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The Crystallography of Bournonite.

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LITERATURE.

Rashleigh,	1797.	Specimens of British Minerals, Plate XIX. p. 84.
Bournon,	1804.	Philosophical Transactions, p. 30.
Smithson,	1808.	Philosophical Transactions, p. 55.
Bournon,	1809.	Nicholson's Journal, Vol. XXIV. p. 225.
Phillips,	1821.	Annals of Philosophy, Vol. XVIII. p. 360.
Haüy,	1822.	Traité de Minéralogie, IV. p. 295.
Haüy,	1822.	Traité de Crystallographie, p. 483.
Phillips,	1823.	Elementary Introduction to Mineralogy, p. 336.
Mohs,	1824.	Grundriss der Mineralogie, II., p. 561.
Dufrénoy,	1836.	Annales des Mines (III.), Tome X. p. 371.
Lévy,	1837.	Description d'une Collection de Minéraux, II. p. 406.
Mohs,	1839.	Naturgeschichte des Mineralreichs, II. p. 531.

Hausmann,	1847.	Handbuch der Mineralogie (II. Theil), I. p. 171.
G. Rose,	1849.	Poggendorf's Annalen, LXXVI. p. 291.
Brooke and Miller,	1852.	Phillips's Mineralogy, p. 201.
Kenngott,	1854.	Sitzungsberichte der k.k. Akad. Wien. XIII. p. 431.
Dufrénoy,	1856.	Traité de Minéralogie, III. p. 239.
Greg and Lettsom,	1858.	Manual of Mineralogy, p. 344.
Zirkel,	1862.	Sitzungsberichte der k.k. Akad. Wien. XLV. (1.) p. 431.
Hessenberg,	1863.	Mineralogische Notizen, V. p. 32.
Zepharovich,	1865.	Sitzungsberichte der k.k. Akad. Wien. LI. (2.) p. 108.
Schrauf,	1872.	Atlas der Krystall-formen des Mineralreiches, IV. Taf. XXXVI.
Sadebeck,	1876.	Angewandte Krystallographie, p. 120.
Zepharovich,	1876.	Lotos. (Neues Jahrbuch, p. 555.)
Quenstedt,	1877.	Handbuch der Mineralogie, p. 889.
Vom Rath,	1877.	Zeitschrift für Krystallographie u. Mineralogie, I. p. 602.
Groth,	1878.	Die Mineraliensammlung der Kaiser Wilhelms Univ., Strassburg, p. 61.
Kokscharow,	1882.	Materialien zur Mineralogie Russlands, VIII. p. 123.

The above table is a list of all publications which contain original crystallographic work, observations, or figures relating to Bournonite; it omits the names of many other works which mention the mineral, but merely contain information compiled from earlier sources; and it refers only to such works as are concerned with the crystalline form. The complete history of the crystallography of Bournonite will therefore be found in the above publications. The most important and comprehensive of these is the monograph of Zirkel published in 1862; this paper contains a summary of the previous literature and the results of many new observations, together with a large number of new figures. There is, however, a serious omission in the review of the earlier literature; no notice is taken of the earliest accurate observations made upon the mineral by W. Phillips in 1821; and it will be found that this omission leads to several errors in Prof. Zirkel's summary of previous crystallographic work, which will be mentioned in detail below.

Since the appearance of Zirkel's memoir the following authors have written :—Hessenberg on twin crystals, and new forms; Schrauf, figures and a new form; Zepharovich, on two new forms from Przibram; Vom Rath on the combination of crystals from Nagyag; Groth, a new form from Horhausen; Kokscharow, measurement of two crystals from Neudorf.

The observations contained in the present paper are the result of a study of the collection of Bournonite in the British Museum, which is particularly rich in splendid specimens from Wheal Boys and Herodsfoot Mine in Cornwall, and contains also many fine examples from other localities, especially Neudorf, Horhausen, and Kapnik.

Figures 2 and 3 represent the general form of crystals from Endellion and Liskeard, and may be added to the numerous figures of Lévy, Zirkel, and Schrauf; while the paper may be regarded as an appendix to the monograph of Zirkel.

Forms.—The latest complete list of observed forms is that given by Hessenberg, who mentions 48. This contains the 40 given in the table of Zirkel, and in addition 8 determined by himself. Since that time two have been observed by Zepharovich, one by Schrauf, and one by Groth. The table given by Zirkel contains 29 forms recorded by previous observers. In this table, however, as is shown below, four of Hausmann's forms and two of Mohs' are wrongly quoted, while two given by Mohs are omitted. Since in addition to this Hausmann himself was led into error in interpreting the measurements given by Phillips in 1823, it follows that these tables must be considerably modified.

It will be found that the only observations of much independent value are those of Phillips, Mohs, and Hausmann.

The measurements of Bournon were made before the reflecting goniometer had come into use, and are totally unreliable.

Those of Phillips given in 1821 are observations made upon 16 crystals with the reflecting goniometer, and those which he gives in his *Mineralogy* in 1823 are doubtless the result of further work. The work of Mohs appears to be quite independent; Hausmann had seen the results both of Mohs and Phillips, but adds forms of his own determination. Most other tables of forms are copied from Mohs (Hartmann's, for example), with the exception of Dufrénoy's in 1856, which is unintelligible as it stands, and which is criticised below.

The following table gives a complete list of the 50 forms hitherto established, with their first observers, and at the same time a comparison between the forms of Phillips, Mohs, and Hausmann.

These refer to the editions of 1823, 1839, and 1847 respectively.

			Phillips.	Mohs.	Haus-mann.	
a	100	$\infty \breve{P} \infty$		$(\mathring{\bar{P}}r + \infty)s$	B	
b	010	$\infty \bar{P} \infty$	M	$(P - \infty)k$	B'	
c	001	$0 P$	P	$(\bar{P}r + \infty)r$	A	
τ	0 1 13	$\frac{1}{13} \bar{P} \infty$	b_1		AB' 13	
β	018	$\frac{1}{8} \bar{P} \infty$	c_1		AB 8	
t	014	$\frac{1}{4} \bar{P} \infty$				Miller.
ψ	027	$\frac{2}{7} \bar{P} \infty$	b_2		AB' $\frac{7}{2}$	
ϵ	013	$\frac{1}{3} \bar{P} \infty$				Hessenberg.
x	012	$\frac{1}{2} \bar{P} \infty$	b_3	$(\bar{P}r)\ p$	AB' 2	
h	023	$\frac{2}{3} \bar{P} \infty$		$\frac{3}{4} \bar{P}r$		
ν	034	$\frac{3}{4} \bar{P} \infty$			AB' $\frac{4}{3}$	
o	011	$\bar{P} \infty$	$b_4\ (c_2)$	$(Pr - 1)o$	D'	
σ	054	$\frac{5}{4} \bar{P} \infty$			B' $A\frac{4}{5}$	
z	021	$2 \bar{P} \infty$	b_5		B' $A\frac{1}{2}$	
δ	031	$3 \bar{P} \infty$				Zirkel.
ζ	041	$4 \bar{P} \infty$				Hessenberg.
η	130	$\infty \bar{P}\ 3$				Hessenberg.
e	120	$\infty \bar{P}\ 2$	d_3	$(\mathring{\bar{P}}r - 1)e$	B' B 2	
l	230	$\infty \bar{P}\ \frac{3}{2}$	d_2		B' $B\frac{3}{2}$	
θ	340	$\infty \bar{P}\ \frac{4}{3}$				Hessenberg.
k	450	$\infty \bar{P}\ \frac{5}{4}$				Zirkel.
m	110	∞P	d_1	$(\mathring{P}r)d$	E	
w	430	$\infty \breve{P}\ \frac{4}{3}$				Miller.
a	320	$\infty \breve{P}\ \frac{3}{2}$			BB' $\frac{3}{2}$	
f	210	$\infty \breve{P}\ 2$		$(\mathring{\bar{P}}r + 1)f$	BB' 2	
i	310	$\infty \breve{P}\ 3$				Zirkel.
d	610	$\infty \breve{P}\ 6$				Zirkel.
Σ	301	$3 \breve{P} \infty$				Schrauf.
n	101	$\breve{P} \infty$		$(\mathring{P} + \infty)^2 n$	D	
γ	203	$\frac{2}{3} \breve{P} \infty$			AB $\frac{3}{2}$	
κ	103	$\frac{1}{3} \breve{P} \infty$				Hessenberg.
g	221	$2 P$				Zirkel.
μ	332	$\frac{3}{2} P$				Hessenberg.
χ	334	$\frac{3}{4} P$			AE $\frac{4}{3}$	
y	111	P	a_8	$(\breve{P}r - 1)^3 = (\breve{P} - 1)^2 y$	P	
p	223	$\frac{2}{3} P$			AE $\frac{3}{2}$	
u	112	$\frac{1}{2} P$	$a_1\ (a_2)$	P	AE 2	
ϕ	113	$\frac{1}{3} P$				Zirkel.
v	121	$2 \bar{P}\ 2$	a_5 ?			
s	122	$\bar{P}\ 2$	a_7 ?	$P - 1$		
⊙	123	$\frac{2}{3} \bar{P}\ 2$	a_3 ?	$(\bar{P} - 1)^{\frac{3}{2}} = (\bar{P}r - 2)^5$		
ξ	124	$\frac{1}{2} \bar{P}\ 2$		$(\bar{P} - 1)^2$		
ω	436	$\frac{2}{3} \breve{P}\ \frac{4}{3}$				Zirkel.
ρ	211	$2 \breve{P}\ 2$				Zirkel.
π	212	$\mathring{P}\ 2$				Zirkel.
r	314	$\frac{3}{4} \mathring{P}\ 3$				Miller.
λ	414	$\mathring{P}\ 4$				Zirkel.
G	236	$\frac{1}{2} \bar{P}\ \frac{3}{2}$				Zepharovich.
☾	136	$\frac{1}{2} \bar{P}\ 3$				Zepharovich.
Δ	4 7 14	$\frac{1}{2} \bar{P}\ \frac{7}{4}$				Groth.

The above table requires several explanatory remarks. The figure in Phillips's *Mineralogy*, reproduced here in fig. 1, evidently represents a twin crystal, which he did not recognise as such; for the angle $c_2 : b_4$ is 60°38′ (instead of 58°28′ as calculated from the values which he gives for Pb_4 and Pc_2), and is the angle oo_1=60°32′ across the twin plane of junction. A simple juxtaposition twin crystal is shown for comparison in fig. 4 (Hessenberg's fig. 31), in which bb_1=93°40′, uu_1=4°0, mm_1=7°20′, oo_1=60°32′. The angles given in Phillips's *Mineralogy* represent actual measurements, as he is careful to state, and are not the result of any calculation; and the angles given for Bournonite are probably those obtained from the actual crystal there figured. In his paper of 1821 in *Nicholson's Journal*, the only measurements given are those which relate to the forms *a b c m o u*; and it appears that there also only twin crystals had been examined, for the angles 001 : 011 and 001 : 101 (P^1b and P^1a) are given as 43°12′ and 43°44′ respectively, and these both denote *co*.

Hence, interpreting Phillips's figure as a twin crystal, it will be seen that a_1 and a_2 are both *u* faces ($a_1\,a_2$=4°50′), d_1 and d_4 are both *m* faces, and c_2 and b_4 are both *o* planes. Then b_1 is (0 1 13) and c_1 is (018). Now these two are evidently the origin of Hausmann's (0 1 13) and (108), while c_2 is probably the origin of his (12 0 11), since (001) : (12 0 11) is 43°35′ with Hausmann's elements, and $P : c_2$=43°51′ (Phillips). Hausmann's (027) is then Phillips's b_2.

Phillips's a_5 and a_7 are probably *v* and *s*. It seems that he occasionally confuses the a_1 and a_2 of his figure, and if this is the case, a_3 may be referred to the form ⊙, and a_4 (distant 3°45′ from c_2) possibly to (1 11 11) given below as *N*. To the face a_6, which makes an angle of only 0°36′ with *u*, definite indices can hardly be assigned. Except for the confusion between a_1 and a_2, Phillips's measurements are no doubt accurate, and lead to nearly the same elements as those of Miller; but it is impossible that MT=90°, and there may also be a confusion between d_1 and d_4.

The table of Mohs represents his independent investigations, which are the earliest that recognise the twinning, and therefore lead to elements that are nearly correct.

NOTE TO TABLE ON p. 62.—In the Manuscript Catalogue of the Allan-Greg Collection (earlier than 1826) Haidinger figures *g* $(\breve{\mathring{P}}-2)^4$ and *z* $(\bar{P}r-2)$ as occurring on crystals from Servoz, with $(\frac{4}{3}\breve{P}-4)^{12}=(661)$ between *my* and $(\bar{P}r+2)^5$ between *uc* in the zone [*cum*]. Also $(\breve{P}r-1)^5$ from Cornwall between *uy*. Perhaps this should be $(\breve{\mathring{P}}r-1)^7=p$.

Hausmann calculates his elements from the observed angles $\chi\chi'$ and mm'. With his parameters Phillips's b_1 c_1 c_2 b_2 correspond to forms {0 1 13} {108} {12 0 11} {027} if the twinning be overlooked, so that Phillips's zone *PT* corresponds to Hausmann's *AB*. To these forms accordingly Hausmann assigns the above faces. As regards his own elements, it is impossible that the face χ can have been observed so well-developed as to be chosen for a parametral face. There may therefore have been, as has frequently been the case, a confusion between the zones *cm* and *cb*, for $m\chi = 46°15' = bo$ nearly. His faces ν σ a γ are here retained because the angles given for them (though calculated from his elements) must represent some measured angles, and there are no forms to which they approximate more nearly than those to which he ascribes them; $AB\frac{4}{3}$=(304) and $B'A\frac{5}{7}$=(075) are probably u and y.

The comparative table given by Zirkel, p. 442, contains several errors. Thus Hausmann's forms {108} {203} {304} are wrongly given as {801} {302} {403}. Hausmann's {12 0 11} is referred to {11 0 12}. Mohs' $\frac{3}{4}\bar{P}r$ is ascribed to the form {430} instead of {023}. $(P-1)^2$ is ascribed to the form {121} instead of {124}, while $(P-1)$ and $(\bar{P}-1)\frac{3}{2}$ are omitted.

These errors are copied into Hessenberg's table. The forms ⊙ and ξ, given as new by Hessenberg, had therefore been already detected by Mohs. The form Σ is given as new by Vom Rath (*N*) in 1877, but it had been previously given by Schrauf, Taf. 37, fig. 17.

Of the above forms $\psi h \nu \sigma \eta a \beta \gamma \chi r$ are rejected by Schrauf.

Of these, however, $h \eta \gamma a \chi$ have been observed by myself, $\psi \nu \sigma \beta$ are supported by Phillips's measurements, ψ and σ by Dufrénoy's, and r is given by Miller. Zirkel's face q [311] is here rejected on Schrauf's authority. (See Zirkel, fig. 34, and compare Schrauf's preliminary remarks on Bournonite.)

There only remains the somewhat elaborate table of forms given with measurements by Dufrénoy in his *Traité de Minéralogie*. This table, which is unintelligible as it there stands, is partly explained by his original memoir in the *Annales des Mines*, which is not mentioned by Zirkel. It will be seen from that memoir that Dufrénoy, like many of the earlier observers, took twin crystals for simple individuals, and also confused the zones [*bc*] and [*mc*]; the zone [*an*] he does not appear to have observed at all.

His statement that there are no angles common to the crystals from

Cornwall and Alais is enough in itself to show that there had been some confusion.

His table of measurements (uncorrected by calculation) is not quite intelligible, but the results may most probably be interpreted by the aid of the following table, in which the letters are those used in the original memoir, and not those of the transcript in the *Traité de Minéralogie*, where there are several misprints.

	Alais.	Oberlahr.	Pontgibaud.	Cornwall.	Kapnik.	Servoz.
b				*MT*	*T*	
c	*P*	*P*	*P*	*P*	*P*	*P*
o	*a*	*a*	*a*	$b_4\ c_2$		c_2
u	*cb*		*cb*	a_1		a_1
y	*bg*	*b*	*b*			
m	*MT*		*MT*	d_1	d_1	
β				c_1		
ψ				b_2		
σ		*f*			*f*	

Here the first column denotes the forms to which the faces mentioned in Dufrénoy's table of measurements are probably to be ascribed.

Finally, the crystal of Wölchite described by Kenngott in 1854, and explained by Zepharovich in 1865 as a simple individual and a combination of the forms *cabm* (304) and (705), may be in reality a twin crystal of the combination *camuy*; since approximate measurements gave $o\mathrm{P} : m\breve{\mathrm{P}}\infty = 33\frac{1}{2}°$ ($=cu$) and $\infty\breve{\mathrm{P}}\infty : m'\breve{\mathrm{P}}\infty = 39°$ (?) ($=my$).

To the above list of 50 forms must now be added 29 new forms, about which there can be no doubt, which are given in the first of the two following tables; while the second table contains 21 forms of which isolated faces have been observed, but which are not free from suspicion.

TABLE I.

Δ	015	$\frac{1}{5}\bar{P}\infty$	S	559	$\frac{5}{9}P$
F	025	$\frac{2}{5}\bar{P}\infty$	E	558	$\frac{5}{8}P$
R	570	$\infty\bar{P}\frac{7}{5}$	K	554	$\frac{5}{4}P$
Π	8 11 0	$\infty\bar{P}\frac{11}{8}$	Z	443	$\frac{4}{3}P$
M	790	$\infty\bar{P}\frac{9}{7}$	Θ	17 17 12	$\frac{17}{12}P$
Ψ	650	$\infty\breve{P}\frac{6}{5}$	Γ	885	$\frac{8}{5}P$
Ξ	10 3 0	$\infty\breve{P}\frac{10}{3}$	Y	535	$\breve{P}\frac{5}{3}$
Φ	410	$\infty\breve{P}4$	D	232	$\frac{3}{2}\bar{P}\frac{3}{2}$
L	510	$\infty\breve{P}5$	V	544	$\frac{5}{4}\bar{P}\frac{5}{4}$
N	1 11 11	$\bar{P}11$	Q	322	$\frac{3}{2}\breve{P}\frac{3}{2}$
v	2 7 14	$\frac{1}{2}\bar{P}\frac{7}{2}$	X	473	$\frac{7}{3}\bar{P}\frac{7}{4}$
U	134	$\frac{3}{4}\bar{P}\frac{3}{2}$	T	231	$3\bar{P}\frac{3}{2}$
I	213	$\frac{2}{3}\breve{P}2$	W	341	$4\bar{P}\frac{4}{3}$
Ω	114	$\frac{1}{4}P$	H	725	$\frac{7}{5}\breve{P}\frac{7}{2}$
P	10 10 19	$\frac{10}{19}P$			

TABLE II.

097	$\frac{9}{7}\bar{P}\infty$	20 20 21	$\frac{20}{21}P$
160	$\infty\bar{P}6$	18 1 19	$\frac{18}{19}\breve{P}18$
13 6 0	$\infty\breve{P}\frac{13}{6}$	10 1 9	$\frac{10}{9}\breve{P}10$
16 5 0	$\infty\breve{P}\frac{16}{5}$	20 19 38	$\frac{10}{19}\breve{P}\frac{20}{19}$
720	$\infty\breve{P}\frac{7}{2}$	11 22 34	$\frac{11}{17}\bar{P}2$
530	$\infty\breve{P}\frac{5}{3}$	1 0 14	$\frac{1}{14}\breve{P}\infty$
850	$\infty\breve{P}\frac{8}{5}$	638	$\frac{3}{4}\breve{P}2$
910	$\infty\breve{P}9$	12 12 11	$\frac{12}{11}P$
17 17 11	$\frac{17}{11}P$	312	$\frac{3}{2}\breve{P}3$.
14 14 11	$\frac{14}{11}P$	104	$\frac{1}{4}\breve{P}\infty$
445	$\frac{4}{5}P$		

Parameters.—The axial lengths deduced by the earlier observers from their measurements are criticised by Zirkel.

Expressed in terms of the elementary angles *bo*, *cn*, *am*, the elements of Bournonite as determined by the only authors who have published original observations are:

		010 : 011	001 : 101	100 : 110
Phillips	...	46°48′	43°44′	46°45′
Haüy ...	...	44·28	44·29	46·4
Mohs ...	...	46·26	41·44½	46·50
Lévy ...	...	46·28	41·42	46·50

	010 : 011	001 : 101	100 : 110
Hausmann ...	47·3	41·8	46·50
Miller	46·17	41·53½	46·50
Dufrénoy, 1856	46·48	31·32	46·50
Zirkel	46·19	41·57	46·44½

The early determinations of Bournon with the hand goniometer are valueless. Lévy (probably), Glocker, Dana, Naumann, and Quenstedt, in editions previous to 1852, copy Mohs; Beudant takes the angles from Phillips; and since 1852 the elements of Miller have usually been adopted.

It has been pointed out above that Phillips's angles are based upon a twin crystal, and that Hausmann's elements are probably to be traced to a confusion between *o* and χ.

The elements of Mohs given above are reduced to Hausmann's and Miller's axes; those of Dufrénoy are deduced from his primitive form, which is totally wrong and due to a confusion of the zones *cb* and *cm*, so that they involve very cumbersome indices even for the faces which he gives. He is wrong in stating that Lévy's primitive form is erroneous.

Haüy refers Bournonite to the same parameters as Stibnite; but his conclusion is only based on the measurement of two faces which make angles of 57° and 33° respectively with the basal plane.

The measurement of a large number of crystals with the view of ascertaining if possible how far the elements vary with the locality or the composition, has led to the belief that the parameters deduced from the best measurements upon several crystals from the same locality, or even from the same specimen, are almost exactly those of Miller. On the other hand, the angles between pairs of individual faces upon a crystal may often differ by as much as 20 minutes from the theoretical value, and individual crystals seem occasionally to require parameters differing to a slight extent from those here adopted.

But as these variations are not consistent, but are characteristic only of particular isolated faces, or at the most of particular crystals, it is very difficult to determine satisfactory parameters for any given crystal, and impossible to find any regularity in their variations. The only law observed is that while the angles in the prism zone [*amb*] are remarkably constant (as is also indicated by the close agreement of the elementary angle of previous observers in this zone), other zones, and especially the vertical zones [*cob*] [*cum*] [*cna*], are occasionally contracted or expanded, pointing to a slight increase or decrease in the vertical axis.

The elementary angles here adopted are—

$$bo=46°17', \ cn=41°53', \ am=46°50';$$

corresponding to the axial ratios $a : b : c = 1{\cdot}06612 : 1 : {\cdot}95618$.

Since the table of calculated angles given by Zirkel (which is the only one of any importance yet given for Bournonite) contains 43 errors which are too large to be neglected, it has been thought advisable to give the following list of over 1,000 angles. Most of these have been calculated in two ways—(1) by the methods of spherical trigonometry, (2) by the general formula for the angle between any two faces in terms of the parameters, and the indices. (See Brezina, *Krystallographische Untersuchungen*, I. p. 306.)

It is hoped that in this way errors have been avoided. (See pp. 69-70.)

Measurements.—It will be necessary to give the measurements by which the faces of Table I. have been established, and those of Table II. supported.

∇ on a crystal from Endellion—$o\nabla=33°7'$, $ox=18°11'$ or $18°20'$.

F and Y on a crystal from Herodsfoot Mine with $bofvs\chi\rho n\epsilon$.

F between x and ϵ, $x\mathrm{F}=4°59'$ Y in the zone $s\chi$, $s\mathrm{Y}=23°29'$.

$x\epsilon=7°49'$ $b\mathrm{Y}=67°2'$.

ΠRM on a crystal from Herodsfoot Mine with $bm\theta el$—

$bR=33°19'$ $b\Pi=34°30'$ $bM=35°52'$.

Π on another crystal from the same specimen, $b\Pi=34°21'$.

R (two faces) on a crystal from Braunsdorf with $cumozxevbn$—

$mR=9°4'$, mR' $(=110 : \bar{5}70)=77°14'$.

Ψ on a crystal from Herodsfoot Mine with $bl\theta maf$ and perhaps (530) and (850), $b\Psi=48°21'$; $b : 530=57°16'$; $b : 850=56°34'$.

Ψ on a crystal from Herodsfoot Mine with $bl\theta\kappa mafi\,\Phi$, $b\,\Psi=48°40'$.

* Ξ on a crystal from Endellion with $cuoynabefmwia\rho\Sigma$. There are two faces of the form, $a\,\Xi=17°53'$, $a\,\Xi'=17°27'$

Φ on a great number of crystals from Herodsfoot Mine.

RLI on a crystal from Herodsfoot Mine with $bousy\rho nemf\,\Phi$, and traces of (104), $bR=33°51'$, $bL=77°59'$, $oI=38°48'$, $ou=28°16'$, $o\,n=58°30'$, $a : 104=77°22'$. I is a fair sized face between un.

N on a crystal from Herodsfoot Mine with $bosy\rho u\odot\xi mfi\Phi$ and perhaps a face (11 22 34). N is a slightly rounded face between os; and (11 22 34) lies between $\odot\xi$ in the zone $es\odot\xi$.

$sN=14°34'$, $so=18°3'$, $s : (11\ 22\ 34)=12°8'$, $s\xi=18°41'$, $s\odot=11°6'$.

v on several crystals from Herodsfoot Mine, $bv=64°19'$, $uv=15°26'$, are the measurements on one crystal.

* This is from one of the two specimens figured in Rashleigh's Plate XIX., the earliest described specimen of Bournonite.

		a.	*b.*	*c.*	*o.*	*m.*	*n.*	*y.*	*u.*	*s.*	*x.*	*e.*	*l.*
0 1 13	*τ*	90°0′	85°48′	4°12′	39°31′	86°56′	42°4′	49°39′	30°18′	42°47′	21°21′	86°12′	86°26′
018	*β*	90·0	83·11	6·49	36·54	85·2	42·21	47·51	28·37	40·28	18·44	83·50	84·13
015	∇	90·0	79·10	10·50	32·53	82·7	43·2	45·12	26·18	36·58	14·43	80·12	80·50
014	*t*	90·0	76·33	13·27	30·16	80·14	43·37	43·33	25·0	34·35	12·6	77·51	78·37
027	*ψ*	90·0	74·43	15·17	28·26	78·55	44·6	42·27	24·12	33·14	10·16	76·12	77·5
013	*ε*	90·0	72·19	17·41	26·2	77·12	44·49	41·4	23·20	31·16	7·52	74·2	75·5
025	*F*	90·0	69·4	20·56	22·47	74·54	45·57	39·19	22·29	28·43	4·37	71·8	72·22
012	*x*	90·0	64·27	25·33	18·10	71·40	47·49	37·8	22·2	25·20	51·6	67·1	68·33
023	*h*	90·0	57·29	32·31	11·12	66·55	51·7	34·36	23·3	21·4	6·58	60·53	62·53
034	*ν*	90·0	54·21	35·39	8·4	64·51	52·47	33·49	24·8	19·37	10·6	58·9	60·23
011	*o*	90·0	46·17	43·43	87·26	59·44	57·27	32·57	28·16	17·57	18·10	51·16	54·8
054	*σ*	90·0	39·55	50·5	6·22	55·59	61·28	33·30	32·31	19·1	24·32	46·1	49·26
021	*z*	90·0	27·36	62·24	18·41	49·44	69·50	37·21	42·7	25·41	36·51	36·39	41·17
031	*δ*	90·0	19·13	70·47	27·4	46·28	75·49	41·39	49·15	32·6	45·14	31·15	36·48
041	*ζ*	90·0	14·39	75·21	31·38	45·7	79·9	44·24	53·15	35·55	49·48	28·51	34·53
130	*η*	72·38	17·22	90·0	48·44	25·48	78·30	44·17	60·25	43·59	65·41	7·46	14·39
120	*e*	64·52	25·8	90·0	51·16	18·2	73·31	40·53	58·35	43·26	67·1	50·16	6·53
230	*l*	57·59	32·1	90·0	54·8	11·9	69·16	38·44	57·27	43·52	68·33	6·53	64·2
570	*R*	56·11	33·49	90·0	54·57	9·21	68·11	38·19	57·15	44·7	69·0	8·41	1·48
8 11 0	Π	55·42	34·18	90·0	55·11	8·52	67·54	38·13	57·12	44·12	69·8	9·10	2·17
340	*θ*	54·53	35·8	90·0	55·35	8·2	67·24	38·4	57·7	44·21	69·20	9·59	3·6
790	*M*	53·53	36·7	90·0	56·4	7·3	66·49	37·54	57·2	44·32	69·37	10·59	4·6
450	*k*	53·7	36·53	90·0	56·27	6·17	66·22	37·47	56·59	44·41	69·49	11·45	4·52
110	*m*	46·50	43·10	90·0	59·44	86·20	62·49	37·20	56·45	46·20	71·40	18·2	11·9
650	Ψ	41·37	48·23	90·0	62·41	5·13	60·3	37·39	56·54	48·9	73·21	23·15	16·22
430	*w*	38·39	51·21	90·0	64·26	8·11	58·34	38·6	57·8	49·21	74·22	26·13	19·20
320	*a*	35·24	54·36	90·0	66·24	11·26	57·1	38·48	57·30	50·47	75·32	29·28	22·35
210	*f*	28·4	61·56	90·0	71·2	18·46	53·54	41·10	58·44	54·27	78·18	36·48	29·55
310	*i*	19·34	70·26	90·0	76·37	27·16	51·0	45·2	60·50	59·17	81·42	45·18	38·25
10 3 0	Ξ	17·44	72·16	90·0	77·51	29·6	50·30	46·0	61·22	60·24	82·27	47·8	40·15
410	Φ	14·56	75·4	90·0	79·44	31·54	49·49	47·33	62·16	62·8	83·37	49·56	43·3
510	*L*	12·2	77·58	90·0	81·43	34·48	49·13	49·14	63·15	63·58	84·50	52·50	45·57
610	*d*	10·5	79·55	90·0	83·3	36·45	48·53	50·25	63·56	65·15	85·40	54·47	47·54
301	Σ	20·23	90·0	69·37	75·25	50·7	27·44	43·51	49·59	58·5	71·41	66·32	60·12
101	*n*	48·7	90·0	41·53	57·27	62·49	83·46	35·27	29·12	44·8	47·49	73·31	69·16
203	*γ*	59·7	90·0	30·53	51·40	69·27	11·1	36·54	24·35	41·37	39·15	77·24	74·13
103	*κ*	73·21	90·0	16·39	46·10	78·42	25·15	42·32	24·32	41·35	30·8	83·1	81·16
114	Ω	77·42	76·52	18·9	32·27	71·51	31·49	34·31	15·6	29·44	17·12	72·46	72·12
113	*φ*	74·6	73·1	23·36	30·13	66·24	30·7	29·4	9·39	24·59	17·42	67·37	66·52
112	*u*	67·58	66·26	33·15	28·16	56·45	29·12	19·25	66·30	17·32	22·2	58·35	57·27
10 10 19	*P*	67·8	65·31	34·37	28·13	55·23	29·18	18·3	1·22	16·40	22·54	57·18	56·8
559	*S*	66·15	64·34	36·4	28·14	53·56	29·28	16·36	2·49	15·26	23·52	55·57	54·43
558	*E*	64·18	62·28	39·20	28·32	50·40	30·5	13·20	6·5	14·12	26·12	52·56	51·33
223	*p*	63·15	61·19	41·9	28·51	48·51	30·33	11·31	7·54	13·35	27·35	51·15	49·47
334	*χ*	61·20	59·15	44·31	29·41	45·29	31·40	8·9	11·16	13·46	30·15	48·11	46·32
111	*y*	57·3	54·33	52·40	32·57	37·20	35·27	74·40	19·25	15·0	37·8	40·53	38·44
554	*K*	54·16	51·29	58·37	36·13	31·23	38·57	5·57	25·22	18·56	42·24	35·44	33·7
443	*Z*	53·34	50·43	60·14	37·13	29·46	40·0	7·34	26·59	19·50	43·51	34·22	31·36
17 17 12	Θ	52·58	50·3	61·42	38·8	28·18	40·58	9·2	28·27	20·56	45·11	33·9	30·15
332	*μ*	52·26	49·27	63·3	39·1	26·57	41·53	10·23	29·48	22·1	46·25	32·3	29·0
885	Γ	51·52	48·49	64·31	40·0	25·29	42·54	11·51	31·16	23·12	47·46	30·52	27·40
221	*g*	50·16	47·2	69·8	43·14	20·52	46·12	16·28	35·53	27·7	52·1	27·19	23·33

		a.	*b.*	*c.*	*o.*	*m.*	*n.*	*y.*	*u.*	*s.*	*x.*	*e.*	*l.*
314	*r*	56°49′	78°47′	35°31′	43°43′	58°54′	13°44′	25°17′	15°28′	31°6′	35°5′	65°53′	62°55′
414	λ	48·55	79·54	42·52	49·23	54·43	10·6	25·21	21·38	34·44	42·31	64·2	60·11
213	*I*	60·20	74·42	34·7	38·40	57·55	18·47	22·26	10·24	26·27	30·36	63·19	60·55
725	*H*	40·43	76·36	52·42	53·2	46·24	16·25	23·40	27·46	36·31	49·27	57·48	53·8
2 7 14	*υ*	83·24	64·38	26·20	19·20	66·58	41·56	31·18	15·26	21·3	6·36	64·7	64·54
136	☾	82·19	64·41	26·36	19·41	66·14	40·59	30·22	14·16	20·27	7·41	63·40	64·20
124	ξ	78·34	64·59	27·50	21·22	63·38	37·45	27·13	10·35	18·44	11·26	62·10	62 23
4 7 14	Δ	76·58	65·9	28·29	22·13	62·34	36·25	25·56	9·0	18·11	13·2	61·34	61·35
236	*G*	74·54	65·23	29·25	23·28	61·12	34·41	24·18	6·56	17·38	15·6	60·49	60·35
436	*ω*	61·39	67·41	37·26	33·16	53·1	24·45	16·16	6·19	19·38	28·21	56·57	55·0
212	*π*	51·1	70·24	45·28	42·23	47·33	19·36	15·51	16·57	26·17	38·59	55·11	51·50
535	*Y*	52·7	66·52	46·48	39·59	45·3	23·8	12·19	16·17	23·20	38·5	51·57	48·48
123	Θ	75·50	58·35	35·9	17·59	56·49	38·29	21·23	10·17	11·25	15·45	54·51	55·8
134	*U*	79·40	55·1	36·55	13·5	57·16	44·22	26·14	15·11	10·56	14·25	53·29	54·28
1 11 11	*N*	86·38	46·23	43·49	3·22	57·5	54·23	29·35	25·17	14·35	18·28	49·29	51·58
122	*s*	72·3	48·54	46·34	17·57	46·20	44·8	15·0	17·32	35·54	25·20	43·26	43·52
544	*V*	50·59	57·31	56·0	39·1	34·31	33·2	6·4	23·1	21·4	42·25	40·59	37·46
322	*Q*	45·48	60·18	58·47	44·12	33·3	31·39	11·15	26·45	26·15	47·4	41·53	37·51
211	*ρ*	37·39	65·2	63·48	52·21	31·50	30·59	19·24	33·23	34·24	54·31	44·4	38·57
232	*D*	62·51	43·7	59·24	29·17	32·23	46·53	11·26	27·18	13·58	39·17	31·17	30·36
121	*v*	67·26	35·5	64·40	28·59	30·45	54·55	19·28	34·0	18·6	42·21	25·20	26·11
473	*X*	63·56	34·56	68·27	33·41	26·3	55·29	20·25	36·2	22·2	46·45	21·45	21·52
231	*T*	59·27	35·36	73·32	39·56	19·48	56·36	23·4	41·10	27·36	52·40	17·49	16·28
341	*W*	55·46	36·54	77·56	45·16	14·28	57·53	26·16	45·12	32·38	57·45	15·37	12·27

	a.	*b.*	*c.*	*m.*	*e.*	*l.*
097	90°0′	39°8′	50°52′	55°33′	45°24′	48°53′
160	81·7	8·53	90·0	34·17	16·15	23·8
13 6 0	26·12	63·48	90·0	20·38	38·40	31·47
16 5 0	18·26	71·34	90·0	28·24	46·26	39·33
720	16·54	73·4	90·0	29·56	47·58	41·5
530	32·36	57·24	90·0	14·14	32·16	25·23
850	33·41	56·19	90·0	13·9	31·11	24·18
910	6·45	83·15	90·0	40·5	58·7	51·14
104	77·21	90·0	12·39	81·23	84·40	83·20
1 0 14	86·20	90·0	3·40	87·30	88·27	88·3
17 17 11	52·9	49·9	63·44	26·16	31·30	28·23
14 14 11	54·4	51·16	59·4	30·56	35·21	32·42
445	60·19	58·8	46·22	43·38	46·31	44·45
20 20 21	57·43	55·18	51·19	38·41	42·4	40·1
18 1 19	46·2	87·48	40·24	61·56	71·23	67·57
10 1 9	45·16	85·42	45·4	57·34	68·29	64·6
20 19 38	66·56	66·37	33·54	56·7	58·17	57·1
11 22 34	76·8	59·17	34·21	57·33	55·39	55·56
6 3 8	70·57	73·29	37·19	54·58	60·58	58·18
12 12 11	56·12	53·37	54·25	35·35	39·21	37·4
312	39·29	74·5	55·0	43·16	54·49	50·4

U on a crystal from the same specimen as the last, determined by the zones $b\xi$ and xs; also on a crystal from Endellion, fig. 5, $oU=13°6'$.

Ω on the same crystal, fig. 5, $m\Omega=71°24'$.

P (two faces) on a crystal from Herodsfoot Mine, fig. 11, mP (above)$=55°15'$, mP (below)$=55°29'$.

S on a crystal from Herodsfoot Mine with *bosyunm*, $mS=53°58'$, $my=37°20'$, $mu=56°40'$.

E on a crystal from Andreasberg between uy, with *nae*; it is a broad face, $uE=6°1'$, $uy=19°29'$.

$K\Gamma$ in a zone containing *myu* and perhaps (12 12 11) on one of a wheel-shaped group of crystals from Herodsfoot Mine, $mu=56°37'$, $my=37°16'$, m: 12 12 11$=35°0'$, $mK=31°11'$, $m\Gamma=25°46'$.

Z in a zone containing $g\mu y$ and perhaps (14 14 11) on a crystal from Herodsfoot Mine which has also the face o well developed, $oy=32°56'$, $yg=16°20'$, $y\mu=10°6'$, $yZ=7°51'$, y: (14 14 11)$=6°17'$, $og=43°8'$, $o\mu=38°48'$, $oZ=37°22'$, o : (14 14 11)$=36°26'$.

D on a crystal from Endellion with *boxuygmvs;* it occurs as a small dull face between yv and nearly between sg, $yD = 12°12'$ about.

V as a good bright face between $y\rho$ with $n\Sigma vQ$ and perhaps (18 1 19) on a crystal from Endellion. V gives two images, $yV=6°11'$ or $5°44'$, $y\rho=19°16'$, $nV=32°57'$ or $33°9'$. Q is a small face not quite between V and ρ. $yQ=10°51'$, $nQ=32°35'$; and (18 1 19) occurs as a small face beyond n in the zone $[\rho n]$ on the broken edge of the crystal, n: (18 1 19)$=2°19'$, $n\rho=30°58'$.

Q (2 faces) on a crystal from Endellion with $cn\Sigma u\rho ymfoa$; it occurs as a large bright face between ρy, $yQ=11°13'$, $yQ'=11°20'$, $cQ=58°42'$.

Also (2 faces) on another crystal from Endellion with $n\Sigma u\rho ymb$, $yQ = 11°17'$, $yQ'=11°8'$, $nQ=31°37'$, $bQ=60°13'$, $bQ'=60°25'$, and also on other crystals from Endellion.

XTW on two crystal fragments from Kapnik; the specimen has bright bacillary groups of Bournonite dispersed upon Freieslebenite.

One fragment (twinned) is shown in fig. 6, on which $oW=45°8'$, $oT=40°4'$, $oX=33°36'$. The other fragment has the faces $b\odot vW$, $bW=87°9'$, $vW=16°12'$.

H on a twin crystal from Neudorf, fig. 7, the face gives two images—$cH=52°22'$ or $52°45'$, $nH=16°8'$ or $16°34'$.

(097) on a crystal from Herodsfoot Mine as a bright but striated face between bo, with *bosu*—$bo=46°7'$, b : 097$=38°55'$.

(160); on the edge bb_1 of a twin crystal from Servoz is a face between ba_1, $ba_1=3°33'$, b: (160) $9°0'$, $bb_1=93°35'$.

(13 6 0). A crystal from Neudorf with the forms *abelθmyno* contains a twin lamina consisting of y_1 (between two *y* faces of the first crystal) and a prism face *j* (13 6 0)? (fig. 8), yy_1=5°50′ (calculated=5°50′), *yj*=41°56′ (calculated 41°55′).

(13 6 0) (16 5 0) on a crystal from the same wheel-shaped group from Herodsfoot Mine which yielded *K*Γ (see above) with *bmfi*, *bm*=43°13′, *mf*=18°42′, *m* : (13 6 0)=20°36′, *mi*=26°29′, *m*: (16 5 0)=28°29′.

(720). A crystal from Endellion (twinned) has the forms *n m u o a* and another prism face, *ma*=46°43′, *a* : (720)=16°45′.

(910) on the same crystal mentioned above, as showing two faces of the form Ξ, *a* : 910=6°55′.

Θ and (17 17 11) on a crystal from Herodsfoot Mine in a zone containing *mμy*, *m* : (17 17 11)=25°55′, *mμ*=26°23′, *m*Θ=27°44′, *my* = 36°55′; on the same crystal *bo*=46°8′, *bm*=43°10′.

(445) on a crystal from Endellion as a curved face, *m* : (445)=44°42′ to 42°52′, *my*=37°28′.

(1 0 14) on the same crystal with the forms *boxuy*⊙*ξnemyρ*, *n* : (1 0 14)=38°11′.

(20 20 21) on a crystal from Endellion with *muyoxξ*, *mu*=56°37′, *m* : (20 20 21)=38°35′, *my*=37°25′, *oy*=32°45′, *o* : (20 20 21)=32°13′.

(10 1 9) on a crystal from Neudorf with *cnuym*, and perhaps a face of (18 1 19), *m* : (10 1 9)=57°21′, *mn*=62°42′; *u* : (18 1 19)=26½°, *un*=29°56′ about.

(14 14 11) and *Z* (2 faces) on two juxtaposed crystals from Herodsfoot Mine in the zone *my*, one crystal gave *my*=37°20′, *mZ*=29°55′, *mμ*=27°10′, *mg*=21°1′, *mg′*=20°53′, *mμ′*=26°56′, *mZ′*=30°6′. The other gave *my*=37°39′, *m* : (14 14 11)=31°14′, *mμ*=27°12′.

(20 19 38) on a crystal from Herodsfoot Mine with *boxsu*, *ux*=27°48′, *u* : (20 19 38)=1°28′ (calculated=1°2′).

Indications of the forms (638) (312) (403) have also been observed.

(638) on a crystal from Herodsfoot Mine in the zone *ρf*, *ρf*=26°10′, *ρ* : 638=25°52′ (calculated=26°30′).

(403) in the zones [*lρ*] and [*an*] on a crystal from Neudorf.

(312) in the zones [*nm*] and [*xa*]. Locality doubtful.

Also a rounded face between *u* and *ρ* on a crystal from Herodsfoot Mine, to which indices could not be assigned.

As examples of measurements from very good crystals the following are added:—

I. (Cornwall). *bf*=61°50¼′, *be*=25°7½′, *b*Φ=75°16′, *fρ*=26°16′.

II. (Cornwall). *bm*=43°3¾′, *bl*=31°48½′, *bm′*=43°10½′, *bo*=46°17′.

III. (Cornwall). $ou=28°22\frac{1}{4}'$, $bm=43°9\frac{1}{2}'$, or $43°10\frac{1}{4}'$, bb_1 (twinned) $=93°42'$.

IV. (Cornwall). $bo=46°9'$, $bs=48°46'$, $bu=66°28'$, $y\rho=19°24'$, $ys=15°0'$, $s\xi=18°41'$.

V. (Cornwall). $oy=32°44'$, $om=59°39'$, $oy'=92°6'$, $ox=18°16'$, $ev=25°20'$, $bm=42°56'$, $f\rho=26°11'$.

VI. (Oberlahr). $cu=33°17'$, $am=46°51'$, $an=48°3'$, $a\Sigma=20°24'$, $ay'=57°4'$, $cy'=52°39'$, $cu'=33°14'$, $mn=62°49'$.

Of the forms given in the first comparative table, all have been observed during the course of the present study of Bournonite, with the exception of $\tau\beta\psi\nu\zeta\lambda G$ ☾ Δ.

Twin-growth.—The subject of Bournonite twins has been so carefully studied by Hessenberg, and so many figures have been given by him and by Schrauf, that the main facts do not require to be re-stated.

The general conclusions drawn from the present examination are—

I. That composition may be either parallel or perpendicular to the twin-plane, but is generally the former.

II. That the twinned crystals are always united by juxtaposition, and not by interpenetration.

The simplest possible case of a twin crystal showing abc as predominating faces will therefore be fig. 4, in which $aa_1=86°20'$, $bb_1=93°40'$, $mm_1=7°20'$.

The corresponding figure with composition perpendicular to the twin-plane is shown in fig. 13, in which

$$aa_1=93°40',\ bb_1=86°20',\ mm_1=0°0'.$$

Figure 4 may be taken as the elementary type of Bournonite twinning; the composition is generally repeated with parallel twin planes m, so as to give rise to a number of twin laminæ (compare Hessenberg, fig. 32). The twin structure of crystals from Neudorf, Horhausen, Endellion, and many other localities seems to be generally of a simple character, and to be complicated mainly by the occurrence of twin laminæ.

But the case of the wheel-shaped groups of Herodsfoot Mine and the Rädelerz of Kapnik requires a somewhat more detailed description, because it is left doubtful by Hessenberg, and has been variously explained.

Zirkel regards the Rädelerz as composed of a number of long thin individuals which cross one another like the spokes of a wheel, each one united with some other by the ordinary twin law (twin face m). He also suggests that the structure results from a central cross composed of two interpenetrating individuals, upon the arms of which are grouped other crystals in twin-position (*cf.* his fig. 39).

Sadebeck (*Angewandte Krystallographie*, p. 120) regards the crystals from Cornwall as interpenetration twins, in which the cruciform structure is not generally apparent because the spaces between the arms are filled up by other individuals twinned upon them. In the crystals from Cornwall and from Siebenbürgen (Transylvania), he says that each cross may be succeeded by another inclined to it at an angle of 3°40′. In this way he suggests that the Rädelerz may be composed of as many as 23 individuals, and 46 rays.

Hessenberg, although he states that he has not observed a genuine interpenetration twin, supposes the Herodsfoot crystals to afford an example of such. The Rädelerz of Kapnik and other complicated groupings he explains as circularly repeated juxtaposed twins bounded by *a* and *b* as the predominating faces in the prism zone, and formed by individuals which may have either (1) their brachy-diagonal, or (2) their macro-diagonal axes radiating from the centre of the compound crystal. Compare Hessenberg's figures 27 and 24. He states in consequence, "Wenn man am Goniometer den Winkel von 172°40′ ein-oder aus-springend in der horizontalen Zone auffindet, so dient er als der sicherste Leitfaden, da es die den Zusammensetzungsflächen paarweise nächst benachbarten Flächen *m* sind, welche zwischen sich mit diesem Werthe geneigt sind."

Quenstedt describes the groups from Cornwall and from Nagyag as interpenetration twins; the Rädelerz of Kapnik and the discs of Cornwall as parallel growths.

The conclusions drawn in the present paper are to some extent at variance with the above explanations, but are based only upon the specimens in this collection.

The suggestions of both Zirkel and Sadebeck start with the idea that the cruciform interpenetration twin is the elementary form, whereas it appears very doubtful whether such a twin of Bournonite has been observed.

The following is perhaps the clearest method of considering complicated twin crystals of Bournonite.

Each successive twinning has the effect of inclining the axes of two individuals at an angle of 3°40′ to one another. It will then be seen that if any number of individuals be ranged beside one another by repeated twinning with inclined twin planes, their axes, and therefore the planes *ab*, will always be inclined to one another at multiples of 3°40′, and their *m* planes at multiples of 7°20′. An uneven number of twin repetitions will bring a of one individual in a neighbouring position to b of another, an even number of repetitions will bring two a or two b faces into neighbouring positions. This will be seen from fig. 14, in which a_1 b_1 is the first position of the axes, m_1 the first twin axis; a_2 b_2 the second position, m_2 the second twin axis, and so on. A measured angle between two a and b faces, or between an a and a b face, will therefore denote at once the number of twin repetitions to which it corresponds.

Thus the angle b_4 b_5=14°40′ (=4×3°40′) of Hessenberg's fig. 26, denotes 4 repetitions; the angle a_1 b_4=11°0′ of his figures 24, 27, and 30 denotes 3 repetitions.

Now in the present examination of the Kapnik Rädelerz, it has generally been found that the angle 7°20′ is that between two a or two b faces, and not between two m faces, as stated by Hessenberg; and that the predominating faces are generally m, and not a or b, while the predominating faces upon the edges of a disc of Rädelerz are almost always u, and not o or n, as they are usually represented in figures.

Thus a cruciform crystal of Rädelerz will be represented by fig. 10. But these groups are far more commonly composed of three or more individuals united, as in fig. 9. II. is twinned upon I., III. is twinned upon II., the twin-planes being shown by dotted lines. I. and III. are therefore irregularly united, and a_1 a_3 7°20′.

Fig. 9 may therefore be added to figures 24, 26, 27, 30, of Hessenberg and figures 15 and 17-21 of Schrauf as a frequently observed mode of combination. The number of individuals, however, varies from 3 to 6 or 7. It may be mentioned that the only safe method of determining the positions of the individuals is by means of the faces *onuy*, &c. From an observation of the prism zone alone it is almost impossible to discriminate between them: 86°20′ or 93°40′ may be the angle between two m faces of one individual; 7°20′ may represent the m faces of a pair of individuals once twinned, or two a or b faces after double twinning; and a b m are all smooth bright faces.

The mode of twinning most common in the Bournonite from Liskeard is totally different. The ordinary form of the individuals is that of fig. 11 (without the faces P) or of fig. 3. Two such crystals are usually united as in fig. 12, so that bb_1 = 86°20′, while the two rounded and uneven a faces form a reentrant angle on the inner side of the group. On the outer side the crystals are bounded by the largely extended m faces, as shown in fig. 12, and thin laminæ may generally be traced on these parts of the crystals. The twin-plane is shown by a dotted line. This at first sight appears to be scarcely a case of composition perpendicular to the plane of twinning; it might be, in fact, because the crystals do not unite regularly otherwise than *along* the twin plane that the Herodsfoot crystals adopt this form; so that the two individuals do not come into contact at all, but break out directly from the mass of the Bournonite, having the direction of the dotted *m* plane in common.

To this reluctance, if the term may be used, of two crystals to combine perpendicular to the plane of twinning (where two *m* planes with a tendency to coincide would be inclined at an angle of 7°20′*) may perhaps be ascribed the distortion of the crystals, and especially of the *a* faces near their junction, also the tendency to grouping of other crystals on the outer side of the two principal individuals, as indicated in fig. 12 (b_2), and the oscillatory twinning at the outer corners.

But, on the other hand, in many cases, and especially in the more nearly circular discs, there appears to be no vacant reentrant angle between the two *a* faces; the crystals come into complete contact, and the two *m* faces, though uneven, often fall into a plane; so that the Herodsfoot crystals must be regarded as presenting a real example of composition perpendicular to the plane of twinning.

Where there is a reentrant angle between the two *a* faces, as in fig. 12, it is generally occupied by a small columnar crystal, either parallel to one of the two larger individuals or twinned on one of them, or it may be itself a compound crystal. The crystals which often range themselves in a long series on the outer sides of the two principal members, nearly parallel to them, have abrupt contact along the uneven face *a*, as shown. The figure also indicates the uneven nature of the face *o*, and the way in which ξ, v, frequently run out from *u* across *o*. A roughly cruciform figure would be produced by the symmetrical repetition of fig. 12 across the dotted line *m*; this is the foundation of the cruciform or circular discs from Herodsfoot, the form being complicated by the grouping of other nearly parallel portions of crystals about these individuals.

Finally then it may be concluded that the twinning of Bournonite is by juxtaposition, and not by interpenetration (*cf.* also Schrauf's figures, which mostly point to the same conclusion); that composition perpendicular to the twin-plane is not rare on Cornish crystals; that the Kapnik Rädelerz is complicated more by parallel repetition than by twinning, the number of individuals rarely exceeding 5; and that figs. 9 and 10 are a more truthful representation of the complicated and cruciform crystals

* "It may be noticed that in the case of Aragonite, with which the twin crystals of Bournonite are often compared, this angle is 52°20′."

than those generally given: it may be added that specimens which have repeated twins with inclined planes do not often show signs of twin lamination or repetition with parallel planes.

Irregular Conjunction.—The paper of Vom Rath quoted above deals with the case of four crystals, which have their *c* faces parallel, but are not twinned; this mode of combination frequently occurs, and complicates the true twins to a large extent; three examples based upon good measurements, and chosen from many observed, are

$$aa_1 = 81°29'\,;\; bb_1 = 82°41'\,;\; bb_1 = 88°12'.$$

Another irregularity which often introduces a fresh difficulty into the Rädelerz is a tendency to twist, which the crystals show both in the compound groups of Kapnik and those of Herodsfoot, so that the individuals form part of a helix about the vertical axis, and their prism faces do not fall into the same zone.

Zones and Faces.—A few notes may be added on the relative development of the principal zones and their faces.

[*amb*]. *a* is generally smooth and bright (except from Liskeard); *b* is very bright, finely striated parallel to the edge *bo*, and sometimes formed of step-like projections running horizontally; *m*, bright, striated vertically, as are also most of the prism faces, especially those between *ma*. Some crystals from Wolfsberg, Kapnik, Mexico, and Liskeard, are columnar, owing to the predominance of this zone.

Some of the crystals from Neudorf, Endellion, &c. have only *amb*, but as a rule those from Endellion show *belma*, while crystals from Herodsfoot Mine are particularly rich in faces between *m* and *a*, Φ being characteristic. On some crystals from Neudorf the zone is not represented.

The faces in this zone are sometimes curiously fretted, and have a worm-eaten appearance; this is due to the recurrence on the prism planes of those faces *osyuρ*, &c. which may be common on the crystals.

[*moun*]. This zone (in which one index is equal to the sum of the other two) is of special importance, owing to the twinning; and the recurrence of twin laminæ causes a striation of the faces parallel to their edges.

o is, after *b*, the brightest and commonest face of Bournonite. It is generally horizontally striated. On Liskeard crystals this face is often either very uneven and dull, or replaced by an uneven concave surface.

u is sometimes bright, sometimes dull; when the *u* faces of two individuals are brought into conjunction by twinning, one is often bright and the other dull.

n, which is one of the commonest faces on the Neudorf crystals, is frequently missing on Cornish specimens, owing to twinning, which brings the zone *cob* into prominence; it is smooth and bright.

The part of the zone represented by *WTX* is only to be observed upon specimens from Kapnik in which bright Rädelerz is dispersed upon crystallised Freieslebenite. As is shown in fig. 6, there is no inducement of these faces on an edge, but they run down as a bright tongue towards the prism zone; they are slightly striated parallel to their edges.

[*cob*]. The faces in this zone are generally horizontally striated; *x* is common, and the edges *ox*, *xc*, are often uneven and replaced by uneven faces.

c is for the most part smooth and bright, and in Kapnik Rädelerz, when smooth, scarcely shows any trace of twin demarcations, except a slight striation parallel to the edge *co*; but on some crystals, especially those from Liskeard, *c* is replaced by an uneven rounded surface tending to form itself into faces towards *x* and *o*. Faces between *b* and *o* are rare, the edge *bo* being sharply defined.

[*osyρ*]. This zone is especially characteristic of the Liskeard crystals (see fig. 11), in which *s* is sometimes dull, while *y* and *ρ* are always very bright.

s is generally quite dull, and especially on Neudorf crystals, where it is a large face.

y, always bright, occurs either as a thin face between *um*, or between *yρ*, or else with nearly rectangular edges on the edge *on*.

[*anκ*]. *N* is usually the only face in this zone between *ao*, and is uniformly smooth; of the others, *κ* is most frequent.

[*uym*]. *uym* are the common faces; the zone sometimes occurs, especially in Cornish crystals, as a series of horizontally striated but bright planes: examples have been given above.

Of other faces *v* (bright) is especially characteristic of Endellion, *ν* (dull) of Liskeard crystals.

Finally, a glance at the projection will show a noteworthy fact about the zones. In the zone [*ac*] the intercepts made on the axes by the common faces are exclusively multiples of 3; in the zone [*bc*] the only common faces are *oxtz*, so that the intercepts are generally multiples of 2; in the prism zone, where the common faces are *eîθwqfiΦd*, they seem to be a combination of both.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Figure of Bournonite from Phillips's Mineralogy.
Fig. 2. Type of crystals from Endellion.
Fig. 3. Type of crystals from Liskeard.
Fig. 4. Twin crystal, combined parallel to twin-plane.
Fig. 5. A crystal from Endellion.
Fig. 6. A crystal from Kapnik.
Fig. 7. A crystal from Neudorf.
Fig. 8. A crystal from Neudorf.
Fig. 9. Type of 3-lings from Kapnik.
Fig. 10. Type of cruciform crystals from Kapnik.

PLATE II.

Fig. 11. A crystal from Liskeard.
Fig. 12. Type of twin crystals from Liskeard.
Fig, 13. Twin crystal, combined perpendicular to twin-plane.
Fig. 14. Scheme of Axes in repeated twin crystals.

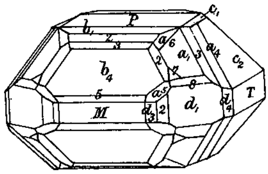


Fig. 1.

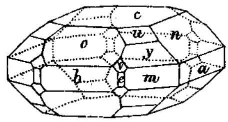


Fig. 2. Endellion.

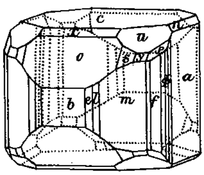


Fig. 3. Liskeard.

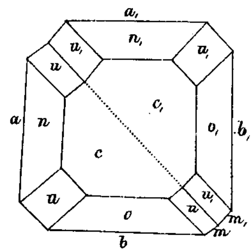


Fig. 4.

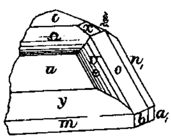


Fig. 5.

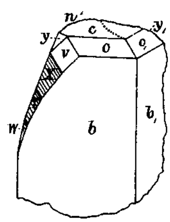


Fig. 6.

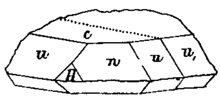


Fig. 7.

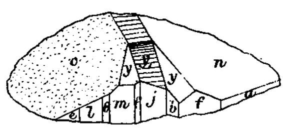


Fig. 8.

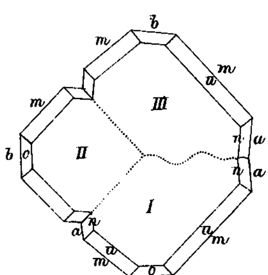


Fig. 9.

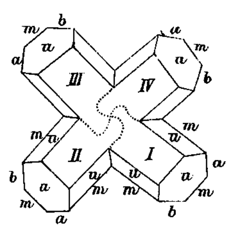


Fig. 10.

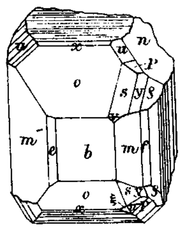


Fig. 11.

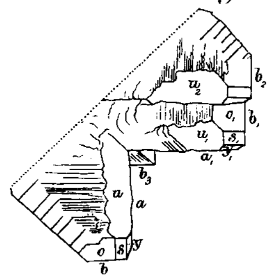


Fig. 12.

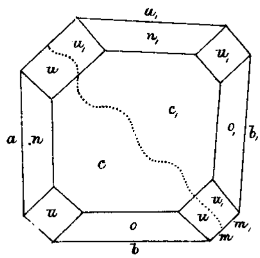


Fig. 13.

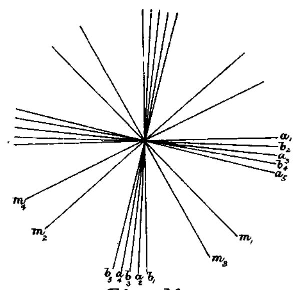
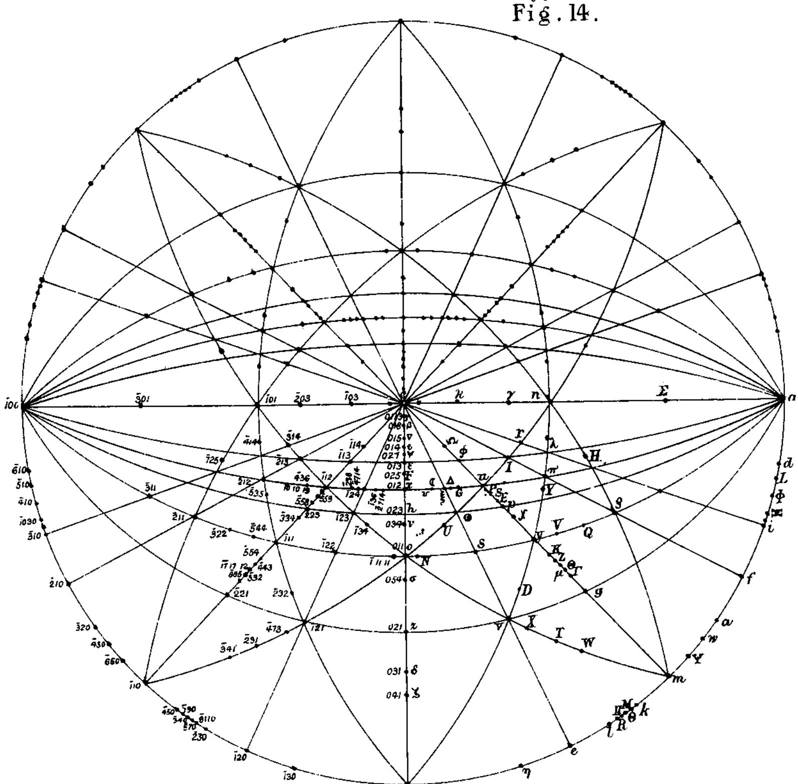


Fig. 14.



Bournonite.

Mintern Bros. lith.