SPENCER

POLARSTAR

POLARIZING MICROSCOPE SERIES 2300, N2300, L2300

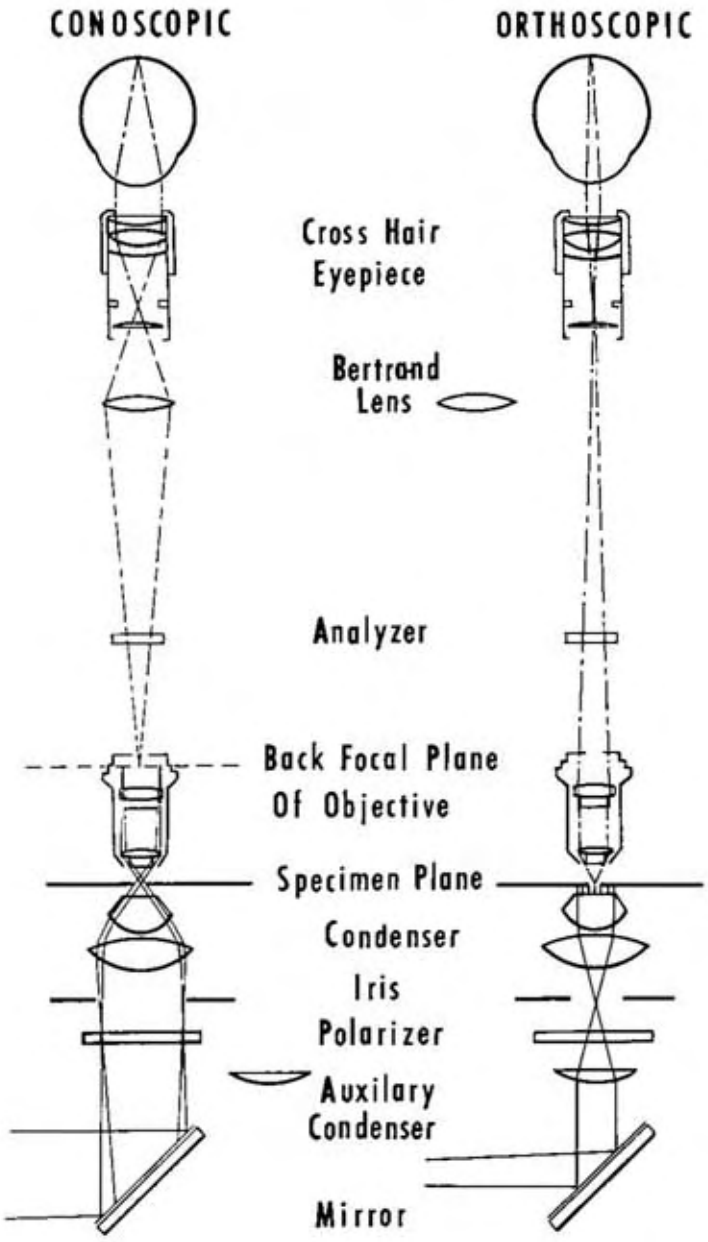
REFERENCE MANUAL

AMERICAN OPTICAL COMPANY • INSTRUMENT DIVISION • BUFFALO 15, N.Y.

The Use of POLARIZING MICROSCOPES

Science has found many uses for the optical phenomenon of polarized light—uses that affect an increasing number of industries and sciences—uses that affect the health, wealth and happiness of the average man. It is used in the determination of sugar concentration, as a test for strain in glass, to eliminate glare in photography or automobile headlights. It has many applications in scientific research, and the polarizing microscope is a most useful tool in industry.

This booklet will give you information which should prove valuable in the fields of petrography, chemical microscopy, and metallography for the study and identification of crystalline material.


CONOSCOPIC
ORTHOSCOPIC
Cross Hair
Eyepiece
Bertrand
Lens
Analyzer
Back Focal Plane
Of Objective
Specimen Plane
Condenser
Iris
Polarizer
Auxilary
Condenser
Mirror

Polarized Light and How it is Obtained

Ordinary light is said to vibrate in all directions perpendicular to its direction of propagation but polarized light is forced to vibrate in only one direction.

The ordinary light delivered to the microscope may be represented as in Fig. 1. The behavior of light that has been polarized could then be illustrated as in Fig. 2.

Polarized light was first obtained with natural crystals such as tourmaline. Later methods used black glass reflectors, or highly selected material called Polaroid.

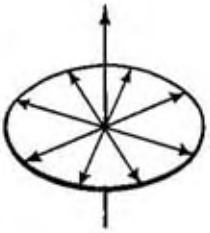


Fig. 1

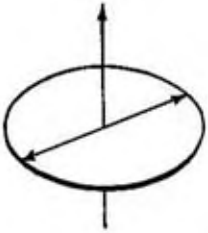


Fig. 2

A Polarizing Microscope includes a polarizer and an analyzer in addition to the optical equipment found in an ordinary laboratory microscope. The light is directed from the mirror or built-in base illuminator or attached illuminator to the polarizer, where it is changed to polarized light. From the polarizer the light passes on through the optical system to the analyzer. The analyzer is in a body tube mount with its vibration direction set at 90° to that of the polarizer as shown in Fig. 4. As a result of this setting none of the light which reaches the analyzer is allowed to pass. The extraordinary ray of the polarizer becomes the ordinary ray of the analyzer and therefore is blocked out of the field of the microscope. The field appears to be black.

Crystals and some other materials exhibit definite optical properties when observed in this field. The crystals rotate the plane of polarization and appear bright or colored on a black background.

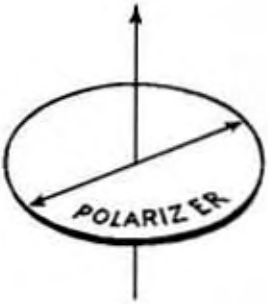


Fig. 3

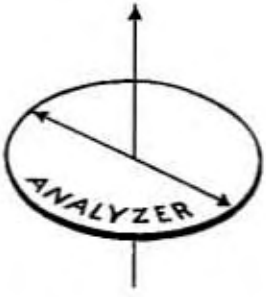
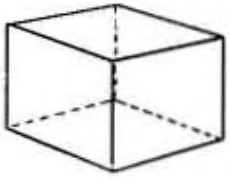


Fig. 4

Crystals and Their Optical Classification

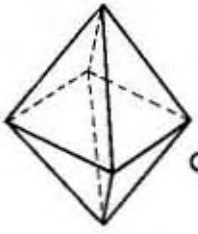
An important use of polarized light is the identification of crystalline material. This booklet gives a brief description of the optical properties of crystals which make possible their identification with a polarizing microscope.

A crystal is a solid body whose physical properties result from an arrangement of atoms into definite geometric forms, such as cubes, hexagons or rhombohedra. Precipitation, condensation and changes in the solid state are common methods of obtaining crystals.



Cube

Fig. 5



Octahedron

Fig. 6

They are generally classified under six systems. However, we are more interested in optical classification because each crystal has a


Wide Field Eyepieces
Bertrand Lens
Interchangeable Reversible Bodies
Polaroid Analyser
Compensator
Nosepiece
Strain-free Objectives
Focusable Stage

Fig. 7

set of optical properties which makes its identification possible. Optical classification divides crystals into three groups:

Isotropic (Isoaxial)
Anisotropic (Uniaxial)
(Biaxial)

Isotropic is a term to describe material which shows no bi-refringent properties or is invisible when observed between crossed polarizer and analyzer. Light travels through this material at uniform speed regardless of the direction of passage through the crystal.

Isoaxial: Such materials as glass not under stress, some transparent substances and certain crystals are "isoaxial", because light travels through them in all directions at the same speed. They are invisible between crossed polarizer and analyzer. These isoaxial crystals are identified by determining their single refractive index by the Becke Line Method.

Anisotropic refers to material which appears alternately bright and dark when rotated between crossed polarizer and analyzer. Light travels through this material at different speeds, depending upon the direction in which it passes through the crystal.

Uniaxial Crystals: In uniaxial crystals, light is said to travel at a definite speed when parallel to one axis. At an angle to this axis the speed is different. These crystals are anisotropic, appearing alternately bright and dark when observed between crossed polarizer and analyzer. They have two refractive indices. Quartz crystals, starch grains and fused sodium nitrate are a few uniaxial substances. Uniaxial material may be identified quickly by inserting the Bertrand lens* and observing a definite pattern, called an interference figure, appearing as a large black cross at the center of the field with colored concentric circles proceeding outward from the center.

Biaxial Crystals: In biaxial crystals, light travels at different speeds in the direction of the two axes. These crystals are anisotropic and have three indices of refraction which are determined by the Becke Line Method. Boric acid, Sulphonal, Topaz and Kyanite are a few biaxial materials. These crystals have several characteristic interference

*Bertrand lens conoscopically brings interference figure to focus in focal plane of eyepiece. Interference figures can also be seen by removing eyepiece and observing, with naked eye, through small apertures.

Fig. 8

Fig. 9

Fig. 10

Fig. 11

figures which are observed by using the Bertrand lens and crossed analyzer and polarizer.

It is not possible to explain the theory of these characteristic figures here. However, one or another of these figures will be observed depending upon how the crystal is oriented with reference to its optic axes.

This method of classifying crystals is used by all chemical microscopists, metallurgists and petrographers who actually identify unknown materials. The chemical microscopist sometimes is more interested in the presence of crystals rather than in their identification. The polarizing light feature is all that is necessary for making this observation. This is the reason why chemical microscopes usually are not equipped with a Bertrand lens.

It is quite impossible to enter upon a complete scientific explanation of all the optical characteristics of crystals in this manual. The main optical properties of crystals, as investigated by petrographers and, in some cases, chemical microscopists, are described in the various text books on the subject.

Explanation of Optical Characteristics

Other properties of crystals are explained below. They are as follows: —

1. Refractive Index
2. Optic Sign
3. Sign of Elongation
4. Optic Axial Angle
5. Extinction Angle
6. Birefringence
7. Pleochroism

1. *Refractive Index:* Refractive index is a measure of the refraction or bending of light rays as they pass, at an oblique angle, from one medium to another, for example glass to air, air to water.

Mathematically, the refractive index is equal to the sine of the angle of incidence over the sine of the angle of refraction.

$$\text{Index of Refraction} = \frac{\text{Sine I}}{\text{Sine R}}$$

The refractive indices of a few common substances are:—

Air	1.000	Canada Balsam	1.537 "cooked"
Water	1.333	Raw Balsam	1.525-26 liquid
Clove Oil	1.530	Quartz	1.544 & 1.553
		Methylene Iodide	1.740

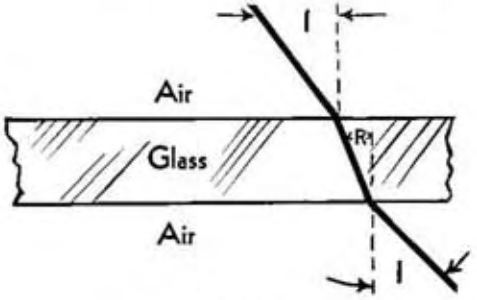


Fig. 12

Becke Line Method—In crystal analysis the index of refraction is determined by the Becke Line Method. The crystals are immersed in oil on a microscope slide whereupon a concentrated bright line appears around the edge of the specimen. As the body tube of the microscope is slowly raised the bright line shifts toward the medium of higher refractive index, either the oil or the crystal. By trial and error method an oil will be found in which the crystal disappears. (A similar condition exists when a glass rod is immersed in a bottle of cedar wood oil.) The index of refraction of the specimen is recorded as the index of the oil which is known.

2. *Optic Sign:* To explain the optic sign of a crystal it is necessary to recall the fact that light is split into two rays traveling at different speeds when it enters certain crystals. One of these rays is called the ordinary ray (O) and the other the extraordinary ray (E), Fig. 16. When the ordinary ray travels faster than the extraordinary, the crystal is positive; when the opposite is true, the crystal is negative.

In practice the quartz wedge, selenite plate or mica plate may be used to determine the optic sign of the crystal.

3. *Sign of Elongation:* Many minerals and crystals specimens are elongated along one axis and appear like long needles or rectangles. Some of these shapes may be illustrated as in Fig. 13. The axis along which the crystal is elongated will determine its sign of elongation, positive or negative. The selenite plate or mica plate may be used for this determination. Further information appears in later pages.

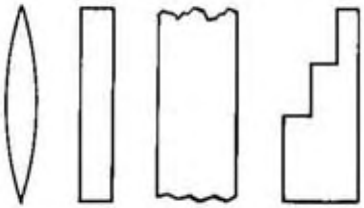


Fig. 13

4. *Optic Axial Angle:* The term optic axial angle refers to biaxial crystals only and is an important factor in the identification of these crystals. The optic axial angle is the angle between the rays of light which follow the two optic axes of the biaxial crystals. This characteristic is denoted as 2V in the description tables, for instance $2V=14°$.

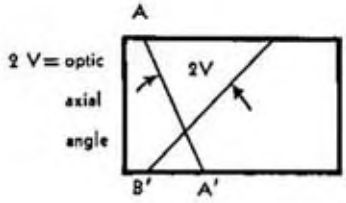


Fig. 14

5. *Extinction Angle:* Uniaxial and biaxial crystals are extinct for certain positions under the microscope when observed between crossed analyzer and polarizer. The angle through which a crystal must be rotated from a position parallel with a cross hair to its extinction position is its extinction angle. This is measured by reading the scale on the rotating stage.

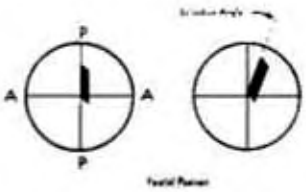


Fig. 15

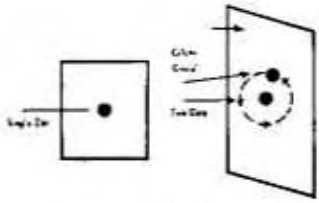


Fig. 16

6. *Birefringence:* Birefringence is the property of a crystal to separate the two polarized rays of light resulting from the original single ray of normal or non-polarized light; that is, the ordinary and extraordinary ray. A crystal of calcite may be used to demonstrate this phenomenon. By placing the calcite crystal over a single dot, two dots will be observed. As the crystal is rotated, one dot will remain stationary and the other will rotate around it. The image of the stationary dot is produced by the ordinary ray, the other by the extraordinary ray. This phenomenon is also called double refraction.

The difference between the index of refraction for the ordinary and the extraordinary ray of the crystal is a quantitative measure of its birefringence. For Example:

Crystals	*Difference Between Indices*	*Birefringence*
Cerussite	.273	Strong
Quarrz	.009	Weak

7. *Pleochroism:* Pleochroism is the property of certain crystals to absorb some wave lengths of light more than others regardless of optical characteristics. This results in a variation in the color of the crystal as it is rotated under the microscope.

Preparation of Crystalline Materials

Some crystalline materials are already in convenient form for identification with a polarizing microscope; others must be prepared.

A representative sample of solid crystralline material, such as a geological or mineralogical specimen, must be crushed in a diamond steel morrar. This breaks the mass into fine crystals which are then selected

by screening through a 100 mesh onto a 200 mesh screen, the screens being of small size such as 3" or 4" diameter.

Mortar for pulverizing rock specimens

Crystal section mounted on slide

A comparatively small number of the selected crystals are mounted in a liquid of known refractive index on a glass slide. The liquids commonly used in making a set of known refractive indices are water, kerosene, glycerine, cedar oil, clove oil, cassia oil and methylene iodide. The index of refraction of two oils mixed together is measured by means of the refractometer. The usual procedure in mounting is to place one or two drops of oil in the center of the glass slide and tap the crystals into the oil from the end of a small blade or spatula. Care should be taken not to clutter the field with crystals because this confuses the petrographer in ascertaining correct optical properties. A cover glass is then placed over the crystals and the sample is properly mounted for microscopic examination.

The preparation of massive crystalline specimens in thin sections for examination under polarized light is a more difficult task. It consists of grinding one surface perfectly flat, mounting the specimen on the glass slide in melted balsam, and grinding the rough side until the sample is from 20 to 40 microns thick. This is necessary in order to bring out detail in the structure of the specimen. Three or more grades of carborundum are used in the hand grinding operation, the finest being No. 600. After grinding is completed, a little Canada Balsam is melted on top of the specimen and a cover glass pressed carefully into the balsam. The result is a permanently mounted thin section.

Microscopic Identification of Crystalline Material

In order to determine the optical characteristics of crystals, the following steps are recommended:

1. *Optical Classifications:* The crystals should be placed on the stage between crossed polarizer and analyzer, the auxiliary lens swung in and a 3.5X, 5X or 10X objective brought into position. If no color

appears as the stage is rotated, the material is said to be *isotropic*. However, if color does appear in the black field, the crystals are said to be *anisotropic*.

Isotropic crystals are identified by rotating the analyzer to "out" position, swinging in auxiliary condenser and using a 3.5X, 5X or 10X objective. This shows the crystal in plane polarized light and the index of refraction is measured by the Becke Line Method.

In classifying anisotropic crystals as uniaxial or biaxial, it is necessary to swing out the auxiliary condenser, insert the analyzer and the Bertrand lens, and use a 20X, 43X or 97X objective. The crystal must be brought directly under the cross hair to obtain the proper interference figure. A uniaxial figure appears as a set of concentric colored circles with a black cross in the center of the field. Fig. 8, page 7) A biaxial figure consists of oval rings around two dark spots, the field being crossed by two hyperbolas as the stage is rotated. (Figs. 9, 10 and 11, page 7)

2. *Refractive Index:* The refractive index of anisotropic crystals is determined by the Becke Line Method. Uniaxial crystals have two indices; biaxial have three indices.

3. *Optical Sign* (+ or −): The optical sign of a uniaxial crystal may be determined by swinging out auxiliary condenser, inserting analyzer and Bertrand lens, and placing either the quartz wedge, quarter wave plate or full wave (1st order red) plate in the slot for compensators. When the quartz wedge is used, the direction in which the color curves move outward on inserting the wedge, the thin end of the wedge entering first, makes the sign with the slow ray of the wedge shown by the arrow.

When the quarter wave (mica) plate is used, the line joining the two black dots will be parallel to the slow ray of the plate as indicated by the arrow if the crystal is negative. The line joining the dots is at right angles to the arrow if the crystal is positive. When the 1st order red plate is used, the line joining the quadrants in which the yellow color appears shows the sign in the same manner as above.

The determination of the sign of biaxial depends upon several other considerations which are too involved to be presented here.

4. *Sign of Elongation:* The analyzer should be thrown in and a 10X or 43X objective should be used. The "first order red" plate (selen-

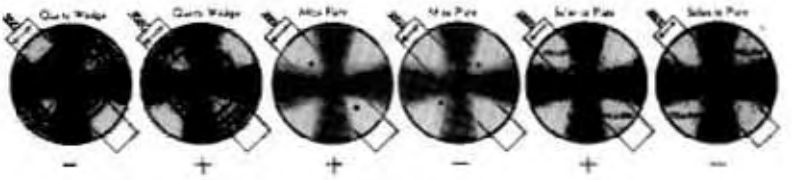
ite) is inserted in the slot for compensators and the center of the crystal is set at the center of the cross hairs. Then the crystal is rotated until its elongated axis is parallel with the arrow on the plate. If the crystal appears yellow, its sign of elongation is negative. If it appears blue, the sign of elongation is positive.

5. *Optic Axial Angle:* The optic axial angle of biaxial crystals is observed by swinging out auxiliary lens, using analyzer and Bertrand lens. A quantitative measure of this angle may be obtained by using an apertometer plate, a coordinate grating in a special eyepiece, or an objective with a calibrated iris diaphragm.

6. *Extinction Angle:* The extinction angle is measured by using the analyzer and rotating the crystal from a position parallel with the cross hairs until it appears black. (See Fig. 15, page 10)

7. *Birefringence:* Birefringence may be measured by means of a graduated quartz wedge and by referring to Newton's color scale or Levy's chart.

8. *Pleochroism:* The auxiliary lens should be placed in the path of light and analyzer "out" to determine pleochroism. If the crystal exhibits two extremes of color as it is rotated, it is called dichroic; three, trichroic.



Procedure for Adjusting Polarizing Microscopes

The final inspection of Polarizing Microscopes as followed by our Inspection Department is described in this bulletin. The steps are given in the proper order. These instruments may get out of adjustment especially when being used by students and should be checked over frequently. To make a complete test of the instrument, the following slides are needed.

1. Stage micrometer
2. Thick quartz section
3. Bichloride of Mercury crystals
4. Thin quartz section

Proceed as follows:

1. *Center objectives:* The objectives on Polarizing Microscopes must be accurately centered. When the objectives on quick-change nosepieces are interchanged, the center of the cross hairs must fall at exactly the same spot as in the previous case. Use the stage micrometer, 10X eyepiece and start the centering with the 10X objective. Move the stage micrometer until the center of the cross hair lies within an O (Fig. 17). If necessary the centering screws are used to bring about this condition. Next, center the highest power objective and without moving the slide, except for rotation of the stage, center all other objectives to the same point.

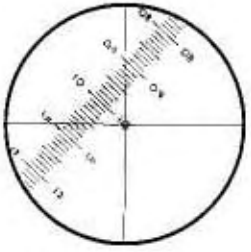


Fig. 17

2. *Eyepieces:* Check the centering of eyepieces while the micrometer is still on the stage, using a 16mm. objective. The eyepieces are centered and the cross lines of all eyepieces must be parallel. Eyepieces are carefully selected and inspected at the factory.

3. *Bertrand Lens:* The Bertrand lens must be checked for clear focus and centering. Set polarizer and analyzer in "crossed" position. Place a thick quartz section on the stage; open both condenser diaphragms; swing out the auxiliary condenser; use the centered 4mm. objective focusing close to the upper surface of quartz section; insert the analyzer and rotate it until the field appears black; throw in the Bertrand lens. Focus this lens on the interference pattern. The pattern should appear as sharp, colored, concentric rings with a large black cross passing through the center of the field. The center of the interference figure should lie at the exact center of the cross hairs of the eyepiece.

4. *Center Substage:* The substage condenser mount must now be accurately centered in order to have the entire optical system in perfect alignment. Remove the slide; use 43X objective, 10X eyepiece,

the analyzer and Bertrand lens. Set the analyzer at "out" for this operation to allow light to pass through the system. Swing in the auxiliary condenser, close the iris diaphragm of the condenser and focus on this diaphragm by means of focusing Bertrand lens. If it is not centered, recenter by means of the condenser mount screws which move the entire substage in its ring.

5. *Proper Setting of Polarizer:* Only in rare cases does the polarizer get out of adjustment. However, the following procedure is valuable as a check. Place a slide of bichloride of mercury crystals on the stage, use the 10X objective, 10X eyepiece and swing in the auxiliary condenser. Select a straight, elongated crystal and make this crystal coincide with the cross hair. Use analyzer at zero. The crystal should appear black, or practically invisible in the field of the microscope.

Fig. 18

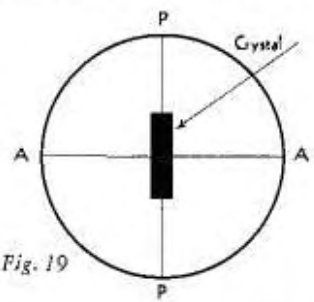


Fig. 19

6. *Analyzer Setting:* The analyzer may possibly get out of adjustment and should be set in the proper relationship to the polarizer. Remove both the objective and the eyepiece, swing in the auxiliary condenser and insert the analyzer into the body tube. Rotate the analyzer until the field appears dark. The analyzer is correctly set if this maximum darkness results when it is set at zero. The slightest movement of the analyzer off zero should cause the field to become brighter. If the analyzer is off, it must be rotated in its mount until the proper relationship exists.

7. *Full-Wave Plate:* (Sometimes referred to as Gypsum or Selenite plate). It is a simple matter to check the orientation of the Full-wave plate. Place a thin quartz section on the stage, use the 43X objective, 10X eyepiece, Bertrand lens, analyzer and place the auxiliary condenser in "out" position. Insert the selenite plate in the slot for compensators.

Check to see that the arrow engraved on the plate is in the direc-

tion as indicated. If this is rrue, yellow spors should appear near the center of the cross in quadranrs 2 and 4.

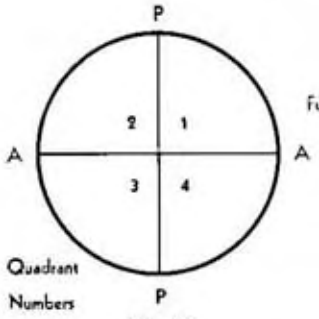


Fig. 20

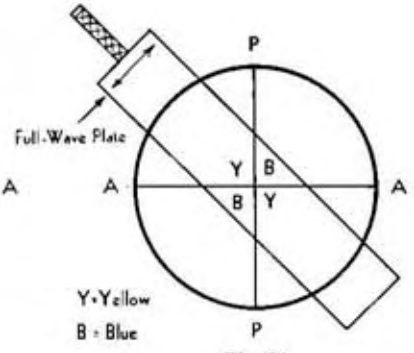


Fig. 21

8. *Quarter-Wave Plate:* Remove the full-wave plate and insert the quarter-wave plare. (sometimes referred to as Mica plate) Two black dots should appear in quadtants 2 and 4. The line joining these dots makes a 45° angle with the cross hairs.

9. *Quartz Wedge:* To check the quartz wedge, remove the thin quarrz section from the stage and replace it by a thick quartz section. Insert rhe wedge in the slot *thin edge first,* the arrow on the wedge marking the thick end. As the wedge is inserted, the color curves should shift outward in quadrants 2 and 4 and contract toward rhe center in quadranrs 1 and 3. The direction of the arrow on these thtee accessories marks the direcrion of vibration of the slow ray of the plate.

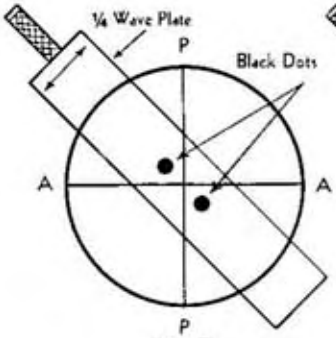


Fig. 22

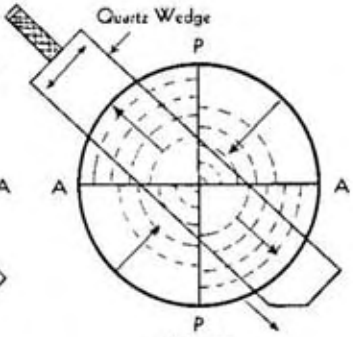


Fig. 23

The Care of the Microscope

Successful microscopy requires skill and the proper care of the instrument. The microscope is a precision instrument made from valuable materials by expert workmen. With reasonable care it will last a long time, but a single bit of carelessness may ruin it.

The microscope should be carried by its arm and, when not in use, should be placed in its case or properly covered to protect it from dust. When the microscope is brought from a cold to a warm room it should be allowed to warm up gradually before being used.

The lenses must be kept meticulously clean. Dust should be loosened and brushed off with a camel's hair brush and the lens cleaned with lens paper. Optical glass is generally softer than window glass and is easily scratched by ordinary cloth or when dust particles are not removed before polishing. Special lens paper is available and it is poor economy not to use it.

Dust on the eyepiece lenses is seen as specks which rotate when the eyepiece is turned while looking through it. Dirt on the objective prevents clear vision and the object appears as if it were in a fog. If a wet preparation touches the objective lens, the lens will have to be cleaned before one can see clearly through it. An eyepiece should always be kept in the tube to prevent dust from collecting on the back lens of the objective or on the prisms. If it does collect there, clean it off carefully with a camel's hair brush or blow it off with an aspirator. An all-rubber ear or infants' enema syringe, obtainable at most drug stores, is a useful aspirator. Do not use one with a metal tip to avoid scratching the glass surfaces.

Should dust settle on the prisms or on the glass protection plates of the binocular body, blow it off with air from an aspirator. Blowing the breath on lenses will cover them with minute drops of saliva which are removed from the lens with difficulty. Compressed air from laboratory pipes may contain traces of moisture or of oil from the compressor, and should not be used unless an absorbent cotton filter is placed on the discharge tube.

If the field does not appear clear, it is well to examine the lower surface of the objective with a magnifying glass. Any dirt or damage to the lens may then be seen easily.

Objective lenses are carefully adjusted at the factory, and should not be taken apart except where they have been made to separate (*e.g.* the divisible 16mm objective and the older style immersion objective with funnel stop). The definition depends on all of the component lenses being centered and the right distance from each other. If they must be taken apart, it should be done at the factory where facilities are available for testing the reassembly.

The dry objectives, the condenser, and the eyepieces may be cleaned with distilled water when a liquid is necessary; an immersion objective and condenser top lens with xylene. Only the smallest amount of solvent should be used and the lens should be wiped dry with fresh lens paper immediately after cleaning. Should the immersion oil become gummed on the lens it should be cleaned off with the least amount of xylene and then the excess wiped off promptly with lens paper. Do not soak the lens with xylene or other solvent because the mounting of the lenses may be damaged if it gets beyond the seal of the front lens into the objective.

Extreme care should be used in cleaning the surfaces which have Americote or other anti-reflection coatings. The best procedure, where these are exposed, is to gently brush off the dirt, using a soft camel's

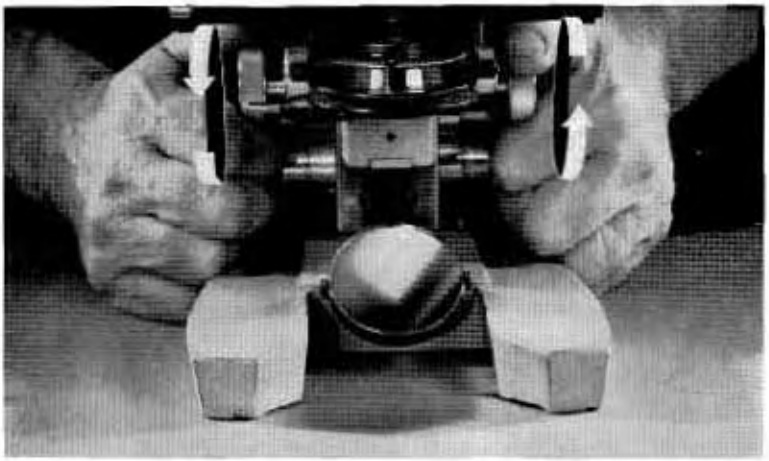


Fig. 24. Adjusting tension of coarse focusing knobs.

hair brush. When this does not clean the surface of prisms, they should be cleaned only by a competent person. The coated surfaces are softer and more readily damaged than the uncoated surfaces of ordinary lenses.

In tropical regions mold will grow on dirty lens surfaces when the relative humidity and temperature exceed 80°F. When the optical surfaces are kept clean, mold growth can be avoided, or minimized, by keeping the optics in a dessicator, or the microscope in a warmed cabinet. Other suggestions include the use of radium or fungicides.

The surface of the microscope is finished with enamel or metal plating and requires little more care than keeping it clean and free from dirt. These finishes resist most laboratory chemicals and ordinarily a little mild soap and water is all that is necessary for cleaning.

The slides of the rack and pinion should be cleaned occasionally with a small amount of oil or light grease. The fine adjustment does not require oiling. After a time wear may make the coarse adjustment turn too easily to support the body tube. To increase the tension grasp the control knob of the coarse adjustment with the right hand and turn the knobs in opposite directions, Fig. 24. To reduce the friction turn the knobs in the other direction. A similar adjustment is possible for the substage adjustments of the Microstar Microscopes. (With former models the paired screws at the top of the stand may be tightened slightly to give sufficient friction to hold the body tube properly.)

Careless handling or dropping may disturb the adjustment of the optical parts of the microscope. If the instrument does not seem to perform properly and there is no dirt on the objective or the eyepiece, it may mean that some of the prisms have become shifted. Do not attempt to adjust any of the prism systems but rather send the instrument to the factory where tools and tests are available for adjustment and for making certain that the adjustment has been done properly.

Testing microscope lenses is a difficult task, and one which should only be attempted by a skilled microscopist. Instructions for the use of test plates and test objects are given by Beck (1938), Belling (1930), and Spitta (1920). Adequate comparison requires the best illumination and adjustment of the microscope and considerable experience with lenses of different quality so that definition and aberrations may be evaluated.

Autofocus

Autofocus prevents damage to objective and reduces slide and cover glass breakage . . . also, facilitates rapid study of slides or series of slides.

Fig. 25. Autofocus mechanism adjusts with Allen Wrench.

How to Use Autofocus

Insert specimen slide and rack up stage to coarse adjustment stop. Critically focus with fine adjustment . . . microscope is now in Autofocus for all objectives. To use oil immersion objective, simply rack down stage and place drop of oil on slide. Rack up stage to coarse adjustment stop . . . oil immersion objective is in oil contact and microscope is still in focus subject to minor corrections with fine adjustment due to thickness of specimen.

The Autofocus mechanism is built-in and can be adjusted with a 1/16" Allen Wrench furnished with the microscope. The wrench is inserted in the opening just back of the stage (fig. 25), and turned to limit the excursion of the coarse focusing control.

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