ART. XXXVI.—*A New Petrographic Microscope*; by FRED.
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EXPERIENCE has shown that the so-called universal instruments are as a rule unsatisfactory, and often do not accomplish in a thoroughly competent manner any one of the several purposes for which they are intended. To fulfill a given set of conditions adequately, it is usually necessary that a special instrument be designed for the purpose. Thus, a small calibre rifle may be admirably suited for small game, but for larger game it is totally inadequate and might even be of more harm than service in an emergency; and vice versa, a large calibre rifle is of little value in hunting small game.

The same principle of adaptability applies equally to microscopes and scientific apparatus in general. The ordinary microscope, which is designed to aid in the examination of thin sections of rocks and minerals, is satisfactory and convenient for such purposes, but is less so for use in the investigation of artificial preparations which are usually very fine-grained, the diameter of the individual grains averaging often not more than $.01^{\text{mm}}$. To determine satisfactorily and with fair accuracy the optical constants of substances in such minute grains, special methods of attack are required, and these in turn postulate certain new conditions to be fulfilled by the petrographic microscope. It was with this end in view, to construct a microscope better adapted than the microscopes now available for the examination and determination of fine-grained artificial silicate preparations, that the present microscope was designed and constructed in the workshop of the Geophysical Laboratory. Several of its features appear to be of general application, and a brief description of its essential parts is therefore justified.

In the construction of the present instrument (fig. 1), a Zeiss microscope No. 1 C for photomicrography served as base, and on it extensive changes were introduced so that the resulting microscope resembles the original only slightly. This particular model was chosen chiefly because of its wide upper barrel, which was well adapted for the introduction of diaphragms and the movable Bertrand lens. The changes which have been introduced are essentially as follows.*

(1) The nicols are revolvable simultaneously about the optic axis of the microscope. They are connected rigidly by the bar T of fig. 1, and their angle of revolution can be read off directly by the vernier on the stage. This method obviates the errors introduced by the usual system of gear-wheels with accompanying lost motion in the moving parts. The details of

* A still further change, made recently and not shown in fig. 1, is the introduction of a block just below the upper tube support. The distance between the stage and the upper tube is thereby increased and the use of the universal stage facilitated.

FIG. 1.

FIG. 1. New petrographic microscope. T, rigid bar connecting two nicols and effecting simultaneous revolution of the same; A, arm connecting upper nicol carriage with T; C, part supporting bar T and revolving about stage; B, arm from lower nicol carriage connecting with bar T; by means of the screw and cross plate at B, this arm can be instantly released from T and the lower nicol either revolved by itself or, after a release by a snap spring not shown in the figure, thrown out of the field altogether. The total angle of simultaneous revolution of both nicols by this device is 190° . O, new mechanical stage, simple in design and construction and fairly dust-proof. H_1 , stage screw with divisions on head reading to $.01^{mm}$ motion of stage plate. Q, sensitive-tint plate inserted above lower nicol, W, and revolvable about microscope axis by means of containing carriage. F. M, combination wedge above objective; a_1 a_2 , fine adjustment screws above objective; U, screw of fine adjustment device of upper microscope tube; V, iris diaphragm below Bertrand lens, diaphragm opened and closed by turning head V, which is connected with iris diaphragm by pin and ratchet movement; E, pin for insertion of Bertrand lens which moves in an accurately fitting carriage, supporting iris diaphragm V, Bertrand lens E and auxiliary lens L, which swings on an arm indicated in fig. 1a and is of such focal length that together with ocular, it forms a small microscope used in focusing the image from the objective in the plane of the iris diaphragm, V. The supporting carriage of V, E, and L, can be moved up and down in the microscope tube and the amount of movement read off on the adjacent scale, thus obtaining different magnifications (6.5 to 15.2 diameters) of the interference figure. G, upper iris diaphragm directly beneath ocular.

FIGS. 1a, 2, 3.

FIG. 1a. Section through microscope of fig. 1, showing working parts. The letters T, A, B, C, H, W, Q, F, O, U, V, E, L, and G, refer to the same parts as in fig. 1. I = lower iris diaphragm; N, upper nicol; X, Y, Z, brass parts effecting revolution of upper nicol; P, revolving stage supporting movable plate, O.

FIG. 2. Section showing stage P and microscope plate supporting stage and other revolving parts and support for revolving nicol device, C; T, cross section of bar connecting two nicols; this bar slides accurately in the arms A and B of fig. 1a.

FIG. 3. Cross section through mechanical plate 1 of stage. I₁, I₂, brass plates screwed to revolving stage P and with wedge-shape sides in which rectangular plate K can move in an east-west direction, the movement being effected by the screw H₂. J₁, J₂ and J₃, three plates attached to under side of stage plate, O, and forming grooves for plate K, permitting stage plate O to move only in north-south direction, the movement being accomplished by screw, H₁, which in turn fits in a sliding block attached to the upper plate O, and traveling in the pin, D.

construction are shown in fig. 1a. By means of the screw and cross bar at B the connecting rod T can be instantly released and the lower nicol withdrawn or revolved by itself

independently of the upper nicol. The total angle through which both nicols can be revolved by this device is 190° .*

(2) A mechanical stage of new design† (fig. 3). This stage is practically dust-proof and mechanically simple in construction. In fig. 3. the vertical edge or rim of the cap, O, of the stage plate is indicated by the shaded broken circle, the upper surface of this plate being considered removed and the working parts as seen from above thus exposed to view. The small plates I₁ and I₂ are attached to the lower stage and are so constructed that wedge-shaped edges allow the rectangular plate K to move only in an east-west direction. This movement is effected by means of the screw H₁. The plates J₁, J₂ and J₃ of fig. 3, on the other hand, are attached to the upper movable plate O, and their wedge-shaped edges are so adjusted that they allow the upper plate to move only in a north-south direction with reference to the rectangular piece K. The screw H₂, which terminates in a block attached to the upper plate and running in a sliding pin D, accomplishes these north-south movements. The heads of both screws H₁ and H₂ have divisions reading to $.01^{\text{mm}}$ movement. Springs not indicated in the figure have been introduced and oppose the forward motion of the screws H₁ and H₂ and thus obviate errors due to lost motion in the screws. The total movement of the stage plate in any direction is 24^{mm} . Mechanically, it is of simple construction and consists of few parts.

(3) The metal part containing iris diaphragm and polarizer can be withdrawn from the optic axis of the microscope by means of a release spring not shown in fig. 1. This part is also revolvable by itself about the axis. This arrangement was adopted in preference to the usual method of inserting and withdrawing the upper nicol because of the disturbing effect which the introduction of the upper nicol causes, both on the focus and position of the field. With the present disposition, the upper nicol‡ remains permanently in the upper tube and the optical system, objective, nicol, and ocular, is not disturbed in passing from ordinary to polarized light. In certain microscopes the effect of the upper nicol on change of focus is compensated by means of a small lens of weak magnifying power, but even after the introduction of this device some shifting of the field may still be experienced on inserting the upper nicol.

* Fuess & Company have recently constructed, at the writer's suggestion, a simplified model of microscope on this principle of a rigid bar connection between the two nicols, so that the two can be revolved simultaneously. (Price 300 mks.)

† This stage was designed by Mr. Chamberlin of this laboratory, and constructed by Mr. Semple.

‡ For certain positions of the reflector and on certain days the light from the reflector is polarized to such an extent that faint polarization colors are observed on minerals in the thin section even after the polarizer has been withdrawn. For this reason it would be an improvement if the upper nicol also could be withdrawn readily, whenever desirable. This is the case on the model constructed by Fuess & Co., noted above.

(4) An Abbe condenser is used, and with it a large nicol prism, or an Ahrens prism, 15^{mm} edge, after the manner of the Fuess microscope No. 1a. With this arrangement the entire condenser lens system remains in position and its upper lens need not be removed when low-power objectives are used. This does away with the devices which have been employed for throwing the upper part of the condenser combination out of the axis of the optic system and which complicate the construction considerably.

(5) The selenite, or quartz, plate of sensitive tint is inserted in a metal case at Q (fig. 1), just below the condenser. It is revolvable in the carriage F about the optic axis of the microscope, an arrangement which often facilitates the determination of the ellipsoidal axis of a particular section because the abrupt rise or fall of interference colors on insertion and rapid revolution of the plate appears more clearly than if the slower moving stage itself were revolved. At M a combination wedge is introduced as in ordinary microscopes.

(6) The Bertrand lens E, fig. 1, is mounted on a sliding arrangement which, in connection with the sliding ocular tube, permits of different magnifications of the interference figure, an arrangement already adopted on several well-known microscopes. In the present microscope the focal length of the Bertrand lens (55^{mm}) has been so calculated that the initial magnification of the interference figures can be varied from .81 diameters to 1.90 diameters. The ocular itself magnifies this image in turn eight-fold, so that the resulting magnifications range from about 6.5 to 15.2 diameters. The fact that the upper nicol intervenes between the objective and Bertrand lens limits very materially the range of magnifications possible by the Bertrand lens. An iris diaphragm is introduced directly below the Bertrand lens and slides up and down simultaneously with it. This diaphragm is opened and closed by means of the pin, V, fig. 1a, which is connected with the diaphragm itself by means of pin and ratchet movement.

(7) A second iris diaphragm is introduced at G, fig. 1, directly below the ocular, and is used in connection with the observation of interference figures by the Lasaulx method without the Bertrand lens. To be of service in this connection, the iris diaphragm should be located precisely in the image plane from the objective, as was emphasised especially by Czapski in 1891,* for in that plane alone can light be excluded from adjacent minerals in the thin section. To realize satisfactorily this condition, the writer has heretofore used the cap stop indicated by fig. 4, with two sets of slides, S₁ and S₂, at right

* Neues Jahrbuch, Beilage Band vii, 506, 1891.

angles to each other. This cap fits the microscope tube and is inserted in place of the ocular. By means of the lens "a" the field is focused in the plane of the slides and any portion singled out for examination.

FIG. 4.

FIG. 4. Device for cutting down the field when interference figures from small grains are being observed as they form in the objective itself (Lasaulx method). Two sets, S_1 and S_2 , of two plates at right angles and sliding in grooves permit the observer to cut off the light from any part of the field. Before observing the interference figure, the image from the objective is first brought to coincidence with the plane of the iris diaphragm by means of the field lens "a."

Because of diffraction phenomena the aperture should not be made less than $.5\text{mm}$ in diameter, but even with this restriction, and with the ordinary objectives, 3 or 4mm focal length, grains not over $.01\text{mm}$ furnish good interference figures which ordinarily would be completely overshadowed and not discernible if adjacent light were not excluded.

Experience has shown that the effects are still clearly recognizable if the diaphragm is at a distance of not over 5cm from the eye, and for convenience sake, therefore, this diaphragm was inserted just below the ocular. The usual round disks with small aperture supplied with microscopes serve the same purpose but are less convenient.

Before stopping down the field by the diaphragm V just below the Bertrand lens, the image plane from the objective should on the same principle be brought to coincide with the plane of this diaphragm and the desired mineral section isolated by shutting off light from the adjacent grains. To accomplish this readily, a small lens, L, fig. 1a (19mm focal length) has been introduced in the present microscope above the Bertrand lens, and in conjunction with the ocular serves the purpose of bringing to sharp focus the image picture in the plane of the Bertrand lens iris diaphragm, in accord with the principle noted above. In place of this small auxiliary lens, the writer has heretofore used a lens of long focal length and viewed the Bertrand lens diaphragm directly from the top of the tube. The new arrangement is more convenient, however, and obviates the necessity of removing the ocular before viewing the interference figure. The lens L swings on an axis and can be instantly thrown out of the field. A small spring with pointer automatically indicates the correct position of the lens when thrown into the field. The Bertrand lens diaphragm ordinarily supplied with microscopes is of little value in the observation of interference

figures by the Lasaulx method without the use of the Bertrand lens, chiefly because of the disturbing effects of diffraction from the small apertures required and the distance of the aperture from the eye of the observer.

In designing this instrument, special attention has been paid to adjustment facilities and arrangements by which adjustments can be readily accomplished by the observer himself. In scientific instruments in general, too much reliance is often placed on the adjustment by the maker and the assumption "once in adjustment always in adjustment" notwithstanding jars and jolts of transportation, and the gradual relief of stress in any complicated mechanical system. Fortunately, the principle, which some manufacturers have adopted, of making all parts rigid and eliminating adjustment facilities, cannot be carried out in the construction of the microscope. In this instrument the axis of both the upper tube and the condenser holder on the microscope must coincide precisely with that of the revolving stage, in order that in every position the optical system remain centered. Since the ocular and the condenser remain automatically centered with respect to the revolving stage, while the objective changes its position slightly on each insertion, it is necessary that centering screws (a_1 , a_2 , fig. 1) be introduced for the objective itself and the direction of motion of centering should be parallel with the cross hairs of the ocular, as the eye estimates much more readily coördinate directions than diagonal directions. The principle sometimes adopted of placing the centering screws with directions of movement along the diagonals is therefore less favorable than along the cross hairs, and places a burden on the microscopist which might easily be avoided. The practice of placing the adjustment screws on the revolving stage instead of above the objective is wrong. The part of the optic system which is not in adjustment is the objective, not the stage. The axis of revolution of the stage should form the starting point for the adjustment of the whole instrument and should always remain fixed in its position. To this axis the ocular, condenser, and objective should be adjusted, and since the ocular and condenser remain practically stationary while the objectives are changed constantly, the only logical point of adjustment, to obtain satisfactory results, is above the objective.

To summarize briefly, the most important changes introduced on the present microscope are: (1) Both nicols revolve simultaneously, the connection between the two being a rigid bar, thus eliminating the errors due to lost motion in the gear-wheels of the systems ordinarily employed for this purpose. Since adopting the above device, the writer has learned that the scheme of revolving the nicols by a rigid connecting bar

was used over thirty years ago by Dick in London, but was applied only to the revolution of a cap nicol above the ocular in conjunction with the polarizer. It was, therefore, slightly different from the present disposition. (2) The upper nicol always remains in the tube and the substage nicol is inserted or withdrawn on passing from ordinary light to crossed nicols. This device eliminates the annoying change of focus and shift of field ordinarily experienced when the nicol is inserted in the upper tube. (3) The sensitive plate is inserted just below the condenser and fits in a carrying device which is revoluble about the axis of the optical system. This disposition has been found convenient in determining the relative ellipsoidal axes in a plate, since the plate can be revolved more quickly and easily than the microscope stage or the two nicols together. (4) It has a new mechanical stage of novel design and simple but effective mechanical construction. The stage is practically dust-proof, has a free upper plate and a movement of 24^{mm} in any direction. (5) The Bertrand lens is fitted in a sliding device such that the magnification of the interference figure can be varied from 6.5 to 15.2 diameters. Immediately below the Bertrand lens, the iris diaphragm is introduced, while above this lens a second lens of short focal length can be thrown into the field which, together with the ocular, serves the purpose of focusing the image picture sharply in the iris diaphragm. (6) The second iris diaphragm at G, immediately below the ocular, is intended for use when observing interference figures directly by the Lasaulx method without the ocular and Bertrand lens. This iris diaphragm is a substitute for the device indicated in fig. 4, and the round cap plates usually furnished with microscopes, and although theoretically less satisfactory, practically it answers the purpose sufficiently well. (7) A large Abbe condenser is used, together with an Ahrens prism of 15^{mm} edge, or large nicol in place of the usual nicol and condenser with removable upper lens. This arrangement, first introduced on the Fuess microscope 1a, is a marked improvement over the usual arrangement and does away with the more or less complicated devices for removing the upper condenser lens from the optic axis of the microscope.