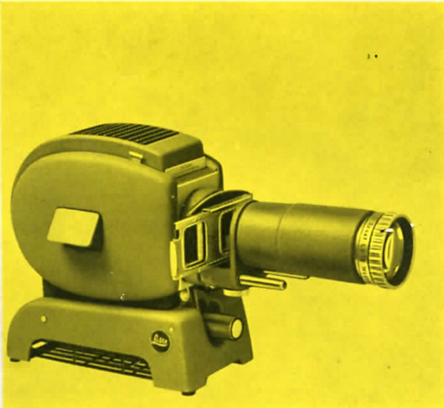
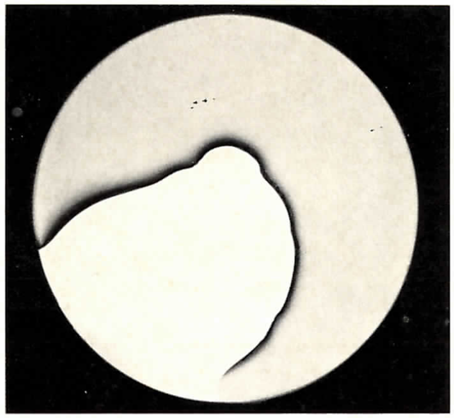
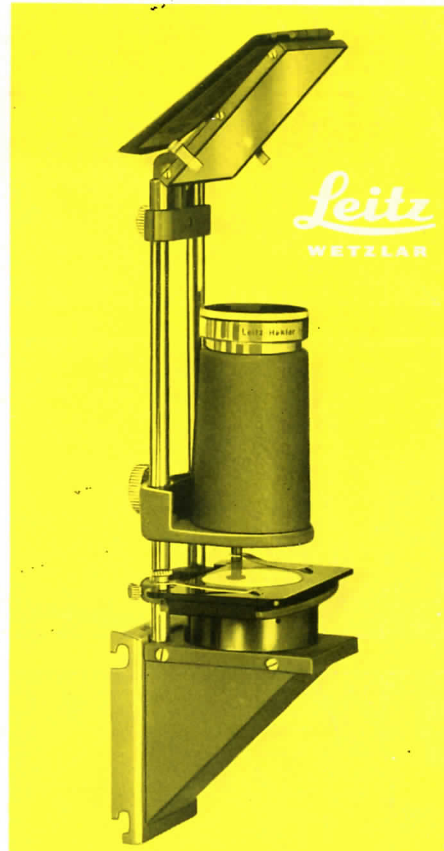




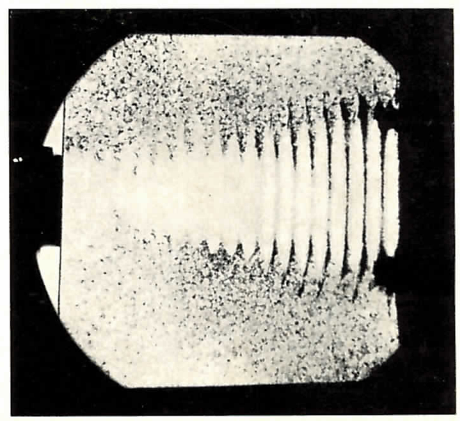


L. BERGMANN

THE 2"x2" SLIDE PROJECTOR IN THE TEACHING OF SCIENCE

A Description
of the Accessories
and Aids available
for Lecture
Experiments
in

PHYSICS
CHEMISTRY
BIOLOGY



Sponsored by: ERNST LEITZ GMBH WETZLAR

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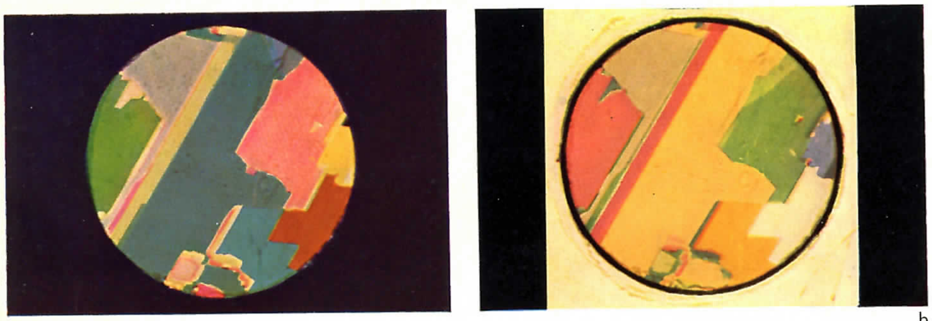
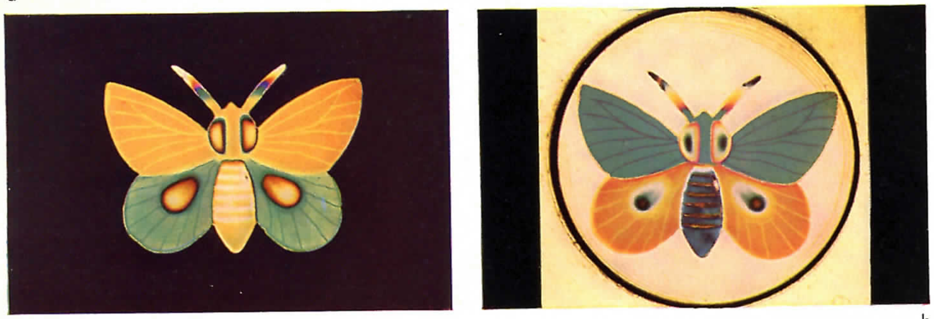


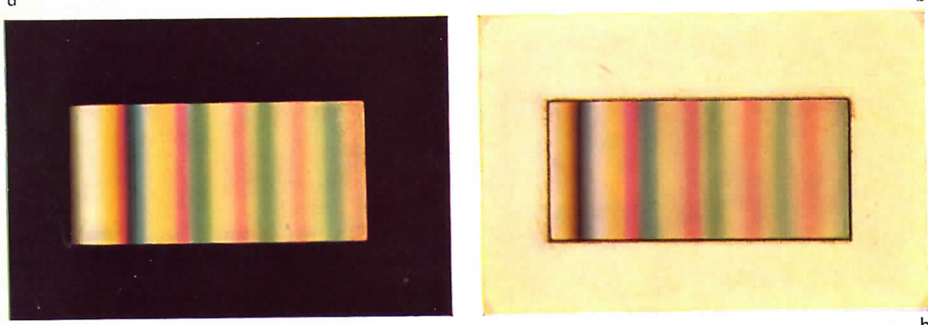
a b

Fig. 49 Mica in linearly polarized light.
(a) Between crossed polarizers.
(b) Between parallel polarizers.



a b

Fig. 50 Picture engraved on a small tabular crystal of gypsum seen by linearly polarized light.
(a) Between crossed polarizers.
(b) Between parallel polarizers.



a b

Fig. 51 Quartz wedge in linearly polarized light.
(a) Between crossed polarizers.
(b) Between parallel polarizers.
Notice the bands of interference colours repeating at uniform intervals and running parallel to the apex of the wedge; with increasing wedge thickness (towards the right) they get less saturated.

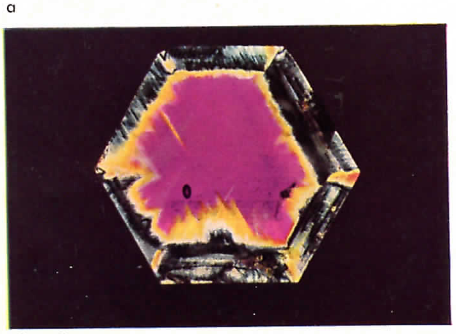


Fig. 52

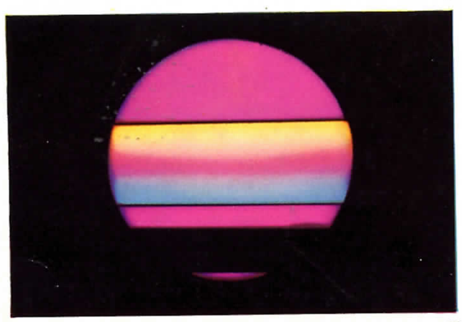


Fig. 57

Fig. 52 Twinned quartz plate cut perpendicular to its optical axis, seen by linearly polarized light between crossed polarizers.

Fig. 57 Bending stresses in a glass rod. The rod is being subjected to a force tending to bend it upwards, and is projected by linearly polarized light between crossed polarizers and with a wave plate (red, first order) in the optical system. Note that the colour of the central unstressed zone remains unchanged, whilst the upper part, under tension, appears yellow, and the lower part, under compression, blue.

The 2"×2" LEITZ-PRADO 250/500 Projector*

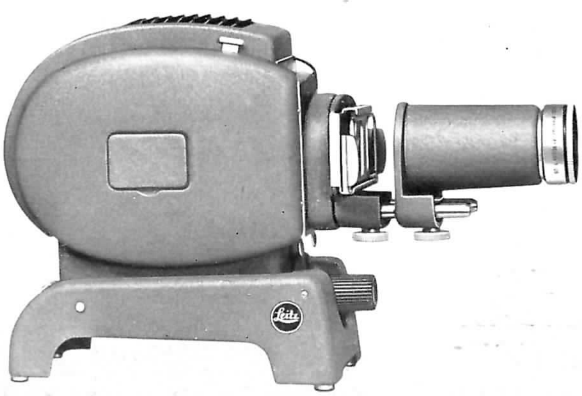
in the Teaching of Science

by Dr. L. Bergmann

Honorary Professor of Physics at the
Justus Liebig University, Giessen.

* Approved in Germany by the "Institut für Film und Bild" as a blower-cooled 2"×2" slide and filmstrip projector for use in schools and universities.

Fig. 1 General view of the LEITZ PRADO 250/500 2"×2" projector.



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CONTENTS

INTRODUCTION

There are many instruments used in the teaching of physics and chemistry which cannot without special equipment be effectively demonstrated to a large audience. In some cases the apparatus used is too small to be seen from the back of the lecture-room; for example, many experiments have as their final result a reading on an electrical meter of some sort. In other cases, the phenomena to be demonstrated occur in a horizontal plane, and cannot therefore be seen from a seat in front of the lecturer's bench; this applies, for example, to electric and magnetic lines of force or to events on the surface of a liquid. Projection of a silhouette is sometimes possible, but is not always satisfactory, and requires in any case a completely darkened room.
The examples given in the following pages will, we hope, show that the problem can be solved by using the PRADO 250/500 Projector and its accessories. Many experiments in the physical sciences can be brilliantly projected, and the equipment is equally suitable both for micro-projection and for the episcopic projection of small objects. This opens up entirely new possibilities in science teaching.**

** The various accessories can be obtained from E. Leybold's Successors, Köln-Bayenthal, Bonner Strasse 504, Germany.

DESCRIPTION OF THE PROJECTOR AND ITS ATTACHMENTS

Fig. 1 shows the complete LEITZ-PRADO 250/500 Projector. It was originally designed expressly for projecting 2″×2″ slides, and a great deal of thought has been given to good design of details and to convenience in use. The constructional details are shown in the diagram (fig. 2). The functionally shaped body, which is mounted on an exceptionally steady base, contains a 250-watt projector lamp* (2), an aspherical condenser (3), reflector (1), and a special heat-absorbing filter (4). The lamphouse can be tilted for vertical positioning of the screen image, and fixed in any position with the clamping screw (6). For normal projection,

* The 500 watt lamp can only be used with the blower.

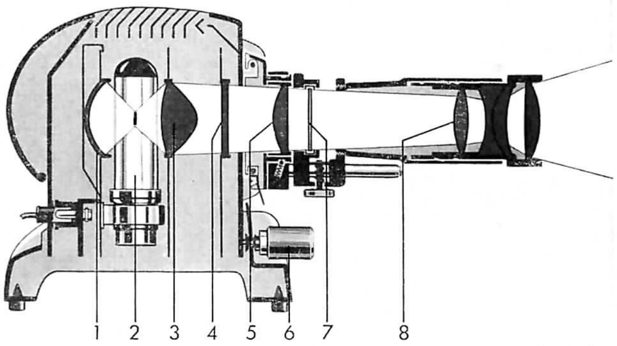


Fig. 2 Diagram of the projector in vertical section.

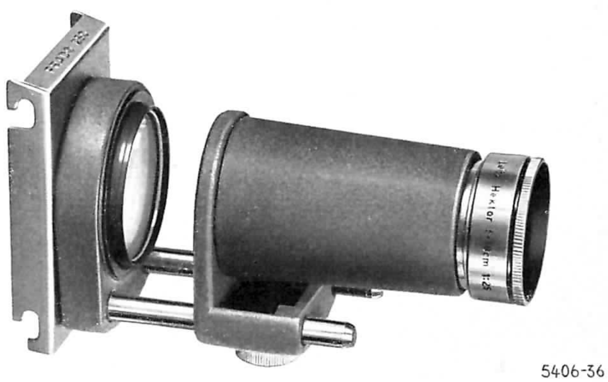


Fig. 4 Normal projection attachment with guide bars.

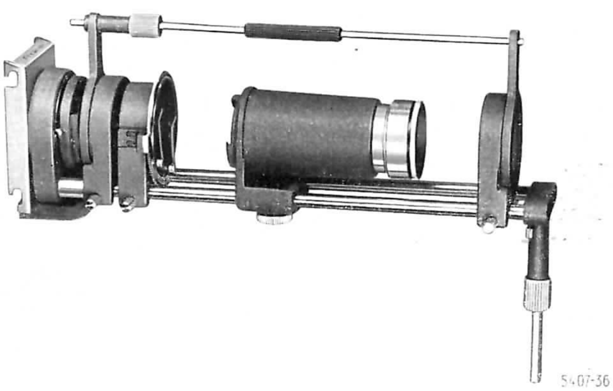
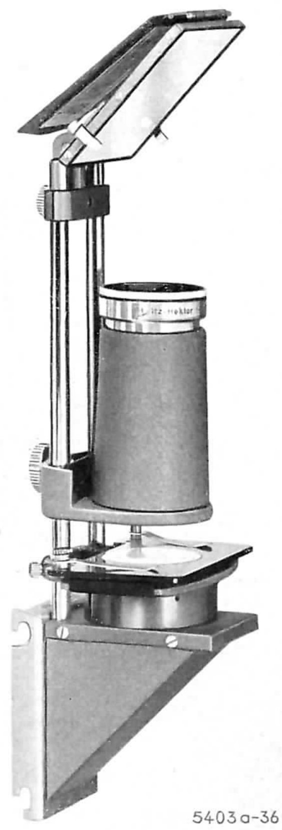


Fig. 3 Lamp housing.



▶ Fig. 5 Vertical projection attachment.

◀ Fig. 6 Large horizontal attachment for experiments in polarized light.

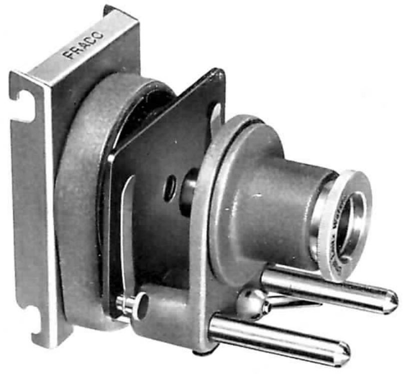


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Fig. 7 Small micro-attachment.

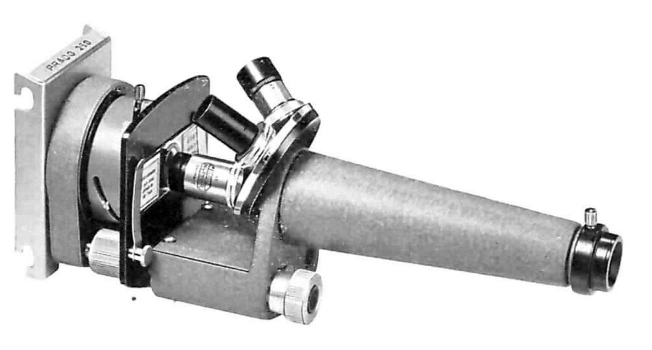

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Fig. 8 Large micro-attachment.

there are (fig. 3) an interchangeable condenser (5), removable slide carrier (7), and interchangeable lens (8). The whole projection system can be detached as a unit and replaced by any one of several other attachments. It is this choice of projection systems which makes the PRADO 250/500 so eminently suitable for a wide variety of class experiments.

For example, the 2"×2" slide attachment and its supporting bars (fig. 4) can be exchanged either for the vertical attachment (fig. 5) with its horizontal object stage, or for an attachment with extra long supporting bars (fig. 6), which is used in all experiments with polarized light. Microscopical preparations can also be projected, for which there are two types of equipment — the small micro-attachment embracing a large field and giving magnifications up to 240× on the screen, and the large micro-attachment giving magnifications up to 2400×. The large micro-attachment can also be used with the vertical attachment to project fluid or unstable preparations (fig. 9). The arrangements shown in figs. 4, 5, and 6 are particularly convenient in that, since the projection lens and mount are movable on the guide bars, sufficient space is available between the condenser and lens for the projection of unusually thick transparent objects. Finally, a special attachment (fig. 10) is available for converting the PRADO 250/500 to a miniature episcope for the projection by incident light of small objects such as crystals, beetles, lepidoptera, plant structures, etc.

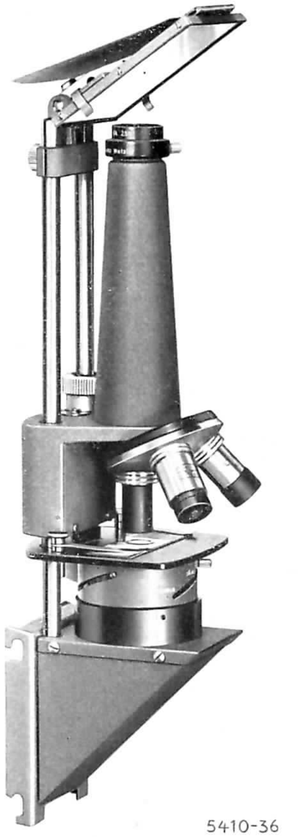

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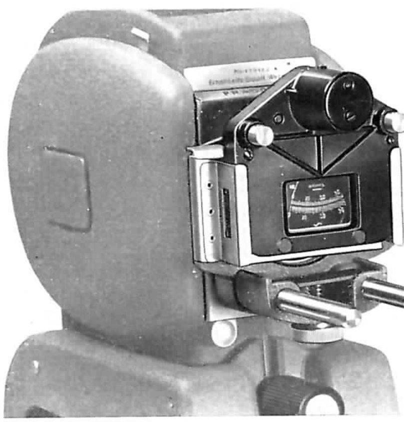
Fig. 9 Large micro-attachment mounted on the vertical projection attachment.
Fig. 10 Attachment for episcopic projection.

PROJECTION OF ELECTRICAL MEASURING INSTRUMENTS

In teaching the laws of electricity, it is very often necessary to measure current or potential, or to show the response of a galvanometer (for example, in measuring resistances with a wheatstone bridge). For CURRENT and POTENTIAL measurements, the 150 or 250/500 PRADO models can easily be adapted to project the scale of a suitable multi-purpose instrument[1]). It is only necessary to fix the instrument in position in place of the slide changer, and to connect it (in series or parallel, according to the type of measurement being made) with the teacher's own instrument, using the latter to bring the pointer to the desired part of the scale. The projected scale then appears on the screen as shown in fig. 12[2]). One great advantage of this arrangement is that the projected scale and pointer are free from parallax. Another is that the very bright image on the screen makes it possible to project in normal room lighting. It is also possible, using an apparatus such as that shown in fig. 13, to project two instruments simultaneously (fig. 14). They may, for example, be a voltmeter and an ammeter used together to demonstrate the relationship between current and potential. The apparatus can be constructed without elaborate workshop facilities from a couple of commercial moving-coil milliammeters such as are used in, for example, photo-electric exposure meters.

In teaching electrostatics, it is frequently necessary to show the response of an ELECTROSCOPE to a CHARGE. Fig. 15 shows a gold-leaf electroscope suitable for this purpose mounted on the projector; it is enclosed between two glass plates which are separated by a metal spacing ring 5 cm. (2 inches) in diameter and 4 cm (1⅝ inches) long. The image on the screen appears as in fig. 16. It is also possible to compare two charges by using the DOUBLE ELECTROSCOPE shown in fig. 17, the image appearing as in fig. 18. With this instrument, all of the usual fundamental experiments in electrostatics can be most elegantly demonstrated.

1) Messrs. Hartmann & Braun, Frankfurt/Main, can supply the MULTAVI-Instrument.
2) This and the other pictures of the projected images were photographed with the LEICA.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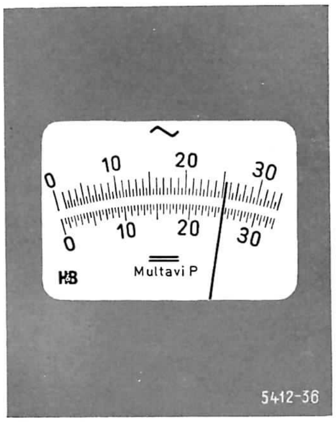
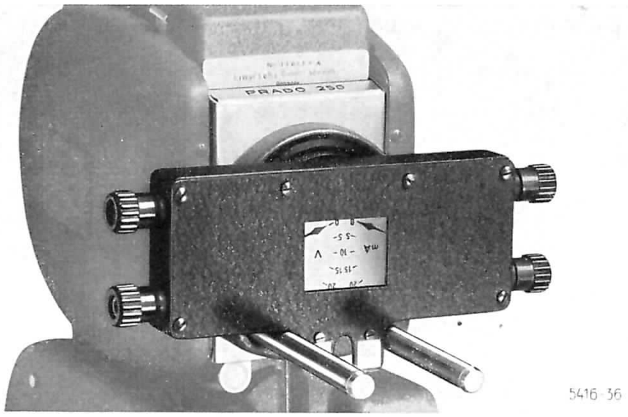


Fig. 11 Method of mounting multi-purpose meter on the PRADO projector.

Fig. 12 Appearance on projection of scale of meter shown in fig. 11.



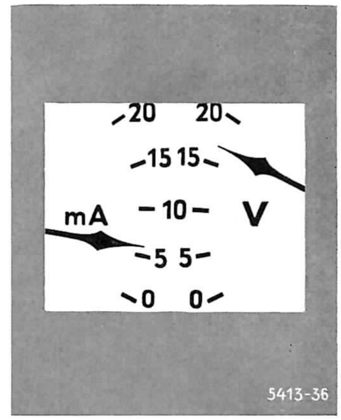
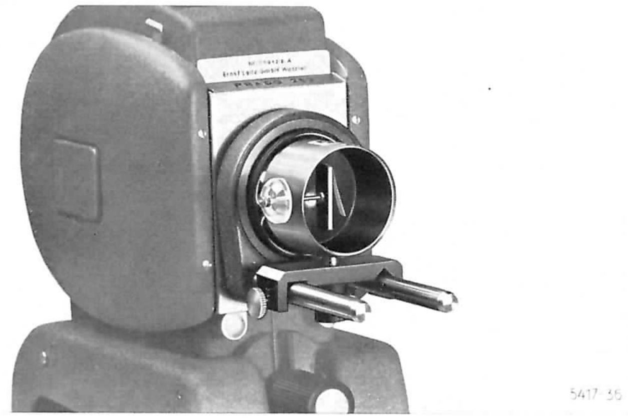


Fig. 13 Combined volt- and ammeter mounted on PRADO projector.

Fig. 14 Projected scales of instrument shown in fig. 13.



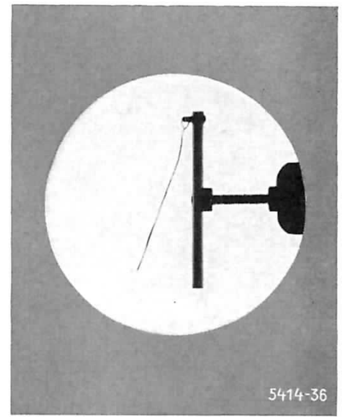
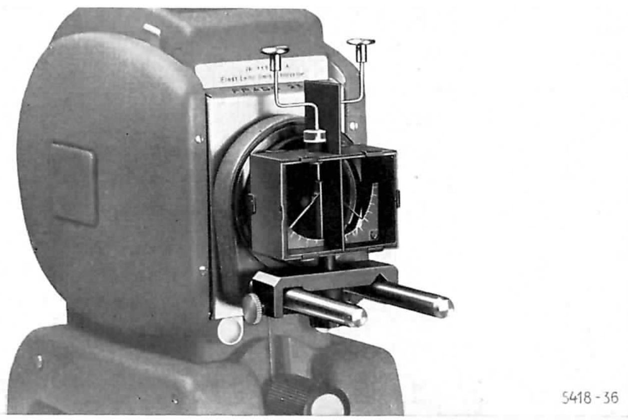


Fig. 15 Method of mounting gold-leaf electroscope on PRADO projector.

Fig. 16 Projected silhouette of the electroscope. The screen image has been brought the right way up with a reversing prism.



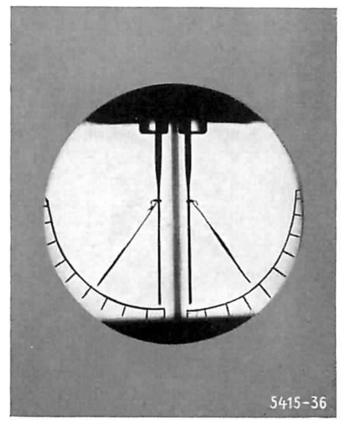


Fig. 17 Double electroscope mounted on PRADO projector.

Fig. 18 Projected silhouette of double electroscope. As in fig. 16, the screen image has been turned through 180°.

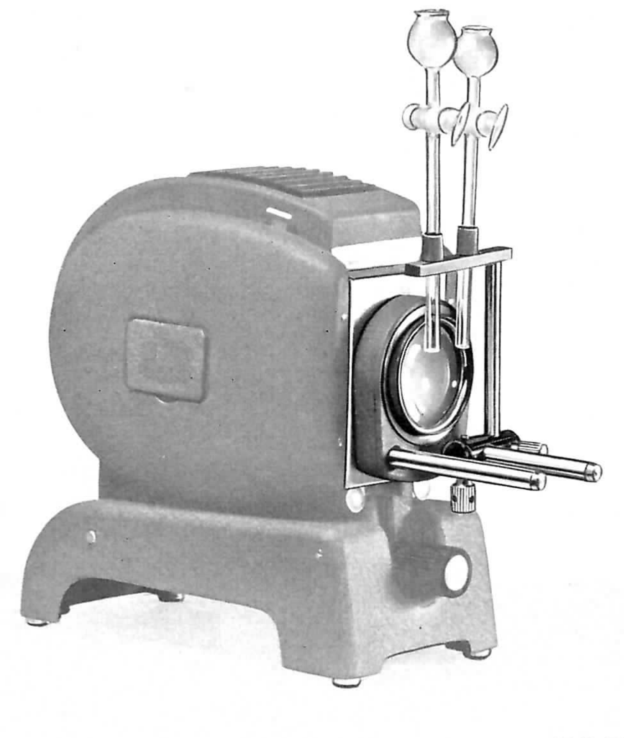


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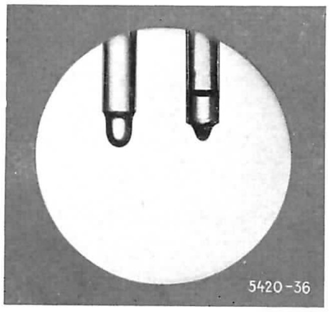
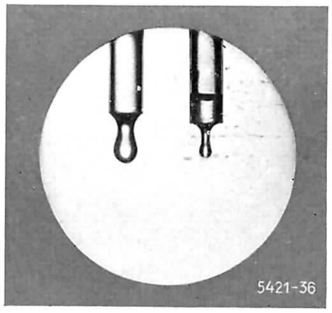
Fig. 19 Projection arrangement for comparing drop formation with water and alcohol.

Fig. 20 Projected image formed by arrangement shown in fig. 19. Left: water. Right: alcohol.

(a) Start of drop formation.



(b) Drops just before breaking off.



OTHER EXPERIMENTS USING THE NORMAL PROJECTION ATTACHMENT AND ITS SUPPORTING BARS

The unusually large separation of the condenser and lens which has already been mentioned, can be utilized to project a variety of phenomena which are otherwise most difficult to show to a large auditorium.

1. Drop Formation

By using the very simple arrangement shown in fig. 19, the process of drop formation can be projected. Two stages in this are shown in fig. 20; water (left) and alcohol (right) are issuing from the ends of glass tubes. As is well known, the size and shape of such drops depend on the surface tension of the liquid, the values of which in this case are: water 72.5 dynes/cm; alcohol 22 dynes/cm.

2. Wine "Tears"

This same difference in surface tension is responsible for the "tears" which can be seen forming on the sides of the glass above any strongly alcoholic liquid — liqueur, fortified wine, etc. They appear as drops which slowly grow and finally run down the sides. They are caused by the film of liquid on the sides of the glass losing alcohol by evaporation more rapidly than the main bulk of the liquid beneath. As the alcohol content of the film falls, its surface tension rises; this draws fresh liquid up the glass surface and, finally, when the amount of liquid on the glass exceeds a certain limit, it coalesces into drops and runs down the side. This will occur only in a wide glass which allows of free evaporation, and not in a narrow-mouthed or closed vessel. The phenomenon is easily shown by projection. A rectangular glass trough about 3 cm (1¼inches) deep is placed between the lens and the condenser of the PRADO, and is filled to a depth of 5—6 mm ($^3/_{16}$ inch) with a fortified wine such as port, or with a 2:1 alcohol/water mixture. The side nearest the condenser is focused on the screen, and the formation and running down of the drops can be clearly seen by the audience. Blowing into the trough to speed evaporation helps the experiment; on the other hand, the process stops at once if the trough is covered with a glass plate.

3. Surface Phenomena

The work of the physicist Plateau showed that the surfaces of liquids and bubbles tend to a MINIMUM, and that more than three liquid films cannot intersect at one point; where three do intersect the three angles thus formed are all equal. This can be demonstrated with the PRADO Projector. A stout glass trough about 1 cm (3/8 inch) between the faces, and containing a little soap solution, is placed in front of the condenser. Air is then blown through the liquid with a thin rubber tube until the resulting bubbles fill the trough and the soap films between them stretch between its opposite faces. The result, when projected, appears as in fig. 22; nowhere do more than three films meet at an angle, and the intersecting angles are all equal (120°).

These examples should suffice to show the variety of experiments which can be clearly projected with the PRADO and its normal projection equipment. It should be an easy matter to devise similar experiments to illustrate the laws of capillarity, molecular physics, heat, electrolysis, etc.

BIOLOGICAL and CHEMICAL phenomena can also be projected in the same way. For example, if a cell (5×5×1.5 cm, or about 2×2×5/8 inches) containing a few shoots of the water-weed **Elodea** is projected, bubbles of gas will be seen forming at the tips of the shoots. These consist of oxygen produced photochemically by the leaves. It can also be shown that actinic (blue) light is most effective in promoting this reaction by interposing a red filter. Another simple test will show that the gas is oxygen: in the same cell the shoots of **Elodea** are immersed in a solution of reduced indigo carmine, which is then covered with a layer of liquid paraffin. The photochemically produced oxygen oxidizes the reduced compound to the dye, which appears as blue clouds around the leaves.

The COLOUR REACTIONS used in CHEMICAL ANALYSIS, as well as PRECIPITATION and CRYSTALLIZATION, can be shown in the same way to a large class. It is also possible to demonstrate OSMOSIS; the same cell is filled with a dilute solution of copper sulphate and a few crystals of potassium ferricyanide dropped into it. A semi-permeable membrane of copper ferricyanide forms immediately at the crystal surfaces, and immediately, since the liquid inside the membrane is a concentrated solution of potassium ferricyanide, osmotic pressure causes solvent to pass through the membrane from outside. In consequence, the membrane swells and eventually ruptures in one or more places, each rupture being immediately sealed with a freshly formed membrane. The ultimate result, which appears on the screen as in fig. 23, is the formation of membranous tubes rising from the crystals, and looking rather like an algal growth.

In all these experiments, the picture on the screen is, of course, upside down. In most cases this is of no importance; if, however, it is essential to show anything the right way up this can be done by using a reversing prism in front of the projector lens.

The screen images shown in figs. 20–23 have all been turned through 180° – i.e. brought the right way up – by a reversing prism.

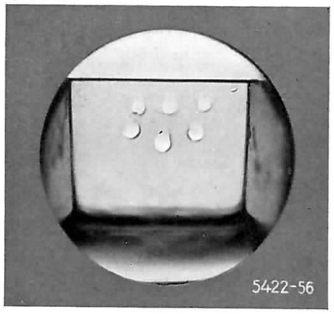


Fig. 21 Drop formation on the wall of a trough containing alcoholic liquor.

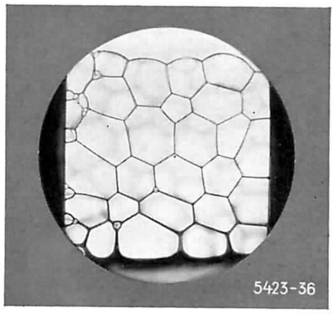


Fig. 22 Soap bubbles filling a glass trough.

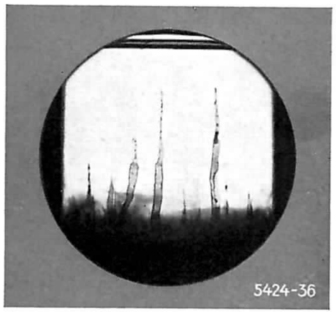


Fig. 23 An osmosis phenomenon.

can be attached to the lens holder (5). The top of the object stage (3) carries two detachable clips and has a glass disc, 48 mm ($1\frac{7}{8}$ inches) in diameter, let into its centre. The whole of this top can be shifted forward out of its carrier. This makes it possible to change the projected preparation very quickly, by having each one permanently mounted on a separate top. The arrangement is particularly suitable for the projection of liquid or unstable preparations, or of phenomena which occur only in a horizontal plane. Some typical examples of this are described below.

For the projection processes occurring in a liquid or at its surface, a flat-bottomed cell such as that shown in fig. 25 may be used. It can be constructed by turning up a ring 8—10 mm (about $\frac{3}{8}$ inch) long and about 60 mm ($2\frac{3}{8}$ inches) diameter out of brass tube, and cementing this to a glass plate with a waterproof cement such as Araldite.

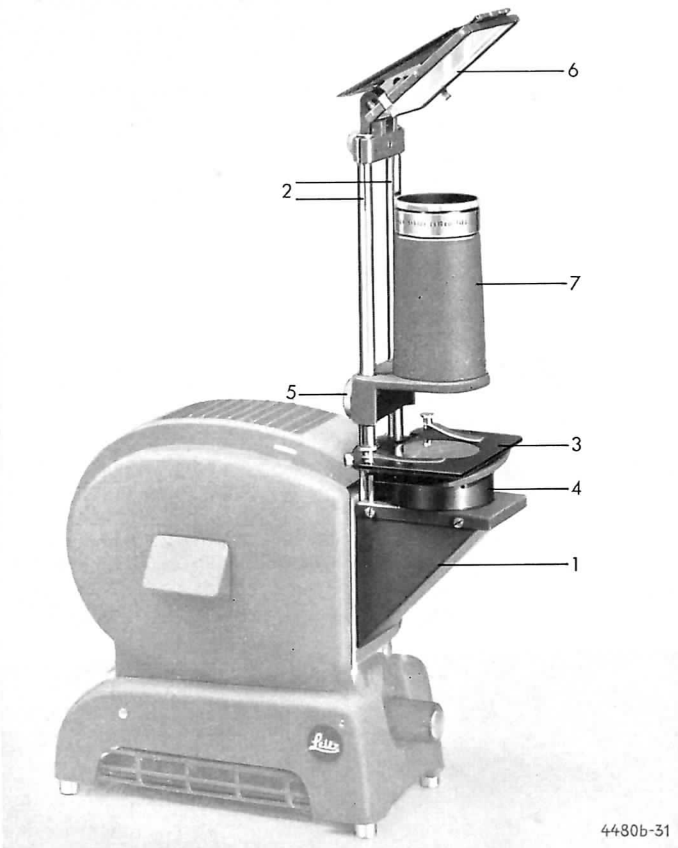


Fig. 24 Method of mounting vertical projection attachment on the PRADO.

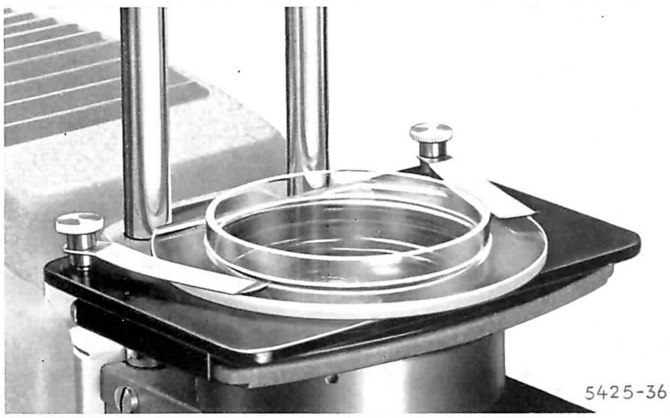


Fig. 25 Method of mounting a glass dish on the vertical projection attachment, for showing phenomena occurring at the liquid surface.

EXPERIMENTS WITH THE VERTICAL PROJECTION ATTACHMENT

The vertical projection attachment is shown in fig. 24. It consists of: the enclosed mirror (1), which deflects the beam of light emerging from the lamp housing upwards through 90°; the vertical bars (2) attached to the mirror housing and carrying the interchangeable condenser (4) and, above this, the object stage (3), the lens holder (5), and the external deflecting mirror (6), which can be adjusted to any angle. Any of the normal projection lenses (50—120 mm focal length) and its supporting tube

1. The Surface Tension of Water and its Effects

It is a well-known fact that surface tension causes the surface of a liquid to behave like a taut "skin", able to support small objects. This can be demonstrated by carefully laying a sewing needle or paper clip on the surface with forceps. If this experiment is projected, it will be obvious that the object is floating on the surface, which can be seen in the picture on the screen to be slightly depressed by the weight (fig. 26). The object sinks if the surface tension is reduced by the addition of a little wetting agent or detergent.

2. Demonstration of the Difference in Surface Tension between Water and Alcohol

A little coloured water, less than enough to cover the bottom, is poured into the flat glass cell (fig. 27a). Alcohol is then dropped with a pipette on to the unwetted part; this will cause the water, on account of its higher surface tension, to "retreat" before the alcohol (fig. 27b). When the alcohol has evaporated, the water resumes its former configuration. This experiment can be repeated several times.

3. Effect of Dissolved Substances on the Surface Tension of Water

A little pure water is poured into the cell, which must be scrupulously clean for this experiment. Then, if a few fragments of camphor are dropped on to the surface, they immediately start to perform irregular gyrations. The explanation of this is quite simple. The solution of a trace of camphor from each fragment causes a local reduction of surface tension, and the consequent flow of liquid from regions of lower to those of higher tension carries the particles along with it. The motion stops immediately if the water surface is "wetted" with a trace of oil; touching it with an oily needle is sufficient. The oil spreads over the surface as a thin film, which extends beneath the camphor particles and separates them from the water.

This effect of camphor on surface tension can be shown by another, slightly more complicated, experiment. A short needle is cemented with a waterproof cement (e.g., Araldite), point upwards, centrally on the bottom of the cell, and a strip of mica is prepared as shown in fig. 28. It should be about 25×12 mm (1×½ inch), have a central hole large enough to admit the needle loosely, and at the ends holes about 4 mm (1/6 inch) in diameter with channels opening to the opposite long sides. On filling the cell with pure water and laying a small fragment of camphor in the entrance to each channel, the mica strip will beginn to rotate on the needle. The explanation is the same as before; a current flows out of each channel, causing the strip to rotate by "jet propulsion".

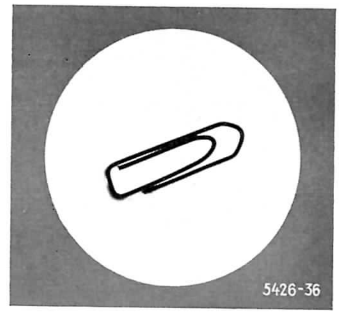


Fig. 26 Paper clip kept floating on water by surface tension.

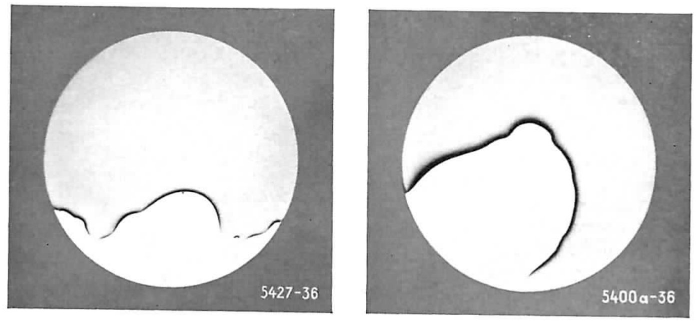


Fig. 27 Experiment showing the difference in surface tension between water and alcohol.
(a) Bottom of glass dish partly covered with water.
(b) Alcohol has been dropped on to the unwetted part of the bottom, and has caused the water to retreat owing to its greater surface tension.

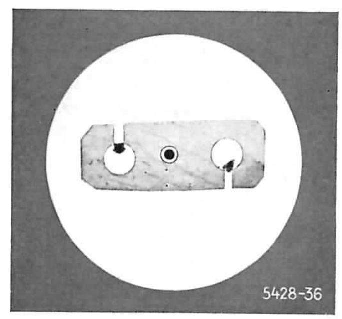
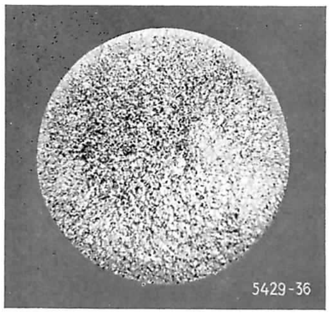
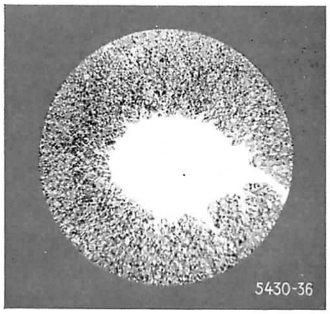


Fig. 28 Apparatus to show the reduction of the surface tension of water by dissolution of camphor.
Two fragments of camphor contained in the holes near the ends of the mica strip cause it to rotate.



a



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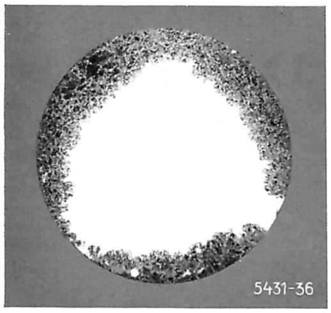


c

Fig. 29 Spreading of oil on water.
(a) Water surface dusted with lycopodium powder.
(b) The same surface after introduction of a trace of oil.
(c) The same surface after introduction of a further quantity of oil.

4. The Spreading of Oil on Water

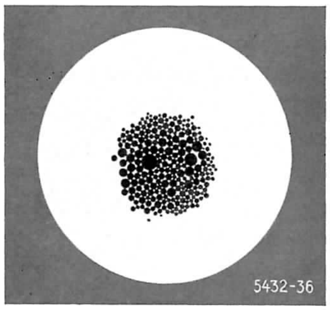
The cell, thoroughly cleaned of all traces of grease, is filled with pure water, and the water surface dusted with a fine powder such as lycopodium or talc. The cell then appears on projection as in fig. 29a. On touching the centre of the surface with an oily needle, the oil immediately spreads out in a thin film, forcing back the powder (fig. 29b). The clear area shows the extent of the oil film, and it can be enlarged by introducing more oil in the same way (fig. 29c).

5. Formation of Minimum Surface by a Liquid

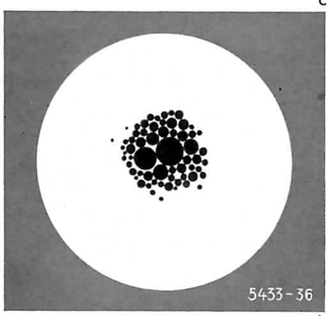
A flattened watch glass filled with acidulated water is laid on the projection stage. Some mercury is squirted into this in small drops with a fine pipette, and, initially, lies on the bottom as a pattern of numerous tiny drops (fig. 30a). The aggregate surface area of these is, of course, relatively very large, and immediately they start to coalesce into larger ones (figs. 30b—c), finally forming one large single drop (figs. 30d—f), which has the smallest possible surface for the given quantity of mercury.

6. Pulsating Mercury Drop

This is a most attractive experiment, which can moreover be demonstrated only by projection. Enough mercury to form a



a



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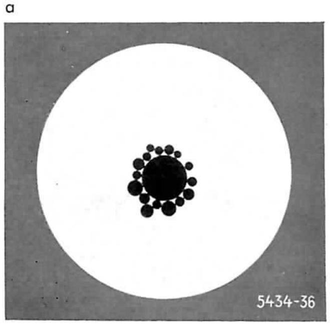

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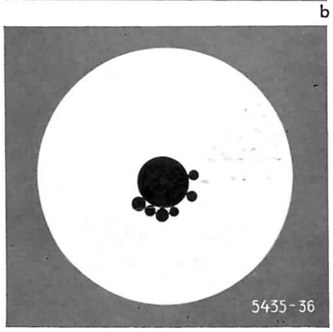

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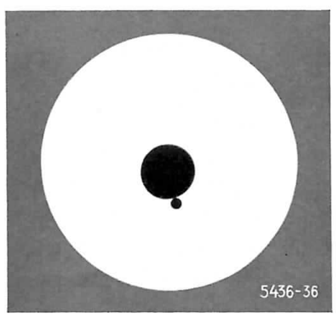
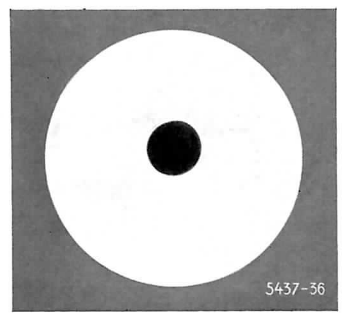


e



f

Fig. 30 Progressive coalescence, over a few minutes, of a large number of minute droplets of mercury (a) lying in water into one large drop (f).

small pool or large drop 10—12 mm (3/8—1/2 inch) in diameter is poured into a watch glass containing water acidulated with sulphuric acid and the side of the drop touched under water with the point of a sewing needle. Immediately the drop suffers a diminution of its surface and therefore contracts; by doing so it breaks contact with the needle, expands again to its former size, touches the needle again, shrinks again, and so on, finally reaching a state of continuous pulsation. The explanation of this is as follows. The mercury and the needle in the dilute sulphuric acid form a voltaic cell. Before the needle touches the mercury, this is an "open circuit", and the mercury acquires a charge, which reduces its surface tension and so causes the drop to spread out slightly under its own weight. When the needle touches the mercury, the circuit is closed and a minute current passes. The resulting polarization potential of the drop alters the charge on its surface and raises its surface tension. The drop therefore contracts to a smaller volume, which breaks the contact with the needle. For the success of the experiment, the mercury electrode must be prevented from becoming polarized by electrolytically liberated hydrogen; this can be done by adding to the acid a few crystals of potassium bichromate, which oxidises the hydrogen as it is formed.

7. Demonstration of Magnetic Lines of Force

Magnetic and electric lines of force can be shown very easily with the vertical projection attachment. The best arrangement for the former is to cement the small magnet or magnets to a glass plate (fig. 31), laying over this a second glass plate previously sprinkled with iron filings. The upper plate is kept horizontal and clear of the magnet by small feet or distance pieces fixed to its narrow ends. The lines of force are "developed" by tapping the plate gently. The projected appearances of various arrangements are shown in figs. 32 a—d.

A somewhat similar arrangement (fig. 33) can also be used to show the lines of force surrounding a WIRE CARRYING A CURRENT (fig. 34). The terminal block is fixed to the top of the object stage and carries a small piece of transparent plastic (e.g. Perspex), perforated for the wire to pass through, on which the filings can be sprinkled. Current can be taken from a 2—4 volt accumulator. The connecting wires should not be too thin.

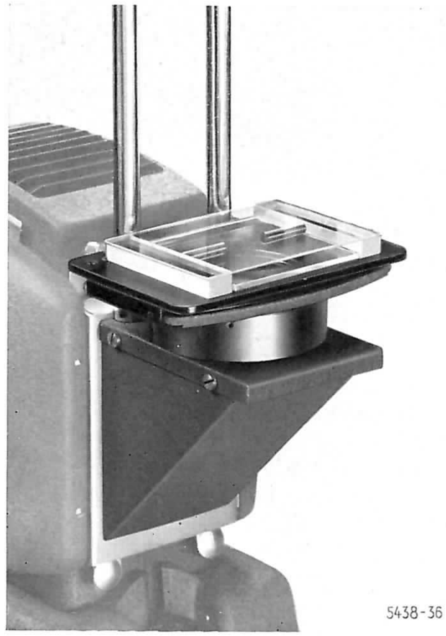


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Fig. 31 Arrangement for the projection of magnetic lines of force.

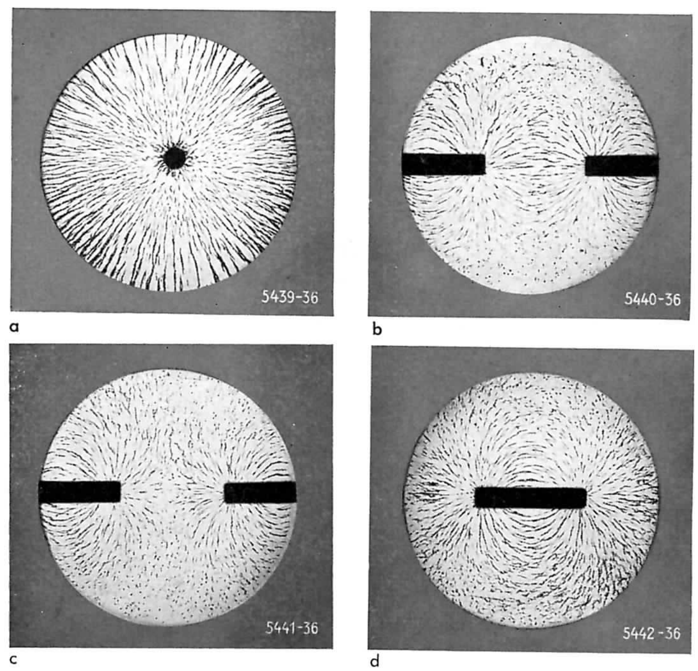
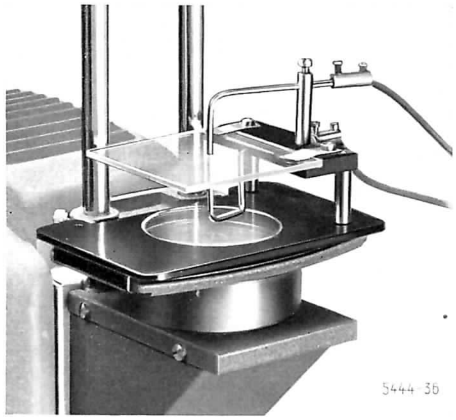


Fig. 32 Projected images of the lines of force surrounding various arrangements of magnets.
(a) Single magnetic pole.
(b) Two unlike poles.
(c) Two like poles.
(d) Single bar magnet.



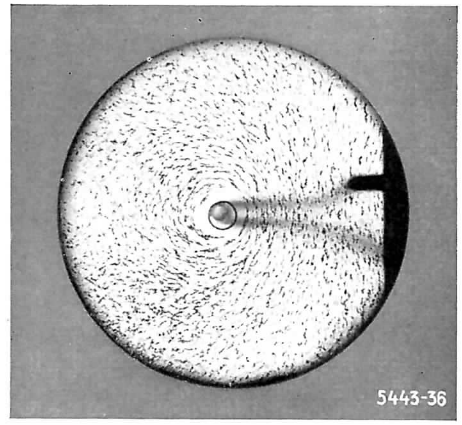


Fig. 33 Arrangement for the projection of the magnetic lines of force surrounding a conductor carrying a current.

Fig. 34 Screen image of the magnetic lines of force surrounding a conductor carrying a current.

8. Demonstration of Electric Lines of Force

Electric lines of force can be shown by projection in several ways. In one, a glass plate coated with shellac carries conductors which have been cut from tinfoil to the shapes to be investigated and stuck on to it, and these are connected to the poles of an electrostatic induction machine. The plate is sprinkled with finely powdered rutile (a form of titanium dioxide) or gypsum and the field turned on; the particles will then align themselves along the lines of electric force when the plate is gently tapped. This is due to neighbouring particles being attracted to each other by virtue of the induced charges on their adjacent ends.

Another method of showing electrostatic lines of force is to set the electrodes in a shallow dish, as shown in fig. 35. This is filled to a depth of several mm (say $^1/_8$ inch) with a fairly viscous insulating oil (e.g., castor oil or turpentine) containing a suspension of finely powdered semolina, and the field applied. The suspended particles then align themselves as before along the bottom of the dish. It is again most convenient to have the whole apparatus mounted permanently on an object stage. Some of the results produced in this way are shown in figs. 36a—d.

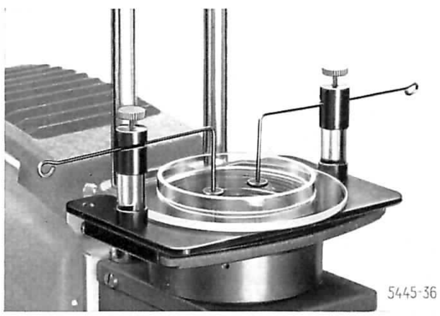
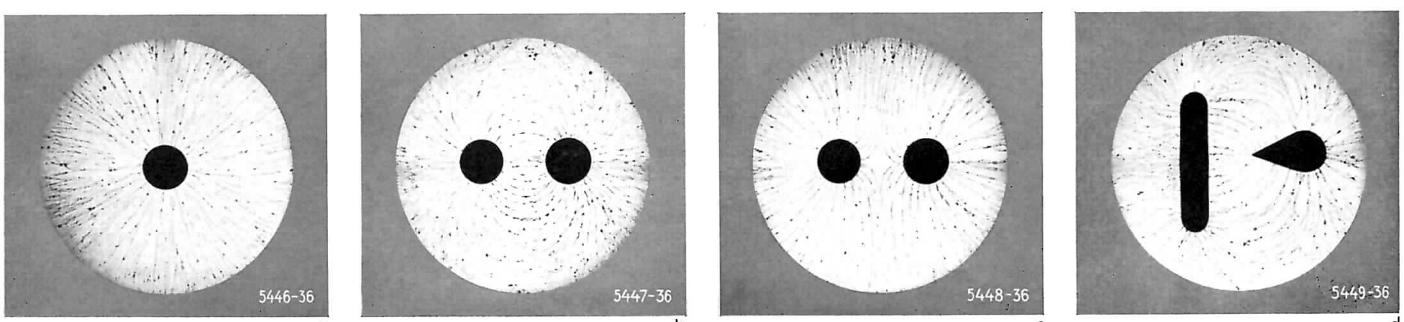


Fig. 35 Arrangement for the projection of electrical lines of force.

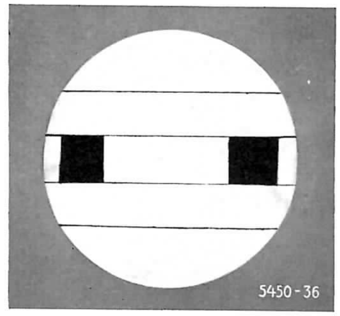
Fig. 36 Projected images of electrical lines of force.
(a) Single charged pole.
(b) Two oppositely charged poles.
(c) Two similarly charged poles.
(d) Point and surface bearing opposite charges.



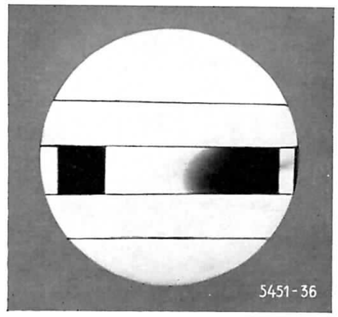
a b c d

9. Demonstration of Ion Migration

The apparatus used in expt. 8 will also serve to demonstrate ion migration. A long shallow trough, made by cementing together four strips of glass, is laid in the dish shown in fig. 35. Small packets of potassium permanganate crystals in blotting or filter paper, and small pieces of nickel foil to serve as electrodes, are laid in each end of the trough, and connections made with the bent wires shown in fig. 35. The cell is finally filled with a very dilute solution of potassium nitrate and covered with a glass slip. At this stage, it will appear on projection as in fig. 37a. When about 10 volts D.C. is applied across the terminals, the red permanganate ions begin to migrate away from the negative electrode (the cathode) along the trough, and the potassium ions migrate from the positive electrode (the anode) in the opposite direction.



(a)
The electrolyte (dilute potassium nitrate solution) is contained in a small rectangular trough between nickel electrodes, beneath which are small packets of powdered potassium permanganate in filter paper.



(b)
On the application of a D.C. potential across the electrodes, red permanganate ions migrate along the trough from the negative electrode (right) and potassium ions migrate from the positive electrode in the other direction, imparting a faint grey tinge to the solution.

Fig. 37 Projected image of ion migration in an electrolyte.

10. Demonstration of Ultrasonic Stationary Waves

(a) — With a Kundt's Tube

A little lycopodium powder is poured into a glass tube of 6—8 mm (¼—⅜ inch) internal diameter, and this is fixed across the opening of the object stage. By tapping the tube, the lycopodium is spread out in a uniform line along its length; the tube is then turned a little on its axis, so as heap up the powder slightly to one side. By blowing an ultra-sonic whistle (Galton whistle, "silent dog whistle"), as high-pitched as possible, in front of the open end of the tube, stationary waves are set up in it by reflection from the closed end. The position of these is shown by the powder; this remains undisturbed at the nodes, where the air is motionless, but at the intermediate antinodes (positions of maximum amplitude) it falls from the wall of the tube in a pattern of fine ripples. The result, projected with a superimposed transparent millimetre scale, is shown in fig. 39.

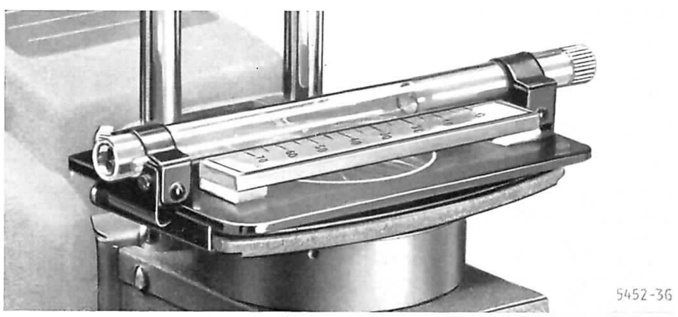


Fig. 38 Arrangement for the projection of stationary waves in a Kundt's tube.

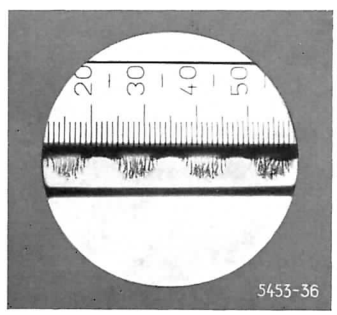


Fig. 39 Projected image of the arrangement shown in fig. 38; the powder shows presence of stationary waves produced by a frequency of 13.080.

The distance between two successive nodes or antinodes, as measured by the scale, is half the wavelength; hence the frequency can be determined by applying the simple formula

Wavelength × Frequency = Velocity of Sound.

In the example shown in fig. 39, the wavelength was 26 millimetres; therefore, taking 340 metres/second as the velocity, the frequency was 13,080.

(b) — With a Piezo-electric Quartz Crystal and an ultrasonic Oscillator

The apparatus for this is shown in fig. 40. The piezo-electric quartz crystal Q, which is about 25 mm (1 inch) long and has a fundamental frequency of 107,600, is mounted on the object stage so that its free end just projects into the picture area. In front of the crystal, and covering the projection window, is a glass plate G, and a reflector consisting of a block of metal about 5 mm ($^{3}/_{16}$ inch) thick is cemented to the plate about 4 cm ($1\,^{5}/_{8}$ inches) from the crystal. The crystal is connected in parallel with the variable condenser in the oscillating circuit of a valve oscillator. The glass plate is lightly dusted with lycopodium powder, and the crystal excited by turning the oscillator. As soon as it starts to oscillate, stationary waves are formed in front of the reflector, and the powder as before remains undisturbed only at the nodes. The result appears on projection as shown in fig. 41. The known distance between the quartz and the reflector enables us to determine the wavelength, which in this case is about 3.2 mm. A supersonic frequency as high as this will cause, as a secondary effect, an air current to flow outward from the oscillating crystal; it will be seen from fig. 41 that the powder is blown away from the immediate neighbourhood of the crystal.

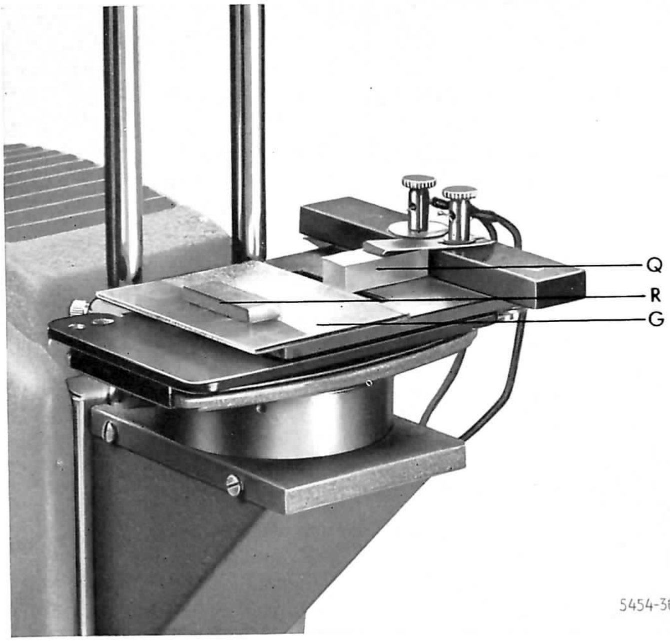


Fig. 40 Arrangement for the projection of stationary waves produced by an ultrasonic piezo-electric quartz crystal.
Q: Quartz. G: Glass plate dusted with lycopodium powder. R: Reflector.

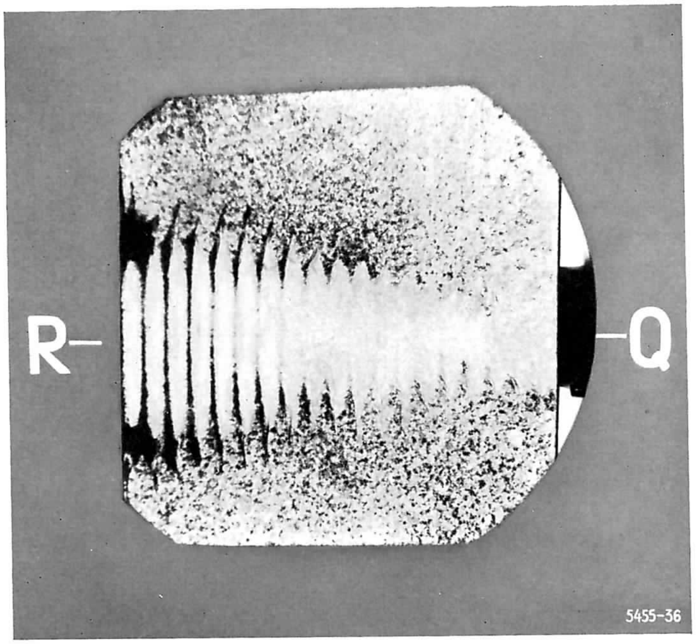


Fig. 41 Projected image of ultrasonic stationary waves revealed by lycopodium powder.

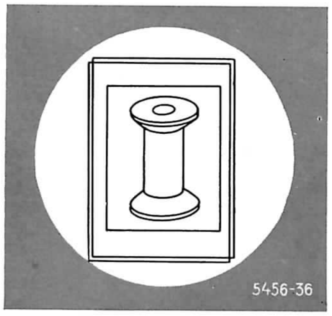
11. Optical Illusions

The LEITZ PRADO, used with its vertical attachment and horizontal object stage, is particularly suitable for the production of optical illusions in teaching physiological optics, as the following experiments will show.

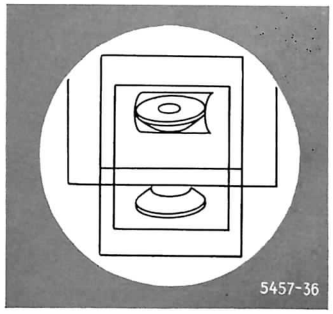
There are many familiar optical illusions in which the relative sizes and geometrical relationships in shapes and drawings are wrongly apprehended. For example, in the projected drawing of a cotton-reel shown in fig. 42a, the length of the central spool part appears distinctly greater than the diameter of the ends. In fact, these dimensions are identical. This can be effectively demonstrated to a large audience by an arrangement which, projected, appears as in fig. 42b. The projected picture 42a was in fact a composite one produced by the superimposition of two separate sketches, each showing a part of the reel, and the illusion can be exposed by turning one of these (as in fig. 42b) so as to compare directly the two lengths in question — a manipulation which is very easy on the horizontal object stage of the PRADO.

Another illusion is that shown in fig. 42c, in which the apparent curvature of the central line in each group of three depends upon the curvature of the outer lines, appearing greater when these are nearly straight then when they are sharply curved. In fact, both central lines have the same curvature, as shown by superimposition in fig. 42d. Lastly, fig. 42e and f shows the well known illusion in which parallel lines (42e) cease to appear parallel when they are crossed by oppositely directed oblique hatching (42f). This illusion is also very easily demonstrated by projecting two superimposed transparencies.

Fig. 42 Projected optical illusions.

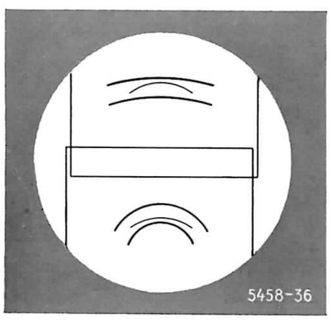


(a)
The vertical central part of the cotton reel looks distinctly longer than the diameter of the ends.

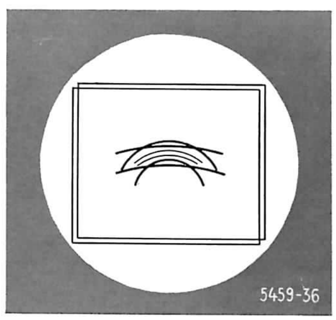


(b)
The two dimensions compared in (a) are in fact identical.

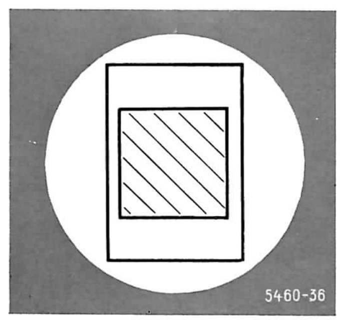
(c)
An arc of a circle lying between two flatter curves (above) appears to have a greater curvature than an identical arc lying between two more curved lines.

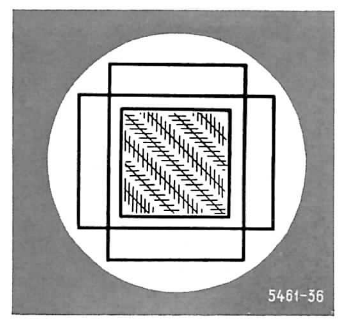


(d)
Both the central arcs shown in (c) have in fact the same curvature.



(e)
Parallel lines no longer appear parallel when they are crossed by oppositely directed oblique hatching.





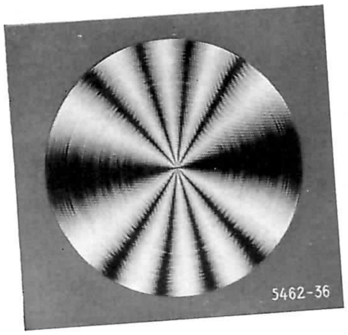
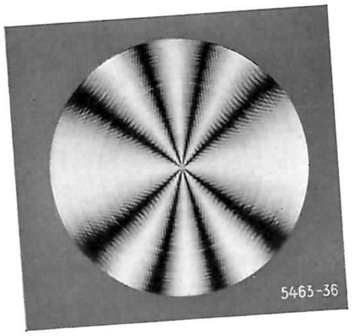
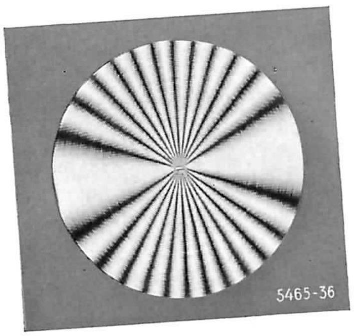


Fig. 43 Projected images of interference between wave trains produced by superimposition of two systems of concentric circles.

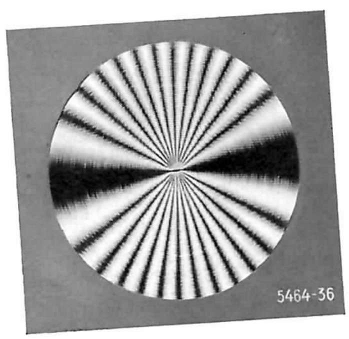
(b)
Centres 2 wavelengths apart.



(a)
Centres 3/2 wavelengths apart.



(c)
Centres 5/2 wavelengths apart.



(d) Centres 6 wavelengths apart.

12. Interfering Wave Systems

By using two transparencies which can be superimposed but moved about independently on the object stage, the patterns produced by the interference of identical wave trains are easily demonstrated. Each transparency bears a large number of concentric and equally spaced opaque circles, the clear and the opaque rings being equal in width throughout. This pattern can be considered as a median section across a train of spherical waves emanating from the centre of the circle, the clear circles representing the "crests" and the opaque circles the "troughs"; the distance between the mid-points of two successive clear or opaque rings is the "wavelength". If now two such transparencies are laid one on top of the other with the centres slightly offset, the resulting pattern will depend on the distance between their centres. If this is an integral multiple of the wavelength, then, in the direction of the line joining the centres, the waves are in the same phase and reinforce each other. If, on the other hand, the centres are separated by an odd multiple of half the wavelength (i.e., 1½, 2½, 3½ . . . wavelengths), the waves along this line are completely out of phase and both wave trains are extinguished. In other directions, interference maxima and minima occur, which are more numerous and closer together the further apart are the centres. Figs. 43a—d show the projected interference patterns produced when the centres are separated by 2 wavelengths (43a), $^5/_2$ wavelengths (43b), 6 wavelengths (43c) and $^{13}/_2$ wavelengths (43d).

13. Experiments with a Rotating Disc

A number of experiments in physiological optics utilize a rotating, sometimes particoloured, disc, and this can also be shown very conveniently to a large class with the PRADO Projector and its vertical attachment. The whole apparatus is shown in fig. 44. A large ball-bearing K, with a central hole of about 40 mm. (1⅝ inches) diameter, is fixed to the stage with four screws and with the opening over the aperture in the stage. A short piece of brass tubing fixed in the hole carries a milled ring S, and the whole can be rotated rapidly by a belt driven from the small electric motor M fixed to the side of the stage. The discs used in the experiments are held in the open end R of the brass tube. They are easily made by photographing the appropriate pattern with a miniature camera on positive film, cutting out circles of the required size, and mounting them between pairs of circular glass plates.

Figs. 45 and 46 show two typical experiments. A pattern of equal black-and-white strips (fig. 45a) appears on rotation as a target-like pattern of white and grey rings (fig. 45b). The same pattern is produced if a black spiral is rotated rapidly around its centre. A bright star (fig. 46a) shows on rotation the pattern seen in fig. 46b. This subjective pattern has some interesting and unexpected features. The annulus enclosing the points of the star does not, as one might expect, appear as a simple transition zone between the bright centre of the star and the dark background. Instead, the bright centre is surrounded by an even brighter ring, and the periphery of the star pattern appears even darker than the surrounding background (fig. 46b). This curious phenomenon was first described by Mach. It always occurs in the perception of an unsharp boundary between dark and light areas, and it is, for example, the cause whereby, in reading black print on white paper, we are able to see the individual letters as sharply defined.
Lastly, among experiments of this type, we may mention the various types of multicoloured discs (Benham's discs) which produce additive mixed colours on rotation. They are easily prepared for projection from coloured gelatin film.

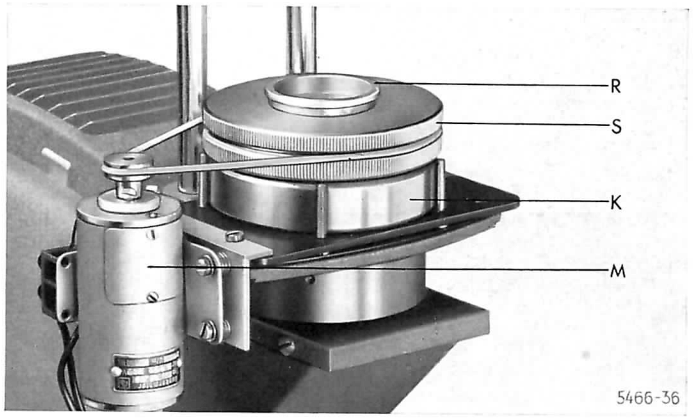


Fig. 44 Arrangement for the projection of a rotating disc.
The ball bearing K is driven through a cord S by the small electric motor M. The disc to be projected is held in by the removable ring R.

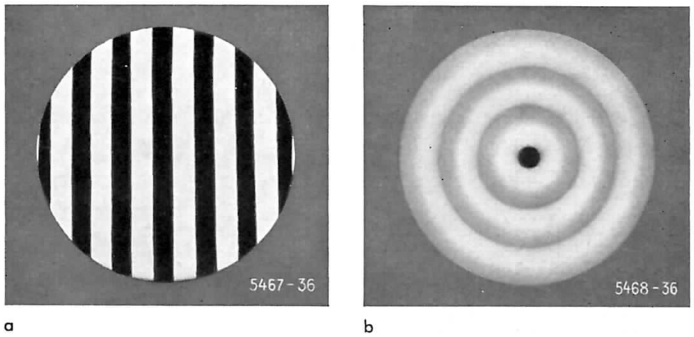


Fig. 45 A pattern of black and white stripes (a) shows on rapid rotation a target-like pattern of rings (b).

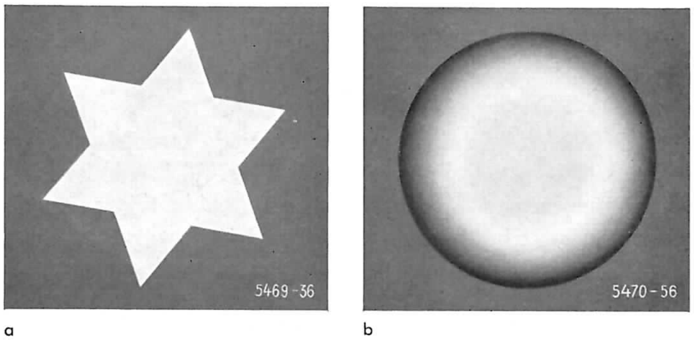
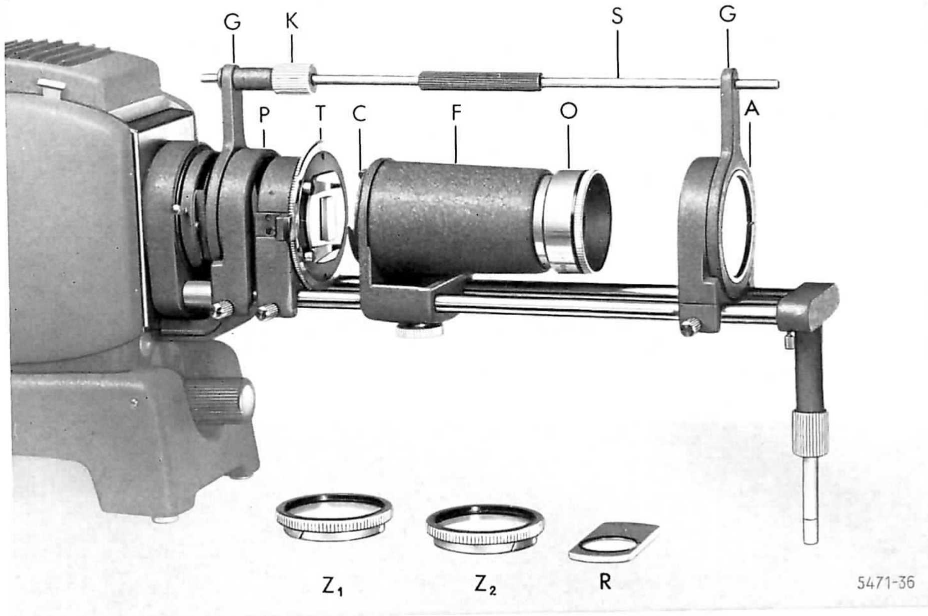


Fig. 46 Rotation of a star (a) produces the pattern shown at (b). The central light area is surrounded by an even lighter diffuse annulus, and the outer circumference of the pattern shows a dark ring even darker than the surrounding background. This subjective phenomenon was investigated by Mach.

Fig. 47 Projection attachment for experiments in polarized light.
P: Polarizer in rotatable mount
T: Rotatable object stage
F: Lens mount
O: Projecting lens
C: Slot for insertion of wave plate (red, first order)
A: Analyser in rotatable mount
S: Rod linking polarizer and analyser, allowing them to be rotated together
K: Screw clamp for rod S
Z_1, Z_2: Quarter-wave plates



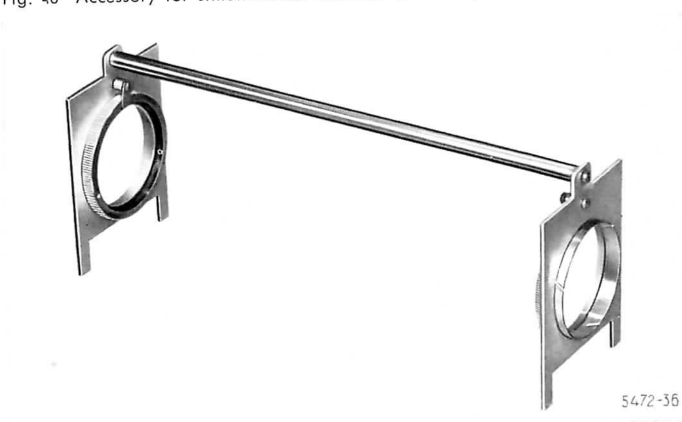
EXPERIMENTS IN POLARIZED LIGHT

Some of the most fascinating and brilliantly colourful optical effects are produced by using polarized light. Such experiments normally require the use of an optical bench together with an arc lamp, condenser, nicol prism, etc. — a fairly complicated and (at current prices) expensive collection of apparatus. Now, by using the PRADO polarization attachment, any polarized-light experiment can be rapidly shown to a large class without any "fiddling" centring and adjustment. The resulting visual demonstration is an impressive one that the students will remember.

1. Experiments with Parallel Light

Fig. 47 shows the projection attachment for experiments using parallel light. It has two bars about 30 cm. (12 inches) long, on which are mounted the polarizer P, a rotatable object stage T, an extension tube F carrying the interchangeable projection lens O, and the analyser A. The polarizer and analyser are made from exceptionally efficient polarizing film, and are mounted so that they can be rotated round the optical axis with the handles G. The light transmitted by the polarizer is polarized in the plane parallel to the direction of its handle; the plane of polarization of the analyser is perpendicular to its handle. The polarizer and analyser can if desired be connected by the rod S, and can then be turned together. In this position, their planes of

Fig. 48 Accessory for simultaneous insertion of both quarter-wave plates.



polarization are perpendicular (i.e., the field is dark). By loosening the screw clamp K, the rod S can be removed, and the polarizer and analyser can then be rotated independently.

For experiments with circularly polarized light, there are two quarter-wave plates Z_1 and Z_2 correctly positioned in the polarizer and analyser. The change-over from linearly to circularly polarized light can be made very quickly by using the accessory shown in fig. 48, which carries both quarter-wave plates, and with which they may be inserted simultaneously in the light path between polarizer and analyser. In addition, there is a slot C in the lens extension tube for holding a wave-plate (red, first order), the path difference of which is added to or subtracted from that of the object to be projected, according to the position of the latter.

With the complete outfit, every possible experiment in parallel, linearly polarized or circularly polarized light can be carried out*. The object under investigation is held in the object stage by two clips, and can be rotated on the optical axis. With a projection distance of about 5 metres (16 feet) and an objective focal length of 8·5—12 cm, the image on the screen will be 1—1·5 metres (3—5 feet) in diameter and quite bright enough to be clearly seen in a moderately dark room.

The following experiments will serve to illustrate the possibilities**. If a thin flake of a doubly refracting crystal (e.g., selenite or mica) is mounted on the rotating stage, it will exhibit a range of colours between crossed polarizers (dark field), as shown in fig. 49a (Plate I). The colours depend on the varying thickness of the crystal. If the crystal is rotated, each colour changes in intensity only there being four positions 90° apart at which the colours have their maximum intensity, and four intermediate positions at which no light is transmitted — that is, at which the colours disappear entirely and the field appears completely dark. If, at one of the bright positions, the analyser is turned through 90° (that is, to what would be the bright-field position in the absence of the double-refracting crystal), the colours change to their complementaries. With this setting, there are also four positions of maximum colour intensity, and four intermediate positions in which all light is transmitted — that is, the field appears bright and colourless.

Since the colour exhibited by the crystal depends upon its thickness, it is possible by skilfully controlled cleavage, or by superimposed mounting of very thin sheets, to make delightfully coloured "pictures", such as the butterfly shown in fig. 50 (Plate I). Fig. 50a was produced with crossed polarizers in the dark field, and 50b with parallel polarizers in the bright field.

The relationship between colour and crystal thickness can also be elegantly demonstrated with a wedge cut at the correct angle from selenite or quartz (fig. 51, Plate I). The sequence of interference colours so produced repeats at an interval corresponding to one wavelength increment in thickness, becoming paler (less saturated) the greater the total thickness.

Finally, fig. 52 (Plate I) shows the appearance in linearly polarized light between crossed polarizers of a plate cut from a twinned quartz crystal mounted perpendicular to the optical axis. A similar piece of uniform quartz would in these circumstances show a uniform colour over the whole field.

All of the experiments so far described have used double-refracting crystals. Isotropic substances such as glass, transparent plastics, etc., can also become double-refracting when elastically deformed by pressure, tension or bending. The following experiment demonstrates this. A small block of glass is mounted in a miniature press between crossed polarizers (fig. 53); as the press is screwed up, the most highly stressed parts of the glass show up as bright areas (fig. 54). Similarly, if a square glass rod is subjected to a bending force with the apparatus shown in fig. 55, then, in the dark field between crossed polarizers, it will appear as in fig. 56. The upper part of the rod, which is in compression, and the lower part, which is in tension, both appear bright, while the central unstressed zone remains dark.

* Sets of either 8 or 16 objects specially chosen for demonstration purposes can be obtained from Messrs. Ernst Leitz, Wetzlar.

** A full discussion of the optical theory underlying the experiments described here would be far beyond the scope of this booklet. Reference should be made to any good textbook of optics or advanced physics.

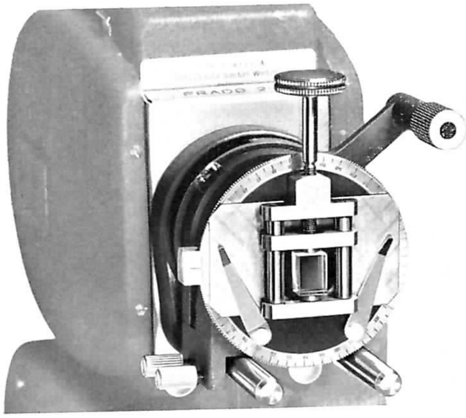


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Fig. 53 Arrangement for subjecting glass block to compressive force in a miniature press.

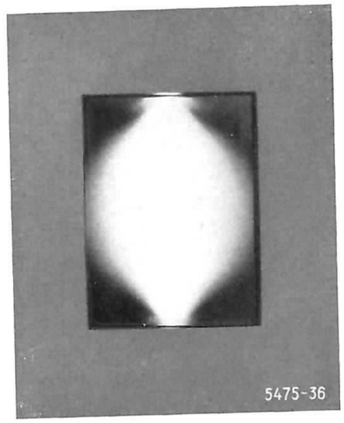

Fig. 54 Stress pattern produced in glass block by arrangement shown in fig. 54.

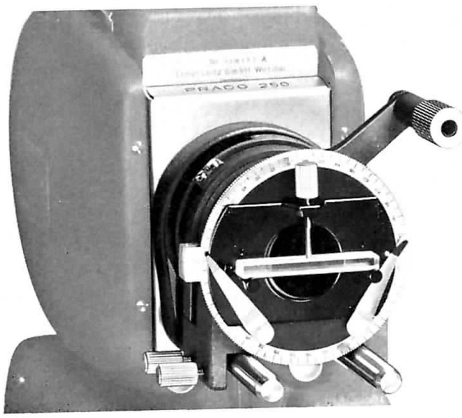

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Fig. 55 Apparatus for subjecting glass rod to bending force mounted on rotatable object stage.

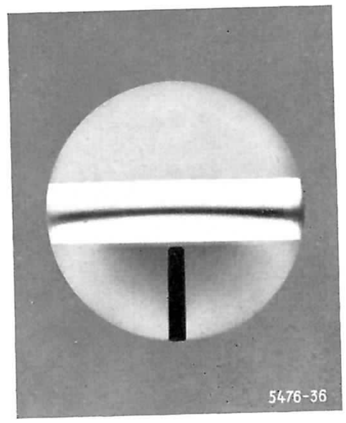
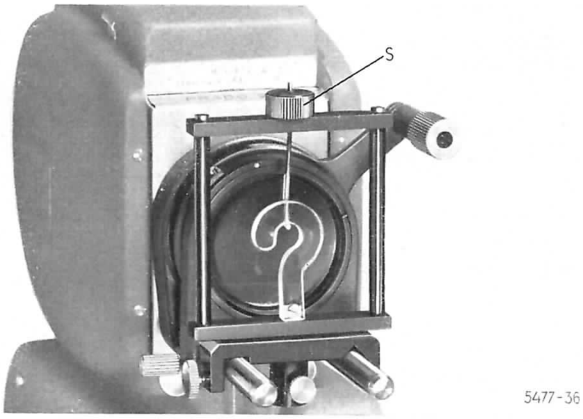


Fig. 56 Stress pattern produced in glass rod by apparatus shown in fig. 55.

It is important in both these experiments that the plane of polarization of the incident light should be at 45° to the direction of the applied force.

By a refinement of the last experiment, it is possible to differentiate between the compressed and the stretched parts of the rod. The wave plate (red, first order) is inserted in the slot of the lens mount, making the whole visual field red through the double refraction of the selenite plate. If now the experiment of subjecting the glass rod to a bending force is repeated, the red colour changes to yellow in the region of tension, and to blue in the region of compression, the colour of the unstrained zone remaining unchanged (fig. 57, Plate I).

This production of double refraction by stress is used in industry to study the stress distribution in the components of a new design. A reduced model of the component in Perspex or other transparent plastic is subjected while mounted between crossed polarizers to forces proportional to those it will have to bear in practice. A simple example is shown in fig. 58; a simulated load is applied to the hook, which is made from Perspex 3 mm ($^1/_8$ inch) thick, by tightening the screw S. Its appearance in



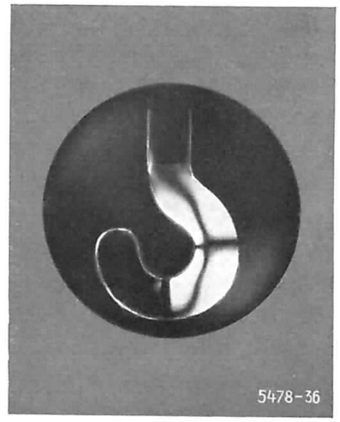


Fig. 58 Arrangement for demonstrating double refraction produced by strain in a loaded Perspec hook.

Fig. 59 Stress pattern in hook shown in fig. 58.

the dark field between crossed polarizers is shown in fig. 59, the stressed (compressed or stretched) regions appearing bright as before.

Glass, which is normally isotropic, can also be made permanently double-refracting by rapid cooling from above its softening point. The resulting contraction of the surface sets up large stresses inside the mass, and these will show up in polarized light. An example of this is shown in fig. 60 (Plate II). In linearly polarized light, a crossed setting of the polarizer and analyser always produces a central dark cross (fig. 60a and c), but in circularly polarized light this is absent (fig. 60b and d).

An isotropic substance can also be made double-refracting by the application of an electric field (the Kerr effect). This can be demonstrated as follows. A small glass trough approximately 15 mm (5/8 inch), between the faces is fixed in front of the opening in the object stage, and two insulated flat electrodes about 1 cm (3/8 inch) square and 1—2 mm (about 1/16 inch) apart arranged to dip into it from above (fig. 61). When the trough is filled with a suitable liquid, (e.g., nitrobenzene or carbon disulphide), and an alternating potential of about 1000 volts applied to the electrodes from a small transformer, the space between them transmits light in the dark field (fig. 62). The explanation of this is that, in the electric field, the liquid acquires the property of a uniaxial crystal with its axis parallel to the field. For showing this effect, the planes of polarization of the polarizer and analyser must be inclined at 45° to the direction of the field.

Fig. 61 Projected silhouette of Kerr cell (unpolarized light).

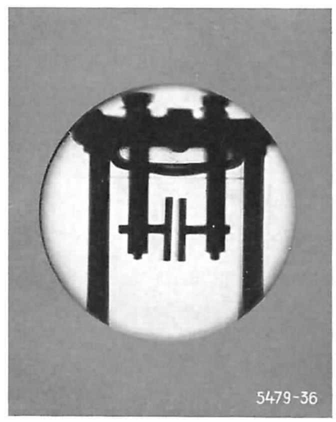
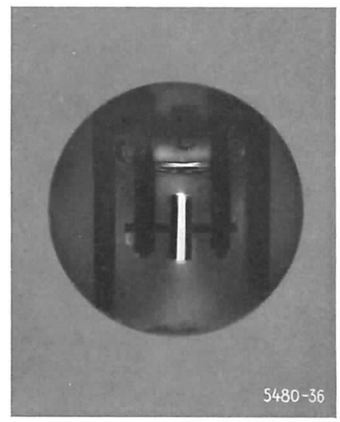


Fig. 62 Projected image of Kerr cell by polarized light between crossed polarizers and with A.C. potential applied to electrodes.



The rotation of the plane of polarization, and the dispersion to which this gives rise, can be clearly shown with the aid of a quartz plate a few mm. (say 3/8 inch) thick cut and polished perpendicular to its axis. In this case, the polarizer and analyser must be disconnected from each other, so that the analyser can be rotated separately. To show the rotation of the plane of polarization, the optically active compound, or a solution of it, is contained in a glass trough giving a path length of several centimetres (say 1—2 inches) and resting on the guide bars in front of the object stage. Suitable liquids are: oil of turpentine, oil of lemon, aqueous solutions of tartaric acid or of sucrose. With the trough empty, and using monochromatic (filtered) light, the apparatus is set to the dark field position (crossed polarizers) and the liquid then poured in; the analyser will now have to be turned through a greater or smaller angle to reach the dark-field position again. For detecting very small degrees of rotation, it is preferable to clip on to the object stage a biquartz plate — that is, one the opposite halves of which consist of two equally thick quartz plates with opposed directions of rotation — and then to set the analyser so that both halves of the field show the same colour.

To demonstrate the magnetic rotation of the plane of polarization (the Faraday effect), the arrangement shown in fig. 63 is used. A coil of several thousand turns is laid on the guide bars between the polarizer and the lens, and a glass tube of about 15 mm (5/8 inch) diameter and with plane ends occupies the centre of the coil, lying along its axis; the tube is filled with monobromonaphtalene. The lumen of the tube is focused on the exit aperture with the lens, and the polarizer and analyser turned to the darkfield position. When the coil is energized, light is transmitted and the field brightens. The direction of rotation depends upon that of the magnetic field — that is, upon the direction of the current in the windings. If the coil is energized with 50-cycle A.C., then there will be 100 pulses per second of transmitted light; in effect, the light is modulated with a frequency of 100, and this can be demonstrated by using a loudspeaker actuated by the amplified current from a photocell mounted in the path of the emergent light.

2. Experiments in Convergent Light

For experiments using convergent light, two condensers are used, one (K_1) mounted at the back of the rotatable object stage, and the second (K_2) mounted in a special holder in front of the stage. The first condenser makes the rays of light strongly convergent, and the second restores their parallelism. The object plane lies at the crossing of the convergent rays and is focused on the screen with the lens.

If a thin crystal of calc spar (Iceland spar) cut perpendicular to its optical axis is mounted on the object stage, the appearance on the screen will be as shown in fig. 65a (Plate II). The dark cross is a result of the polarizer and analyser positions; if they are turned together, the cross turns also; it remains stationary, however, when the crystal on the stage is rotated around the optical axis. The cross disappears in circularly polarized light (fig. 65b, Plate II).

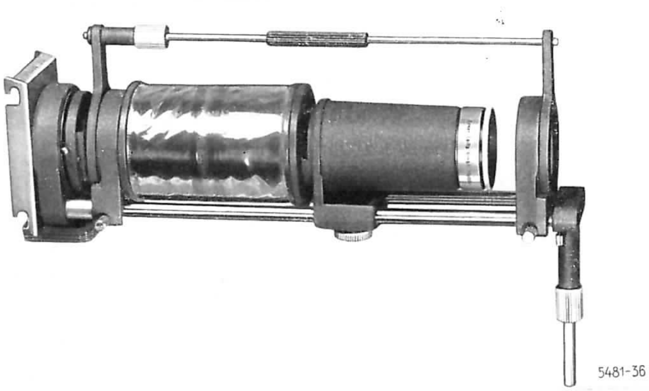


Fig. 63. Arrangement for demonstrating magnetic rotation of plane of polarization (Faraday effect).

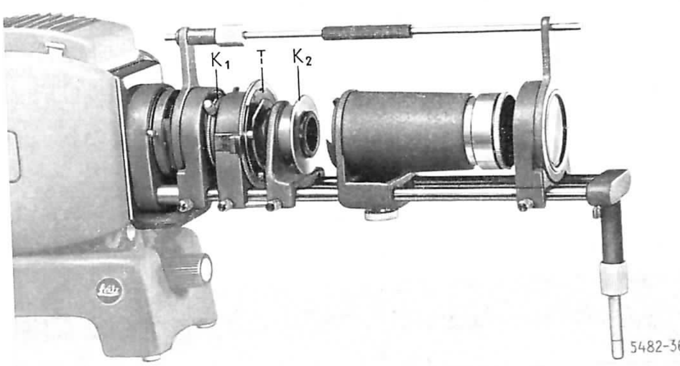


Fig. 64 Projection attachment for experiments in convergent polarized light.
K_1 = First condenser mounted behind rotating stage.
K_2 = Second condenser.

With an optically biaxial crystal (e.g., mica) convergent linearly polarized light gives the appearance shown in fig. 66a (Plate II). In this case also, the dark cross disappears in circularly polarized light (fig. 66b, Plate II). This last figure shows clearly the two systems of rings corresponding to the two axes. If the object stage and crystal are turned, the centres of the rings on the screen rotate round each other — a proof that the axes occupy fixed positions in the crystal.

EXPERIMENTS WITH THE MICRO-ATTACHMENTS

The biology teacher who wishes to project microscopical preparations will find his task much facilitated if he takes advantage of the possibilities of the PRADO micro-attachments shown in figs. 7—9 (p. 25 and 26). The preparations, whether permanent or fresh, can be brilliantly projected with a minimum of "fiddling" adjustments.

The small micro-attachment (fig. 7) comprises a special condenser to replace the interchangeable condensing lens (5 in fig. 2), a stage with two holding clips, and a 10× simple lens which acts as a projecting objective and which has a fine-adjustment for focusing.

This micro-attachment is primarily designed for projecting the whole of small objects up to 6—8 mm (¼—⅓ inch) across, such as insects and animal parasites. These may be permanently mounted in Canada balsam (or one of the newer synthetic mounting media) after clearing in xylol. With the 10× lens, which is normally used at a distance of about 25 cm (10 inches), (the distance of normal close vision) a throw of 6 metres (about 19 feet) gives a total magnification of about 240×; hence an object 7 mm. (¼ inch) across will have a screen image about 150 cm (5 feet) across. At this comparatively low magnification, there is sufficient depth of focus to show the whole preparation. Because of this, even living organisms contained in an "aquarium" cell (micro-trough) can be projected. A suitable cell, which has a liquid space 20 mm (just over ¾ inch) in diameter and 1·5 mm ($^1/_{16}$ inch) thick between the faces, is shown in fig. 67. As well as for showing living preparations to a large class, it can also be used to show microchemical tests — e.g., the effect of pH on the colour of the anthocyanins. A simple extract of red cabbage suffices for this; the micro-cuvette filled with it projects purple, the colour changing to red on addition of acid and to blue on addition of alkali.

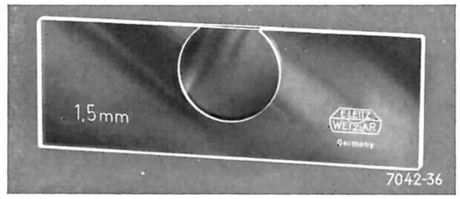


Fig. 67 Micro-trough

The large micro-attachment (fig. 68) consists in effect of a small microscope with a rotating nosepiece, a tubular body, and a stage with an adjustable condenser beneath it. After the interchangeable aspherical condensing lens has been removed, the

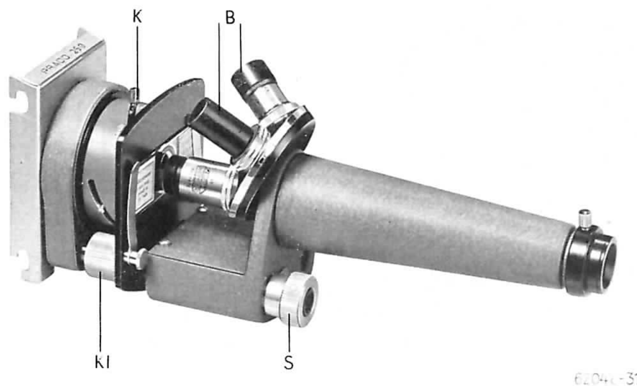


Fig. 68 Large micro-attachment for the PRADO projector.
K = Condenser, Kl = Clamping screw, S = Micrometer focusing screw, B = Protective cover for objective.

whole assemblage can be slid on to the guide bars of the normal projection attachment, and locked in position with the clamping screw Kl. Focusing is done with the micrometer screw S. With the three objectives normally fitted (3·5/0·10, 10/0·25 and 25/0·50), all of which have detachable protective caps (B), brilliant and contrasty projection is possible up to a distance of 6 metres (18—20 feet), with magnifications up to 2400×. The 25/0·50 objective is fitted with a spring-loaded mount to protect the front lens of the objective and the preparation on the slide during focusing.

Fig. 60 Double refraction induced by strain in rapidly cooled glass.
(a) and (c) In linearly polarized light between crossed polarizers.
(b) and (d) In circularly polarized light.

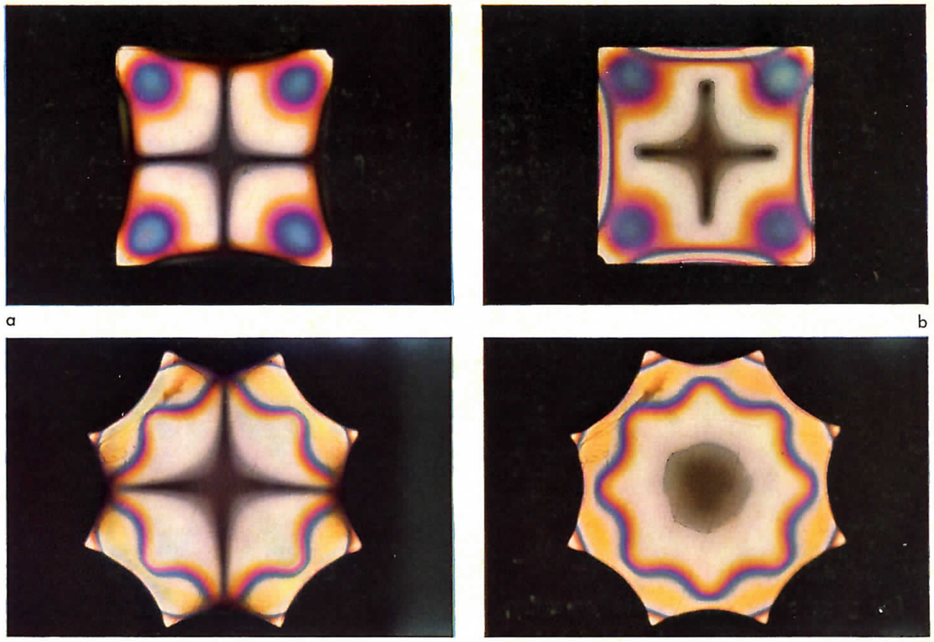


Fig. 65 Interference figures produced by a crystal of calc spar cut perpendicular to its optic axis (uniaxal crystal); convergent polarized light.
(a) Linearly polarized light between crossed polarizers. The dark cross is an effect of the polarizer and analyser position, and rotates as they are rotated.
(b) Circularly polarized light. The dark cross has disappeared. The central dark point corresponds to the intersection of the crystal axis.

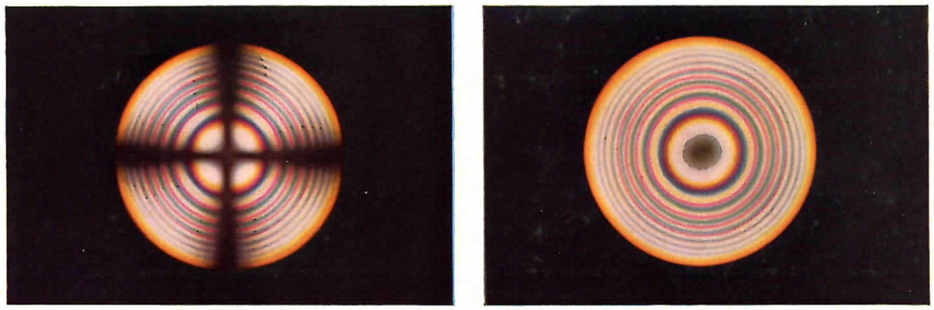
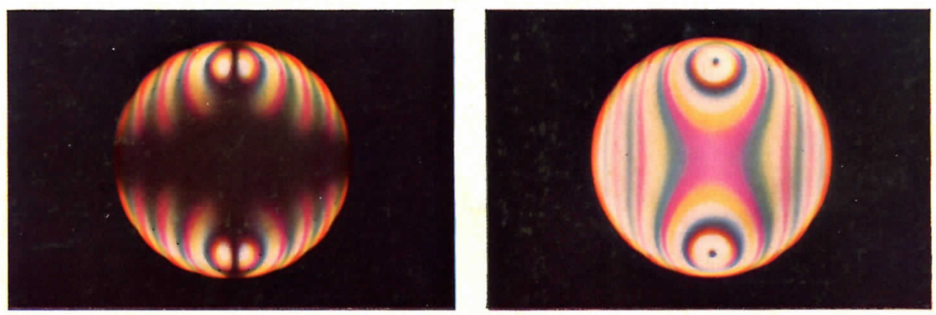


Fig. 66 Interference figures produced in convergent polarized light by a crystal of mica (biaxial crystal) cut perpendicularly to the primary axis.
(a) In plane polarized light between crossed polarizers.
(b) In circularly polarized light. The centres corresponding to the two axes are clearly visible; they will rotate around each other as the crystal is rotated on the object stage.



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Technisch-Pädagogischer Verlag Scharfes Druckereien KG · Wetzlar/Germany

Printed in Germany II/60/GX/SD

List **31-28**/Engl.