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An Instrument for Grinding Section-Plates and Prisms of Crystals of Artificial Preparations Accurately in the Desired Directions

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XIV. *An Instrument for Grinding Section-plates and Prisms of Crystals of Artificial Preparations Accurately in the Desired Directions.*

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The most difficult operations in connection with the investigation of the optical properties of the crystals of artificially-prepared substances, which are usually endowed with a much lower degree of hardness than the crystals of naturally-occurring minerals, are those which involve the preparation of the necessary section-plates and prisms. It is of primary importance that the plates should be truly parallel to the desired plane, or perpendicular to the desired direction in the crystal, and that they should possess plane surfaces truly parallel to each other. The prisms should likewise possess two plane surfaces, inclined to each other at an angle which may not usually exceed 70°, and whose edge of intersection is always required to be parallel to a given direction in the crystal; moreover, the two surfaces may with advantage be symmetrical to, or one of them parallel with, a given plane in the crystal. It is not too much to say that the accuracy of the determinations of the optical constants of crystals depends fundamentally upon the degree of precision with which these requirements are attained.

The preparation of section-plates and prisms of these relatively soft and friable crystals, when, as happens in the large majority of cases, the crystals do not exhibit the desired planes, or do not present them sufficiently prominently developed to enable them to be utilised as plates and prisms, must of necessity be carried out by grinding. In very few cases, indeed, are the crystals of artificial preparations endowed with sufficient hardness to withstand a preliminary cutting, by means of an extremely fine fretsaw, or thin wire lubricated with oil or a solvent for the crystallised substance. The crystals usually require delicate handling, their relative softness or brittleness, together with the development of cleavage, rendering them particularly liable to fracture and splitting. Moreover, owing to their greater freedom from distortion, striation, and facial curvature, the smaller crystals are always to be preferred for the purposes of accurate investigations, and the preparation of sections and prisms from small crystals must necessarily be carried out entirely by grinding.

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The first surface of a section-plate is usually ground by holding the crystal firmly between the finger and thumb, and moving it gently to and fro over the surface of a finely-ground and slightly-convex glass plate, employing as lubricant either oil or a slow solvent for the crystal, endeavouring to avoid movement of the wrist, which would cause the ground surface to be more or less convex. If the crystal is tolerably hard, and not brittle, a case which but rarely happens, a holder may, perhaps, be safely improvised out of the two halves of a split cork, but, in most cases, grinding between the finger and thumb has to be resorted to. Having thus ground one face, it is polished upon a piece of silk fabric, and tested as to its planeness, and whether it is approximately true to the desired direction by adjusting it upon the goniometer, observing the character of its reflection of the signal of the collimator, and actually measuring at least two angles which it makes with developed faces of the crystal. If the results are not satisfactory, grinding must be resumed and continued until upon similarly testing the indications are satisfactory. A second face is then to be ground parallel to it in a similar manner, until a plate is obtained sufficiently but not too thin to exhibit (in the polariscope of the axial angle goniometer, which is to be employed for measuring the separation of the optic axes, supposing the crystal to be biaxial) the interference figures with inner rings of very small size, when the hyperbolic brushes, whose separation is to be measured, are best defined. Before grinding the second face it is usually found most convenient to mount the crystal by the first ground surface upon a small glass plate by means of Canada balsam. The plate is more easily held during the grinding, the chance of breaking is diminished, and, if the crystal is strongly doubly-refracting so that a very thin section is required, approximate parallelism is more easily attained. When the crystals are not very small, the second surface may be ground more truly parallel to the first by employing the small apparatus made by FUESS, of Berlin. The crystal is cemented by its first-ground face upon one end of a closed white metal cylinder, two and a-half inches long, and a little over an inch in diameter, the ends of which are plane and fixed as nearly as possible perpendicularly to the axis. The cylinder slides vertically, with the crystal downwards, in an outer tube of brass from the lower end of which radiate horizontally three arms carrying levelling screws with fine threads; these are adjusted, by use of a graduated wedge, so that the ends of the arms are at the same height above the surface of the grinding-plate, when the cylinder will be perpendicular to the latter. By moving the apparatus to and fro over the lubricated grinding-plate, exerting at the same time a gentle pressure upon the cylinder, a second surface of the crystal is ground parallel to the first. This mode of grinding the second surface is not found convenient in the case of small crystals.

The grinding of the first face of a prism from a small artificial crystal is carried out by hand in the same manner as the first surface of a section-plate. The second face is naturally more difficult to obtain true to the desired direction; it is usually, also, accomplished by hand.

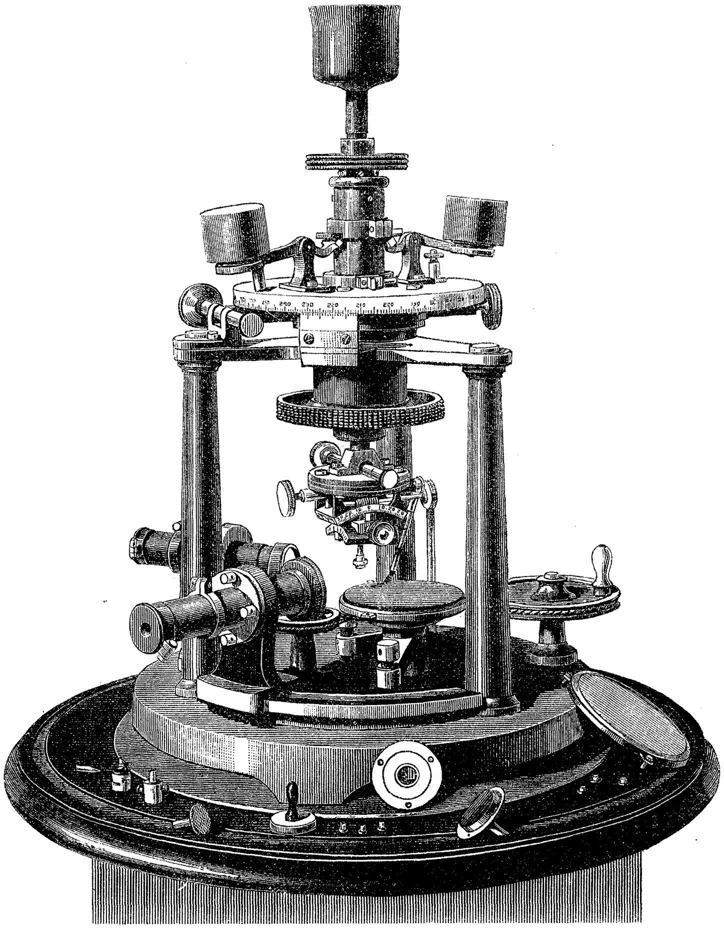
It will be evident that this mode of procedure can, at the best, only furnish plates and prisms whose surfaces are approximately plane and true to the desired directions. For the difficulty must at once be apparent of holding a small crystal, perhaps only one or two millimetres in its longest dimension, so that a certain plane, judged by reference to the developed faces of the crystal, is parallel with the grinding plate. Moreover, even after long practice, it is impossible, other than exceptionally, to grind a truly plane surface. The use of a very slightly convex grinding-plate helps but little to counteract the effect of an involuntary turn of the wrist. It is a most disagreeable, but frequently-recurring experience, to grind and polish, after considerable trouble, a smooth and apparently plane surface without accident from fracture, and then to find upon goniometrical examination that it is perhaps five or more degrees out of the desired direction. It also often happens that many hours are wasted by the fracture of crystal after crystal during the grinding. It will thus be seen that the preparation of a large number of sections and prisms by the current method, for the purposes of an extensive investigation, is attended by a prodigious amount of labour, and is a severe tax upon the patience of the investigator, while the results can rarely be more than approximate.

The instrument now to be described is the result of an attempt to replace these wearying and approximate methods by a method of precision, which shall eliminate the fatigue of hand work, while assuring that the ground surface shall be truly plane and shall lie in the right direction. The attempt has met with success, and it is possible by the use of the instrument to grind and polish a truly plane surface in any direction in a crystal, so as to be true to that direction to within ten minutes of arc, an amount of possible error which would exercise no measurable influence upon the values of the optical constants. Moreover, this result may be achieved in a small fraction of the time hitherto required, and with only the very slightest risk of fracturing the crystal. An arrangement is also provided by which a second surface may be ground parallel, with a like degree of accuracy, to the first. It is also found easily possible, by the use of it, in cases where the double refraction is low, so that fairly thick sections are required to exhibit small rings in the interference figure, to grind and polish two pairs of parallel faces, perpendicular to the first and second median lines respectively, upon the same crystal. It is likewise an easy matter, and can be made the usual course of procedure in the case of biaxial crystals, whatever the amount of double refraction, provided the crystals are not too minute, to grind a pair of prisms in such directions upon the same crystal as will afford all three refractive indices. Indeed, when crystals of low double refraction and of three or more millimetres diameter are available, it is not difficult to grind two section-plates and two prisms upon the same crystal, from which the whole of the optical constants may be obtained. The sections and prisms furnished by the instrument possess the further advantage of being so highly polished as to enable them to be employed directly, without the intervention of cover glasses, for the purposes of the determinations of the optic axial angle and the refractive indices, and the results obtained from them are no longer only approximate, but precise.

Construction of the Instrument.

A general view of the instrument and its principal accessories is given in fig. 1.

Fig 1.



It consists essentially of the following five parts :—

1. A rotatable horizontal divided circle and fixed vernier.

2. A suspended vertical axis, rotating with the circle and capable of vertical motion, carrying at the lower extremity the crystal and its means of adjustment.

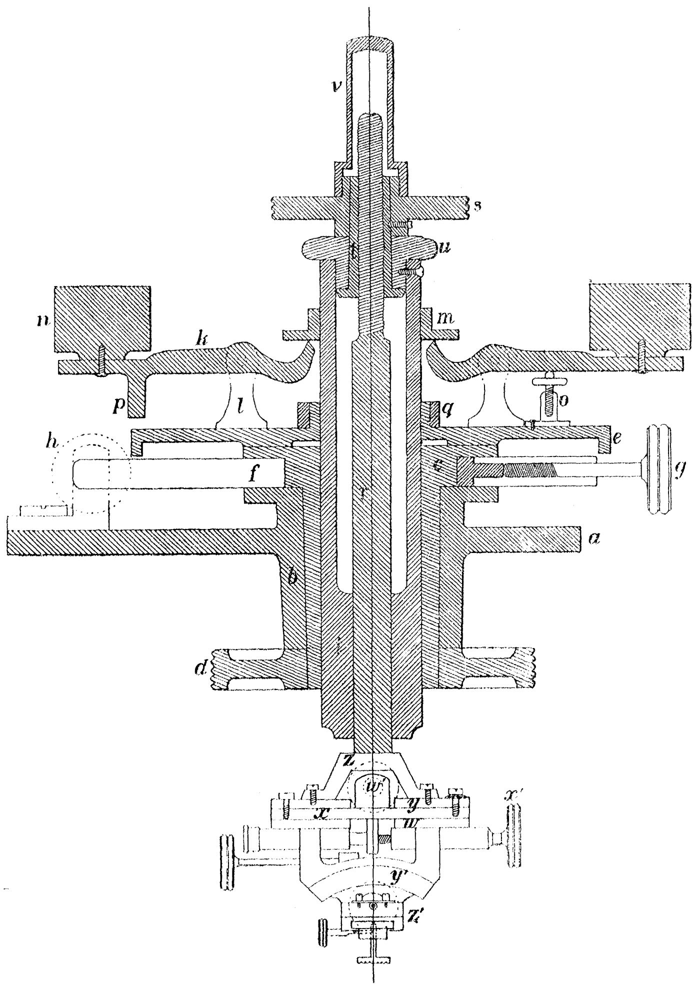
3. A rotatable grinding disc, whose surface is parallel to the circle and perpendicular to the suspended axis.

4. A horizontal collimator and telescope, for goniometrically observing the crystal.

5. An arrangement for wholly or partly relieving, or for increasing, the pressure with which the crystal bears upon the grinding disc during grinding.

Upon a circular solid metal base are erected three brass columns, which support a strong metal cross-plate, triangular in shape with somewhat concave edges, represented at *a* in the section given in fig. 2. In the centre of this plate, and forming part of the same casting, is carried the outer fixed cone *b*, in which the various movable axes are supported. The vernier plate, of silver, is fixed to a short arm springing from between two of the main arms of the cross-plate. Within the outer fixed cone *b*, a second one *c* is capable of rotation by means of a large ebonite milled disc *d*, which is firmly attached to it immediately below the termination of the fixed cone. Above, the upper flange of this movable cone is screwed to the circle *e*, so that rotation of the ebonite disc effects rotation of the circle.

Fig. 2.



The circle is fitted with a thick silver tyre, upon which the graduations are engraved. These read directly to half-degrees, and with the aid of the vernier to single minutes. Immediately below the circle the cone *c* is loosely encircled by a collar *f*, which can, when desired, be firmly fixed to it by means of a clamping screw *g*, provided with milled head. The screw passes through an arm radiating from the collar, and presses a small friction brake against the flange of the cone *c*. The collar similarly tails off into an arm upon the other side of the centre; and this arm, together with the collar, the cone *c* (when fixed to the latter), and all that moves with it, is capable of being slowly moved by means of a fine adjusting screw *h*, provided with milled head. The arm is always pressed against the end of the screw by a piston actuated by a strong spring confined in a cylinder closed at one end. The long cylindrical nut of the screw, and the cylinder containing the spring and piston, are arranged on opposite sides of the arm in the same straight line, and both are fixed to the cross-plate *a*. Rotation of the milled head in either direction consequently produces slow motion of the collar and circle, and all that moves with them.

The angle of the conical bore of the fixed cone *b*, and of the exterior of *c*, is but slight, and the bore of *c* is made truly cylindrical. Within this cylindrical socket slides an axis *i* of gun-metal, independent rotatory motion being prevented by grooving it longitudinally and fixing a corresponding metal rib upon the interior surface of *c*. Hence this axis always rotates with the circle, but is capable of free upward and downward motion. It is held in position at a convenient height by means of a pair of levers *k*, heavily weighted at the ends of the power arms; their fulcrum supports *l* are fixed upon the circle-plate, and their shorter curved arms press upwards against a split collar *m*, which is fixed to the axis by means of a square-headed tightening screw worked by a key. The counterpoises *n* are so adjusted that when the lever arms are approximately horizontal the whole weight of the axis *i* and all that it carries is nicely balanced, and the slightest touch of the levers is sufficient to cause up or down movement of the axis. The function of the axis *i* and the counterbalancing arrangement is to enable the pressure with which the crystal bears upon the grinding disc to be modified according to the strength of the crystal, and the mode of using it will be hereafter described.

It is found convenient to have an adjustable screw *o*, resembling an electrical binding screw in shape, without the lateral holes, slightly to the outside of the fulcrum of one of the levers; the cylindrical nut in which the screw works is fixed to the circle-plate right under the long arm of the lever, so that the head of the screw may be made to support it at any convenient height. This lever is thus capable of free motion in the direction in which the counterpoise goes upwards, but it is prevented from moving in the opposite direction. The other lever is not so restricted, but it is prevented from moving so that its weighted arm becomes inconveniently depressed, by means of a fixed elbow *p*. The ease with which the axis *i* slides in its socket may be modified by another split collar *q*, which encircles a flange (also split) standing up from the circle-plate and binds it more or less tightly to the axis according to the manner in which the square-headed tightening screw is arranged. The collar is made to loosen readily, upon retrocession of the screw, by connecting the two projecting ends through which the screw passes by a strong spring bent closely upon itself.

The gun-metal axis *i* is internally bored in the manner shown in fig. 2, the bore being fairly wide for the upper two-thirds of its length, but more constricted in its lower portion, in order to permit a central axis of steel *r* to slide in it freely but without lateral play, independent rotation being likewise prevented by means of a groove and rib as in the case of the axis *i*. This inner steel axis carries at its lower extremity the crystal holder and the movements necessary for adjusting the crystal, and terminates at the upper end in a rapid-threaded screw. By means of a milled head *s* and attached nut *t*, which latter passes through the cap *u* closing the bore of the gun-metal axis *i*, the steel axis and the crystal may be raised or lowered so as to remove or approach the latter from or to the grinding plane. The emergent upper portion of the screw thread is protected by means of a tubular cap *v*, which screws down upon the milled head *s*. Over this cylindrical cap may be placed a short tube carrying above a brass cup, shown in fig. 1, which is intended for the reception of small shot or weights, whenever it is considered desirable to increase the pressure between the crystal and the grinding disc over and above that which can be effected by manipulation of the levers.

The centering and adjusting apparatus carried at the lower end of the inner steel axis *r* consists of two centering motions, acting in directions at right angles to each other and actuated by milled-headed traversing screws, and two circular adjusting motions of the type first employed by VON LANG, actuated by tangent screws also arranged at right angles to each other. These movements are constructed rather more strongly than for ordinary goniometrical purposes. For centering, an arrangement has been adopted which has been employed for some time by the firm of Troughton and Simms for centering purposes, and which was used by them in the vertical circle goniometer described by MIERS.* This arrangement affords greater strength and is less liable to develop looseness than the usual rectangular form. The centering is attained by the relative movement of two circular discs *w*, *x* about each other, and of these two about a third *y*. The third disc *y* is rigidly fixed to the lower end of the steel axis *r* by means of the bridge *z*. The second disc *x* is pivoted to *y* at a point near the circumference, and the movement of *x* about *y* is limited by means of a pin screwed into *x* and passing through a curved slot, concentric to the pivot, cut out of *y*, close contact of the two discs being maintained by means of a spring washer, pressed between the broad head of the pin and the disc *y*. The rotation of *x* about the pivot is effected by means of the upper milled-headed traversing screw, which is arranged along the diameter at right angles to that joining the pivot and the pin and passes under the bridge *z*. The end of the screw presses against a short upright fixed to the disc *x* and passing through a central hole in *y*, and the upright is maintained pressed against the end of the screw during retrocession by a piston and spring arrangement *w′* similar to that employed in the fine adjustment of the circle. The lower disc *w* is made capable of rotation about the central disc *x* in a precisely similar

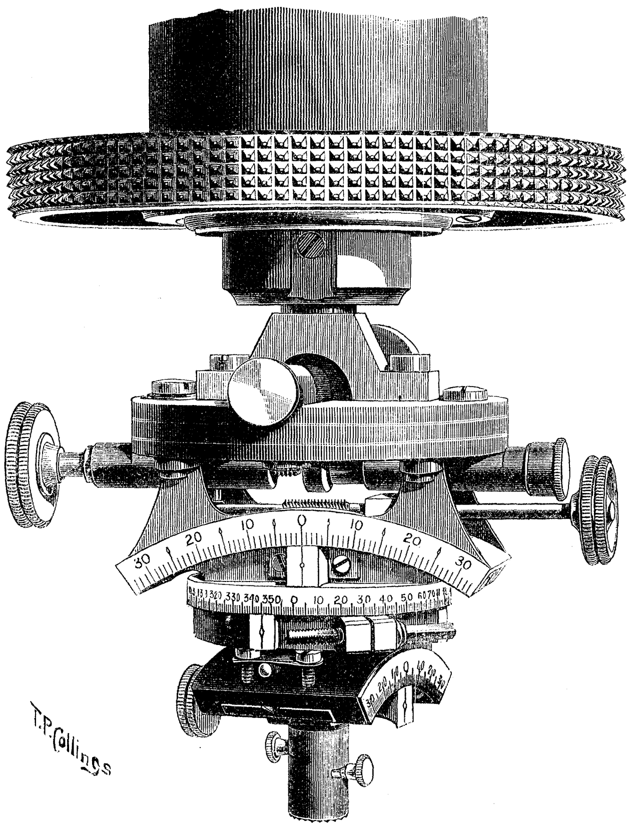
* 'Mineralogical Magazine,' March, 1891, p. 214.

manner, by means of a milled head x', but in a direction at right angles to that brought about by the movement of the upper screw.

The adjusting movements y' and z' are the usual pair of circular motions employed on the most accurate goniometers, brought about by endless screws and segments of wheels, arranged at right angles to each other. They are constructed more strongly than usual, and particular care has been taken that the axes of the two movements are as nearly as possible crossed at 90°. An innovation is introduced, however, in order to be able to adjust the crystal so that any desired direction in it may be exactly parallel to the grinding plane. This consists in graduating the movements. Upon one cheek of the guiding frame of each segment a silver plate of the same curvature is fixed, carrying engraved graduations reading to single degrees. The movable segment itself, actuated by the milled-headed tangent screw, carries at the centre of its arc, and brought out to the side flush with the scale, a silver indicator upon which a zero mark is engraved. The graduations and the zero mark are so fine that, with the aid of a pocket lens, ten minutes of rotation can with ease be accurately estimated. The scale graduations commence from the centre and extend for a little over 35° on each side. Hence, when the segments are in the normal position, their ends flush with those of the guiding frames, the indicators point to 0°; the amount of movement of either segment, brought about by rotation of the corresponding tangent screw, on either side, is consequently at once given by the scale-reading to which the indicator carried by the moving segment points.

In addition to this pair of circular adjusting movements whose planes are fixed at right angles to each other, another pair is provided in which the planes of circular motion may be arranged at any desired angle to each other. This alternative adjusting arrangement is useful in certain rarer cases of crystals of monoclinic symmetry, in which faces are not developed which would lend themselves readily to the adjustment of the desired axis of optical elasticity by means of circular motions in planes at right angles, and also for use, if preferred, with triclinic crystals. The same centering arrangement is employed. It is only necessary to remove the ordinary rectangular adjusting apparatus by taking out the four screws which fix its brackets to the lower of the three centering discs, by means of a convenient screw-driver supplied, and to replace it by the alternative apparatus, the screw-holes in whose brackets are likewise made to correspond exactly with the tapped holes of the disc. Fig. 3 represents it in position. The lower circular movement is made capable of rotation in a horizontal plane about the upper, and the amount of rotation is registered by a silver divided horizontal circle fixed to the upper segment, and four indicators arranged at 90° apart carried by a disc rigidly attached to the guiding arc of the lower segment and rotating in close contact with the circle. In order to afford room for the introduction of the two discs the upper segment is made of somewhat larger radius than in the ordinary adjusting apparatus. The circle is divided, like the graduated arcs of the circular motions, into single degrees, and ten minutes can be easily estimated. When any of the indicating marks are brought opposite the zero of the circle the movements are either parallel or crossed at 90°, so that when the movements are otherwise inclined the inclination is immediately given by the circle reading indicated. The lower movement may be clamped to the upper one in any position by means of a double tightening screw, which fixes the indicating disc to the circle, and which can be manipulated from either side by means of a key supplied.

Fig. 3.



The crystal is directly attached, by means of a readily fusible but quickly and rigidly setting wax, to a small holder consisting of a brass disc deeply cross-grooved on the under side in order to prevent the slipping of the wax; to the centre of the disc a short steel rod is attached, which slides easily in a hole bored in the centre of the under surface of the lowest segment of the adjusting apparatus, rotation being again prevented by grooving the rod and fixing a corresponding rib in the hole. Two such holders are provided, one whose disc has a diameter of $\frac{3}{8}$ inch and another of $\frac{5}{8}$ inch, in order to suit smaller and larger crystals. The smaller one is seen in position in fig. 1, and the larger one lies on the circular base-board somewhat to the left. In addition to these, two special holders are provided, one of which permits of a certain amount of rotation of the crystal, in order to be able to adjust any face parallel to one of the tangent screws, and the other, of more complicated structure, is employed for the purpose of grinding a second surface parallel to one already ground. These will be described at a later stage.

The telescope and collimator are carried upon rigid supports which slide upon a circular guiding bed, whose centre of curvature lies on the vertical axis of the instrument. The use of three columns instead of four for the purpose of carrying the circle and suspended axis is of advantage, inasmuch as it enables nearly 120° of guiding bed for the optical tubes to be employed, and permits of arranging them in the same straight line so as to directly view the slit whenever desired. The sliding bases of the supports for the optical tubes are maintained firmly pressed against the circular steel guides by means of slightly curved springs placed between the edge of the latter on the inner side and the rabbet of each sliding base. Both telescope and collimator are capable of being adjusted to the same horizontal plane, perpendicular to the axis of rotation of the instrument, towards which also the optical tubes can be precisely directed. For this purpose the main outer tube of each carries a collar, which is screwed to the stouter collar of the support by means of two adjusting screws arranged near the extremities of the vertical diameter; these enable the altitude to be slightly varied; a third adjusting screw on one side at 90° from the others enables adjustment for azimuth to be effected. Both telescope and collimator are capable of sliding in the outer tube, so as to be approached nearer to or receded from the crystal; they may be fixed in any desired position by means of split rings tightened round the outer tube of each, which is also split for a short distance, by means of a tightening screw. The telescope is capable of accurate adjustment for parallel rays, the eyepiece being carried in an inner draw-tube; the cross wires are placed in a short tube forming a continuation of the latter, to which it is attached by means of a fine screw thread, which permits of the necessary focussing of the cross wires. By means of a split-ring collar furnished with clamping screw and carrying a small projecting wedge which fits into a corresponding notch in the objective tube, the eyepiece may be fixed, after adjustment, so that the two clearly defined cross wires are respectively vertical and horizontal and a distant object is clearly focussed. In front of the objective a movable lens is carried, capable of rotation upon a pivot fixed to the objective frame, of such focus that when rotated into position the telescope is converted into a low-power microscope, the focus of which is occupied by the crystal, which is consequently well defined in the centre of the field. The collimator carries at the end of an inner draw-tube a slit of the form devised by WEBSKY, produced by employing portions of two circular metal discs as jaws instead of straight edges. This form of slit combines the advantages of a narrow central portion, which can be adjusted to a cross wire with the greatest accuracy, with wider ends which pass more ight. The inner tube which carries the slit is provided, like the eyepiece tube, with a split-ring collar carrying a wedge which fits into a notch in the wider tube carrying the collimating lens, so that the slit may be fixed after adjustment to the focus of the lens and to the vertical position. Both telescope and collimator may be fixed at any angle to each other, in any position upon the circular guide, by means of clamping screws passing through the rabbeted base of each support and actuated in each case by a short lever.

The grinding plane consists of a circular disc of ground plate-glass, mounted in a strong supporting disc of brass with raised edges, bevelled upon the outside. The finely ground surface of the glass is made as truly plane as possible. The brass supporting disc is screwed beneath concentrically by three screws to a pulley firmly fixed to the stout axis of rotation; the latter projects a little above the upper plane surface of the pulley, so as to fit tightly into a central hole bored in the under side of the brass supporting disc, which ensures the attainment of concentricity, and passes downwards into a rigid cylindrical bearing. The axis of rotation is carefully fixed truly perpendicular to the pulley and the grinding plane. The adjustment of the latter exactly perpendicular to the axis of rotation of the circle is provided for in the mode of supporting the cylindrical bearing. From the upper part of the bearing radiate three legs, terminating in strong levelling screws, which rest directly upon the metal base. The bearing itself passes down through a fairly wide hole in the base, which is raised somewhat from the supporting wooden base (intended for the reception of a protective glass shade when the instrument is not in use) and which is also somewhat hollowed underneath to afford room for the purpose; some little distance below the metal base the bearing cylinder terminates in a broad head, between which and the under surface of the base a strong spiral spring is confined, so that the ends of the three levelling screws are pulled tightly down upon the base. The axis of the grinding disc is prevented from rising in the cylindrical bore of the bearing by means of a suitable flange, and both the broad upper end of the bearing and the boss of the pulley which bears upon it are worked quite plane. A small quantity of lubricating oil can be introduced into the bore of the bearing by means of a small bent side tube which rises from it at a convenient angle. The grinding plane thus rotates without a trace of wobbling, and with a minimum of friction. The rotation is effected by means of the pulley seen to the right in fig. 1, whose diameter is about the same as that of the grinding disc. This pulley is mounted in a true bearing upon a stable fixed support, which raises it to the same height as the smaller pulley fixed to the brass disc which supports the grinding plate, and is provided with an ivory handle, fitted loosely upon a vertical rod furnished with suitable head. In order to equalise the pressure on both sides of the axis of the grinding disc a third pulley, of the same size as that beneath the latter, is introduced to the left, similarly fitted to the large driving pulley, but without handle. The band of strong cat-gut crosses on each side of the central pulley, and provision is made for tightening it whenever necessary by making the support of the third pulley capable of a certain amount of sliding in a short slot in the metal base, rigid fixation in the desired position being effected by means of a strong broad-headed screw manipulated from underneath the base. The rotation of the grinding disc is thus brought about in a steady and almost frictionless manner upon turning the driving pulley by means of the handle. For each rotation of the driving pulley the grinding disc rotates twice, a gain of speed which is not too great to permit of careful watching of the progress of the grinding, and quite sufficient to enable the grinding to be achieved as rapidly as possible without the crystal becoming unduly heated, which, if it had no injurious effect upon the crystal itself, would soften the wax in which it was held, and thus bring about movement of the crystal.

The surface of the grinding plane may, of course, be ground with any desired degree of fineness. It is a great advantage to have two such planes, the second one being fitted over the one just described in a manner which enables it to be readily removed and replaced as desired. The permanent one may then be ground so finely that it is all but perfectly transparent, and employed exclusively for giving a final polish to the surface of the crystal ground by the other plane; the latter may be relatively much rougher, a surface similar to that of the finer varieties of photographic focussing screens being suitable. This second prinding plane is seen reared up against the base to the right in fig. 1. It consists of a thick disc of plate glass, both surfaces of which are ground to a true plane, and are truly parallel to each other, the upper surface having the texture just indicated. It is slightly larger than the fixed disc, and is mounted in a narrow but strong brass frame which carries three small projecting pieces corresponding to a similar three projecting horizontally from the permanent brass disc which supports the polishing plane. Through a tapped hole in the centre of each projecting piece carried by the frame of the grinding disc is screwed a short screw; when this disc is laid upon the polishing plane, glass to glass, the narrow metal frame of the grinding disc lying outside the circle of the polishing disc, the three screws are arranged to pass easily through three holes in the projecting pieces of the polishing disc. By means of three small milled nuts, seen lying near the grinding disc in fig. 1, the two discs can be rigidly fixed together. Removal of the grinding disc can very rapidly be effected by placing a little glass crystallising dish partly under it, bringing each screw over the dish in turn, and with one finger giving a good twist to the little nut, when it almost immediately drops into the dish.

After a few weeks' use the rough grinding plane becomes smoothed down and ceases to grind with its former rapidity. It will be observed that, for obvious reasons, the grinding table is so arranged that the grinding will occur somewhat near the circumference of the disc. By making use of the centering motions above the crystal, the position of the latter may be varied upon the grinding plate; as one part becomes smooth the other parts of greater and less radius may be used. When the width of the smoothed annulus becomes inconvenient the plate may be re-ground in a very simple manner. In front of the instrument in fig. 1, very slightly to the left, is seen a thick disc furnished with a central handle. The disc is one inch in diameter and its surface on the side upon which the handle is not placed is made a true plane. A disc of the finest emery cloth is cemented to it by a thin film of any suitable liquid cement. The surface of the grinding disc is moistened with turpentine, and the little emery plane is moved to and fro diametrically over it; the surface thus ground bites better in grinding a crystal and does not produce striæ upon the crystal surface so much as when the grinding is done concentrically.

The instrument is conveniently mounted upon a rigid rectangular box, which is best not quite so broad as the mahogany base-board, in order that the telescope may be at the height of the observer's eye when seated, and that the eye may be conveniently approached quite close to the eyepiece.

As the instrument is usually employed in a darkened room or at night a lamp is required. The table lamp, fitted with the most recent rare-earth mantle and burner, and with an opal shade, supplied by the Incandescent Gas Light Company, is admirably adapted, especially when it is arranged to be able to lower the flame till it is all but extinguished, and to instantly raise it again as often as may be desired by means of a lever-tap fitted with stop-pin, and fixed within reach under the table. An electric incandescent lamp manipulated by a table switch is equally suitable.

In addition to the above table lamp a goniometer lamp is required. One which has been specially constructed to meet the requirements of goniometrical work is employed by the author. It is shown in the background in fig. 7 of the communication concerning the new monochromatic light apparatus (p. 933). A mantle and burner with glass or mica chimney, similar to that of the table lamp, but fitted in addition with by-pass, are supported upon an arm capable of sliding upon a tall standard and of being fixed at any height by means of a clamping screw. The observer is shielded from the brilliant light by means of an enveloping copper cylinder supported in a ring, whose arm is likewise capable of sliding along and of being clamped to the standard, a counterpoise being provided to facilitate the sliding. A circular aperture, $1\frac{1}{4}$ inch in diameter, is cut in the cylinder at a little more than one-third of its height. The slider which supports the cylinder is first adjusted so that the aperture is opposite the end of the collimator, and the slider which supports the lamp is then adjusted so that the brightest part of the mantle is opposite the centre of the aperture and the slit of the collimator, and in a continuation of the axial line of the latter. During the goniometrical operation of bringing an image of the slit, reflected from a crystal face, to the cross-wire of the telescope, the table light is switched off and the observer is shaded from stray light from the aperture of the copper cylinder by means of a screen enveloping the half of the instrument nearest the lamp, and which is pierced by a hole for the passage of the collimator. In order to read the vernier the table light is temporarily switched on; it is again turned down while bringing the next image to the cross-wire, and so on, the operations of switching on and off being readily performed with one hand, while using the other in manipulating the instrument and recording the readings. When the goniometrical observations are concluded the table light is switched permanently on for the operation of grinding.

Adjustment of the Instrument.

It will have been observed that every part of the instrument is provided with its own means of adjustment, in order to be capable of accurately performing the duties relegated to it.

The adjustment of the telescope exactly perpendicular to the vertical axis of rotation is performed in the usual manner, after clearly focussing a distant object, by so manipulating the two adjusting screws arranged in the vertical diameter of the collar that the images of the cross-wires reflected in succession from the two surfaces of a small mirror silvered on both sides, and carried upon the crystal holder instead of a crystal, or from two brilliant parallel faces of an opaque crystal, can be made to coincide with the wires themselves as seen through the telescope. The telescope then requires to be further adjusted for azimuth; that is, its axis must be directed right at the axis of rotation, so as to intersect the latter. In order to effect this the crystal holder is replaced by the short pointed rod seen to the extreme left of the base-board in fig. 1. This is centred by use of the centering movements, so that when observed through the telescope, arranged as a microscope by addition of the movable lens, the point appears stationary upon rotating the axis. The lateral adjusting screw of the telescope collar is then so manipulated, if alteration is necessary, that the point occupies the centre of the field.

The adjustment of the collimator is then readily effected by manipulating the screw of its collar so that the image of the slit, illuminated by the goniometer lamp, seen directly by arranging telescope and collimator in the same straight line, is clearly focussed, perfectly upright, and is bisected at its narrowest central point by the horizontal cross-wire.

The adjustment of the grinding surface parallel to the plane of the axes of the telescope and collimator, and therefore perpendicular to the vertical axis of rotation, is achieved in the following manner. It is first ascertained that, for all positions of the collimator and telescope along the circular guiding bed, their plane remains perpendicular to the axis of rotation which carries the crystal. The telescope is then fixed at the extreme right of its guiding bed, almost touching the pillar, and the collimator brought to the nearest end of its guiding arc, the angle between the two optical tubes being thus about 120°. A glass cube or prism, of about 1 inch side, and of which two faces are ground quite plane, and are accurately inclined at 90°, is next required. By goniometrically testing a few glass models of cubes or prisms, or a number of rectangular reflecting prisms, one can usually be found which exhibits two faces inclined at 90° to within a very few minutes. A small cubical glass ink-well was found to possess two faces inclined at 89° 58′, and answers the purpose admirably. If available, a large natural crystal which exhibits two such faces free from distortion is better still, as being probably within one or two minutes of 90°. The object chosen is placed near the edge of the grinding disc, resting upon one of the true surfaces. It is so arranged that the other surface, inclined at 90°, reflects the image of the curved slit of the collimator, illuminated by the lamp, along the axis of the telescope. It is then observed whether the image of the slit is bisected by the horizontal cross-wire, as it ought to be if the grinding plane is parallel to the plane of the optical tubes. If this is the case, it only proves that the particular diameter of the grinding plane which is parallel to the normal to the reflecting face is correctly adjusted; the plane may still be tilted about this diameter. A second observation, with the reflecting object rotated on the fixed plane for about a right angle, is necessary to ascertain this. The telescope and collimator are therefore moved round, each about 90° upon their guiding arcs, the lamp is also correspondingly moved, and the reflecting object is likewise moved round until the image of the slit is again observed in the centre of the field. If in both positions the image is symmetrical to the horizontal cross-wire, the parallelism of the grinding surface and the plane of the optical tubes is established. The test is still more delicate if the slit is arranged horizontally instead of vertically. If in either or both of the positions the image is not symmetrical to the horizontal spider-line, the levelling screws of the grinding table must be adjusted, by means of a tapering steel rod supplied, slightly bent near one end so as to permit it to be inserted more conveniently into the holes of the screw heads, until such is the case.

The Grinding of the First Surface of a Section-plate.

In describing the mode of grinding the first surface of a section-plate, it will be convenient to consider four typical cases, taken from biaxial crystals, which will illustrate the uses of the various movements provided with the instrument.

1. The simplest case is that of a crystal belonging to the rhombic system which exhibits a well-marked zone comprising two pairs of pinacoid faces, or a pair of pinacoid faces and faces of the basal plane, together, perhaps, with interlying prism or dome faces, or consisting of prism or dome faces alone. Let the axis of this zone be the median line to which it is desired to grind a section perpendicular, such a section not being available ready formed owing to the absence or inadequate development of faces (pinacoidal or basal) parallel to the plane in question. The crystal is cemented upon the holder by means of the easily fusible but rapidly setting wax, previously referred to; it should be well embedded in the wax, which should also be pressed closely round it and into the grooves of the holder while warm, attention to these points being essential in order to avoid fracture during grinding. The crystal is arranged with the zone of faces referred to parallel to the axis of the holder, so that when the latter is fixed in its socket the zone is approximately vertical. The telescope is then fixed in a convenient position fronting the observer, the collimator at

an angle of 90°–120° from it, and the goniometer lamp in front of the slit. The zone of faces is then adjusted in the ordinary goniometrical manner with the aid of the centering and adjusting movements, so that the images of the vertically-arranged slit reflected from the various faces of the zone are bisected by the horizontal spider-line upon rotation of the crystal and all that moves with it by means of the ebonite milled disc. The plane which it is desired to grind will then be parallel to the grinding disc. Even in this simple case the graduations of the circle are valuable, as enabling the observer to make quite certain, by taking the angular distances of the faces, that the adjusted zone is really the one which it was desired to so adjust.

During these operations, any vertical motion of the crystal, in order to raise or lower it to the height of the axis of the optical tubes, is brought about by movement of the inner steel axis *r* by means of the milled head at the top of the axis, the gun-metal axis *i* being fixed, the elbow *p* of the lever carrying such being kept down upon the circle plate. The other lever should be adjusted to rest approximately horizontally by suitably arranging the screw *o*. It will now be found that while the elbow of the front lever rests upon the circle, its short curved arm is alone supporting the axis, the terminating blunt knife-edge of the short arm of the horizontal lever being, perhaps, a quarter of an inch below the collar fixed to the axis. By allowing the elbow lever to rise, gently assisting it at first, the axis falls until at length its collar likewise rests upon the knife-edge of the horizontal lever, when any further downward movement of the axis occurs with practically the whole weight counterbalanced by both levers. About this point the weight above the crystal can be varied almost to any extent, according to the judgment of the manipulator as to the strength of the crystal. The grinding plane should now be fixed in position over the polishing plane, and a few drops of sweet oil placed upon it. The oil should be evenly distributed over the marginal portion of the grinding surface, where the grinding occurs, by means of a camel-hair brush, carried by a small movable stand; the brush also serves the purpose of sweeping the plane in front of the crystal.

The inner steel axis *r* is then lowered by means of the upper milled head until the crystal is not more than an eighth of an inch above the grinding surface, keeping the left hand upon the lever so that its elbow still rests upon the circle plate. The lever is then gently assisted upwards, its rapidity being kept under full control until the crystal just touches the grinding disc, when rotation of the latter may be commenced, very slowly at first. If the crystal is not extremely friable the horizontal lever may be allowed to remain out of action till the grinding is nearly finished, for the collar of the axis will still be more than one-sixteenth of an inch higher than the knife-edge of that lever. The maximum pressure on the crystal will therefore be equal to about half the weight of the axis, and a very large number of artificial crystals will not break under this pressure. The weight with which the crystal bears upon the grinding disc can, however, be beautifully regulated by gently holding the counter-poise of the lever between the thumb and first finger of the left hand, steadying the hand, if necessary, by resting the little finger upon the top of the left column. One can detect so accurately by the delicate sense of touch how the grinding is proceeding, whether the crystal is bearing it easily, or whether there is too much strain, and can either reduce the pressure by gently adding to the weight of the lever by slight downward pressure of the finger and thumb upon the counterpoise, or can increase it by exerting a slight upward pressure, and thus diminishing the counterpoising effect. Moreover, as the crystal is ground away, one is able to preserve contact with the grinding surface by the same slight upward pressure upon the lever, which, even when very friable crystals are under operation, may be safely exerted at frequent intervals. With fairly hard crystals (potassium sulphate, for instance), the effect of the counterpoise may be entirely removed every few seconds by lifting the lever out of action, without fracturing a good specimen, provided the rotation of the grinding surface is steady and its rate does not exceed two revolutions per second. For still harder crystals, those that are only just softer than glass, the cup at the top of the axis may be weighted with more or less small shot or other convenient weighting material, but the grinding must be slow, and carefully watched. If, on the contrary, the crystal is soft or brittle, both levers must be brought into action, the horizontal one by lowering its screw support, and the pressure regulated as before by manipulation of the elbow lever. If cleavage is largely developed there is less chance of splitting if the grinding is made to occur in the direction of the trace of the cleavage plane, and not at right angles to it.

It is best in all cases to finish grinding with both levers in action, as the relative coarseness of the ground surface is rendered considerably smoother thereby, and the after polishing is much more rapidly achieved. The crystal holder may at any time be removed in order to inspect the ground surface, and to see whether grinding has proceeded sufficiently far, without any danger of disturbing the adjustment, the groove in the rod of the holder running tightly along its guiding rib. When this is the case, and the final gentle grinding has been done, it is advisable, before removing the grinding plate, to again test the correctness of adjustment of the crystal in order to be certain that no movement has occurred during the grinding. The crystal is well cleansed from oil with a silk handkerchief, the goniometer lamp, whose small by-pass has been left burning, is re-lit, and the images from the various faces of the adjusted zone are reviewed. If they are still, as is usually the case, symmetrical to the horizontal cross-wire, polishing can be proceeded with; if there is any slight evidence of movement, due, perhaps, to softening of the wax by the heat caused by too rapid grinding, the crystal must be re-adjusted, again ground for a minute or so, and the images again reviewed, when they should be perfectly satisfactory. The grinding plate is then removed, and the polishing performed upon the lower permanent polishing disc, likewise lubricated with oil, the same method of manipulating the elbow lever according to the "feel" of the polishing being followed. As a rule, the grinding need not occupy more than fifteen minutes, and the polishing five; polishing for this length of time usually furnishes a surface almost like that of ordinary glass, and is of great value, as it enables measurements of the optic axial angle to be made without the use of cemented cover-glasses.

It is so easy to give a last glance at the images from the adjusted zone after polishing that it should always be done, for one is then absolutely certain that the desired surface has been obtained. It may be remarked that the use of a solvent for the crystal as lubricating liquid is to be deprecated, as it destroys the faces of the crystal, and so prevents the possibility of thus checking the adjustment.

2. As the second typical case, a monoclinic crystal may be considered, for which determinations of extinction (for sodium light) in the symmetry plane, which i considered to be developed as a prominent face, and an examination of the same plane in convergent polarised light, have been carried out. These, it may be supposed, reveal the fact that one of the median lines perpendicular to which we desire to grind a surface, is inclined at a certain angle smaller than 45° to the intersection (edge) of the symmetry plane with either a prism, orthopinacoid, or dome face, or the basal plane. Four operations are necessary in order to adjust such a crystal so that this known direction of the median line shall be perpendicular to the grinding plane. The crystal must first be cemented upon the holder in such a manner that the zone of faces parallel to the edge just mentioned is approximately perpendicular to the grinding plane; suppose, for instance, it is the prism zone of faces parallel to the vertical axis, containing the symmetry plane (clinopinacoid), the orthopinacoid, and several prismatic forms. The symmetry plane must, in the second place, be made exactly parallel to the upper tangent screw of the adjusting apparatus. The whole zone should, in the third place, be exactly adjusted perpendicular to the grinding plane. It then only remains to carry out the fourth operation of rotating the tangent screw so as to move the segment round the required number of degrees to bring the direction of the median line exactly perpendicular to the grinding plane; for, as the symmetry plane is parallel to the screw, and hence to the circle of motion, it remains perpendicular as a plane, and we only require to rotate it until the desired direction in it is perpendicular to the grinding plane.

For use in all cases in which it is required to adjust any crystal face parallel to a tangent screw a special crystal holder is provided, which permits of nearly 90° of rotation of the crystal after placing in its socket, and subsequent fixing in any position. The two parts of this holder are seen in fig. 1, to the left of the larger ordinary holder, recognized by its cross grooves; it is also shown in position in fig. 3. It consists of a grooved steel rod, similar to those of the other holders, carrying below a small solid brass cylinder. The latter fits closely into an outer hollow cylinder, closed below; the outer side of the end is cross-grooved like the discs of the other holders, for the more secure holding of the wax with which the crystal is to be cemented on to it. This hollow cylinder is pierced by two horizontal slots of slightly more than 90° extent, on opposite sides of the cylinder, and at different heights, for reasons of strength. The outer cylinder is held in position round the inner one by small milled-headed screws passing through the slots and screwing into the solid cylinder at opposite sides, the direction of the screws being approximately parallel to the upper tangent screw when the holder is fixed in its socket. After adjustment of the crystal these screws can be used as clamping screws to fix the outer cylinder rigidly to the inner core.

In order to carry out the four operations above specified, the crystal is cemented in the usual manner to the end of the hollow cylinder of the special holder, with the zone of faces to be adjusted placed approximately parallel to the axis of the cylinder, and with the clinopinacoid, the symmetry plane, arranged not very far from parallel to the direction of the clamping screws arranged at the centres of the slots. The wax employed sets so rapidly that there is only time to make the roughest approximation to this position, which, however, is all that is necessary. The operation may be conveniently carried out with the inner cylinder inserted. For the purpose of adjusting a face exactly parallel to either tangent screw, a small plate of microscope cover-glass is cemented to the face of the lowest portion of the lower segment, immediately above the position to be occupied by the crystal holder, and parallel to the plane of movement of the segment. Before attaching the cylindrical crystal holder the axis is lowered until the glass plate is about the height of the axes of the telescope and collimator, the image of the slit reflected from the surface of the plate is adjusted to both cross-wires, and the reading of the circle for this position recorded. The cylindrical holder is now attached, the circle is set to the recorded reading if the face is to be adjusted parallel to the lower tangent screw, or at 90° from that position if the face is to be made parallel to the upper tangent screw, the outer cylinder of the crystal holder is rotated until the image of the slit reflected from the face is bisected by the vertical cross wire, and the tangent screw at right angles to the face is manipulated, if necessary, so that the image is also bisected by the horizontal cross wire. The cylinder is then fixed to its core by means of the small clamping screws.

Having in this manner adjusted the clinopinacoid parallel to the upper tangent screw, the third operation of adjusting the other faces of the zone perpendicular to the grinding plane is then carried out by use of this upper tangent screw. Lastly, the whole zone now being exactly perpendicular to the grinding plane, the reading of the scale of the upper segment is noted, and the tangent screw is worked until the segment has moved over the required arc (the angle of extinction with respect to the axis of this zone) correctly set to within ten minutes, when the direction of the median line will likewise be perpendicular to the grinding plane. Grinding and polishing is then carried out precisely as in the first case.

3. The case may next be considered of a rhombic crystal which only exhibits one of the three principal planes parallel to two of the crystallographic axes, the remaining planes being of prismatic, domal, or pyramidal character. Suppose, for instance, the only faces exhibited are those of the basal plane and four prism faces belonging to the same form, and that it is desired to grind a plane parallel to one of the undeveloped

pinacoidal faces. The basal plane is set parallel to the upper tangent screw, and the zone containing it and one pair of prism faces is adjusted perpendicularly in the manner previously described. Knowing the angle between the prism faces from a previous goniometrical measurement, the upper tangent screw is rotated in the proper direction until the segment has described an angle equal to half the goniometrical angle between (the normals to) one of the adjusted prism faces and an adjacent prism face not so adjusted, when the theoretical pinacoid will be parallel to the grinding plane. If sufficient rotation cannot be effected by starting from the neighbourhood of zero, the preliminary adjustment of the zone is carried out with the segment rotated well over in the contrary direction, when an ample amount of rotation will be available.

The case of a rhombic crystal exhibiting none but dome forms—a rectangular pyramid—is to be similarly treated, the only difference being that one of these faces is to be set parallel to the upper tangent screw instead of the basal plane or pinacoid in the simple case just considered, and after adjusting perpendicularly the zone containing this face and an adjacent one, or, in other words, the edge between these two faces, and rotating both segments by means of the tangent screws for the calculated number of degrees, the plane containing the two crystallographical axes parallel to which it is desired to grind a surface will be parallel to the grinding disc.

4. For the case of a monoclinic crystal which does not exhibit the clinopinacoid (the symmetry plane), but only prism faces in the principal zone, the special form of adjusting apparatus represented in fig. 3 will be found useful. The usual course of grinding a section parallel to the symmetry plane can first be carried out, by simply adjusting parallel to the axis of rotation of the instrument the zone of faces perpendicular to the symmetry plane containing the basal plane and orthodomes. The results of the stauroscopical observations with this section will, of course, reveal the positions of the axes of optical elasticity. Suppose it is, then, desired to grind a section perpendicular to that axis of optical elasticity which is inclined at an angle less than 45° to the vertical axis of the crystal. If the clinopinacoid were developed this could readily be carried out by the method of Case 2; if the orthopinacoid were present there would also be no difficulty, for if that were set parallel to the lower tangent screw, and the zone of prism and orthopinacoid faces adjusted perpendicular to the grinding plane, the direction of the axis of optical elasticity could be brought vertical by rotation of the upper tangent screw, which is set at right angles to the lower one, and therefore parallel to the symmetry plane. As, however, there are only prism faces present in the vertical zone, symmetrically inclined to the symmetry plane, it is evident that the two circular motions fixed at right angles will not directly enable the axis of optical elasticity to be brought vertical. But the necessary rotation of the symmetry plane in its own plane can evidently be effected by two equal motions in planes equally inclined to the symmetry plane. The special adjusting apparatus, in which the plane of the lower circular motion can be set at

any desired inclination to the plane of the other instead of being fixed at right angles, enables this to be carried out. It is only necessary to set the two motions parallel to the two faces of a prism of the same form, one on either side of the symmetry plane, and to rotate the segments by means of the tangent screws for the calculated number of degrees. The calculation is a very simple one, the total amount of desired rotation in the symmetry plane (the extinction angle) and the inclination of the two circular motions to that plane being known. In order to set the motions parallel to the two prism faces, it is sufficient to set one parallel in the usual manner to the lower tangent screw, then starting with the motions parallel, the indicator at zero, to rotate this lower motion about the upper for the number of degrees (read upon the small horizontal graduated circle which registers the rotation) corresponding to the known angle of the prism. In order to be able to carry out this adjustment easily, it is advisable to take somewhat more than the usual care to cement the crystal upon the holder so that the prism zone is as nearly as possible in the approximately correct position parallel to the axis of the holder, so that very little preliminary adjustment is necessary before rotating the segments for their calculated arcs.

The same adjustment may be attained even more easily by employing this alternative pair of circular motions in another manner. One of the prism faces is set parallel to the lower tangent screw, and the lower segment then rotated about the upper one, by means of the horizontal circle, for the number of degrees corresponding to the angle between the prism face in question and the symmetry plane, so that the plane of the upper circular motion will be parallel to the symmetry plane. The approximate preliminary adjustment of the prism zone parallel to the axis of rotation of the instrument is then rendered perfect by a few successive approximations with the two motions thus inclined. The axis of optical elasticity perpendicular to which a section is to be prepared may then at once be brought vertical with respect to the grinding plane by rotation of the upper segment for the number of degrees corresponding to the determined extinction upon the symmetry plane, that is, corresponding to the known deviation of the median line to be adjusted from the vertical axis of the crystal.

The above four cases illustrate the possibilities of usefulness of the instrument, but it will rarely happen that the more difficult cases will have to be resorted to. Crystals will usually be found which exhibit primary faces which will enable the desired plane to be immediately set parallel to the grinding disc without any preliminary calculation. Even if such faces are only developed to the extent of a mere line, that is quite sufficient, for usually a reflection of the Websky slit will be afforded of sufficient brightness to enable the adjustment to be effected. The case of triclinic crystals is, of course, more difficult, and no general statement of their mode of treatment can be given; the plan of operations must be thought out for each crystal. With the information afforded by stauroscopical and convergent light observations through the various pairs of faces, an approximation to the positions of the axes of optical elasticity can be arrived at and recorded upon the spherical projection of the crystal. It is then only a matter of interpreting the spherical projection mechanically, and utilising the movements provided with the instrument so as to bring the median lines perpendicular to the grinding plane.

Grinding of the Second Surface Parallel to the First.

Having thus ground the first surface of the plate, it now only remains to grind a second surface parallel to it. This may be done if desired with the aid of the apparatus supplied by FUESS, alluded to at the commencement of this communication. It can, however, be much more neatly and accurately achieved, and without the disagreeable noise made by the steel screws grating over the grinding plate, by use of the instrument now described, with the aid of a special crystal holder.

The crystal is first detached from the holder upon which it has been fixed during the grinding of the first surface, by removing the wax around it with a penknife; the hard-setting wax employed by opticians is very convenient, as a gentle pressure of the knife-blade under the crystal after removing the wax around its sides is generally sufficient to detach it intact and unsoiled by the wax. It is then cemented by its ground and polished surface to the centre of a circular glass disc, half an inch in diameter, cut out of the thinnest variety of microscope 3-inch by 1-inch slips, and with neatly ground circumference. Micro cover-glasses are too thin, they are too easily fractured. It is best to have a gross of glass discs made at once, cut exactly to the same size with the same tool. The cement used will depend upon the nature of the crystal. If it is an anhydrous salt which will not be likely to be injured by being raised to 60°–70°, Canada balsam, which has previously been heated for some days to about that temperature so that it sets immediately upon cooling, may be employed. With care the same mounting material may be used with many substances which contain water of crystallization, and the grinding of the second surface can consequently be immediately proceeded with. It is safe, however, to employ balsam or other cement dissolved in a quickly evaporating solvent, such as a concentrated solution of hard balsam in benzene, so as to avoid all risk, either of strain or of decomposition, by raising the temperature. Any good liquid cement which has effectual binding properties, hardens in a night, and is without action on the crystal, will answer the purpose, and a slight brown colour is no detriment provided it does not stain, for the well-polished section is to be unmounted again before use for the measurement of the optic axial angle. The disc upon which the crystal is mounted, after hard setting of the cement, is placed in the receptacle for it in the special holder, which will now be described.

It consists of two parts, which are shown in fig. 1 in front of the base, very slightly to the right. The upper portion, which is represented nearest the front and most to the right in the illustration, consists of a thick brass disc, 1 inch in diameter, resembling the one employed for re-grinding the surface of the grinding plate; one side of this disc is made a true plane, and to the centre of the other side the steel grooved attaching rod is fixed as in the other holders, special care, however, being taken to attain 90° exactly. Upon the side to which the rod is attached a shallow white metal cap is fitted and rigidly fixed by means of three small screws; it envelopes the thick disc down to half its depth and extends outwards for a quarter of an inch as a flange parallel to the plane surface. The flange is bored with three small holes at symmetrical points. The lower portion, constructed entirely of very hard white metal, resembles the cap in shape, and the uncovered lower half of the thick disc fits neatly in it; the outer flange is of like diameter and width to the one carried by the upper part of the arrangement, and carries three fixed projecting screws, which pass through the holes in the latter. In the centre of this lower cap a circular depression has first been braced out of such diameter and depth that any of the glass discs used for mounting the crystal will nicely fit in it, but cannot sink quite flush; a concentric hole of slightly smaller diameter has then been cut quite through. The thickness of the cap is such that the little annulus thus left to support the disc is only about the thickness of ordinary note paper.

When it is desired to use the arrangement, the upper portion is placed in position beneath the ordinary adjusting motions at the lower end of the axis of the instrument, and the rod firmly fixed in its socket by means of the milled-headed screw. The axis is then lowered by means of the large milled head at its summit until the truly plane surface of the thick disc is within one-eighth of an inch of the grinding plane. It is then gently lowered by manipulating the near counterpoised lever until it all but touches the plane. By placing a white screen in the background the relatively large 1-inch disc can be adjusted by means of the tangent screws, so that its truly plane surface is exactly parallel to the grinding plane, as evidenced by the equal thickness of the fine line of white background seen between the two planes upon sighting with the eye at the same level. This should also be the case when the axis and holder are rotated 90°, and, of course, likewise for all positions of the circle. The holder may then be removed from its socket; as its attaching rod is grooved and the groove is guided by a closely-fitting rib in the socket, the same position will be taken up when it is again placed in position. The disc carrying the cemented crystal is now placed in the circular depression of the lower part of the arrangement, crystal downwards, so as to pass through the hole, care being taken that there is no cement left on the margin of the disc, where it is supported by the thin annulus. The upper part is then inserted and the two parts are screwed together by means of three small milled-headed nuts, seen in fig. 1 in the centre of the front of the baseboard, which engage with the screws projecting through the upper flange. As the upper surface of the glass disc is not quite flush with the inner surface of the lower cap, it is firmly pressed against the truly plane surface of the thick disc when the nuts are screwed tightly down. Care should be taken that the slight space between the two flanges is equal all round. The whole arrangement is then again suspended from the axis of the instrument, and the grinding proceeded with until the section is sufficiently thin to exhibit the interference figure in convergent light. This may be ascertained without any disturbance of the adjustment by removing the holder from time to time from the axis, unscrewing the little nuts, taking out the glass disc carrying the section, and examining it upon the stage of the polariscope, or better, between the polarizing and analyzing tubes of the axial angle goniometer which is to be actually employed in measuring the axial angle. Grinding should cease when small rings are clearly visible round the hyperbolic brushes. When this is ascertained to be the case, the apparatus enclosing the section is again put together and replaced at the end of the axis, the grinding disc is removed, and the parallel surface well polished by use of the polishing disc. Provided care had been taken while cementing the crystal that the surface of the glass disc and the polished artificial surface of the crystal were truly parallel, that is, only separated by a very thin film of cement of equal thickness, the second ground surface will be truly parallel to the first. If the crystal is one of the first type, the parallelism can be verified while the holder is in position (after removal of the oil by a silk handkerchief) by observing whether the images of the slit of the collimator reflected from the faces on the edge of the section are symmetrical to the horizontal cross-wire of the telescope.

The thinness of the sections which can be thus prepared is, of course, limited by the tenuity of the annulus which supports the glass disc in the holder; as the latter is made so thin it will rarely happen that the double refraction is so powerful that a section cannot be ground sufficiently thin to exhibit small rings in convergent light. Whenever such is the case, however, the difficulty can be overcome by cementing the glass disc directly on to the truly plane surface of the thick disc.

Sections prepared in the manner which has now been described will never fail to exhibit the interference figures precisely in the centre of the field of the polariscope For the purposes of the measurement of the separation of the optic axes the crystal plate may be unmounted from the glass disc, if desired, by dissolving off the cement with benzene or other solvent which does not attack the crystal. The highly-polished section may be conveniently cemented, at a suitable point about its edge, by means of a little marine glue (or other cement which resists the action of the highly-refracting liquid, α-monobromnaphthalene, in which the crystal is to be immersed for the measurement of the angle $2\mathrm{H}a$ or $2\mathrm{H}o$), to the end of a small rectangular strip of thin glass, which can be held in the spring holder of the axial angle goniometer.

The Grinding of Prisms.

Prisms can be prepared by means of the instrument as readily as section-plates. The mode of setting any desired imaginary plane in the crystal parallel to the grinding disc, in order to grind a surface in that direction, will be clear from the foregoing. In the case of prisms two such surfaces are required, inclined at about 60° to each other. It is especially convenient that the two surfaces shall be equally inclined to one of the principal planes of optical elasticity, and this can be achieved in a very simple manner by use of the instrument now described. The most convenient mode of proceeding is to adjust this plane of optical elasticity parallel to the grinding plane, and the direction of the edge of the desired prism parallel to the lower tangent screw. Then, by movement of the upper tangent screw at right angles to the first, the corresponding segment may be rotated for an angle of about 30°, the exact amount of which should be noted. A surface is then ground and polished in this direction. As a movement of 120° would be required in order to bring the plane of the other desired surface parallel to the grinding plane if the same setting were retained, the crystal is unmounted. The hard black optician's wax used lends itself particularly well to unmounting, for, after detaching the wax surrounding the crystal at the side with the point of a penknife, the crystal may usually be detached, intact and unsoiled by wax, by a gentle pressure. If this is not the case, the crystal is loosened by the application of benzene or other solvent incapable of attacking the crystal. It is then cleansed from oil by a silk handkerchief, and re-set upon the crystal holder, after turning over, so that the second surface may be conveniently adjusted. After the re-adjustment of the same plane of optical elasticity parallel to the grinding plane, and the direction of the edge parallel to the lower tangent screw, the upper tangent screw is rotated for exactly the same number of degrees in the neighbourhood of 30° as in adjusting the first surface. The second surface is then ground and polished precisely similarly to the first. The two surfaces will then be inclined at about 60°, exactly 60° if desired; they will also be symmetrical to the plane of optical elasticity in question, and the refracting edge will be parallel to the desired axis of optical elasticity. It will frequently happen that a zone of faces will be developed perpendicular to the principal optical plane in question, so that its adjustment can be immediately effected, and the adjustment of the direction of the desired edge will usually be achieved in a simple manner with reference to existing faces. Even in more complicated cases a little consideration will enable the movements provided with the instrument to be utilised so as to achieve the desired result with accuracy. If the crystal is not very small a pair of surfaces may be ground while adjusted in each position, one 30° on each side of the plane of optical elasticity, so that a pair of prisms may be obtained, and the refractive indices thus determined in duplicate upon the same crystal. It is quite easy, moreover, to grind another pair of prisms symmetrical to another plane of optical elasticity, so that all three refractive indices of biaxial crystals may be determined, two in duplicate and one four times repeated upon the same crystal.

The faces of the prisms need not be covered with thin glass plates, cemented by a solution of balsam in benzene, if a little time and trouble is taken to fully utilise the polishing disc. Moreover, prisms may be prepared by this method even from very small crystals, such as one could never hope to fit satisfactorily with cover glasses, and, if carefully polished, the brightness of the refracted images of the Websky slit of the spectrometer will be ample to enable accurate determinations of refractive index to be made. The images reflected by the polished surfaces furnished by the instrument are invariably well-defined and single, enabling excellent measurements of the angle of the prism, as well as of the angles of minimum deviation of the refracted rays, to be made.

It may be remarked, in conclusion, that the instrument in the form described is somewhat too delicate to be employed for grinding sections of naturally-occurring crystals harder than glass, by substituting a small lapidary's wheel for the ground-glass grinding disc. The author expects shortly to be able to describe an instrument, now in course of construction, specially adapted for preparing sections and prisms of mineral crystals.

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