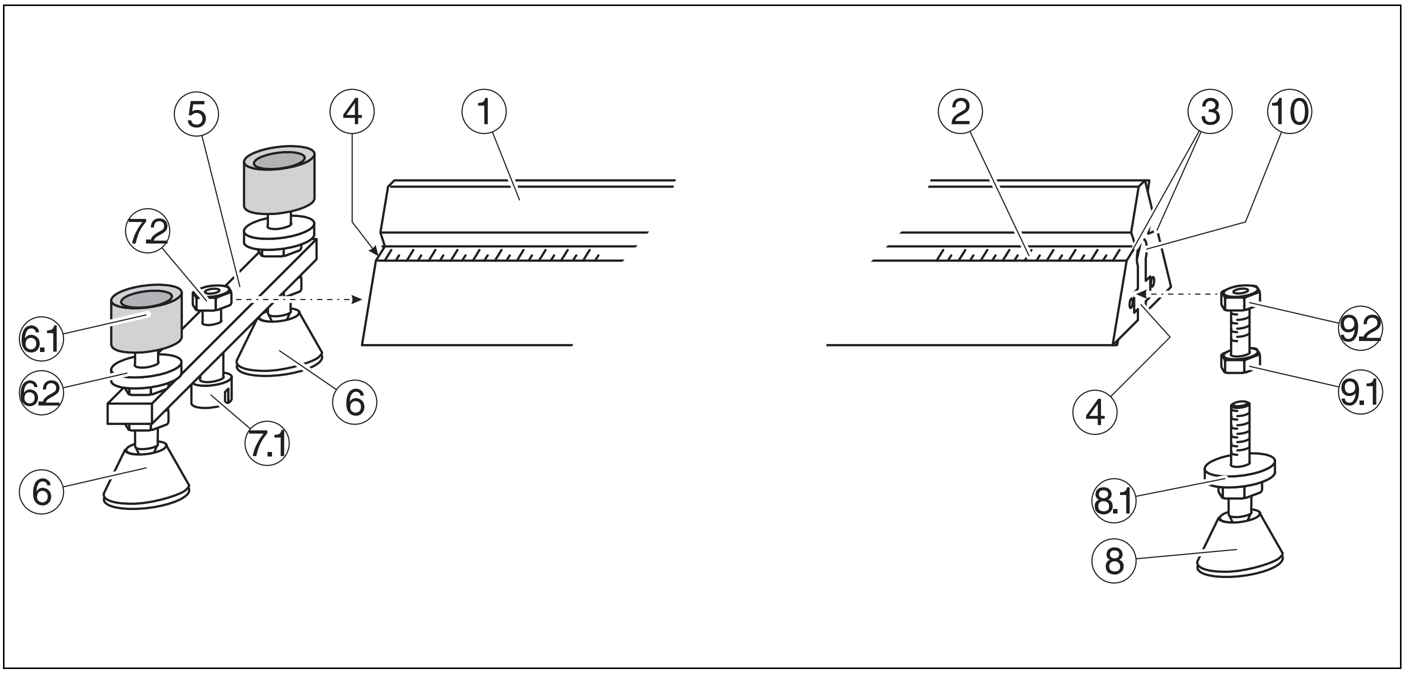

Fig. 1.1 Precision optical bench, standardized cross-section, 1 m and 2 m (460 32/33)

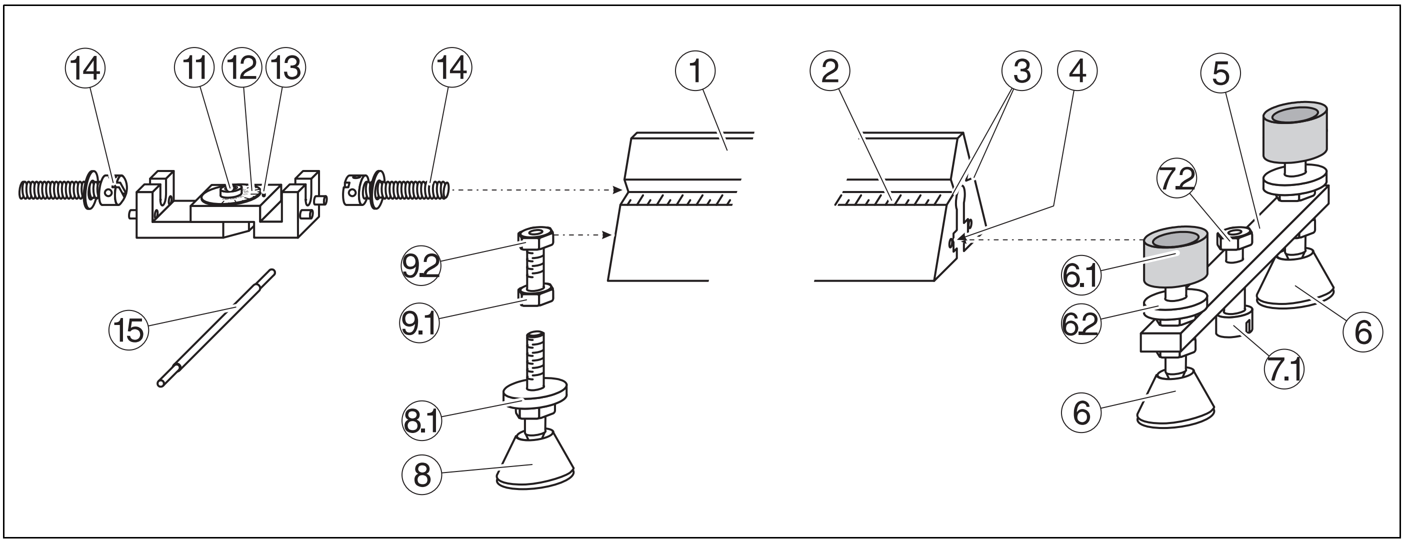

Fig. 1.2 Auxiliary bench with swivel joint and protractor (460 34)

1.2 Auxiliary bench with swivel joint and protractor (460 34)

① - ⑩ Auxiliary rail like optical benches with standardized cross-section (460 32/33), see section 1.1; Length: 0.5 m
⑪ Swivel joint for connection of optical benches (460 32/33) to the auxiliary bench (460 34)
⑫ Protractor, ± 90°, with 5° divisions
⑬ Marking pin for indication of angle
⑭ Screws with transverse hole with washers, for mounting swivel joint ⑪ in holes ⑩ (Fig. 2)
⑮ Tool for ⑭

Weight: approx. 1.8 kg

2 Operation

2.1 Assembly

2.1.1 Assembling the three-point stand base (required only before first use)

Insert screw (7.1) through the mounting hole of support ⑤; fix the lock nut (7.2) in position in groove ④ and support ⑤ by tightening screw (7.1) at a distance of about 5 cm from the beginning and end of the optical benches.

Screw lock nut (9.2) onto screw with transverse hole (9.1) and insert it in groove ④. Tighten the screws with transverse hole about 5 cm from the beginning and end of the optical bench and screw the leveling foot into the threaded hole of (9.1).

2.1.2 Swivel joint between optical benches (460 32/33) and auxiliary bench with swivel joint and protractor (460 34); see Fig. 2

Screw the screws with transverse hole ⑭ into holes ⑩ (no more than two full turns), place them in swivel ⑪ as shown in Fig. 2 and tighten them using the tool ⑮.

2.2 Recommended clamp riders and setup aids:

For setting up components in the optical axis:
Optics riders (460 351/2/3/7)

For tilting components out of the optical axis:
Tilting rider (460 354)

For moving components perpendicular to the optical axis:
Sliding rider (460 355)

For positioning components over the swivel point of two linked optical benches:
Cantilever arm 100 mm (460 356)

For attaching apparatus with threaded rods (e.g. flint-glass square with holder, 560 481)
Rider base with threaded holes, 1 x M8 and 4 x M5 (460 358)

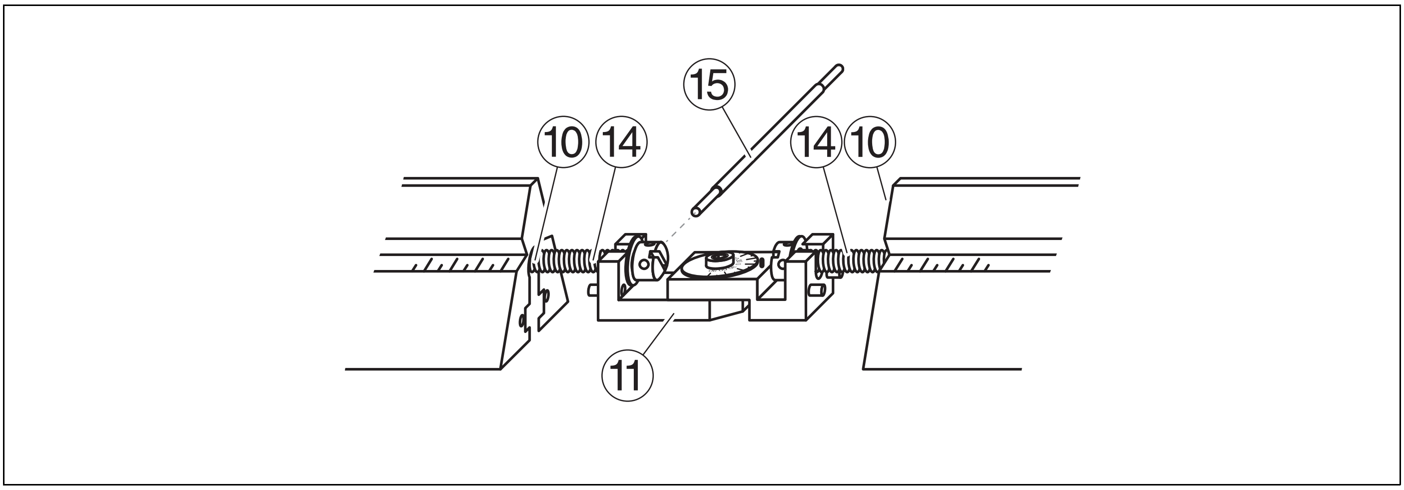

Fig. 2

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Gebrauchsanweisung
Instruction Sheet

472 40

Paar Polarisationsfilter
Pair of Polarization Filters

Polarisationsfilter dienen zur Herstellung von linear polarisiertem Licht sowie zur quantitativen Untersuchung von Polarisationsvorgängen.

1 Sicherheitshinweis

Falls das Filter unmittelbar vor der Lichtquelle angeordnet ist, Wärmeschutzfilter verwenden, um eine unzulässige Erwärmung der Folie auszuschließen.

2 Beschreibung, technische Daten

Die Filter bestehen aus dichroitischen Kunststoff-Folien (Ø 40 mm), die zwischen Glasplatten eingebettet sind. Der Dichroismus wird durch die ausgerichteten, angefärbten Fadenmoleküle der Folien bewirkt. Die Lichtwellen, deren elektrischer Vektor parallel zu den Fadenmolekülen schwingt, werden praktisch vollständig vom Farbstoff absorbiert. Die dazu senkrechte Schwingung wird nur geringfügig geschwächt. Der Polarisationsgrad beträgt über 99% und ist im sichtbaren Bereich nahezu unabhängig von der Wellenlänge.

Die Polarisationsfilter sind in Fassungen (Ø 13 cm) drehbar eingesetzt. Der drehbare Teil der Fassung ist mit einem Zeiger und einer Skala (0° ... ±90° mit 5° - Teilung) versehen. Die Filter sind so eingesetzt, daß der elektrische Vektor des durchgehenden Lichtes in Richtung des Zeigers schwingt.

3 Handhabung

Da die Fassungen der Filter dieselbe Größe haben wie die Linsenfassungen, können die Filter leicht bei optischen Aufbauten auf der Kleinen Optischen Bank (460 42) verwendet werden. Meist dient das erste Filter als Polarisator, das zweite als Analysator. Man kann sie aber auch mit Analysatoren (z.B. Spiegelanalysator 472 79) verwenden.

Man verwende die Filter möglichst im parallelen Strahlengang, da die Polarisationswirkung für stark von der optischen Achse abweichende Strahlen grundsätzlich schlechter ist.

Außerdem ist zu beachten, daß die Filter nicht zu sehr erwärmt werden dürfen. Besonders ein unmittelbar vor der Lampe stehendes Filter ist bei längerer Versuchsdauer gefährdet.

Geeignete Wärmeschutzfilter:
Bildschieber mit eingebautem Wärmeschutzfilter (450 66) zur Halogenleuchte 12 V/50 W/-100 W (450 64) oder Spiegelglaskasten (z.B. 477 20) mit schwacher Kupfersulfatlösung.

Polarization filters are used to produce linearly polarized light and to qualitatively investigate polarization phenomena.

1 Safety note

If the polarization filter is placed directly in front of the light source, use a heat protection filter to prevent damage to the plastic foil from overheating.

2 Description, technical data

The filters consist of dichroic plastic foils (40 mm dia.) embedded between glass plates. The dichroism is realized by the aligned, dyed filamentary molecules of the foils. The light waves with an electric vector parallel to the filamentary molecules are almost completely absorbed by the dye. An electric vector perpendicular to the filaments is only slightly attenuated. The degree of polarization is more than 99%, and within the visible range it is virtually independent of the wavelength.

The polarization filters are fitted in holders (13 cm dia.) so that they can rotate. The rotating part of the holder is equipped with a scale (0° ... ±90° with 5° scale divisions). The filters are fitted in such a manner that the electric vector of the transmitted light oscillates in the direction of the indicator.

3 Use

The holders of the filters are of the same size as the lens holders, and therefore the filters can easily be used on the small optical bench (460 42). Generally the first filter is used as the polarizer and the second filter as the analyzer. They can also be used in combination with analyzers (e.g. mirror analyzer 472 79).

In view of the fact that the polarizing effect on rays diverging considerably from the optical axis is by nature weaker, the filters should be used in a parallel light beam.

Furthermore, care should be taken that the filters are not damaged by overheating. For a filter mounted immediately in front of the lamp, the risk of damage is particularly great in the case of longer experiments.

Recommended heat protection filters:
Picture slider with built-in heat protection filter (450 66) for halogen lamp 12 V/50 W/100 W (450 64) or plate glass cell (e.g. 477 20) filled with a weak solution of copper sulfate.

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Gebrauchsanweisung
Instruction Sheet

472 60

Viertel-Wellenlängen-Platten
Paire of quarter-wave plates

Mit den Viertel-Wellenlängen-Platten kann linear polarisiertes Licht in elliptisch und zirkular polarisiertes Licht umgewandelt werden und dieses wieder zurück in linear polarisiertes Licht. Die Platten werden meistens paarweise benötigt, und daher auch paarweise geliefert, denn in vielen Versuchen wird zunächst mit der einen Platte das elliptisch polarisierte Licht erzeugt und mit der anderen wieder analysiert.

1 Beschreibung

Eine Viertel-Wellenlängen-Platte, auch Verzögerungsfolie genannt, hat als wesentlichen Bestandteil eine Kunststoff-Folie geeigneter Dicke, die doppelbrechend ist. Zum Schutz vor Beschädigungen ist sie in eine weitere Kunststoff-Folie von 40 mm Ø eingegossen, die in einer drehbaren Kunstsoff-Fassung befestigt ist. Die Fassung ist mit einer Gradeinteilung (-90° ... 0° ... 90°) versehen. Sie wird über einen Hebel in einer festen äußeren Fassung (Ø 13 cm) mit Strichmarke bewegt.

Die äußere Fassung trägt einen 10 mm dicken Stiel zum Aufbau an einer Optischen Bank (z.B. 460 43). Das Gerät ist durch die Aufschrift "λ/4"* gekennzeichnet.

-----
*) λ/4 = eine viertel Wellenlänge

2 Prinzip

Fällt ein paralleles Lichtbündel senkrecht auf die Folie auf, so wird es in dieser wegen ihrer doppelbrechenden Eigenschaften in zwei Komponenten zerlegt, die senkrecht aufeinander stehende Schwingungsebenen und etwas unterschiedliche Phasengeschwindigkeiten besitzen. Die Dicke der Folie ist so gewählt, daß die Lichtkomponente, deren elektrischer Vektor parallel zum Drehhebel schwingt, gegenüber der dazu senkrecht schwingenden Lichtkomponente um (140) ±20 nm verzögert ist. Der so entstehende Phasenunterschied der beiden Komponenten beträgt eine viertel Wellenlänge, für praktische Zwecke ausreichend, im gelben und langwelligen grünen Licht. Wegen der mäßigen Dispersion im sichtbaren Licht sind jedoch die Abweichungen in den Randgebieten des Spektrums nur gering.

3 Handhabung

Zur Erzeugung von elliptisch oder zirkular polarisiertem Licht verwendet man im Anschluß an die Lichtquelle zunächst ein Polarisationsfilter als Polarisator, dann eine im allgemeinen direkt dahinter aufgestellte Viertel-Wellenlängen-Platte und schließlich ein weiteres Polarisationsfilter zur Analyse des Lichtes. Wird das erste Polarisationsfilter auf seine 0°-, das zweite auf seine 90°-Marke gedreht, dann herrscht ohne λ/4-Platte Dunkelheit. Mit λ/4-Platte tritt im allgemeinen eine Aufhellung des Gesichtsfeldes ein, jedoch findet man durch Drehen der Platte in ihrer Fassung zwei scharf ausgeprägte, senkrecht zueinander befindliche Stellungen, in denen Dunkelheit bleibt. Dann stimmen die Schwingungsebenen der Platte mit denen der Polarisationsfilter überein und das auffallende linear polarisierte Licht kann die Platte unbeeinflußt passieren.

The quarter-wave plates can be used to change plane-polarized light into elliptically or circularly polarized light and can also change these back into plane-polarized light. The plates are usually required in pairs and are therefore catalogued in pairs, because in many experiments the elliptically polarized light is produced by means of one plate and analyzed by means of the other.

1 Description

The essential component of a quarter-wave plate (also called a retarder) is a double refracting plastic foil of suitable thickness. To protect it from damage it is sealed into an additional foil of 40 mm dia., which is fixed in a rotatable frame. The frame is provided with a graduation (-90°...0°...90°). It is moved via a lever in the fixed outer frame (diam. 13 cm) with index mark.

A 10 mm thick rod is attached to the outer frame by means of which the quarter-wave plate can be arranged on the optical bench (e.g. 460 43). The plate is marked λ/4*.

-----
*) λ/4 = quarter-wave length

2 Principle

If a beam of parallel light travels perpendicularly through the foil it is split into two components due to its double refracting properties. The two components have planes of oscillation perpendicular to one another and slightly different phase velocities. The thickness of the foil is so chosen, that the light component whose electrical vector oscillates in parallel to the rotation lever lags by 140 ±20 nm behind the other perpendicularly oscillating light component. The phase difference thus created between the two components amounts to a quarter-wave length, which is satisfactory for practical use, in the yellow and in the longwave green range. Due to the moderate dispersion in the visible light the deviations in the outer ranges of the spectrum are slight.

3 Operation

For producing elliptically or circularly polarized light a polarizing filter is used as polarizer next to the source of light. This is normally followed by a quarter-wave plate arranged immediately behind it and by a further polarizing filter to analyze the light. If the first polarizing filter is turned to 0° and the second is turned to its 90° mark there will be total extinction without the quarter-wave plate. The latter generally produces an illumination of the field of view, but, by turning it in its frame, two very clearly defined positions which are perpendicular to one another are found for which the field of view remains dark. In these positions the planes in which the oscillations of the light transmitted through the quarter-wave plate occur, coincide with those of the polarizing filter, and the incident plane-polarized light is transmitted through the plate without being affected.

Wird der Polarisator von 0° auf seine 45°-Marke gestellt, dann liefert die λ/4-Platte zirkular polarisiertes Licht. Beim Drehen des Analysators bleibt jetzt die Helligkeit des durchgehenden Lichtes unverändert.

Bei Verwendung von nicht monochromatischem, z.B. weißem Licht zeigt sich allerdings eine kleine Farbänderung. Sie ist eine Folge der oben erwähnten Abweichungen der Platten von der λ/4-Bedingung in den Randgebieten des sichtbaren Spektrums.

Die Entstehung des zirkular polarisierten Lichtes wird dadurch erklärt, daß das auffallende linear polarisierte Licht jetzt in der λ/4-Platte in zwei Komponenten zerlegt wird, die wegen der 45°-Stellung gleiche Amplitude besitzen.

Stellt man den Polarisator auf andere Werte zwischen 0°, 45° und 90°, dann haben die beiden Komponenten in der λ/4-Platte verschieden große Amplituden und setzen sich hinter ihr zu elliptisch polarisiertem Licht zusammen. Dies läßt sich je nach der Größe des eingestellten Winkels durch Drehen des Analysators mehr oder weniger stark abschwächen, jedoch nicht vollständig auslöschen.

Die zweite Viertel-Wellenlängen-Platte findet Verwendung, wenn vor dem Analysieren das zirkular oder elliptisch polarisierte Licht wieder in linear polarisiertes zurückverwandelt werden soll. Dafür wird diese zweite Platte irgendwo im Strahlengang zwischen der ersten λ/4-Platte und dem Analysator angebracht.

Die geeignetste Einstellung für Versuche in zirkular polarisiertem Licht ist folgende:

Polarisator auf 0°; Analysator auf 90°; erste λ/4-Platte anbringen und auf Dunkelheit drehen; zweite λ/4-Platte anbringen und ebenfalls auf Dunkelheit drehen; die Schwingungsebenen in beiden λ/4-Platten stimmen jetzt überein. Wird nun der Polarisator auf 45°, der Analysator auf 135° gestellt, dann ist zwischen den λ/4-Platten zirkular polarisiertes Licht vorhanden.

Jetzt können zwei verschiedene Fälle vorliegen:
Entweder wird in der zweiten λ/4-Platte die im zirkularen Licht voreilende Komponente um eine Viertel-Wellenlänge verzögert. Dann sind beide Komponenten wieder in Phase und addieren sich zu linear polarisiertem Licht mit der gleichen Schwingungsebene wie das einfallende Licht. Der gekreuzt stehende Analysator führt zur Auslöschung.

Im anderen Fall verzögert die zweite λ/4-Platte die schon in der ersten Platte zurückgebliebene Komponente nochmals um eine Viertel-Wellelänge. Dadurch bekommen die beiden Bestandteile einen Phasenunterschied von 180° und addieren sich zu linear polarisiertem Licht, das senkrecht zum einfallenden Licht schwingt. Die Anordnung zeigt maximale Helligkeit, die für die Versuche meist ungeeignet ist. Man drehe in diesem Fall eine λ/4-Platten um 90° und erhält dadurch die Verhälnisse des vorigen Falles.

4 Zur Beachtung

Für die Viertel-Wellenlängen-Platten gelten die gleichen Vorschriften wie für Polarisatiuonsfilter. Die Platten sollen nicht zu sehr erwärmt werden, weil dies zur Beschädigung der Folien führen kann. Man soll sie also insbesondere nicht zu nahe der heißen Lampe anbringen.

Die Platten arbeiten nur dann richtig, wenn sie von möglichst parallelem Licht senkrecht durchsetzt werden. Geringe Konvergenz oder Divergenz schadet allerdings nicht.

5 Versuche

Außer zu Versuchen über die Eingenschaften von zirkular und elliptisch polarisiertem Licht, dient das mit den Platten erzeugte zirkulare Licht zur Vorführung der Spannungsdoppelbrechung mit dem Satz spannungsoptischer Modelle (471 95) und zur Demonstration der inneren mechanischen Spannungen bei Sicherheitsglas (Sekuritglas, 471 92) oder bei schnell gekühltem Glas (471 61).

If the polarizer is turned from 0° to its 45° mark, the quarter-wave plate will provide circularly polarized light. In this position, turning the analyzer will not affect the brightness of the transmitted light.

But when using non-monochromatic light, for example white light, a small change of colour will be observed. This is due to the above-mentioned deviations of the plates from the quarter-wave condition in the outer ranges of the visible spectrum.

The production of circularly polarized light is explained by the incident plane-polarized light being split into two components in the quarter-wave plate, which have equal amplitudes due to the 45°-position.

When adjusting the polarizer at other values between 0°, 45° and 90°, then the two components have different amplitudes in the quarter-wave plate and recombine behind it to form elliptically polarized light. Depending on the angle of adjustment of the polarizer, this light can be weakened to a greater or lesser extent by turning the analyzer, but it cannot be completely extinguished.

The second quarter-wave plate is used if it is intended to change the circularly or elliptically polarized light back into plane-polarized light before analyzing. For this purpose the second plate is inserted into the path of rays anywhere between the first quarter-wave plate and the analyzer.

The most suitable arrangement for experiments with circularly polarized light is the following:

Set the polarizer at 0°; set the analyzer at 90°; put the first quarter-wave plate in position and turn it to give darkness; mount the second quarter-wave plate and likewise turn it to give darkness; now the planes of oscillation in the quarter-wave plates coincide. On turning the polarizer to 45° and the analyzer to 135°, there will be circularly polarized light between the two quarter-wave plates.

Now we have one of two possible cases:
First, the second quarter-wave plate retards the component leading in phase of the circularly polarized light by a quarter of a period. The two components are again in phase and add up to plane- polarized light the oscillations of which occur in the same plane as the incident light. Since the analyzer and polarizer are crossed there will be total extinction, that is, darkness.

In the second case, the second quarter-wave plate will again retard the component which was lagging behind in the first quarter-wave plate, so that the components are 180° out of phase after going through the second quarter-wave plate. They add up to plane-polarized light which oscillates in a plane normal to the incident light. This arrangement will produce maximum brightness, which is generally unsuitable for experiments. Therefore, one of the quarter-wave plates may be rotated through 90° to obtain the conditions of the previous case.

4 Please note:

The quarter-wave plates should be treated like the polarizing filters. They must not be heated too much, otherwise the foils might be damaged. In particular, they must not be fixed too near the hot lamp.

The plates will give the intended effect only when they are perpendicularly penetrated by light which is as aparallel as possible. But slight convergence of the light is not harmful.

5 Experiments

Apart from the experiments on the properties of circularly and elliptically polarized light, the circularly polarized light produced in the quarter-wave plates serves to demonstrate birefringence on using a set of photoelastic models (471 95), and to demonstrate the internal stresses in safety glass (Securit glass plate, 471 92) or in rapidly cooled glass (471 61).

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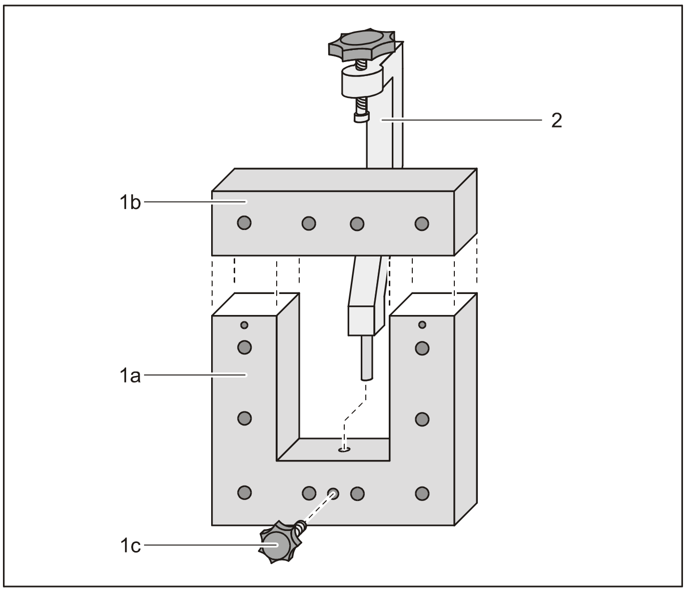


Instruction sheet 562 11

U core with yoke (562 11)
Clamping device (562 121)

1 U core (1a) **with yoke** (1b), fixing bolt (1c)

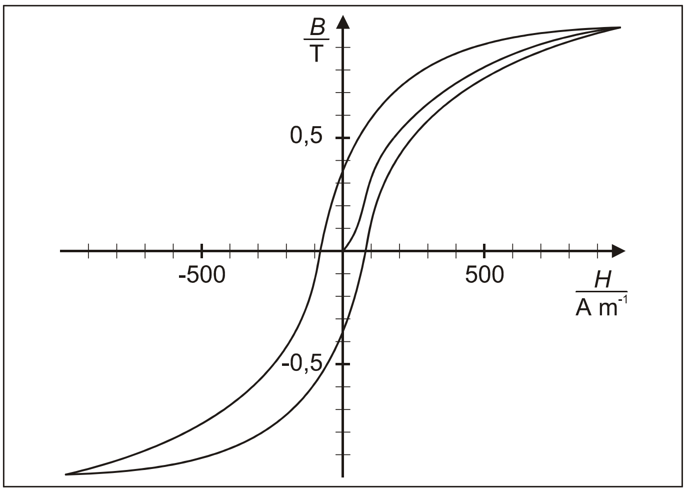
2 Clamping device

1 Description

The U core with yoke (562 11) and the clamping device (562 12) are intended for the assembly of the demountable transformer with the coils indicated in chapter 3.

2 Technical data

Cross section:	4 cm × 4 cm
Width of U core and length of yoke:	15 cm
Heigth of U core:	13 cm
Material:	Iron, laminated
Max. relative permeability μ_r at the initial curve:	approx. 2200 at H = 120 A m^{-1}



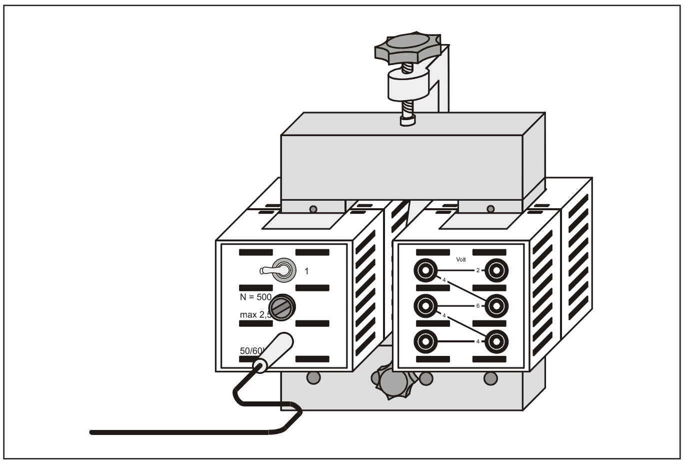
Hysteresis curve of the U core with yoke

3 Suitable coils

Low voltage coil N = 250	562 13
Low voltage coil N = 480, I = 10 A	562 131
Low voltage coil N = 500	562 14
Low voltage coil N = 1000	562 15
High voltage coil N = 10000	562 16
High voltage coil N = 23000	562 17
Extra-low voltage coil N = 50	562 18
Mains coil 230 V	562 21
Mains coil 115 V	562 22

4 Use

- Mount primary and secondary coil.
- Put unpainted side of the yoke on the U core.
- Clamp yoke using the clamping device.



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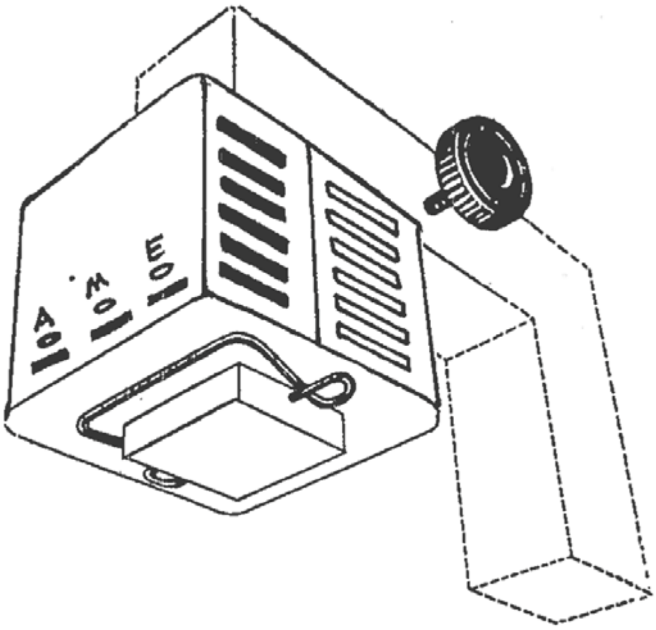
5 Clamps

The clamps are used to secure coils to the U-core of the demonstration transformer in case it is used without pole pieces.

The two clamps are made of steel wire and so bent that their ends can engage resiliently with the two pairs of lateral bores of a U-core



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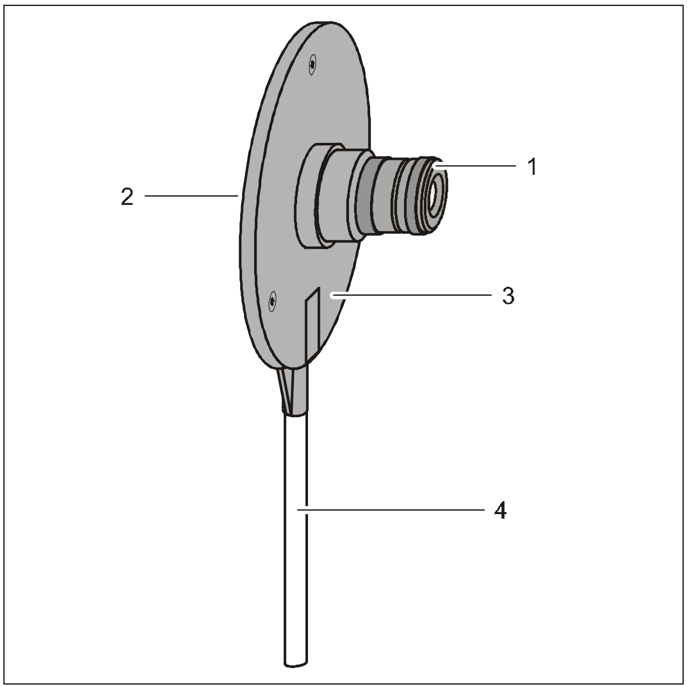


Instruction sheet 460 135

Eyepiece with line-graduated scale, in barrel (460 135)

1 Eyepiece, adjustable
2 glass plate with horizontal line-graduated scale
3 barrel
4 shaft

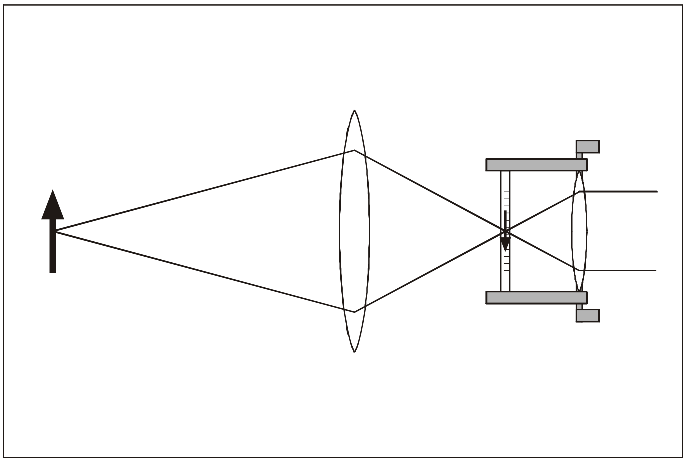
1 Description

The eyepiece with line-graduated scale serves to measure a real image in an optical construction. For that the image in the plane of the line-graduated scale is observed with the eyepiece. The glass plate with the line-graduated scale is situated in the focus of the eyepiece.

2 Technical data

Eyepiece magnification:	times-ten
Line-graduated scale:	100 graduation marks in 10 mm
Diameter of the barrel:	13 cm
Diameter of the shaft:	10 mm
Mass:	200 g

3 Handling



- Focus on the line-graduated scale individually by turning the eyepiece (vary the distance from the scale).
- Displace either the eyepiece with the line-graduated scale or the image plane so that the image plane and the plane of the scale coincide.

4 Care and cleaning

- To prevent the eyepiece from getting dusty, do not store it lying.

- If necessary, wipe the lens and the glass plate carefully with a piece of lint-free cloth.

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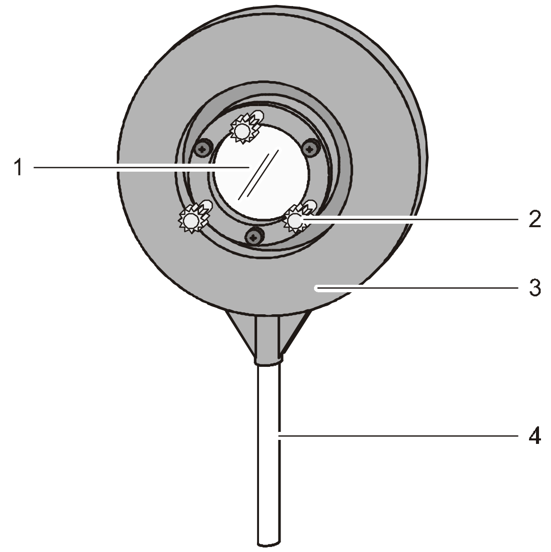


Instruction sheet 471 221

Fabry-Perot etalon in holder (471 221)

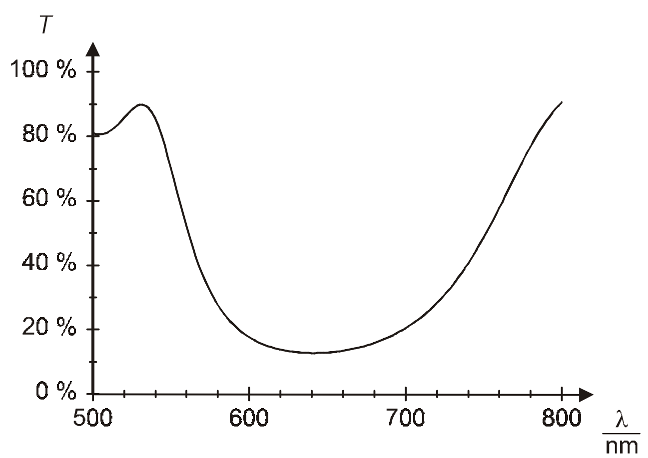
1 Stationary etalon
2 Adjusting screws
3 Holder
4 Handle

1 Description

The Fabry-Perot etalon is used to construct a high-resolution interferometer suited for experiments dealing with the Zeeman effect. The built-in stationary etalon is an extremely planeparallel glass plate with a semi-transparent mirror plating. The mirror plating is optimized for the red Cd line (λ = 643.8 nm). When slightly divergent monochromatic light passes the plate, the interference fringe of equal inclination appears as a system of concentric circles behind the Fabry-Perot etalon.

The inclination of the stationary etalon relatively to the optical axis can be varied by means of adjusting screws.

2 Transmission curve



3 Technical data

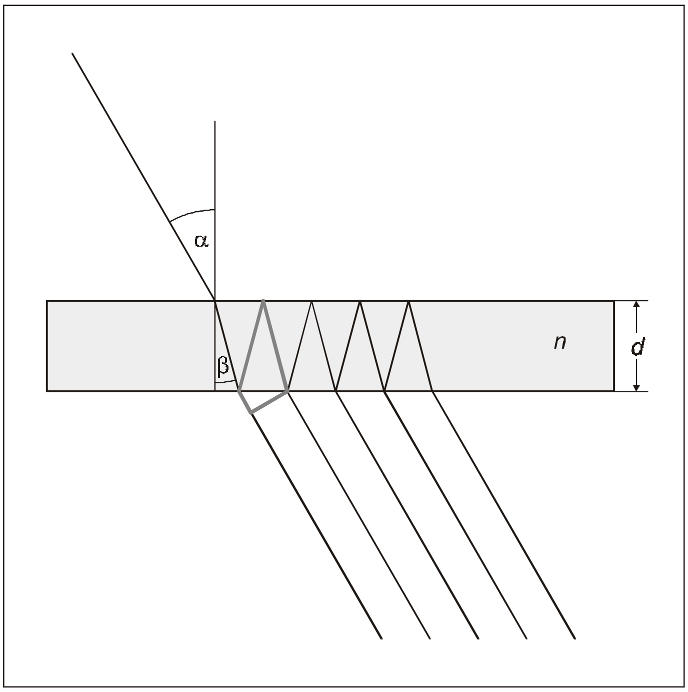
Stationary etalon:	
Diameter:	25 mm
Thickness:	4 mm
Flatness:	32 nm (λ/20)
Material:	Suprasil
Refractive index:	1.457
Transmission:	approx. 15 % at 644 nm (see transmission curve)
Resolution:	approx. 400 000 at 644 nm
Holder:	
Diameter:	13 cm
Diameter of the handle:	10 mm
Mass:	approx. 300 g

4 Storage and cleaning

- Keep the Fabry-Perot etalon standing to prevent it from getting dusty.
- If necessary, wipe the etalon with a piece of lint-free cloth.

5 Principle of operation

5.1 Optical path through the stationary etalon:

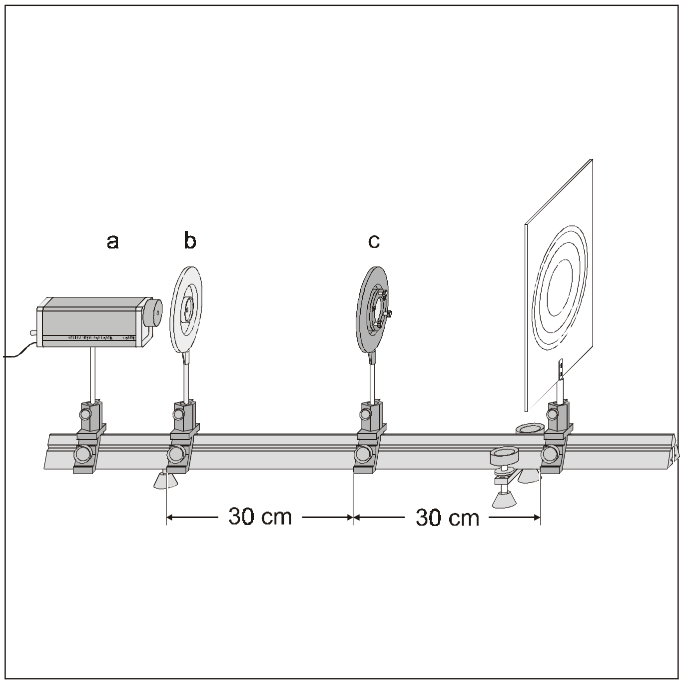


5.2 Condition for interference:

$$k \cdot \lambda = 2 \cdot d\sqrt{n^2 - sin^2\alpha} = 2 \cdot d \cdot n \cdot cos\beta$$

6 Example of an experiment

Observing the ring-shaped interference pattern:



a He-Ne laser, 632.8 nm (471 480)

b Lens f = + 5 mm (460 01)

c Fabry-Perot etalon

When the light passes the etalon, the system of circles formed by narrow red lines (632.8 nm) can be observed on the screen.

The reflected light generates the inverse image, that is, narrow (black) circles on a red background. To observe this, hold a sheet of white paper immediately near the expansion lens.

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Determining the focal lengths at collecting lenses through autocollimation

Objects of the experiment

- Determination of the focal length of a collecting lens by the method of autocollimation.

Principles

The focal length of lenses can be determined by a variety of means. The basis for the different procedures are the laws of imaging.

In this experiment the method of autocollimination is used to determine the focal length of a collecting or convergent lens. This method makes use of the reversibility of the ray path for incident parallel light propagated along the axis and for rays through the focal point:

The parallel light beam is reflected by a mirror behind the lens so that the image of an object is viewed right next to that object (Fig. 1). The distance d between the object and the lens is varied until the object and the image are exactly the same size. Then, the focal length is given by:

$$f = d \qquad (I)$$

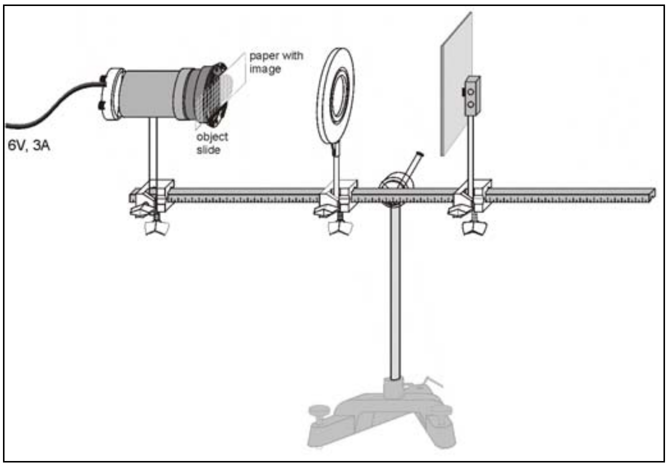

Fig. 1: Schematic diagram of the experimental setup.

Apparatus

1 Incandescent lamp 6 V / 30 W	450 51
1 Lamp housing with cable	450 60
1 Aspherical condenser with diaphragm holder	460 20
1 Transformer 6 V / 12 V	521 210
1 Lens in frame f = +150 mm	460 08
1 Lens in frame f = +300 mm	460 09
1 Pair of objects for investigating images	461 66
1 Plane mirror with ball joint	460 28
1 Small optical bench	460 43
1 Stand base, V-shaped, 20 cm	300 02
3 Leybold multiclamp	301 01
1 Steel tape measure, l = 2 m/78"	311 77

Setup

- Set up the lamp with the aspherical condenser on the optical bench as depicted in Fig. 1.
- Position the lens f = +150 mm in such a manner that the light passes through the lens along the optical axis. The distance between the lens and the diaphragm holder of lamp should be in the order of magnitude of the expected focal length.
- Insert the transparency with the grid pattern (object) and a white sheet of paper (screen to observe the image of the object) according Fig. 1 into the diaphragm holder of the lamp. Both the white paper and transparency should cover half of the condenser lens.
- Arrange the mirror behind the lens. The plane of the mirror should be inclined slightly (around 1° to 3°) with respect to the plane of the lens. The distance between the lens and the mirror can be chosen to be less then the focal length.

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Carrying out the experiment

The experiment should be performed in a darkened room.

- Position the lens f = +150 mm about the expected focal length apart from the diaphragm holder of the lamp.
- Shift the mirror towards the lens until the distance between lens and mirror is in the order of magnitude of half of the expected focal length. A diffuse image of the grid pattern should occur adjacent to the original on the white paper in the diaphragm holder.
- Vary the distance of the lens until a sharp image of the object can be observed on the white paper in the diaphragm holder. It might be necessary to adjust the positions of the mirror and the lens until the image has the same size as the original.
- Measure the distance d between lens and object plane (image plane) with the steel tape measure.
- Repeat the experiment with other lenses.

Measuring example

Table. 1: Comparison of the measured and given focal length

Focal length f / mm given	+300	+150	+200*	+100*
Focal length f / mm measured	295	151	198	101

**Lenses from experiment P5.1.2.1*

Evaluation and results

If the light emitted by a illuminated (or luminous) object arranged in the focal plane of a convergent lens is incident as a parallel light beam on a planer mirror positioned behind the lens, it is reflected in the opposite direction as parallel light behind the lens refracted towards the focus. Thus an image of the original object is produced in the plane of the lens (principle of determination of the focal length by autocollimation).

Observing the normal *Zeeman* effect in transverse and longitudinal configuration

Spectroscopy with a *Fabry-Perot* etalon

Objects of the experiment

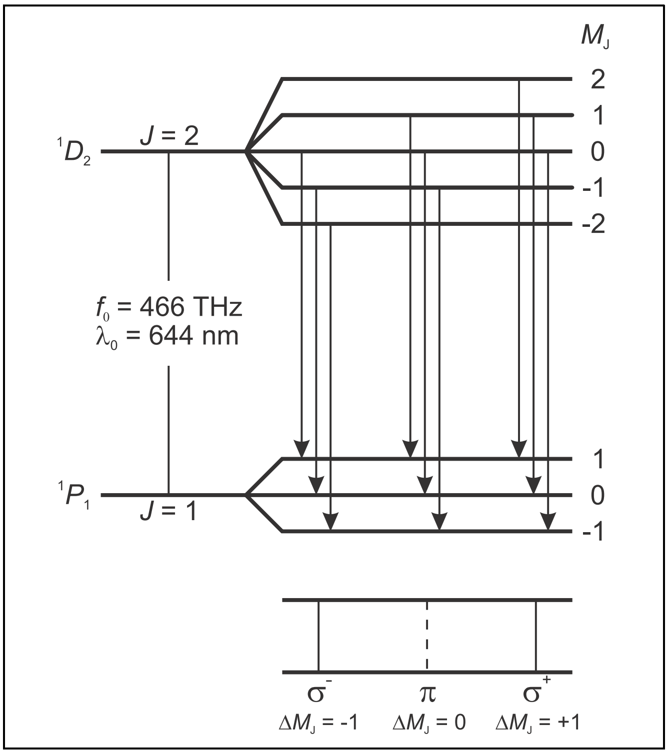
- Observing the line triplet for the normal transverse *Zeeman* effect.
- Determining the polarization state of the triplet components.
- Observing the line doublet for the normal longitudinal *Zeeman* effect.
- Determining the polarization state of the doublet components.

Principles

Normal Zeeman effect:

The *Zeeman* effect is the name for the splitting of atomic energy levels or spectral lines due to the action of an external magnetic field. The effect was first predicted by *H. A. Lorenz* in 1895 as part of his classic theory of the electron, and experimentally confirmed some years later by P. *Zeeman*. Zeeman observed a line triplet instead of a single spectral line at right angles to a magnetic field, and a line doublet parallel to the magnetic field. Later, more complex splittings of spectral lines were observed, which became known as the anomalous *Zeeman* effect. To explain this phenomenon, *Goudsmit* and *Uhlenbeck* first introduced the hypothesis of electron spin in 1925. Ultimately, it became apparent that the anomalous Zeeman effect was actually the rule and the "normal" Zeeman effect the exception.

Fig. 1 Level splitting and transitions of the normal Zeeman effect in cadmium



The normal *Zeeman* effect only occurs at the transitions between atomic states with the total spin $S = 0$. The total angular momentum $\boldsymbol{J} = \boldsymbol{L} + \boldsymbol{S}$ of a state is then a pure orbital angular momentum ($\boldsymbol{J} = \boldsymbol{L}$). For the corresponding magnetic moment, we can simply say that:

$$\mu = \frac{\mu_B}{\hbar}\mathbf{J} \qquad \text{(I)}$$

where

$$\mu_B = \frac{\hbar e}{-2\, m_e} \qquad \text{(II)}$$

(m_B = *Bohr's* magneton, m_e = mass of electron, e = elementary charge, $\hbar = h/2\pi$, h = *Planck's* constant).

In an external magnetic field ***B***, the magnetic moment has the energy

$$E = -\mu \cdot B \qquad \text{(III)}$$

The angular-momentum component in the direction of the magnetic field can have the values

$$J_z = M_J \cdot \hbar \text{ with } M_J = J, J-1, \ldots, -J \qquad \text{(IV)}$$

Therefore, the term with the angular momentum J is split into $2J + 1$ equidistant *Zeeman* components which differ by the value of M_J. The energy interval of the adjacent components M_J, M_{J+1} is

$$\Delta E = \mu_B \cdot B \qquad \text{(V).}$$

We can observe the normal *Zeeman* effect e.g. in the red spectral line of cadmium (λ_0 = 643,8 nm, f_0 = 465,7 THz). It corresponds to the transition $^1D_2$ (J = 2, S = 0) → $^1P_1$ (J = 1, S = 0) of an electron of the fifth shell (see Fig. 1). In the magnetic field, the $^1D_2$ level splits into five *Zeeman* components, and the level $^1P_1$ splits into three *Zeeman* components having the spacing calculated using equation (V).

Apparatus

1 cadmium lamp for Zeeman effect	451 12
1 U-core with yoke	562 11
2 coils, 10 A, 480 turns	562 131
1 pair of pole pieces with large bores	560 315
1 Fabry-Perot etalon	471 221
2 positive lenses with barrel, 150 mm	460 08
1 quarter-wave plate	472 601
1 polarization filter	472 401
1 holder with spring clips	460 22
1 filter set, primary	467 95
or	
1 holder for interference filter	468 41
1 interference filter, 644 nm	468 400
1 ocular with line graduation	460 135
1 precision optical bench, standardized cross section, 1 m	460 32
1 rider base with thread	460 358
7 optics rider 60/50	460 351
1 universal choke for 451 12	451 30
1 high current power supply	521 55

Optical transitions between these levels are only possible in the form of electrical dipole radiation. The following selection rules apply for the magnetic quantum numbers M_J of the states involved:

$$\Delta M_J \begin{cases} = \pm 1 & \text{for } \sigma \text{ components} \\ = 0 & \text{for } \pi \text{ components} \end{cases} \qquad \text{(VI)}$$

Thus, we observe a total of three spectral lines (see Fig. 1); the π component is not shifted and the two σ components are shifted by

$$\Delta f = \pm \frac{\Delta E}{h} \qquad \text{(VII)}$$

with respect to the original frequency. In this equation, ΔE is the equidistant energy split calculated in (V).

Connecting leads with conductor cross-section 2.5 mm^2

Angular distribution and polarization

Depending on the angular momentum component ΔM_J in the direction of the magnetic field, the emitted photons exhibit different angular distributions. Fig. 2 shows the angular distributions in the form of two-dimensional polar diagrams. They can be observed experimentally, as the magnetic field is characterized by a common axis for all cadmium atoms.

In classical terms, the case $\Delta M_J = 0$ corresponds to an infinitesimal dipole oscillating parallel to the magnetic field. No quanta are emitted in the direction of the magnetic field, i.e. the π- component cannot be observed parallel to the magnetic field. The light emitted perpendicular to the magnetic field is linearly polarized, whereby the ***E***-vector oscillates in the direction of the dipole and parallel to the magnetic field (see Fig. 3)

Conversely, in the case $\Delta M_J = \pm 1$ most of the quanta travel in the direction of the magnetic field. In classical terms, this case corresponds to two parallel dipoles oscillating with a phase difference of 90°. The superposition of the two dipoles produces a circulating current. Thus, in the direction of the magnetic field, circularly polarized light is emitted; in the positive direction, it is clockwise-circular for $\Delta M_J = +1$ and anticlockwise-circular for $\Delta M_J = -1$ (see Fig. 3).

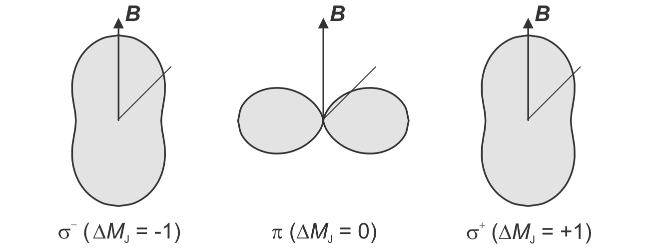


Fig. 2 Angular distributions of the electrical dipole radiation (ΔM_J: angular-momentum components of the emitted photons in the direction of the magnetic field)

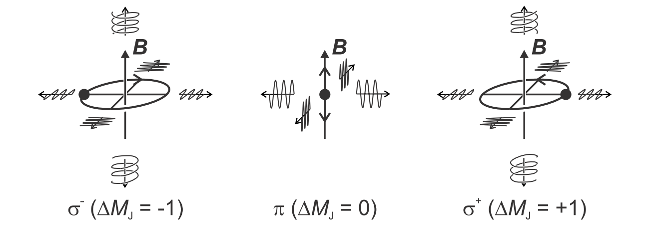


Fig. 3 Schematic representation of the polarization of the Zeeman components (ΔM_J: angular-momentum components of the emitted photons in the direction of the magnetic field)

Spectroscopy of the Zeeman components

The Zeeman effect enables spectroscopic separation of the differently polarized components. To demonstrate the shift, however, we require a spectral apparatus with extremely high resolution, as the two σ components of the red cadmium line are shifted e.g. at a magnetic flux density $B = 1$ T by only $\Delta f = 14$ GHz , respectively $\Delta\lambda = 0{,}02$ nm.

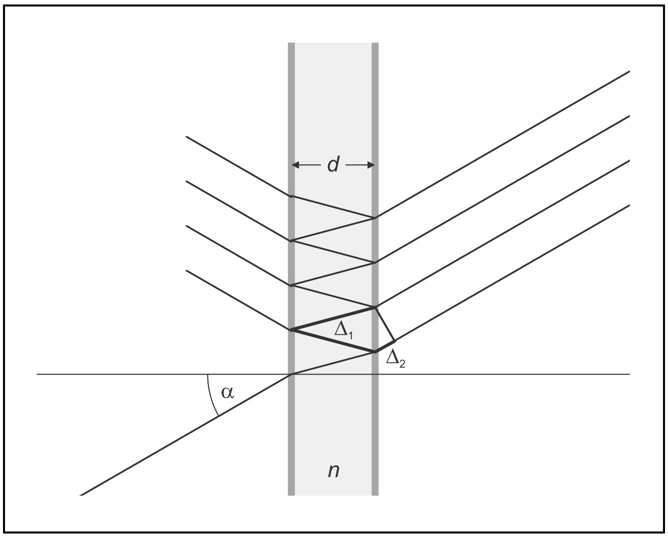


Fig. 4 Fabry-Perot etalon as an interference spectrometer. The ray path is drawn for an angle $\alpha > 0$ relative to the optical axis. The optical path difference between two adjacent emerging rays is $\Delta = n \cdot \Delta_1 - \Delta_2$.

In the experiment a Fabry-Perot etalon is used. This is a glass plate which is plane parallel to a very high precision with both sides being aluminized. The slightly divergent light enters the etalon, which is aligned perpendicularly to the optical axis, and is reflected back and forth several times, whereby part of it emerges each time (see Fig. 4). Due to the aluminizing this emerging part is small, i. e., many emerging rays can interfere. Behind the etalon the emerging rays are focused by a lens on to the focal plane of the lens. There a concentric circular fringe pattern associated with a particular wavelength λ can be observed with an ocular. The aperture angle of a ring is identical with the angle of emergence α of the partial rays from the Fabry-Perot etalon.

The rays emerging at an angle of α_k interfere constructively with each other when two adjacent rays fulfil the condition for "curves of equal inclination" (see Fig. 4):

$$\Delta = 2d \cdot \sqrt{n^2 - \sin^2\alpha_k} = k \cdot \lambda \qquad \text{(VIII)}$$

(Δ = optical path difference, d = thickness of the etalon, n = refractive index of the glass, k = order of interference)).

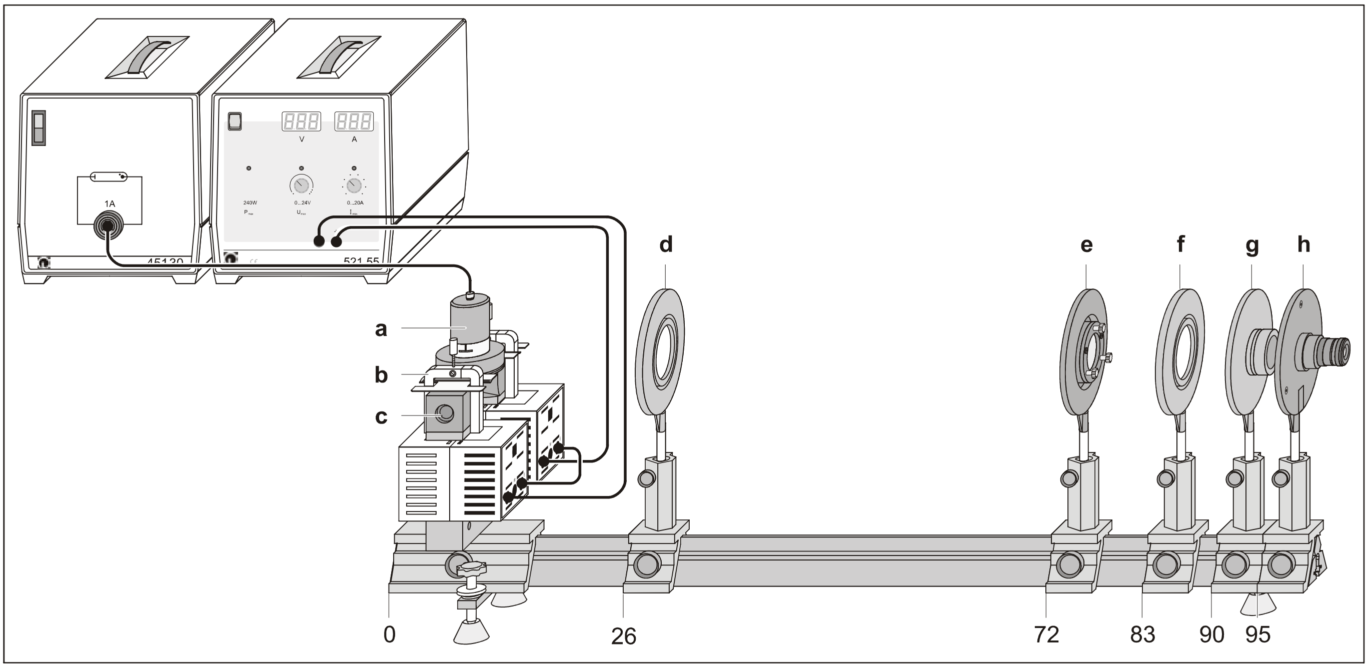
A change in the wavelength by $\delta\lambda$ is seen as a change in the aperture angle by $\delta\alpha$. Depending on the focal length of the lens, the aperture angle α corresponds to a radius r and the change in the angle $\delta\alpha$ to a change in the radius δr. If a spectral line contains several components with the distance $\delta\lambda$, each circular interference fringe is split into as many components with the radial distance δr. So a spectral line doublet is recognized by a doublet structure and a spectral line triplet by a triplet structure in the circular fringe pattern.

Setup

The complete experimental setup in transverse configuration is illustrated in Fig. 5.

Fig. 5 Experimental setup for observing the *Zeeman* effect in transverse configuration. The position of the left edge of the optics riders is given in cm.

- **a** Cadmium lamp with holding plate
- **b** Clamps
- **c** Pole pieces
- **d** Positive lens, f = 150 mm (condenser lens)
- **e** Fabry-Perot etalon
- **f** Positive lens, f = 150 mm (imaging lens)
- **g** Colour filter (red) in holder
- **h** Ocular with line graduation



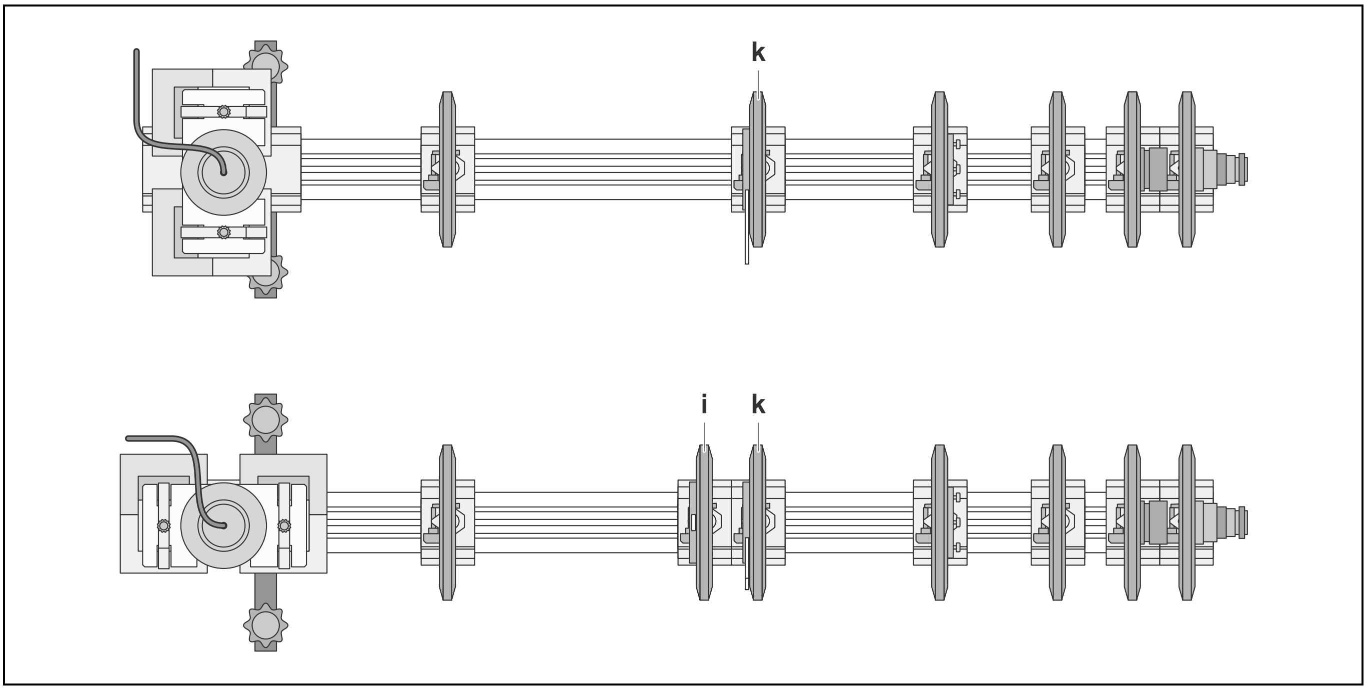


Fig. 6 Setup in transverse configuration (above) and in longitudinal configuration (below), as seen from above.
i Quarter-wavelength plate
k Polarization filter

Mechanical and optical setup:

- Screw the threaded rod into the base of the rider.
- Put the U-yoke over the threaded rod on the base of the rider so that it is freely rotatable and put on the coils.
- Mount the pole pieces and the holding plate of the cadmium lamp using the clamps so that a distance of approx. 10 mm is left between the pole pieces and that the opening of the holding plate points to the back. Do not yet fasten the screws of the clamps.
- Cautiously insert the cadmium lamp between the pole pieces.

  See to it that the cadmium lamp is exactly in the middle of the pole pieces, that the point where the bulb is sealed off points to the back and that the supply leads are swivelled out of the ray path as far as possible.
- If necessary, reduce the distance between the pole pieces in order that later on a stronger magnetic field is available.
- Fix the pole pieces and the holding plate with the screws of the clamps.
- Mount the optical components according to Fig. 5.

Electrical connection:

- Connect the cadmium lamp to the universal choke; after switching on wait 5 min until the light emission is sufficiently strong.
- Connect the coils of the electromagnet in series and then to the high current power supply.

Adjusting the observing optics:

Remark: the optimum setup is achieved when the red circular fringe pattern is bright and contrasty with its centre on the line graduation. While adjusting do not yet insert the polarization filter and the quarter-wave plate in order that the observed image is as bright as possible.

- Focus the ocular at the line graduation.
- Move the imaging lens until you observe a sharply defined image of the circular fringe pattern.
- Move the condenser lens until the observed image is illuminated as uniformly as possible.
- Shift the centre of the circular fringe pattern to the middle of the line graduation by slightly tipping the Fabry-Perot etalon with the adjusting screws.

If the adjustment range does not suffice:

- Rotate the Fabry-Perot etalon with its frame or adjust the height of the imaging lens and the ocular to each other.

Carrying out the experiment

a) Observing in transverse configuration:

– First observe the circular fringe pattern without magnetic field (I = 0 A).
– Slowly enhance the magnet current up to about I = 3 A until the split fringes are clearly separated.

For the distinction between π and σ components:

– Introduce the polarization filter into the ray path (see Fig. 6), and set it to 90° until the two outer components of the triplet structure disappear.
– Set the polarization filter to 0° until the (unshifted) component in the middle disappears.

b) Observing in longitudinal configuration:

– Rotate the entire setup of the cadmium lamp with the pole pieces on the rider base with thread by 90°.
– First observe the circular fringe pattern without magnetic field (I = 0 A).
– Slowly enhance the magnet current up to about I = 3 A until the split fringes are clearly separated.

For the distinction between σ+ and σ- components:

– Introduce a quarter-wavelength plate into the ray path between the cadmium lamp and the polarization filter (see Fig. 6), and set it to 0°.
– Set the polarization filter to +45° and –45°. In each case one of the two doublet components disappears.

Measuring example and evaluation

a) Observing in transverse configuration: see Fig. 7

b) Observing in longitudinal configuration: see Fig. 8

Additional information

The total intensity of all *Zeeman* components is the same in all spatial directions. In transverse observation, the intensity of the π component is equal to the total intensity of the two σ components.

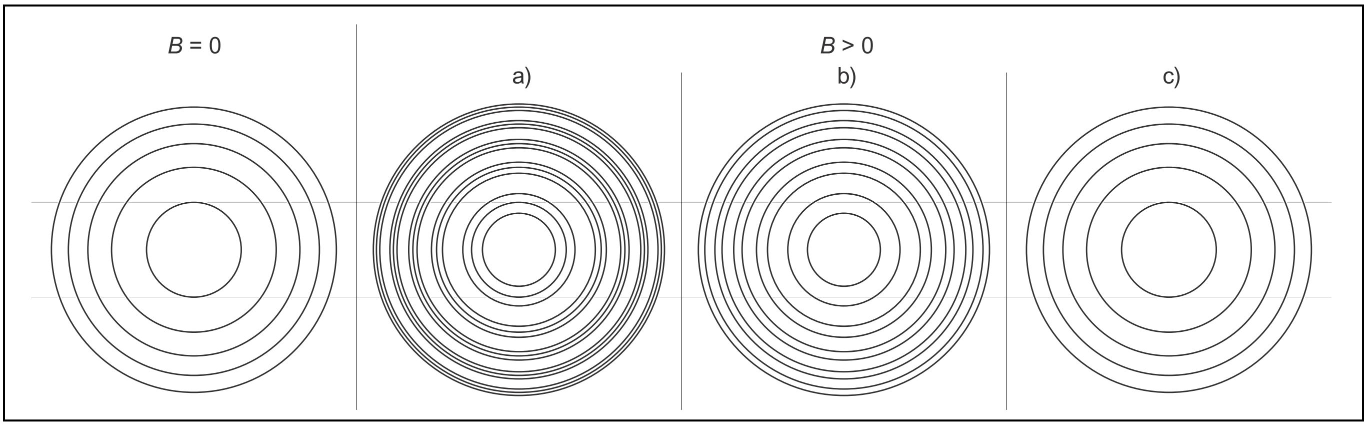


Fig. 7 top: Circular fringe pattern associated with the Zeeman effect in transverse configuration
a) *without polarization filter*
b) *direction of polarization perpendicular to the magnetic field*
c) *direction of polarization parallel to the magnetic field*

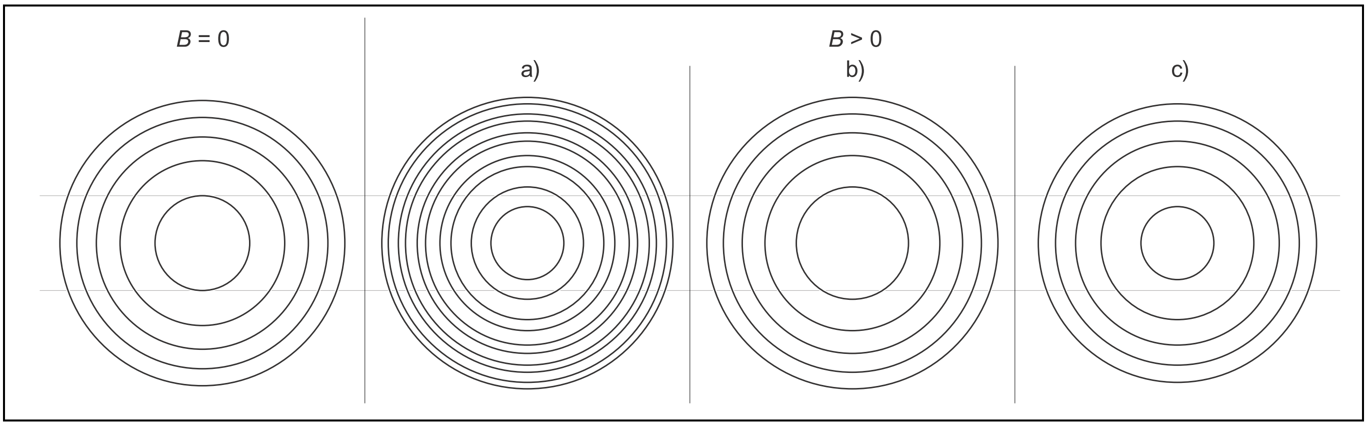


Fig. 8 bottom: Circular fringe pattern associated with the Zeeman effect in longitudinal configuration
a) without quarter-wavelength plate
b), c) with quarter-wavelength plate and polarization filter for detecting circular polarization

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