An apparatus for cutting crystal-plates and prisms.

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THE apparatus to be described has been designed for the cutting of parallel plates and of prisms of crystallized substances in any required direction. The authors have endeavoured to design a small apparatus, simple in construction and easy to manipulate, which at the same time will be capable of yielding results of sufficient accuracy for most optical work on minerals. Several instruments have been devised with the same objects in view, notably those of E. A. Wülfing, G. Halle, and F. Stöber. The well-known cutting and grinding goniometer of Dr. Tutton is an instrument of an entirely different class.

The apparatus designed by Wülfing [1] in 1901 consists of a tripod, two legs of which are formed by movable screws, the third leg being the crystal itself. By means of the two screws the crystal, set on a suitable holder, can be brought into any desired position with respect to a grinding-lap. In practice, Wülfing showed that this apparatus was capable of yielding very accurate results but, theoretically, the fact that the grinding of the crystal is constantly shortening the third leg of the tripod necessitates frequent corrections and presents many disadvantages.

In 1889 Wülfing had devised another apparatus [2] in which the adjustments were similar to those in his present (1901) model, but the third

[1] E. A. Wülfing, 'Ueber einen vereinfachten Apparat zur Herstellung orientirter Krystallschliffe.' Neues Jahrbuch Min., 1901, vol. ii, pp. 1–22.

[2] E. A. Wülfing, 'Ueber einen Apparat zur Herstellung von Krystallschliffen in orientirter Lage.' Zeits. Kryst. Min., 1890, vol. xvii, pp. 445–459.

leg of the tripod was formed by a fixed screw, and the crystal was mounted on a sliding cylinder on the centre of the tripod. This cylinder could not be rotated about its own axis. The use of this apparatus involved rather complicated calculations, and it was on this account that Wülfing abandoned it in 1901.

The apparatus now to be described originated in a small instrument for cutting parallel plates and low angle prisms, devised by one of us working with Professor O. T. Jones several years ago. When we came to improve on this instrument we were able to borrow many useful ideas of construction from Wülfing's apparatus, and we have used a series of holders cut at various angles, similar to those used in both of Wülfing's instruments. From the following description it will be seen that we have entirely altered the method of adjusting the crystal, and have endeavoured thereby to simplify the calculations involved, and have described a possible means of replacing them by graphical solutions.

Description.—The body of the apparatus[1] consists of a triangular brass plate B (fig. 1) surmounted by a brass cylinder D, which is graduated on its upper surface into divisions representing 5°. This outer cylinder carries inside it another brass tube d, which is capable of rotation about a vertical axis; a clamp C enables it to be fixed in any position. The centre of the instrument is occupied by a solid gun-metal plunger P, capable of independent vertical movement only, and restrained from rotation by a pin p, which fits into a slot cut in the rotating tube d. The bed-plate B of the instrument is traversed vertically by three screws S, S_1, S_2, of $\frac{1}{2}$ mm. pitch, which are placed at the apices of an equilateral triangle of which the axis of the instrument is the centre. They are rounded at their lower ends, are made of hardened steel, and are fitted with nuts W which will screw up and clamp them in any desired position. The screw S is provided with a head graduated into six divisions, and reads against the index-finger I. The pitch of the screw S and the distance between its axis and the line joining the screws S_1, S_2 have been so adjusted that one complete revolution of the screw S will give the instrument a tilt of $\frac{1}{2}°$ about the line $S_1 S_2$. The graduated head, therefore, reads to 5′ of arc.

The lower end of the plunger P is drilled for the reception of a series of chucks K, on which the crystals are mounted preparatory to being cut. These chucks have been bevelled at various angles ranging at intervals of 10° from 0° to 90°, but in all cases a small surface which is

[1] The instrument has been constructed by Messrs. James Swift & Son, Ltd., 81 Tottenham Court Road, London, W.

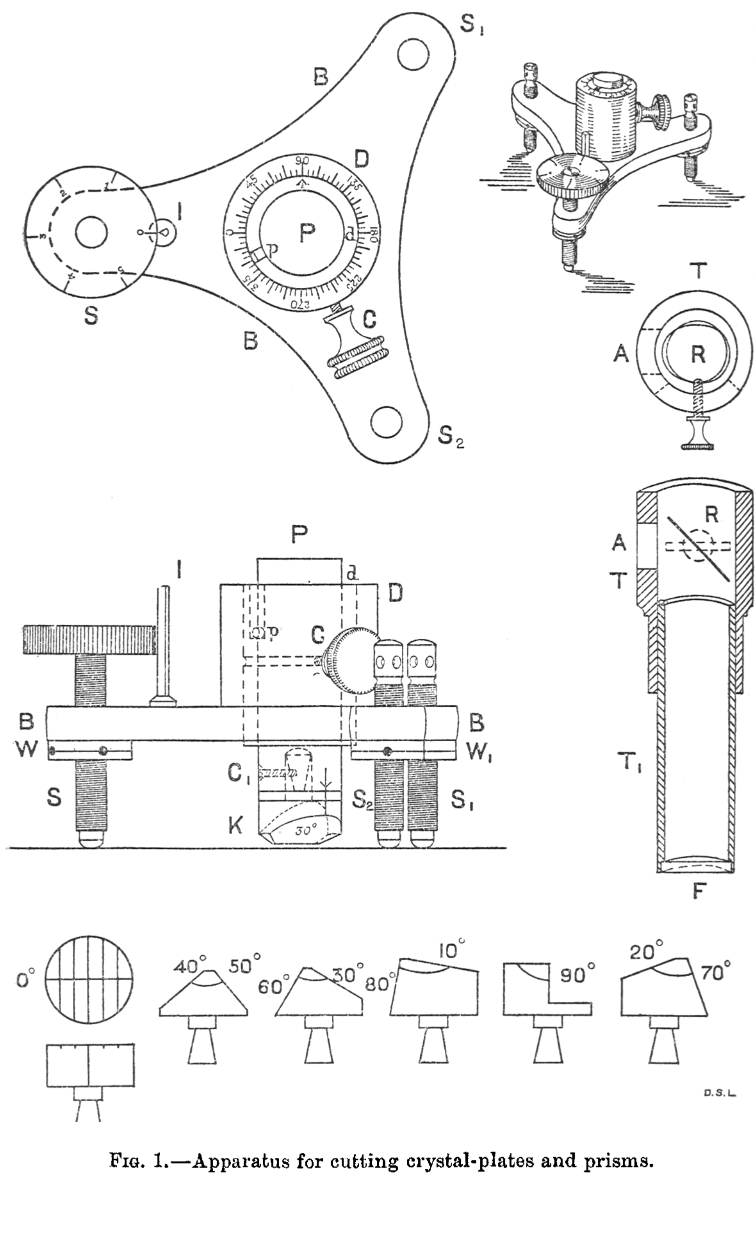

Fig. 1.—Apparatus for cutting crystal-plates and prisms.

normal to the axis of the instrument has been retained, giving a narrow plane between the cut surfaces. Each chuck has an engraved line on its side which can be brought into coincidence with an index engraved on the side of the plunger, and there clamped by the screw C_1. The ends of the chucks are conical, so that, as the screw C_1 works on an inclined surface, the chuck is drawn up into the plunger, and a good contact between the chuck and the plunger is thus insured. The zero chuck has its face engraved with a series of parallel lines crossed centrally by a single line at right angles. When the index on the cylinder d stands at 0°, and the lines on the sides of the chucks are coincident with the index on the plunger, the parallel lines on the zero chuck, and the straight edges of the inclined chucks, are parallel to the line joining S_1, S_2.

By the elevation or depression of the screw S, and the consequent tilting of the instrument, the angular value of any of the chucks may be increased or diminished, and thus any intermediate value may be reached.

The principle underlying the application of the instrument is that a crystal mounted on any of the holders may be rotated in two directions at right angles to each other, one of the axes of rotation being that of the plunger P. By means of these two movements it is possible to bring any desired direction in a suitably mounted crystal normal to the grinding surface.

To set the axis of the instrument normal to the grinding surface.—It will at once be seen that in order to cut a plane on a crystal in any definite direction it is necessary to commence operations with the instrument in some position of reference, which may be termed its zero position. This position is attained when the graduated circle around the plunger stands at 0°, bringing the lines and straight edges of the chucks parallel to the line S_1, S_2, and when the vertical axis of the instrument is normal to the grinding surface.

To fulfil the last condition, the usual method employed is that of standing the instrument on an accurately levelled surface, placing a spirit-level on the instrument and turning the screws S, S_1, S_2 until horizontality is obtained. This method, however, is open to serious objections; the small size of the spirit-level used on the instrument does not conduce to accuracy, and it was found, on trial, that some better method must be sought. We have devised a method which renders the apparatus independent of levels, and at the same time is capable of making adjustments of far greater accuracy.

The instrument is placed on a blackened glass plate. The plunger P is lifted out, and its place is taken by a tube T_1 of the same diameter, which carries a plate of optically flat glass F at its lower end, set normal to the axis of the tube. The tube is pushed down the instrument until the optical flat is close to the glass plate on which the instrument is standing. The upper end of the tube carries a vertical illuminator T, of the usual pattern, fitted with an inclined cover-glass R.

If light from a signal at a moderate distance away (say 5 feet) is allowed to fall on the cover-glass R, and is reflected down the tube T_1, the observer looking down the tube will see two images of the signal; one reflected from the surface of the optical flat and the other from the glass plate on which the instrument is standing. By turning the screws S, S_1, S_2 these images may be brought into coincidence, and it is then obvious that the axis of the instrument is normal to the surface on which the ends of the screws are resting. The proximity of the optical flat to the glass plate does away with parallax, for the light forming the two images travels practically the same length of path in each case. This method is sensitive to 2′ of arc.

To cut and polish a plane surface.—The crystal is mounted on a chuck by means of a thin film of Canada balsam, or of some other convenient medium, and the chuck placed in position in the plunger. In the case of easily cleavable substances it is sometimes found advisable to cover the crystal after mounting with plaster of Paris, to protect the edges while grinding. The instrument is placed on a sheet of plate glass, a small quantity of flour emery[1] or finest carborundum is introduced beneath the crystal and moistened with a little water. A drop of oil is placed beneath the end of each screw to ensure smooth running. The instrument is held in the hand and moved about on the grinding-plate so that the crystal describes a small circle within the patches of oil in which the screw-legs move. The weight of the plunger is sufficient to keep the crystal in contact with the grinding surface. If carborundum is used, the plane should receive a further grinding on fine emery before it is polished. When a sufficiently large face has been ground, the crystal is cleaned from abrasive material, the screws are wiped free from oil, and the instrument is transferred to a plate of pitch spread with finest washed rouge and water, and moved about as before. A brilliant polish may be obtained by this means on most crystalline substances.

The pitch plate is prepared by pouring well-boiled and strained

[1] Fine emery, taking at least twenty minutes to settle in water.

'British pitch', which can be bought by the pound, inside a brass hoop, 10 inches in diameter, and $\frac{3}{4}$ inch high, which rests on a plane iron plate. The iron plate should not be polished; it should be warm to the hand, and moistened with glycerine to prevent the pitch adhering. When cold, the pitch, with its enclosing ring, may be slid, not lifted, off the iron plate; it will be found to have an excellent lower surface.

Mr. Swift informs us that for some substances, especially calcite, a brilliant polish may be produced by the finest washed putty-powder spread on satin tightly stretched over a plane iron plate.

As in this instrument we are only cutting and polishing a small central portion of a relatively large area represented by the triangle $S\,S_1\,S_2$, the planes so cut and polished are exceptionally flat, and take a polish to their extreme edges.

To cut a face parallel to a given face.—The instrument being set in its zero position, the crystal is mounted on the given face on the zero holder. It is then ground to a suitable thickness, and polished in the manner described above. Faces so cut are accurately plane and vary very little from true parallelism. The only error introduced is that entailed in setting the given face on the holder, which can be reduced to a minimum by using the thinnest possible film of mounting medium.

To cut a plane O, in a zone of which the axis is represented by an edge $[r_1 r_2]$.—With the instrument in its zero position, the crystal is mounted on a face parallel to one of the faces of reference, r_1, on the chuck whose angle, ϕ, most nearly approximates to the angle $O \wedge r_1$, with the edge $[r_1\,r_2]$ parallel to the straight edge of the chuck. The difference, δ, between the angle $O \wedge r_1$ and ϕ is corrected for by rotating the screw S in the required direction, and a small face O_1 is ground and polished. The cutting and polishing of this small face need take only a few minutes. The crystal on its holder is then transferred to a goniometer, and the position of O_1 is accurately determined.

Two errors may have been introduced; one in setting the face r_1 parallel to the face of the chuck; the other in setting the edge $[r_1\,r_2]$ parallel to the straight edge of the chuck, i.e. to the line $S_1\,S_2$ joining the two fixed screws. To determine these errors the measurements made on the goniometer are transferred to a stereogram by the following method:

Let C, the centre of the projection (fig. 2), represent the pole of the axis of the instrument, P the pole of the normal to the face of the chuck, where $CP = \phi$, the angle of the chuck. Then, when the instrument is in its zero position, C is also the pole of the grinding surface and the screw S lies in the plane CPS. Let δ be the tilt given to the instrument by the screw S, then the pole of the grinding surface, and therefore of the face ground, will move to O_1, where $C \wedge O_1 = \delta$. The position of O_1 is therefore fixed with respect to C and P.

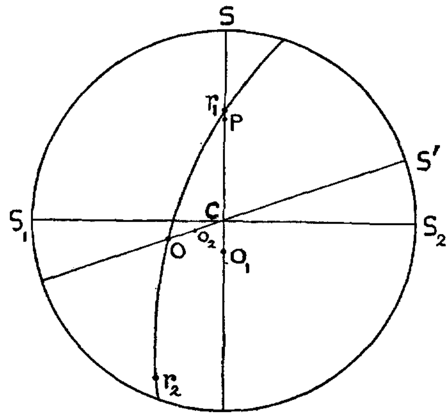

FIG. 2.

Let O_1r_1 be the angle measured on the goniometer between these two faces. If the setting of the face r_1 parallel to the face of the chuck has been effected accurately, the angle $O_1r_1 = \phi + \delta$, and the point r_1 will coincide with P. In any case, the difference should be almost negligible and the pole r_1 may be plotted on the zone CPS at a distance $O_1 r_1$ from O_1.

By drawing small circles from O_1 and r_1 with radii of angles O_1r_2 and r_1r_2 as measured on the goniometer, the position of r_2 can be determined. If the edge $[r_1\ r_2]$ has been set accurately parallel to the line $S_1 S_2$ the face r_2 will lie in the zone CPS, but as this setting is only done by eye the face r_2 may be found to lie off this zone, as indicated on the stereogram. For the sake of clearness the errors have been exaggerated in the figure. Having fixed the positions of r_1 and r_2 with respect to the instrument, the position of the required face O can be determined. It lies on the zone $[r_1\ r_2]$ at an angle Or_1 with r_1.

It is now required to bring the pole of the grinding-lap from O_1 to O. This is accomplished by turning the plunger through an angle equal to the angle SCS', the effect of which is to bring the screw S and the pole of the grinding-lap into the plane CO. The pole of the grinding-lap is now at O_2, where $CO_2 = CO_1$. By applying a correction in the tilt represented by the angle $CO - CO_2$ the pole of the grinding-lap is moved to O, and the desired face O is then ground and polished.

The poles r_2 and O are usually so close to the zone r_1CO_1 that the necessary corrections cannot be determined graphically on a stereographic projection; they can, however, be computed by solving the spherical triangles $r_1r_2O_1$ and r_1OC whereby the angles r_1CO and CO can be found.

General Case: To cut a plane on a crystal in any desired direction.—Certain prominent faces of the crystal are chosen as planes of reference, and the position of the required plane with respect to these faces is

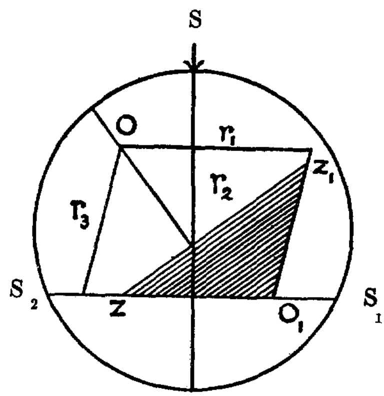

FIG. 3.

determined. Two faces of reference are sufficient, but the presence of a third face to which measurements can be made acts as a useful check on the calculations. Let O be the plane required, r_1 and r_2 being the planes of reference (fig. 3).

If neither of the zones Or_1 or Or_2 is represented by an edge on the crystal, it is mounted on the zero chuck with one face, say r_2, parallel to the face of the chuck and the edge $[r_1r_2]$ parallel to the lines engraved on it. The plunger is then rotated about its axis through the angle between the zones $[r_1r_2]$ and $[r_2O]$, so that the zone-axis $[r_2O]$ comes into parallelism with the line S_1S_2 joining the two fixed screws. A suitable tilt is now given to the instrument by means of the screw S and a small face is ground. This at once gives an edge ZZ_1 parallel to the zone-axis $[r_2O]$. The crystal is then removed from the zero chuck, and is mounted on the same face r_2 on a chuck whose angle most nearly approximates to $r_2 \wedge O$, with the edge ZZ_1 parallel to the straight edge of the chuck. The requisite correction is applied by turning the screw S, and the face O is cut by the method given above.

An example which serves to illustrate this general case is the cutting of a plate normal to the optic axis from a small cleavage rhombohedron of calcite.

The rhombohedron is cemented with a thin film of Canada balsam on to the zero chuck with one of its edges $[r_1r_2]$, parallel to the lines engraved on the chuck, and therefore parallel with the line S_1S_2. The plunger P is now turned through half the angle between the zones $[r_2r_3]$ and $[r_1r_2]$, namely 39° 3′. The graduated screw S is turned through 20 complete revolutions (= 10°). Grinding now gives a face at an angle of 10° with r_2 and in the zone Or_2 [111, 100]. This face need not be polished. The instrument is now brought back to its zero position. The crystal is removed from the zero chuck and cemented on the 40° chuck with r_2 parallel to its face, and the edge of reference just obtained parallel to the straight edge of the chuck. As $r_2 \wedge O$ in calcite is 44° 36′ it is necessary to add a tilt of 4° 36′ by means of the graduated screw S. Grinding will now give a face approximately parallel to O. The crystal, still on the chuck, is measured on the goniometer, and the poles are projected on a stereographic projection.

Here an additional error may have been introduced owing to the re-setting of the crystal on the 40° chuck, but with careful manipulation the face ground should not be more than 2° from the required position. The corrections may be computed by a modification of the method described in the preceding case, but where the errors are small the following graphical method commends itself for its simplicity and sufficient accuracy.

The crystal is removed from the inclined chuck, and re-cemented on the ground face on the zero chuck with the edge ZZ_1 (fig. 3) parallel to the lines engraved on the chuck, and a small parallel face is ground and polished. The angles made by this face O_1 with the faces of the rhombohedron are measured on the goniometer.

Let the calculated angles between the face required, O, and the faces of reference be: $O \wedge r_1 = \theta_1$, $O \wedge r_2 = \theta_2$, $O \wedge r_3 = \theta_3$; and let the angles measured from O_1 be: $O_1 \wedge r_1 = \theta_1 \pm d_1$, $O_1 \wedge r_2 = \theta_2 \pm d_2$, $O_1 \wedge r_3 = \theta_3 \pm d_3$, where d_1, d_2, and d_3 represent the differences between the observed and calculated angles. These angles are plotted on a greatly magnified stereographic projection of which only the central portion, represented by a small circle of 2° radius, is utilized.

Let O_1, the centre of projection (fig. 4), be the pole of the face which has been cut and of the axis of the instrument. The poles of the faces of reference, r_1, r_2, and r_3, lie at great distances away in the directions O_1r_1, O_1r_2, and O_1r_3, and these lines represent great circles passing through the poles of the faces of reference and of the face cut. As the distance from O to O_1 is very small—less than 2°—the angles r_1Or_2 and $r_1O_1r_2$ may be taken as equal. Small angles near the centre of this enlarged projection may be expressed as linear ratios, and small circles drawn round the poles of the planes of reference and passing near the centre of the projection may be drawn as straight lines.

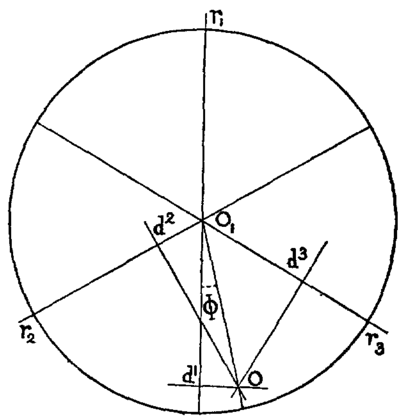

FIG. 4.—The radius of the circle represents 2°, the measured angles O_1r_1, O_1r_2, and O_1r_3 are 42° 54′, 45° 6′, 45° 48′, and the values of d_1, d_2, d_3 are −1° 42′, +0° 30′, +1° 12′.

With O_1 as centre, describe a circle of which the radius represents some convenient angle, say 2°, slightly greater than the largest error found in the measured angles. In the directions of r_1, r_2, and r_3, lay off distances proportional to d_1, d_2, and d_3, negative values of d_1, d_2, and d_3 being measured away from the poles of reference. Through the points so obtained draw lines perpendicular to the lines O_1r_1, O_1r_2, O_1r_3. These lines will be found to meet in a point O, which represents the pole of the face required.

It will be seen that a rotation of the crystal in the plane of projection through an angle Φ, and a tilt measured by OO_1 given by the screw S, in a plane at right angles to the plane of projection will bring the pole of the grinding surface from O_1 to O.

In an actual experiment on a cleavage rhombohedron of calcite, the application of corrections by this method gave a face for which the maximum difference between the measured and calculated angles amounted to 9 minutes.

The description of this graphical method has been given in some detail, as it illustrates a case that may frequently arise where the face required does not lie in a zone between two given faces. The cutting of certain faces in different crystals requires special treatment in each case. The method of computing the necessary corrections from the stereographic projection as outlined for the case of a face in a zone between two given faces is always applicable, but it must be left to the ingenuity of the individual to take full advantage of the habit of each crystal and to devise simple methods for the solution of each problem.

The instrument has been very carefully constructed, and the angular values given by the inclined chucks and by the rotation of the screw S are sufficiently accurate for most purposes. The angles given by the screw S may show errors of 10 minutes in an angle of 5°. For accurate work this screw can be calibrated by setting a plate of soft glass on the zero chuck, cutting a parallel face, and then cutting a series of small faces for successive rotations of the screw head. In cutting parallel plates the difference from parallelism may amount to 3 minutes, but here the error depends on the setting of the plate on the chuck; by using the thinnest possible film of mounting medium, this error may be made practically negligible. As mentioned above, the errors introduced in preparing a plate of calcite normal to the optic axis showed a maximum value of 9 minutes, so that the degree of accuracy obtained seems to be sufficient for most optical work on minerals.

Those who have occasion to use this apparatus will doubtless encounter many difficulties and some disappointments. Patience, cleanliness, and some skill in manipulation are requisite for the preparation of accurately orientated plates and prisms, but, when the working of the instrument is understood, the results obtained with it seem to amply justify the somewhat lengthy computations and corrections involved.