On the remarkable problem presented by the crystalline development of Calaverite.

By G. F. HERBERT SMITH, M.A., F.G.S.
With a Chemical Analysis by G. T. PRIOR, M.A., F.G.S.
Assistants in the Mineral Department of the British Museum.

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THE validity of Haüy's great law of the rationality of intercepts — better known as the law of rational indices—or its equivalent, the law of homogeneity of arrangement of the ultimate particles in a crystalline structure, has as yet never been seriously called into question: nevertheless, in the crystals of the telluride of gold, calaverite, we find characters which are to all appearance at variance with this law. As far as the author is aware and can ascertain, no difficulty of a precisely similar kind has ever been encountered before [1]. Certain substances do, indeed, display the so-called optical anomalies; but these are, as was first established by Mallard, in reality in strict accordance with the actual crystalline arrangement. In calaverite we are confronted with a problem of a different nature: here, if we pay attention merely to the morphological development of the faces, we immediately conclude that the crystals have the symmetry of the monoclinic system; there is evidently an axis of digonal symmetry parallel to the prism edge, and on many crystals a face may be noticed perpendicular to this edge, and, save in those which are obviously twins, there are no re-entrant angles [2] to suggest that the crystals are other than simple; their opacity prevents any optical investigation. When, however, we proceed to assign indices to the forms we find that with the exception of a few, to which by a suitable choice of the crystallographic axes and parametral plane we necessarily give simple indices, all the forms receive symbols of great

[1] The faces with high indices but simple mutual relations, lying in the same zone, in such a mineral as meneghinite may possibly be due to a similar cause, but in this case the common faces present no difficulties at all.

[2] Re-entrant angles do occur in the prism zone, but are due to its oscillatory and striated character.

and unsatisfactory complexity. So few, indeed, are the forms which receive anything approaching to simple indices that it is difficult to believe that this interpretation adequately represents the actual symmetry of calaverite. It will be shown in the course of this paper that the faces do possess zonal relations and do obey the law of simple anharmonic ratios in every zone, but they cannot be referred to a single lattice. In fact there appear to be as many as five distinct lattices, which are incongruent but not independent. The exact relations between them and the possible meaning of such a remarkable conjunction are discussed below (pp. 140–1).

Until quite recently practically nothing was known of the crystallographic characters of calaverite. The name was given by Genth[1] to a massive telluride of gold from the Stanislaus Mine, Calaveras County, California. The material from Cripple Creek, Colorado, analysed by Dr. W. F. Hillebrand, was, indeed, in part well crystallized, but so small and unsymmetrically developed were the crystals that Professor Penfield[2], to whom they were sent for examination, was unable to determine with certainty even the system of crystallization, and could only conclude that the crystals were probably triclinic and near sylvanite in their angles and axial ratios. Better material having since that time become available, Professor Penfield and Mr. W. E. Ford[3] have recently published a paper in which they place calaverite in the monoclinic system, but confess that the symbols which must be assigned to most of the faces are inexplicably high.

During the past two years and a half the Mineral Collection of the British Museum has been enriched by the acquisition, mainly through the kind consideration of Mr. Milton Moss, of a fine suite of specimens from the Cripple Creek District, Colorado. Conspicuous among these are numerous brilliant, yellowish crystals, which were stated to be calaverite. With the view of establishing their identity and determining the crystallographic characters of this mineral, a goniometric examination of the best crystals was begun by the author early in November, 1900, and continued almost without interruption for some months, during which time more material came to hand. The preliminary results of the investigation were discussed at the meetings of the Society held on

[1] Amer. Journ. Sci., 1868, ser. 2, vol. xlv, p. 314.

[2] 16th Annual Report U. S. Geol. Survey, 1894–5 (1895), pt. ii, pp. 135–6; also Amer. Journ. Sci., 1895, ser. 3, vol. l, p. 131.

[3] Amer. Journ. Sci., 1901, ser. 4, vol. xii, pp. 225–46; a German translation appeared in Zeits. Kryst. Min., 1902, vol. xxxv, pp. 430–51.

March 19 and June 18, 1901. The brief notice of the earlier meeting which appeared in 'Nature[1]' attracted the attention of Professor Penfield, and he communicated with the present writer, who in reply gave a more detailed account of his conclusions; in consequence a paragraph[2] referring to them was inserted in the paper of Penfield and Ford already mentioned.

In the course of this investigation measurements were made of no fewer than forty-nine crystals, of which nineteen were removed from the matrix for the purpose and thirty had been already isolated. Nine crystals were taken from a specimen stated to have come from the Midget Mine, Gold Hill; one from a specimen from the Doctor Jackpot Mine, Raven Hill, and fifteen isolated crystals came from the same mine; four isolated crystals came from the Victor Mine, Bull Hill; and eight isolated twin crystals from the Elkton Mine, Raven Hill: the exact localities of the remaining specimens are not stated on the labels. Twenty-six are what may be called simple crystals, and twenty-three are crystals twinned according to ordinary laws; of the twenty-six simple crystals seventeen are left-handed and nine right-handed, in the sense employed by Penfield and Ford. They are associated with quartz, iron-pyrites, fluor and kaolin, and are, when on the matrix, firmly embedded in the gangue. Consequently crystals terminated at both ends are exceedingly rare; indeed only one such instance was noticed, and that in the case of one individual of a cross twin; in another case, where faces occur at the lower end they really belong to the second individual of a twin. When fresh, the crystals are silver-white in colour, but become more or less deep bronze-yellow on exposure.

The crystals differ considerably in size but are very similar in appearance, the cross-section varying from a narrow oblong to a square (see figs. 1 and 2); those removed from the matrix are small, with a cross-section of about $0{\cdot}5 \times 0{\cdot}5$ mm., in the case of the smallest measured of $0{\cdot}2 \times 0{\cdot}2$ mm.; the isolated crystals are very much larger, some being as much as 7 mm. in length with a breadth varying from 1–5 mm. Many of the large crystals are skeletal, with a remarkable development of internal faces which are all consistent with the development of the exterior; it is not uncommon to find pits on a large face lined with faces in harmony with the crystalline development. Many crystals which, judged from the exterior, appear to be compact are found on fracture to be more or less hollow.

The crystals are prismatic in habit. The prism zone is so much

[1] Nature, 1901, vol. lxiii, p. 554. [2] Loc. cit., p. 241.

striated parallel to its edge that a definite single image rarely occurs corresponding to any particular face; the terminal faces, on the other hand, give good definite reflections in most cases, although many of the faces, even on the large crystals, are so minute that when viewed through the microscope of low power, into which the telescope of the goniometer may be converted, only a speck of light is visible and no certain contour is discernible. The figures, though intended to be representative, have been drawn from actual crystals; in figs. 1, 2, 4, 5, and 6 the line

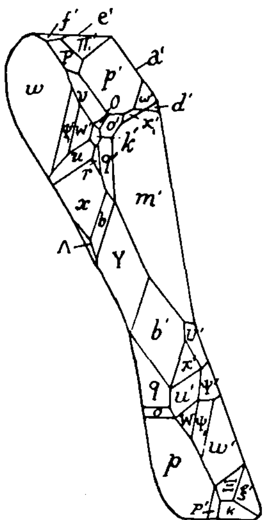

FIG. 1.

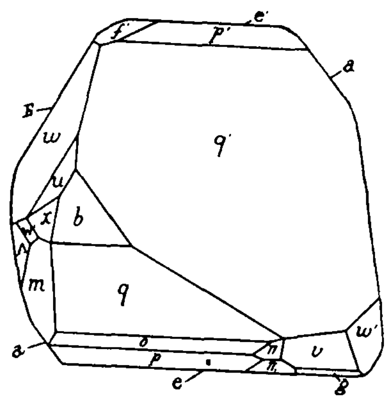

FIG. 2.

Untwinned crystals.

of sight is supposed to be parallel to the edge of the prism. The crystal drawn in fig. 1 has a cross-section of $3{\cdot}5 \times 0{\cdot}7$ mm. and possesses no fewer than sixty-two terminal faces representing forty-two different forms. Nearly half of these are so minute that it was impossible to include them in the drawing. The proportionate size even of the smaller faces given in the figure had necessarily to be somewhat exaggerated. This figure is typical of all those with many faces; a few faces, such as *p*, *o*, *q*, *b*, *y*, &c., are comparatively large, but the remainder, situated at the edges or on the corners of the large faces, are almost infinitesimal in size; nevertheless they give measurable, if very faint, images. The crystal drawn in fig. 2 has a cross-section of $2{\cdot}2 \times 2{\cdot}2$ mm. It is remarkable for the unusual number of definite faces in the prism zone which give distinct images.

The crystals are very brittle, but exhibit no cleavage. Their fragility is so great that many of the isolated crystals are broken in parts (cf. figs. 4, 5, and 6).

In carrying out the examination of these complex crystals the author had at his disposal an instrument conveniently adapted to the purpose in the three-circle form of goniometer[1] designed by him, whereby the zonal relations of the terminal forms can be determined by direct observation. It may here be repeated that the method of using this instrument is to adjust the edge of some prominent zone—in this case the prism zone—parallel to the axis of the third circle, *C*[2], and to make measurements from any pole in this zone which is crystallographically possible, but does not necessarily represent an existing face. For any terminal face the readings of the circles *A* and *B*, duly corrected for the zero reading, give respectively the polar distance and the azimuth. The azimuths when measured from such a pole must, in the case of a simple crystal, obey the law of rational anharmonic ratios, and we have, therefore, a convenient method of determining the indices of any terminal face as the intersection of two known zones.

As has been already stated, the prism zone of calaverite is invariably striated; this, of course, does not in any way prevent, but on the contrary tends to facilitate, the accurate adjustment of its edge parallel to the axis of *C*. On the other hand, no face is found to give a sufficiently well defined image which can invariably serve as pole of reference, and any such pole had to be determined from the intersection of a cross zone with the prism zone. Fortunately there happens to occur on all the measured crystals, with the exception of a few cross twins, a markedly prominent zone, which contains at least two, and usually three or four, well developed faces, giving bright and distinct reflections. The adjustment of this zone could, therefore, be made with considerable certainty, and, indeed, whenever it was deemed necessary to re-measure any crystal, there was very close agreement between the two sets of readings; any discrepancy is generally due to a slight want of parallelism in the prism zone, or, if it occurs in a few particular readings, to a want of definition

[1] This Magazine, 1899, vol. xii, pp. 175–82; a translation appeared in the Zeits. Kryst. Min., 1900, vol. xxxii, pp. 209–16. Cf. also this vol., p. 75.

[2] This is the same notation as that employed in the papers mentioned above: *A* is the horizontal circle, whose axis is fixed in space; *B* the vertical circle, whose axis lies in a horizontal plane; and *C* the third circle, whose axis may take any direction in space.

in the reflected images. Unless the corresponding image is much striated any reading may be regarded as accurate within 5′; a point to which we refer later. The point of intersection of the above-mentioned zone with the prism zone served as pole of reference for the whole of the crystals measured, with the exception of the twins alluded to. These measurements are given in Table I.

In this table the whole of the observations made on forty-two crystals are incorporated, and have been duly weighted in deducing the mean values; the remaining seven crystals examined, all cross twins, do not possess the particular cross zone sufficiently well developed for the accurate determination of the pole of reference. The symmetry revealed by the measurements is discussed later, but we may mention here that the fundamental constants and the indices of the forms have been calculated by the method of least squares, from the angles marked with an asterisk, on the hypothesis that the symmetry is triclinic, and becomes pseudo-monoclinic owing to twinning about an axis parallel to the edge of the prism zone. The symbols given in the first column are the indices which the faces receive when referred to the principal lattice, on which most of the large and prominent faces lie. Many which receive complex indices, when referred to this lattice, have simple indices, when referred to a second; these symbols are given in the second column. As will be seen below, a few, such as Y and μ, which cannot be referred to either of these lattices, lie on a third. The prism zone is common to all three. The constants of the second lattice are computed from the calculated values in Table I; those of the third lattice from the values calculated for the prism zone and from the mean observed azimuth and distance of J, namely, 90° 0′ and 105° 11′½.

The fundamental constants of the three lattices are:—

$\mathbf{T}_1$. First and principal (triclinic) lattice:

$$a : b : c = 2{\cdot}0013 : 1 : 1{\cdot}1713;$$
$$\alpha = 83^\circ\ 58', \beta = 100^\circ\ 39', \gamma = 96^\circ\ 19';$$
$$010 : 001 = 94^\circ\ 59', \quad 001 : 100 = 79^\circ\ 54\tfrac{1}{2}', \quad 100 : 010 = 84^\circ\ 41'.$$

$\mathbf{T}_2$. Second (triclinic) lattice:

$$a : b : c = 2{\cdot}0990 : 1 : 1{\cdot}2231;$$
$$\alpha = 72^\circ\ 14', \beta = 104^\circ\ 48', \gamma = 108^\circ\ 37';$$
$$010 : 001 = 104^\circ\ 7', \quad 001 : 100 = 79^\circ\ 54\tfrac{1}{2}', \quad 100 : 010 = 74^\circ\ 48\tfrac{1}{2}'.$$

$\mathbf{M}_3$. Third (monoclinic) lattice:

$$a : b : c = 1{\cdot}9868 : 1 : 1{\cdot}1634;$$
$$\beta = 100^\circ\ 5\tfrac{1}{2}'.$$

TABLE I.

Measurements from e (101).

Form.				Calculated Values.		Observed Means.		Edges.	Limits of Observation.		Remarks. Characters of faces and images.
	T_1	T_2	M_2	Azi-muth.	Dis-tance.	Azi-muth.	Dis-tance.		Azimuth.	Distance.	
				° ′	° ′	° ′	° ′		° ′ ° ′	° ′ ° ′	
e	101	...	...	0 0	0 0	0 0	0 1	33	... ...	359 41 – 0 30	Small; image distinct.
e_1	705	...	...	,, ,,	7 36½	,, ,,	7 35	2	... ...	7 23, 7 47	Striated.
e_2	302	...	...	,, ,,	9 15						
e_3	201	...	...	,, ,,	16 8	,, ,,	?	...	... ...	10°–17°	,,
e_4	401	...	...	,, ,,	30 57						
e_5	501	...	...	,, ,,	34 42	,, ,,	?	...	... ...	30°–38°	,,
a	100	...	...	,, ,,	52 18½	,, ,,	52 28	42	... ...	51 30 – 53 9	Often large; single image.
E_{12}	10.0.$\bar{1}$	...	...	,, ,,	62 8	,, ,,	62 11½	8	... ...	61 20 – 62 38	Striated.
E_{11}	60$\bar{1}$	...	...	,, ,,	68 44	,, ,,	69 7	42	... ...	68 15 – 69 58	,,
E_{10}	25.0.$\bar{6}$	...	...	,, ,,	75 48	,, ,,	75 54	3	... ...	75 42 – 76 11	,,
E_9	11.0.$\bar{3}$	...	...	,, ,,	78 50½	,, ,,	78 41	10	... ...	78 1 – 79 32	,,
E_8	30$\bar{1}$	...	...	,, ,,	84 13						
E_7	50$\bar{2}$	...	...	,, ,,	89 41	,, ,,	?	...	... ...	84°–96°	Much striated and oscillatory.
E_6	20$\bar{1}$	...	...	,, ,,	96 58½						
E_5	90$\bar{5}$	...	...	,, ,,	100 33						
E_4	70$\bar{4}$	...	...	,, ,,	101 31	,, ,,	101 0	16	... ...	99 58 – 102 42	Striated.
E_3	80$\bar{7}$	...	...	,, ,,	115 40	,, ,,	115 20	5	... ...	114 39 – 115 53	,,
E	10$\bar{1}$	...	...	,, ,,	119 40½	,, ,,	119 19½	24	... ...	118 11 – 120 6	Distinct face and image.
E_1	30$\bar{4}$	...	...	,, ,,	127 18	,, ,,	127 5½	8	... ...	125 48 – 127 52	Striated.
E_2	10$\bar{3}$	...	...	,, ,,	141 8½	,, ,,	140 28	6	... ...	140 13 – 140 51	,,
c	00$\bar{1}$	...	...	,, ,,	152 24	,, ,,	152 18	44	... ...	151 24 – 152 40	Small; image distinct.
e_7	$\bar{1}$0$\bar{2}$	...	...	,, ,,	167 44						
e_6	7.0.$\bar{1}\bar{2}$	...	...	,, ,,	170 0	,, ,,	?	...	... ...	168°–171°	Striated.

η	21.4.3	...	...	21 19	69 25	21 9	69 18	1	... ...	... ...	Small; image good.
β	69.20.5	810	...	31 28½	65 53	31 38	66 2	2	31 37, 31 39	65 59, 66 5	Small; images good.
χ	310	...	...	36 30½	61 33½	36 32½*	61 40	1	... ...	... ...	Small; image good.
γ	$52\bar{1}$	...	...	" "	77 39½	" "	77 55	1	... ...	... ...	Minute; image poor.
σ	$21\bar{1}$	...	...	" "	95 56	" "	96 1	1	... ...	... ...	" "
ξ	$82\bar{3}$	...	...	" "	113 6½	" "	113 2½	6	36 20 – 36 42	112 43 – 113 15	Small; images distinct.
w_1	$11\bar{2}$	...	...	" "	126 51½	...	...	...	... ...	... ...	See Table III.
ρ_1	59.20.5	521	...	39 7	55 32	39 12	55 11	1	... ...	... ...	Minute; image poor.
ρ	49.20.5	210	...	" "	71 1	39 9	71 1	12	38 22 – 39 25	70 42 – 71 54	Small; images distinct.
Z	$39.20.\bar{15}$	$32\bar{1}$	...	" "	89 54	39 12	89 52	2	39 0, 39 24	89 50, 89 54	Minute; images poor.
K	$29.20.\bar{25}$	$11\bar{1}$	...	" "	108 48	39 0	108 45	1	... ...	... ...	" image poor.
K_1	$19.20.\bar{35}$	$12\bar{3}$	...	" "	124 19½	...	...	...	... ...	... ...	Not observed; a possible plane of twinning.
a	521	...	...	46 34	50 22	46 30½*	50 27	1	46 13 – 46 48	... ...	Minute; image poor.
ϕ	210	...	...	" "	66 31½	" "	66 33	9	" "	66 11 – 66 59	Small; images distinct.
θ	$32\bar{1}$	...	...	" "	87 41½	" "	87 47½	9	" "	87 20 – 88 7	" "
w	$11\bar{1}$	...	...	" "	109 28½	" "	109 27½	51	" "	109 11 – 109 48	Common face: usually small; images good.
Δ	39.20.5	321	...	50 27½	59 7	50 35	59 21½	2	50 14 – 50 49	59 18, 59 25	Minute; images poor.
Λ	29.20.5	110	...	" "	79 48½	" "	79 27	7	... ...	79 5 – 79 56	Small; images fair.
Ψ	$19.20.\bar{15}$	$12\bar{1}$	...	" "	103 25	" "	103 35	7	... ...	103 23 – 103 40	" "
R_3	11.6.3	...	...	55 53	52 20	54 35	52 20	1	... ...	... ...	Minute; image poor.
R_2	531	...	...	" "	58 6½	" "	59 10	1	... ...	... ...	" "
R_1	$56\bar{3}$	...	...	" "	97 12½	55 0	96 26½	5	54 48 – 55 19	96 20 – 96 31	Small; images fair: indices uncertain.
R	$23\bar{2}$	...	...	" "	105 26	55 55	105 31	1	... ...	... ...	Minute; image poor.
d_1	211	...	...	61 30½	36 12½	61 31½*	37 0	1	61 12 – 61 50	... ...	Minute; image bad.
d	321	...	...	" "	53 57	" "	54 2½	15	" "	53 50 – 54 15	Small; images distinct.
τ_1	541	...	...	" "	63 55	" "	63 15	1	" "	... ...	Minute; image bad.

K

TABLE I (*continued*).

Measurements from *e* (101).

	Form.			Calculated Values.		Observed Means.		Edges.	Limits of Observation.		Remarks. Characters of faces and images.
	T_1	T_2	M_3	Azimuth.	Distance.	Azimuth.	Distance.		Azimuth.	Distance.	
				° ′	° ′	° ′	° ′		° ′ ° ′	° ′ ° ′	
m	110	...	...	61 30½	75 54	61 31½	75 54*	63	61 12 – 61 50	75 29 – 76 25	Very common and large; images
r	34$\bar{1}$	...	...	” ”	89 16½	” ”	89 34	1	” ”	... ...	Minute; image poor. [good.
u	12$\bar{1}$	...	...	” ”	102 43	” ”	102 38½	39	” ”	102 28 – 102 56	Common and fairly large; images
u_1	143	...	...	” ”	114 53	” ”	113 10	1	” ”	... ...	Minute; indices doubtful. [good.
M	01$\bar{1}$	...	...	” ”	125 5	” ”	125 5	17	” ”	124 54 – 125 18	Small; images fair.
ω	29.20.15	111	...	67 8½	47 10½	67 29½	47 10	8	66 44 – 69 9	46 32 – 47 26	Small; images poor.
x_1	19.20.5	121	...	” ”	66 52½	” ”	66 53	2	” ”	66 45, 67 1	Minute; ”
x	9.20.5	010	...	” ”	94 10	” ”	94 8½	26	” ”	93 24 – 94 36	Common and fairly large; images
X	$\bar{1}$.20.$\bar{15}$	$\bar{1}$2$\bar{1}$	...	” ”	119 48	” ”	119 54	3	” ”	119 44 – 120 0	Minute; images poor. [fair.
Ω	$\bar{11}$.20.$\bar{25}$	$\bar{1}$1$\bar{1}$	...	” ”	137 0½	” ”	136 55	3	” ”	136 35 – 137 15	” ”
N_2	471	...	...	72 41	75 56½	72 12	76 13	1	... ...	... ...	” image bad.
N_1	370	...	...	” ”	84 9	73 13	85 8	1	... ...	... ...	” ”
N	477	...	...	” ”	133 1½	72 55	133 30	1	... ...	... ...	” ”
i	323	...	...	82 6½	32 14	82 7½	32 14½	13	81 30 – 82 40	32 3 – 32 40	Small; images poor.
p	111	...	...	” ”	43 38½	” ”	43 39*	76	” ”	43 17 – 44 2	Very common and large; images
n	343	..	...	” ”	52 3	” ”	52 5	2	” ”	51 55, 52 15	Small; images fair. [good.
o	121	...	...	” ”	62 55½	” ”	62 55*	61	” ”	62 11 – 63 43	Very common and large; images
											good. [good.
q	141	...	...	” ”	76 22	” ”	76 21½*	60	” ”	76 0 – 76 36	Very common and large; images
l	161	...	...	” ”	81 18½	” ”	81 14	1	” ”	... ...	Minute; image poor. [usually good.
b	010	...	...	” ”	91 30	” ”	*91 30½	57	” ”	91 3 – 92 15	Very common and large; images

L	$\bar{1}6\bar{1}$	...	...	,, ,,	101 36	,, ,,	101 22	2	,, ,,	101 16, 101 28	Minute; images poor.
Q	$\bar{1}4\bar{1}$	...	...	,, ,,	106 25½	,, ,,	106 25½	7	,, ,,	106 12—106 39	,, images fair.
y	$\bar{1}2\bar{1}$	...	...	,, ,,	119 24	,, ,,	119 27	20	,, ,,	119 17—119 54	Small; ,,
P	$\bar{1}1\bar{1}$	...	...	,, ,,	137 45	,, ,,	137 45	12	,, ,,	137 11—137 53	,, ,,
I	$32\bar{3}$	...	...	,, ,,	148 36	,, ,,	148 30	2	,, ,,	148 25, 148 35	Minute; images poor.
A	5.32.3	...	...	87 50½	90 9½	87 27	90 26	4	87 18—87 40	90 14— 90 33	,, ,,
Π_2	29.20.35	112	...	89 0	29 21	89 6	29 30	1	88 24—90 0	... ...	,, image poor.
Π_1	19.20.25	123	...	,, ,,	38 58½	,, ,,	39 2	4	,, ,,	38 42— 39 12	Small; images fair.
Π	9.20.15	011	...	,, ,,	55 15½	,, ,,	55 26½	7	,, ,,	54 47— 55 37	,, ,,
ψ	$\bar{1}.20.5$	$\bar{1}21$	...	,, ,,	81 24½	,, ,,	81 38	6	,, ,,	81 15— 82 14	Minute; images poor.
λ	$\bar{1}\bar{1}.20.5$	$\bar{1}10$	...	,, ,,	111 22	,, ,,	111 27	2	,, ,,	111 26, 111 28	,, ,,
δ	$\bar{2}\bar{1}.20.\bar{1}\bar{5}$	$32\bar{1}$	...	,, ,,	133 2	,, ,,	132 52	2	,, ,,	132 40, 133 4	,, ,,
π	$\bar{3}\bar{1}.20.\bar{2}\bar{5}$	$21\bar{1}$	...	,, ,,	145 53	...	...	...	... ..	... ...	Given by Penfield and Ford.
Y	5.24.3	...	010	89 46½	89 42½	90 0[1]	90 0[1]	23	90 12	90 8	Common and large; images good.
J	$\bar{1}\bar{1}.24.3$	...	141	,, ,,	104 54	,, ,,	105 11½	6	... ...	105 4—105 16	Minute; images fair.
O_1	$\bar{1}41$	...	...	93 37½	84 56½	93 22	85 5	1	... ...	... ...	Minute; image poor.
O	$\bar{1}20$	...	...	,, ,,	100 19½	93 30	100 17	1	... ...	... ...	,, ,,
C_1	9.10.15	...	...	95 55½	35 24½	96 1	35 37	1	95 10—96 48	... ...	,, ,,
C_2	$\bar{4}.15.5$	...	...	,, ,,	81 39½	,, ,,	82 14	2	,, ,,	82 8, 82 20	,, images poor.
C	$\bar{3}50$	...	...	,, ,,	102 0½	,, ,,	102 11	9	,, ,,	101 35—102 23	Small; ,,
C_3	$\bar{4}\bar{1}.60.5$	...	...	,, ,,	106 52½	,, ,,	106 57	2	,, ,,	106 53, 107 1	Minute; ,,
C_4	$\bar{2}\bar{6}.35.5$	...	...	,, ,,	110 11	,, ,,	110 12	1	,, ,,	... ...	,, image poor.
C_5	$\bar{1}\bar{1}.10.5$	...	...	,, ,,	126 59	,, ,,	127 15	1	,, ,,	... ...	,, ,,
C_6	$\bar{2}\bar{7}.20.\bar{1}\bar{5}$	...	...	,, ,,	135 39½	,, ,,	135 22	1	,, ,,	... ...	,, ,,
H_1	$\bar{1}42$	...	...	99 20	74 27½	98 52	74 24	1	... ...	... ...	,, ,,
H_2	$\bar{1}\bar{1}.16.1$	...	...	,, ,,	100 46½	98 51	100 48	2	98 50, 98 52	100 47, 100 49	,, images poor.
H	$\bar{3}40$	...	...	,, ,,	104 25½	99 40	104 46	2	99 30, 99 50	104 40, 104 52	,, ,,

[1] The mean values of the co-ordinates of Y cannot be determined because there is no possibility of ascertaining whether a measurement is greater or less than a right angle.

TABLE I (*continued*).

MEASUREMENTS FROM *e* (101).

Form.				Calculated Values.		Observed Means.		Edges.	Limits of Observation.		Remarks. Characters of faces and images.
	T_1	T_2	M_2	Azimuth.	Distance.	Azimuth.	Distance.		Azimuth.	Distance.	
				° ′	° ′	° ′	° ′		° ′ ° ′	° ′ ° ′	
h_1	7·15·5	...	...	100 27½	85 12	99 57	85 49	1	... ...	... ...	Minute; image poor.
h	$\bar{4}$50	...	...	,, ,,	105 12	100 43	105 6	2	100 40, 100 46	104 32, 105 40	,, images poor.
h_2	$\overline{13}$·10·5	...	...	,, ,,	128 50½	100 50	128 30	1	... ...	... ...	,, image poor.
ϵ	$\overline{11}$·24·9	...	$\bar{1}$41	101 12	83 16½	101 19½	82 7	1	101 5 – 101 40	... ...	,, image poor.
μ	$\overline{17}$·24·3	...	$\bar{1}$20	,, ,,	98 25½	,, ,,	98 40½	19	,, ,,	98 31 – 98 47	Small; images fair.
ζ	$\overline{23}$·24·3	...	34$\bar{1}$	,, ,,	112 30	,, ,,	112 50	3	,, ,,	112 40 – 112 55	Minute; ,,
f	112	...	...	104 52	29 28	104 51½*	29 30	25	104 24 – 105 35	29 5 – 29 42	Small; images good.
g	123	...	...	,, ,,	38 45½	,, ,,	38 48½	11	,, ,,	38 37 – 39 3	,, images fair.
v	011	...	...	,, ,,	54 11½	,, ,,	54 17	6	,, ,,	54 12 – 54 24	,, ,,
r	$\bar{1}$21	...	...	,, ,,	78 51½	,, ,,	78 48½	23	,, ,,	78 20 – 79 4	,, ,,
r_1	$\bar{4}$51	...	...	,, ,,	96 37½	,, ,,	96 35	1	,, ,,	... ...	Minute; image poor.
t	$\bar{1}$10	...	...	,, ,,	108 7½	,, ,,	107 58	23	,, ,,	107 25 – 108 22	Common, but not large; images fair.
D	32$\bar{1}$	...	...	,, ,,	130 25½	,, ,,	130 18	3	,, ,,	130 4 – 130 27	Small; images poor.
k_2	9·20·35	012	...	111 8	36 10½	111 24½	36 15	1	110 33 – 112 30	... ...	Minute; image fair.
k_1	$\bar{1}$·20·25	$\bar{1}$23	...	,, ,,	49 15	,, ,,	49 30½	4	,, ,,	49 22 – 50 0	,, images poor.
k	$\overline{11}$·20·15	$\bar{1}$11	...	,, ,,	70 25	,, ,,	70 30½	14	,, ,,	69 55 – 71 10	Small; images fair.
z	$\overline{21}$·20·5	$\bar{3}$21	...	,, ,,	98 33	,, ,,	98 10	10	,, ,,	97 27 – 98 50	,, ,,
z_2	$\overline{13}$·10·0	$\bar{7}$41	...	,, ,,	111 58	,, ,,	110 45	1	,, ,,	... ...	Minute; image poor.
z_1	$\overline{31}$·20·5	$\bar{2}$10	...	,, ,,	123 16½	,, ,,	124 5	1	,, ,,	... ...	,, ,,

V_1	$\bar{3}43$	...	...	115 4	73 54	114 55	73 59	1	... ...	... ...	,, ,,
V	785	...	...	,, ,,	80 32	115 45	81 10	1	... ...	... ...	,, ,,
U_1	$\bar{6}87$	...	...	117 23	69 $44\frac{1}{2}$	117 47	70 17	3	117 38 – 117 56	70 10 – 70 29	,, images poor.
U	$\bar{9}84$	...	...	,, ,,	89 $33\frac{1}{2}$	116 36	89 $27\frac{1}{2}$	2	116 25, 116 47	89 25, 89 30	,, ,,
T	$\bar{3}32$	...	...	118 8	81 $9\frac{1}{2}$	118 47	80 31	1	... ...	... ...	,, image good.
G_1	$\bar{1}47$	...	...	123 48	43 $57\frac{1}{2}$	123 47*	44 20	1	123 13 – 124 41	... ...	,, image poor.
G	$\bar{1}23$	...	...	,, ,,	50 $56\frac{1}{2}$	,, ,,	51 10	1	,, ,,	... ...	Small ; ,,
W	$\bar{1}11$	...	...	,, ,,	70 10	,, ,,	70 11	12	,, ,,	69 51 – 70 25	,, images fair.
W_1	$\bar{8}76$	...	...	,, ,,	76 $56\frac{1}{2}$	,, ,,	77 14	1	,, ,,	... ...	Minute; image poor.
Θ	$\bar{3}21$	...	...	,, ,,	95 9	,, ,,	94 $53\frac{1}{2}$	7	,, ,,	94 35 – 95 14	Small; images fair.
Φ	$\bar{2}10$	...	...	,, ,,	118 $24\frac{1}{2}$	,, ,,	118 $19\frac{1}{2}$	9	,, ,,	117 30 – 118 37	,, ,,
Ψ_1	$\bar{2}9.24.27$	...	$\bar{1}11$	128 48	70 $3\frac{1}{2}$	129 0	70 $16\frac{1}{2}$	4	128 58 – 129 4	70 11 – 70 21	Small ; images fair.
Γ_1	$\bar{5}20$	...	...	131 4	121 19	131 55	119 23	1	... ...	... ...	Minute ; image poor.
κ	$\bar{1}12$	...	...	137 2	50 33	136 $43\frac{1}{2}$	50 30	2	136 32 – 136 57	50 29, 50 32	Small; images good.
Ξ	$\bar{3}23$	...	...	,, ,,	65 38	,, ,,	65 41	2	,, ,,	65 40, 65 42	,, ,,
Σ	$\bar{2}11$	...	...	,, ,,	85 15	,, ,,	85 10	1	,, ,,	... ...	Minute; image fair.
Γ	$\bar{5}21$	...	...	,, ,,	106 0	,, ,,	106 1	1	,, ,,	... ...	,, ,,
Υ	$\bar{2}1.20.45$	325	...	140 4	48 $22\frac{1}{2}$	139 34	48 18	1	... ...	... ...	,, ,,
ν	$\bar{1}5.4.1$	...	...	145 $54\frac{1}{2}$	119 $22\frac{1}{2}$	146 19	119 24	1	... ...	... ...	,, ,,
F	$\bar{1}7.4.3$	...	...	152 $0\frac{1}{2}$	109 $57\frac{1}{2}$	...	...	1	... ...	... ...	See Table III.

As has already been stated, the prism zone is considerably striated parallel to the edge of the zone, so much so that in some cases no reliable measurements are obtainable. A few crystals, however, do possess definite faces giving bright and distinct reflections: one of these is exhibited in fig. 2. From a consideration of the measurements on all the crystals we may be certain of the existence of the forms *a* (100), *c* (001), *e* (101), *E* ($\bar{1}$01); but in the remainder of the zone measurable images are rare, and it is doubtful what forms are represented. Certain parts of the zone give an almost unbroken band of light.

A glance at the table shows that there is considerable variation about the mean value even in the case of measurements on which most reliance may be placed. We have remarked above that this variation cannot be explained as entirely due to errors of adjustment or observation; it must, therefore, have a real existence, and is, moreover, in accordance with the observations of those who have studied the characters of crystals growing in a saturated solution [1].

For convenience of reference the letters employed by Penfield and Ford to denote the terminal forms have as far as possible been retained in this paper. A study of Table II will show what changes have been made. In this table the monoclinic symmetry and the orientation of these authors have been adopted. The distances are given from the face perpendicular to the edge of the prism zone, and the zero azimuth passes through *m* (110). The values of these coordinates given on the left-hand side have been computed directly from the calculated values in Table I; on the right-hand side they are taken from the paper of Penfield and Ford [2], the observed values being the means of all those given in the different tables [3]. The symbols on the left-hand side assigned to the forms have been derived by transformation, with some slight alteration in certain cases for the sake of the resulting simplification. Keeping the zone [*c*, *f*, *p*, *m*, *w*] unchanged, and substituting for *o* (121) the indices (18·22·10) of Penfield and Ford, we arrive at the following equations of transformation from one system to the other:—

$$(\lambda\mu\nu) = (9l + 2m,\ 11m,\ l - m + 11n);$$
$$(lmn) = (11\lambda - 2\mu,\ 9\nu,\ -\lambda + \mu + 9\nu);$$

where lmn, $\lambda\mu\nu$ are the symbols of any form according as the symmetry

[1] Cf. H. A. Miers: 'On a New Method of Measuring Crystals, and its Application to the Measurement of the Octahedron Angle of Potash Alum and Ammonia Alum.' Report Brit. Assoc., 1894 (Oxford), pp. 654–5.

[2] Loc. cit., p. 243.

[3] Loc. cit., pp. 230 et seq.

TABLE II.—COMPARISON WITH THE OBSERVATIONS OF PROF. PENFIELD AND MR. FORD.

Constants: $a:b:c = 1{\cdot}6304:1:1{\cdot}1468$; $\beta = 90^\circ\ 10'$ (calculated from Table I).
$a:b:c = 1{\cdot}6313:1:1{\cdot}1449$; $\beta = 90^\circ\ 12\frac{2}{3}'$ (Penfield and Ford)[1].

	Form.		Calculated from Table I.					Form.	Calculated Values.				Observed Means.				No.
	T₁	M	Azimuth.		Distance.				Azimuth.		Distance.		Azimuth.		Distance.		
			°	′	°	′			°	′	°	′	°	′	°	′	
m	110	110	0	0	31	31½	*m*	110	0	0	31	30½	0	0	31	29	34
μ	$\overline{17}$·24·3	13·33·1	9	33½	13	59	*μ*	17·40·2	9	30	14	28½	9	58	14	22	2
								33·80·4	9	47½	14	24					
x_1	19·20·5	441	19	56½	32	4	*e*	441	19	35	33	5	20	21	32	10	1
								42·44·11	20	26	32	1					
t	$\bar{1}$10	7·11·2	24	9	23	17	*t*	13·20·4	23	38½	23	32½	23	48	23	14	10
q	141	17·44·8	32	42	15	42½	*q*	11·29·5	32	52	15	30½	32	44	15	37	10
ζ	$\overline{23}$·24·3	20·33·10	37	6½	25	0	*h*	21·37·11	36	40	23	30½	36	40	23	19	1
ω	29·20·15	20·15·12	39	30	47	29	*ω*	20·15·12	40	26	47	8	40	16	47	12	1
o	121	13·22·10	47	11½	28	7	*o*	13·22·10	47	30½	28	18	47	4	28	5	40
n	343	11·14·10	52	15	38	38	*n*	11·14·10	52	12	38	17½	52	13½	38	41	3
p	111	111	54	46	46	52	*p*	111	54	48	46	54½	54	47	46	52	33
i	323	10·7·11	57	17	58	6	*i*	10·7·11	57	18	58	29	57	9	58	6	2
π	$\overline{31}$·20·$\overline{25}$	658	61	37½	55	53	*π*	22·18·27	60	5	56	31	59	46	56	10	1
f	112	112	70	29	61	37	*f*	112	70	29	61	40	70	21	61	36½	2
							g_1	10·15·22	71	36	52	38	72	6	52	49	1
g	123	4·7·10	73	52	52	46	*g*	4·7·10	74	7	52	22	73	53	52	46	1
y	$\bar{1}2\bar{1}$	5·22·14	75	56	30	21	*y*	296	76	38	30	54	76	26	30	27½	7
v	011	2·11·10	81	48½	38	23	*v*	2·11·10	81	48	38	43½	81	57	38	20½	4
k	$\overline{11}$·20·15	$\overline{10}$·37·22	107	37	28	30½	*k*	$\overline{10}$·32·21	108	18	31	6	108	27	31	3	1
r	$\bar{1}$21	$\bar{5}$·22·8	114	42½	18	30	*r*	$\overline{10}$·44·15	114	54	18	10½	114	41	18	28	9
w	11$\bar{1}$	$\bar{1}$11	125	1	46	48	*w*	$\bar{1}$11	124	55	46	48½	125	11	46	46	7
u	12$\bar{1}$	$\overline{13}$·22·12	126	55	30	59	*u*	$\overline{11}$·18·10	127	32	31	28	127	17½	30	58½	10
K	29·20·$\overline{25}$	30·22·$\overline{27}$	128	32½	53	19½	*j*	756	129	11½	53	31	128	50	53	30	1
x	9·20·5	$\overline{11}$·20·6	141	36½	23	13	*x*	$\overline{11}$·20·6	142	4	23	5	142	22½	22	53	5
							s	$\overline{11}$·62·6	142	4	7	50					
b	010	$\bar{2}$·11·1	141	24½	8	2	s_1	$\bar{2}$·11·1	144	28	7	47	142	31½	8	4	29
							σ	$\bar{2}$·10·1	144	28	8	33					
τ	34$\bar{1}$	$\overline{35}$·44·12	153	45	28	30	*τ*	$\overline{31}$·38·11	153	8	29	14	153	16	28	55	1
z	$\overline{21}$·20·5	$\overline{15}$·22·1	174	52	22	43½	*z*	$\overline{15}$·22·1	174	34	22	46	174	22	22	39	8
ρ	49·20·5	$\overline{17}$·9·1	176	8½	53	22	*ρ*	$\overline{44}$·21·2	176	18	52	9	176	32	52	45	1

[1] Loc. cit., p. 227.

is assumed to be triclinic or monoclinic. It will be noticed that there are two sets of the former corresponding to one of the latter, according to the sign given to the middle symbol.

To avoid the confusion due to the multiplicity of symbols, the following notation is adopted in this paper:—

(lmn) or (lmn) $\mathbf{T}_1$ are the indices of any form based on the first, the principal lattice;

(lmn) $\mathbf{T}_2$ are those based on the second lattice;

(lmn) $\mathbf{M}_3$ are those based on the third lattice;

($\lambda\mu\nu$) $\mathbf{M}$ are those based on the monoclinic symmetry and orientation of Penfield and Ford.

There are two points which call for remark in Table II: the distance of k and the azimuth of π differ appreciably from the values calculated from Table I. The discrepancy is probably due to the difficulty of correctly determining the position of a faint and indistinct image. The form k has been observed fourteen times by the author, and there can be little doubt of its true position; π has not been observed, but it falls very near a pole on the second lattice.

We may now return to the consideration of Table I. The positions of nearly all the forms recorded in that table are marked in fig. 3, which is a gnomonic projection on a plane perpendicular to the edge of the prism zone. The thick lines represent the zones of the principal lattice, and the thin lines those of the second lattice. The corresponding zones of the twin lattices are not drawn, to avoid complicating the diagram.

Almost without exception the terminal forms fall into zones passing through e (101)—it is in fact rare to find a zone without at least three forms in it, though not necessarily on any single crystal—and the angles between the forms in the same zone almost invariably obey the law of simple anharmonic ratios. After a few crystals had been measured in the manner described above, it was found that all the prominent faces lie in certain zones whose azimuths are approximately: $36\frac{1}{2}°$, $46\frac{1}{2}°$, 56°, $61\frac{1}{2}°$, 75°, 82°, 68°–69°, 90°. Measurements were also made from the pole of intersection of the prism zone with that including the forms [x, b, b', x']; but no zonal relations could be found except those which naturally follow from the fact that the pole of reference is tautozonal with x and b, namely: [ω, p, P']; [x_1, o, y'], etc. Now in the case of ordinary crystals, which are not twinned, the azimuths of pyramidal forms, when measured from a pole in the prism zone, representing an actual or a possible face, obey the law of simple anharmonic ratios. Such relations were accordingly looked for among the azimuths at e (101);

but without success, until it was noticed that the first six do give simple ratios, but only if arranged in the following manner: $36\frac{1}{2}°$, $46\frac{1}{2}°$, $61\frac{1}{2}°$, 82°, 105°, 124°, the last two being the supplements of 75° and 56°; this is tantamount to assuming that the crystals have triclinic symmetry, and are pseudo-monoclinic owing to twinning about an axis parallel to

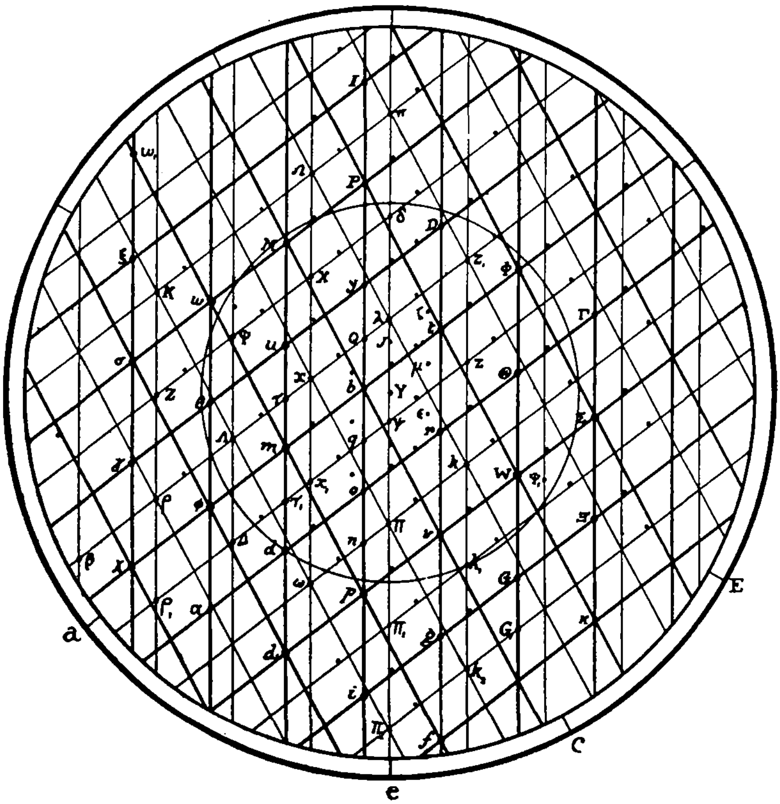

FIG. 3.—Gnomonic projection on a plane perpendicular to the edge of the prism zone (left-handed termination).

the edge of the prism zone. Further investigation revealed the existence of other zones, whose azimuths, 21°, 137°, 146°, also fall in with this arrangement.

The next step was to investigate the existence of cross-zonal relations, and accordingly measurements were made from the pole of intersection of the prism zone with the zone containing the forms [*m*, *b*, *t*], at which a face, ***a*** (100), was frequently observed. Here again certain zones were

TABLE III.—MEASUREMENTS FROM a (100).

	Form.	Calculated Values. Azimuth. °	′	Calculated Values. Distance. °	′	Observed Means. Azimuth. °	′	Observed Means. Distance. °	′	Edges.	Limits of Observations. Azimuth. ° ′ – ° ′	Limits of Observations. Distance. ° ′ – ° ′
e	101	0	0	52	$18\frac{1}{2}$	...		...		...	... ...	... ...
p	111	53	$1\frac{1}{2}$	58	50	53	1	58	$56\frac{1}{2}$	14	52 28 – 53 20	58 43 – 59 22
v	011	”	”	78	52	”	”	78	48	3	” ” ”	78 42 – 78 56
W	$\bar{1}11$	”	”	101	55	”	”	101	49	3	” ” ”	101 48 – 101 50
F	$\overline{17}.4.3$	61	$42\frac{1}{2}$	149	$56\frac{1}{2}$	61	54	150	37	1	... ...	... ...
d	321	72	$4\frac{1}{2}$	48	19	72	4	48	23	3	71 32 – 72 26	48 9 – 48 30
o	121	”	”	67	$58\frac{1}{2}$	”	”	68	$2\frac{1}{2}$	14	” ” ”	67 51 – 68 15
r	$\bar{1}21$	”	”	94	$38\frac{1}{2}$	”	”	94	38	6	” ” ”	94 35 – 94 39
q	141	83	47	75	$32\frac{1}{2}$	83	41	75	$36\frac{1}{2}$	16	83 10 – 83 59	75 26 – 75 50
μ	$\overline{17}.24.3$	89	$54\frac{1}{2}$	103	59	90	0	104	$20\frac{1}{2}$	7	89 55 – 90 7	104 12 – 104 34
ϕ	210	96	2	42	3	95	$54\frac{1}{2}$	42	$1\frac{1}{2}$	6	95 0 – 96 18	41 48 – 42 10
m	110	”	”	59	0	”	”	59	$2\frac{1}{2}$	22	” ” ”	58 34 – 59 25
b	010	”	”	84	41	”	”	84	$40\frac{1}{2}$	18	” ” ”	84 25 – 84 50
t	$\bar{1}10$	”	”	112	$31\frac{1}{2}$	”	”	112	29	8	” ” ”	112 14 – 112 48
Φ	$\bar{2}10$	”	”	132	$41\frac{1}{2}$	”	”	132	32	3	” ” ”	132 29 – 132 45
x	$\dot{9}.20.\bar{5}$	107	46	74	$48\frac{1}{2}$	107	$45\frac{1}{2}$	74	54	9	107 37 – 107 57	74 30 – 75 7
θ	$32\bar{1}$	118	9	55	24	118	7	55	23	3	117 45 – 118 24	55 20 – 55 30
u	$12\bar{1}$	”	”	76	$29\frac{1}{2}$	”	”	76	$29\frac{1}{2}$	12	” ” ”	76 12 – 76 40
y	$\bar{1}2\bar{1}$	”	”	101	$51\frac{1}{2}$	”	”	101	$51\frac{1}{2}$	7	” ” ”	101 42 – 101 59
D	$\bar{3}2\bar{1}$	”	”	123	$25\frac{1}{2}$	”	”	123	16	2	” ” ”	123 11 – 123 21
w	$11\bar{1}$	133	$57\frac{1}{2}$	72	0	133	$57\frac{1}{2}$	71	$49\frac{1}{2}$	14	133 49 – 134 12	71 9 – 72 6
M	$01\bar{1}$	”	”	92	$26\frac{1}{2}$	”	”	92	$25\frac{1}{2}$	7	” ” ”	92 6 – 92 45
P	$\bar{1}1\bar{1}$	”	”	112	$18\frac{1}{2}$	”	”	112	14	3	” ” ”	112 4 – 112 21
w_1	$11\bar{2}$	151	15	81	$49\frac{1}{2}$	151	5	81	29	1	... ...	... ...

The faces F and w_1 were observed only on a skeletal crystal, and owing to the peculiar shape of the crystal no measurements could be made of these faces from e (101).

encountered which obey the same law, but only if arranged in the following manner: 53°, 72°, 84°, 96°, 118°, 134°. Measurements from this pole are given in Table III (p. 138), but only those of the more prominent forms made on fourteen crystals are included.

The zones of one individual very nearly coincide with those of the twin individual. For instance, the face q (141) of one lies very nearly in the zone $[m, b, t]$ of the other; in fact, on many crystals the agreement is so close that the slight difference may be due to error of adjustment; but, as a reference to the table will show, there is on the whole a small difference in the azimuths, amounting in the mean values to 24′.

Measurements were further taken from the intersection of the prism zone with the prominent zone containing the forms $[f, p, m, w]$; this pole is c (001) whichever class of symmetry be chosen, and frequently represents an actual face. Here again the azimuths satisfy the law of simple anharmonic ratios, but only if arranged in the following manner: $58\frac{1}{2}$°, 70°, 77°, 98°, $111\frac{1}{2}$°. Measurements from this pole are given in Table IV (p. 140), but only those of the more prominent forms made on thirteen crystals are included.

The concordance between the calculated and the mean observed values of the coordinates of the faces passing through the nodes of the principal lattice is so close that we can scarcely regard the agreement as accidental, and we must conclude that this lattice has a real existence in calaverite.

There are many forms which clearly from the complexity of their indices do not harmonize with the principal lattice: the most prominent of these are x (9·20·5), ω (29·20·15), k ($\overline{11}$·20·15), z ($\overline{21}$·20·5), Π (9·20·15), Λ (29·20·5), Ψ (19·20·$\overline{15}$), ρ (49·20·5). The indices, though complex, indicate that the faces are in harmony with a second lattice. The symbols which they receive on this hypothesis are given in another column of Table I. The prism zone is common to the two lattices, and the zones at a (100) are very nearly, if not quite, coincident. The positions of the forms of this group vary considerably. x (9·20·5), which is the best developed form, on some crystals lies very nearly in the zone $[o, r]$, but on others it lies an appreciable distance away. Again, the azimuth of the zone $[x, x_1, \omega]$ usually exceeds that of the zone $[k, z]$, but on some crystals it is distinctly less.

There still remain the common forms Y (5·24·3), μ ($\overline{17}$·24·3) and the rarer forms J ($\overline{11}$·24·3), Ψ_1 ($\overline{29}$·24·27), ζ ($\overline{23}$·24·3), ϵ ($\overline{11}$·24·9), which do not harmonize with either of the above lattices, but do harmonize with a third, a monoclinic, lattice. Here again the prism zone is the same as before.

TABLE IV.

MEASUREMENTS FROM c (001).

Form.		Calculated Values.		Observed Means.		Edges.	Limits of Observations.	
		Azimuth.	Distance.	Azimuth.	Distance.		Azimuth.	Distance.
		° ′	° ′	° ′	° ′		° ′ ° ′	° ′ ° ′
e	101	0 0	27 36	...	...	...	... ...	... ...
f	112	58 28½	33 54	58 28½	33 58	5	58 7 – 58 57	33 20 – 34 6
p	111	,, ,,	53 19	,, ,,	53 21	17	,, ,, ,,	53 7 – 53 36
m	110	,, ,,	89 55	,, ,,	89 58½	12	,, ,, ,,	89 45 – 90 19
w	$11\bar{1}$	,, ,,	126 34	,, ,,	126 33½	10	,, ,, ,,	126 13 – 126 46
o	121	70 6	69 43	70 5½	69 43½	14	69 55 – 70 20	69 25 – 70 1
u	$12\bar{1}$	,, ,,	114 14½	,, ,,	114 16	5	,, ,, ,,	114 10 – 114 20
x	9·20·5	71 23	104 7	71 27	104 15	3	71 17 – 71 40	104 12 – 104 19
q	141	76 42	81 33	76 48	81 27½	7	76 40 – 77 5	81 10 – 81 45
v	011	83 41	52 3½	83 40	52 14	3	83 25 – 83 59	52 11 – 52 17
b	010	,, ,,	94 59	,, ,,	95 0	6	,, ,, ,,	84 52 – 85 25
M	$01\bar{1}$	,, ,,	133 39	,, ,,	133 43	3	,, ,, ,,	133 40 – 133 45
r	$\bar{1}21$	98 0½	73 16	97 57	73 20	6	97 45 – 98 10	72 41 – 73 30
y	$\bar{1}2\bar{1}$	,, ,,	119 23	,, ,,	119 25½	3	,, ,, ,,	119 6 – 119 30
k	$\bar{1}\bar{1}$·20·15	99 25	62 58	99 38	63 3	4	99 10 – 100 0	62 9 – 63 38
W	$\bar{1}11$	111 24½	57 6	111 16½	57 15	2	111 7 – 111 30	57 15
t	$\bar{1}10$	,, ,,	99 22	,, ,,	99 20	5	,, ,, ,,	99 16 – 99 38

We are, therefore, driven to the remarkable conclusion that five distinct lattices may be traced in calaverite, which are incongruent but not independent. The prism zone is common to all. The faces [x, b, Y, b', x'] which lie on the different lattices are tautozonal; a fact which does not immediately follow from the symbols assigned to forms x and Y, namely (9·20·5) and (5·24·3) respectively, but these have merely been selected because they are the simplest which accord with the observations. There seems, indeed, from direct observation with the goniometer, no doubt that the faces in question do lie in a zone, and further we have $\tan Yx = 3 \tan Yb$, because this equation is satisfied by their azimuthal angles; for $\tan 82° 6\tfrac{1}{2}' = 3 \tan 67° 25'$, which agrees closely with the mean observed azimuth of x, namely, $67° 29\tfrac{1}{2}'$. The zones of the different lattices passing through $a(100)$ apparently coincide. Such is not the case at c (001); nevertheless there is a relation, as is clear from a study of the first two indices of the various forms, e.g.:—z (21·20·5), k ($\overline{11}$·20·15), x (9·20·5), Ψ (19·20·$\overline{15}$), ω (29·20·15), etc., and μ ($\overline{17}$·24·3), J ($\overline{11}$·24·3), Y (5·24·3), etc.; there is a regular decrement in the first very simply related to the second symbol. This relation is very clearly shown on the gnomonic projection; for, in consequence, the linear distances of points lying on parallel lines are multiples of the same unit. These several relations involve other tautozonal relations connecting poles on different lattices, such as: $[\rho, m, b', \Lambda']$, $[w', \Psi_1, W, k]$, $[Y, m, \beta]$, etc., in all of which the law of simple anharmonic ratios is obeyed. Finally, the two individuals of the two pairs of triclinic lattices are connected by twinning about Y or, what comes to the same thing, the edge of the prism zone.

The question now arises, what explanation can be offered of the unique anomalies presented by calaverite? On the one hand, we have a morphological development of the faces which is completely in accord with monoclinic symmetry. This view of the symmetry is confirmed by the frequent occurrence of a face of the form Y, which invariably gives a single distinct image, and not one blurred or double, such as would be expected did it really belong to two or more separate individuals. The faces also occur in positions similar to those of their poles on the sphere of projection, and there are none of the markings or re-entrant angles (beyond those in the prism zone) which usually accompany twinning, however much concealed. Later on, when we proceed to consider twin crystals, we shall find that the planes of twinning except that of the fourth, a doubtful type, have simpler indices on the hypothesis of monoclinic symmetry.

Yet, on the other hand, how can we be satisfied with an interpretation which necessitates the assigning of such complex symbols to even the commonest and best developed forms? The fundamental constants possess no meaning beyond the concise representation of the lattice of the space-partitioning. The crystal faces pass through the nodes of such a lattice, and the commonest faces are those in which the nodes are most crowded. Faces of this kind have simple indices; faces with complex symbols are usually due to corrosion. Although corrosion frequently does produce bright plane faces having high indices, we can scarcely regard all the faces of these crystals to be the result of corrosion.

Owing to the opacity of the crystals no optical test is possible, and, even if it were, it would not be infallible, since we know that if a crystal be composed of several overlapping individuals the resulting optical phenomena are precisely those of the symmetry simulated. Etching tests are more searching, but were in this case without result. A plane ground approximately perpendicular to the edge of the prism zone was etched with nitric acid and with aqua regia; the former produced numerous fine markings roughly in the same direction, and the latter merely a ripple effect.

A comparison of calaverite with the other gold tellurides, sylvanite and krennerite, does not throw much light on the problem, except for the interesting fact that the principal zone [*e*, *p*, *o*, *q*, *b*] of calaverite is similar to one zone of sylvanite and two zones of krennerite.

TABLE V.

Calaverite. Distance from 101.		Sylvanite[1]. Distance from 101.		Krennerite[1]. Distance from 100.			
	° ′		° ′		° ′		° ′
323	32 14	323	31 38½	301	31 52	320	32 5½
$3\bar{2}3$	31 24						
111	43 38½	111	42 45	201	43 0	110	43 15
$1\bar{1}1$	42 15						
121	62 55½	121	61 35	101	61 48	120	62 0½
$1\bar{2}1$	60 36						
141	76 22	141	74 56	102	74 59½		
$1\bar{4}1$	73 34						
010	91 30	010	90 0	001	90 0	010	90 0
$0\bar{1}0$	88 30						

The zone [*c p m*] also has a counterpart in sylvanite.

TABLE VI.

Calaverite.	Azimuth.	Distance.	Sylvanite[1].	Azimuth.	Distance.
	° ′	° ′		° ′	° ′
111	58 28½	53 19	111	58 32	52 44
110	" "	89 55	110	" "	89 47

It is owing to this similarity that constants so nearly equal to those of sylvanite are obtained from calaverite on the hypothesis of monoclinic symmetry, and with the orientation of Penfield and Ford. If, indeed, we imagine the zone [*c*, *p*, *m*] kept fixed, and the remaining zones moved in such a way that *b* is brought into coincidence with *Y*, we obtain very nearly the constants and angles of sylvanite.

[1] The values are taken from Dana's 'System of Mineralogy,' 6th edition, 1892.

Calaverite differs from sylvanite and krennerite in displaying no cleavage, although it is extremely brittle. If calaverite be really isomorphous with sylvanite, as is suggested by certain characters—the similarity of certain angles and zones, and the twinning about a similar face (type 1)—we should expect from analogy with the felspars, that even if they belong to different systems of symmetry both would display similar cleavage; but this is not the case. The brittleness of calaverite indicates that there is a facility of parting which is not in the same direction at every point. If the crystals are composed of two or more individuals so intimately intermixed that the separation is not visible to our perceptions, and if each individual has a cleavage in corresponding but not parallel directions, the brittleness would be explained: and further, if the constituent individuals at particular points are sufficiently small, the fractured surfaces would not give distinct and definite reflections; the surfaces in fact give a blur of light.

In the present state of our knowledge we can do little more than conjecture what may be the actual arrangement of the ultimate parts in any particular mineral, although we are agreed that it must belong to one of 230 different classes. The case of calaverite is one of peculiar perplexity. Professor W. S. Myers[1] has found that the composition of krennerite from the Cripple Creek District is essentially the same as that of calaverite; but the former crystallizes in the orthorhombic system and presents no anomalies. Whatever meaning may be attached to the three or, including the corresponding twins, five lattices apparently existing in calaverite, it is obvious that if they coexisted at every or, indeed, any point of the crystal, heterogeneity would be the necessary consequence of their incongruence. The only hypothesis remaining appears to be the existence of a minute skeletal structure of some kind—an infinitesimal framework composed of material with an arrangement according to one lattice intercalated with material with an arrangement according to another lattice. Since the lattices, while not congruent with one another, have a zone in common, i.e. the rows parallel to its edge equidistant, or at least congruent, in parallel planes, and have other relations, discussed above (pp. 140–1), interaction at some of the boundaries separating the differently constituted sections would seem to be indicated. This hypothesis is in harmony with the suggestion made above as to the origin of the brittleness of crystals. The frequent occurrence of pits on the faces, and the existence of skeletal and hollow crystals, suggest breaks in continuity of the homogeneous arrangement.

[1] Amer. Journ. Sci., 1898, ser. 4, vol. v, p. 376.

As the facts require the parts of the hypothetical structure to be referable to three or more distinct structures, calaverite would then be in no way similar to such a substance as leucite, which exhibits optical anomalies. The optical investigation of such a substance shows that there is a clear and definite separation between the individuals which build up the crystal; on calaverite the faces occur just as they would if the crystal were composed of a single homogeneous individual.

Such are a few of the speculations that arise, but an adequate explanation is not forthcoming. Perhaps similar zonal relations may be found to exist in other minerals, and increased knowledge may furnish a clue which will ultimately lead to the elucidation of the mysterious symmetry of a most remarkable mineral.

Twin Crystals.

Whatever may be the explanation of the remarkable symmetry presented by calaverite, the crystals are susceptible of twinning in the usual manner about certain faces. Three types of twinning have been established, and to these possibly a fourth may be added.

Type 1. *Plane of twinning*: e_1 (705) T_1, (101) M.

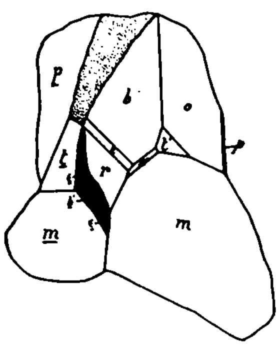

Fig. 4.
Twinned crystal (Type 1).

This, a very common type of twinning, has already been described by Penfield and Ford[1]. The twin striae mentioned by these authors were not noticed on any of the crystals measured, eleven in number. The plane of composition is usually either parallel or perpendicular to the plane of twinning. Fig. 4 shows the former mode and fig. 6 both; fig. 5 would probably have shown both had the crystal been unbroken. One large crystal possesses faces at the lower end which are in the positions required by this type of twinning, and the plane of composition is in this case at right angles to the edge of the prism zone. A line of demarcation runs round the prism zone, roughly at right angles to its edge.

In this type the faces of the form p (111) of the two individuals composing the twin are parallel, and the plane through the poles of these faces and the edge of the prism zone becomes one of symmetry. The crystals were measured in the usual manner, and one adjustment of the crystal is sufficient, since the direction of the edge of the prism zone

[1] Loc. cit., p. 237.

is the same in the two individuals. The difference in the readings of the circle C, when each individual is in the position to be measured from a face of the form e (101) as pole of reference, gives at once the distance between the two positions of these faces. The mean of eight observed values, ranging from 14° 50′–15° 35′, is 15° 13′; the value calculated from the azimuth and distance of p (111), given in Table I, is 14° 56′, the half of which is 7° 28′. The calculated distance of e_1 (705) from e (101) is 7° 36½′. The plane of twinning might, of course, be in the prism zone distant a quarter of a revolution from e_1 (705), i.e. at a distance from e (101) of 82° 32′, the complement of 7° 28′. The nearest pole with simple indices is E_6 ($\bar{2}$01), the distance of which is 83° 1½′.

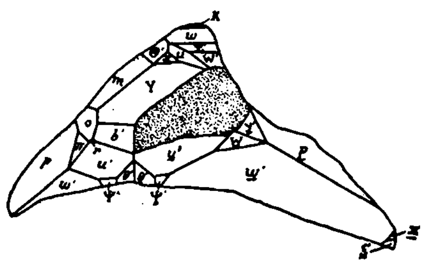

FIG. 5.

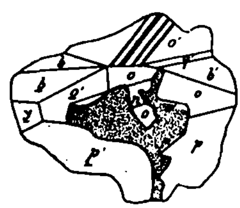

FIG. 6.

Twinned crystals (Type 1).

Some of the twins have a number of such minute faces on the boundary between the two individuals that considerable difficulty was experienced in determining to which of the two any particular face belonged. It may be remarked that, when the plane of composition is parallel or at right angles to the plane of twinning, the ends of the two individuals which compose the termination of the twin crystal are of opposite hands.

Type 2. *Plane of twinning*: p (111).

Penfield and Ford refer to this type, but the material at their disposal was not sufficiently good for the determination of the law of twinning. Fig. 7 represents an actual twin of this kind. The small portion to be noticed projecting from one individual is in the position required by the law of type 3. The other individual is remarkable for possessing both terminations. The angle in the prism zones towards the observer is re-entrant. The terminations of the crystals observed, four in number, have comparatively few faces.

These and other cross twins are easily measured on the three-circle goniometer. The prism edge of one individual is adjusted parallel to the axis of the circle *C*. The angle of crossing of the prism zones of the two individuals is at once determined, and measurements of the terminal faces of both may be made from the pole of intersection of the two zones. The individual, whose prism edge is in adjustment, may be measured in the usual way from the pole *e* (101). The second individual may then be adjusted and measured in a similar manner. The plane of twinning is now readily found. Measured from the pole of crossing, its distance is 90° and azimuth either half the acute angle or half the obtuse angle of crossing. Both will probably not give possible poles, but any doubt is removed by a consideration of the positions of the terminal forms of both individuals measured from the pole of crossing.

The plane of twinning does not seem to quite coincide with *p* (111). On the crystal figured the zone [*e*, *p*, *o*, *b*] is well developed on both individuals, and the two were found not to be in coincidence, as they should be. The mean value of the angle of crossing measured on the four crystals, ranging from 86° 33′–86° 54′, is 86° 41′; the calculated value is 86° 15′. The mean of four values of the distance of the pole of crossing from *e* (101), ranging from 82° 4′–82° 17′, is 82° 10′; the calculated value is 82° 32′.

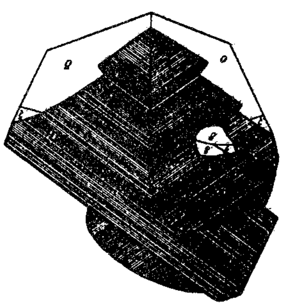

Fig. 7 (Type 2).

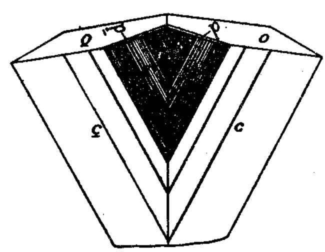

Fig. 8 (Type 3).

Twinned crystals.

Type 3. *Plane of twinning*: *β* (69·20·5) T_1, (310) T_2, (310) M.

In this type the prism zones cross at a much smaller angle (fig. 8). As in the previous type the terminations have comparatively few faces. Altogether six twins were observed, including that shown in fig. 7. They were measured in a similar manner to those of the preceding type. The mean of five values of the angle of crossing, ranging from 56° 29′–57° 38′, is 57° 5′; the calculated value is 56° 55′. No reliable measurements of the distance of the pole of crossing from *e* (101) were obtainable, owing to the insufficient development of the principal zone [*e*, *p*, *o*, *b*]. Four values were observed; 27° 43′, 28° 16′, 28° 47′, 29° 24′, the mean of which is 28° 37′; the calculated value is 27° 42′. The zones, therefore, cross very nearly in the pole *c* (001), the calculated distance of which from *e* (101) is 27° 36′. The faces of this form, belonging to the two individuals, seem to be coincident on the crystal figured.

One of the observed crystals is composed of three individuals, the middle one having an individual on each side in the positions required by twinning about the faces β and β'.

There are two crystals which call for special remark. At first sight they appear to be twins of type 3, and the angle of crossing is, indeed, the same; but on measuring one crystal, which is much better developed than the other, from the pole of crossing of the two prism zones it was found that the distances of the most prominent faces, evidently belonging to the form *o* (121), are not the same on the two individuals; on one the measurements were 69° 45′ and 69° 40′, and on the other 65° 19′ and 65° 31′. From further investigation it appeared that we have here a combination of the laws of types 1 and 3. Careful search was made for an intermediate individual, but no trace of such could be perceived on either crystal. The zone [*e*, *p*, *o*, *b*] is sufficiently well developed on one to furnish a fairly accurate setting for *e* (101), and the distance from this pole to the pole of crossing of the prism zones can be measured; it was found to be 41° 59′: the calculated value is the sum of 14° 56′ and 27° 42′, or 42° 38′. The calculated values of the distance of the faces of the form *o* (121) on the two individuals from the pole of crossing are 70° 6′ and 65° 17′, which are in fairly close agreement with the observed values given above.

Type 4. *Plane of twinning* (?): K_1 (19·20·35) T_1, (123) T_2.

The existence of this type requires further confirmation. Only one such crystal (fig. 9) has been observed, and that was encountered at the close of the investigation. Were it not for the occurrence of the crystals just described it would have been assumed to be a fortuitous conjunction of two distinct crystals. Each individual is capable of being measured with considerable accuracy, and each in turn was adjusted with its prism edge parallel to the axis of the circle *C*. The pole of crossing is not at the same distance from *e* (101) in the two cases; on the individual whose

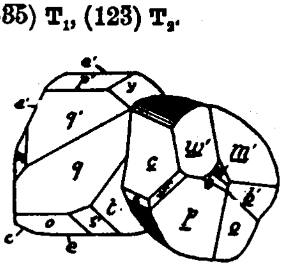

Fig. 9.
Twinned crystal (Type 4).

prism edge is perpendicular to the plane of the paper in fig. 9, the distance measured is 25° 54′; on the other an accurate reading was not obtainable, but it is approximately 40° 35′. The difference between the two measurements is very suggestive, because it is very nearly that demanded by the law of type 1 as the angle between the two positions of *e* (101). We may, therefore, have again a combination of two laws, one belonging to type 1 and the other to a type to be determined. The observed angle of crossing is 60° 27′. The plane of twinning which satisfies the conditions best is K_1 (19·20·$\overline{35}$) T_1, (123) T_2, a form which has not yet been observed. The calculated value for the angle of crossing is 62° 49′, and that of the distances of the pole of crossing from *e* (101) on the two individuals is 41° 21′ and (less 14° 56′) 26° 25′. The agreement, therefore, between the calculated and observed values is not sufficiently close to prove the certain existence of this type of twinning.

Pseudomorphs.

The British Museum collection contains numerous altered crystals both on the matrix and isolated. They are usually prismatic with indications of terminal faces, but twins of types 2 and 3 have been noticed. Some consist apparently of pure gold, and others are merely altered on the surface. The colour is a rusty reddish-yellow or a pale buff-yellow. The alteration is evidently due to the oxidation of the telluride.

Chemical Composition.

Quantitative analyses were made by Mr. G. T. Prior on crystals carefully picked out from specimens from Raven Hill, and also on large isolated crystals without terminal faces, the exact localities of which are not stated on the labels.

The mineral was decomposed by aqua regia, and the small amount of silver chloride separated. In the filtrate the gold was precipitated by means of ferrous sulphate, and the tellurium by means of ammonium sulphite.

Results of analyses:—

	(1) Raven Hill crystals.	(2) Isolated crystals.
Weight of material used	0·5096 gram.	0·4196 gram.
„ Au	0·2123	0·1758
„ AgCl	0·0056	0·0034
„ Te	0·2949	0·2389

	(1)	(2)	Calculated. $AuTe_2$
Au	41·66	41·90	44·03
Ag	0·77	0·79	....
Te	57·87	56·93	55·97
	100·30	99·62	100·00

The material contains, therefore, little silver. The numbers obtained in the analyses agree fairly well with the formula $AuTe_2$.

The following determinations of the specific gravity (i.e. the weight of 1 cc.) were made on isolated crystals, which were broken up into small fragments, but not crushed to powder, before being weighed:—

Weight of material used.	Specific gravity.
0·8131 gram.	9·163
0·7612	9·148
0·4259	9·153
Mean value	9·155

The numbers here given agree closely with the determinations of Genth and Hillebrand; all are appreciably lower than the numbers given by Penfield[1], namely, 9·328 and 9·388.

Summary.

The following are the main points discussed in this paper:—

Judged merely from its morphological development, calaverite appears to crystallize in the monoclinic system, the axis of symmetry being parallel to the edge of the prism zone; but the indices which must be assigned to the faces on this hypothesis are exceedingly complex. The faces are, however, found to lie in zones, but these cannot be referred to a single space-lattice: in fact there appear to be in all five distinct lattices which are incongruent, but not independent; the relations between them are discussed above (pp. 140–1). Since the morphological development of the crystals cannot be referred to one lattice, calaverite cannot resemble in structure those transparent substances which display the so-called optical anomalies. The actual co-existence of two or more incongruent lattices would result in heterogeneity, and the only plausible hypothesis, by which we may explain the strange phenomena displayed by this mineral, seems to be that there is a close intermixture

[1] Loc. cit., p. 246.

throughout the structure of arrangements corresponding to different lattices.

Four types of twin crystals are described, of which the fourth depends on a single crystal, and requires confirmation. In the case of two remarkable twins one individual may be derived from the other by means of successive half-turns about the twin axes of types 1 and 2; no trace of an intermediate individual is discernible. The crystal representing type 4 may be another instance of this double twinning.

The crystals contain little silver, and in chemical composition approximate to the formula $AuTe_2$.