extinction angle with the two curves for the two ends of the crystal would again give two possible compositions, and these two possible compositions would be the same ones that were found in the preceding case.

Conclusion

The confusion caused by the simultaneous use of two conflicting conventions for the sign of the extinction angle can and should be resolved by adherence to the one convention that the sign of the extinction angle is positive if the line generating the angle is turned clockwise from the reference direction to the X'-vibration direction no matter which end of the crystal is being viewed. (It must always be remembered, of course, that under the microscope one actually turns the stage and crystal with respect to the line, the North-South crosshair, which remains stationary. Thus if one first sets the trace of the 010–cleavage to coincide with the North-South crosshair and then rotates the stage counter-clockwise through an angle less than 90° to a position of extinction, and if the vibration direction which then coincides with the North-South crosshair is the X'-vibration direction, the sign of the extinction angle is positive.) This convention leads to simple, straightforward technique and to consistent statements of all the optical relations.

STUDIES OF BORATE MINERALS: 1—*X*-RAY CRYSTALLOGRAPHY OF COLEMANITE[1]

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As part of a general *x*-ray study of borate minerals begun in the U. S. Geological Survey laboratories, the crystal structure of the most common calcium borate, colemanite, is being investigated. This investigation has begun with a redetermination of the space group and of precise lattice constants for colemanite. Powder patterns using Cu and Cr radiation have been measured and indexed.

The crystals of colemanite used came from Meyerhofferite Tunnel in Twenty Mule Team Canyon, Death Valley, Inyo County, Calif.; they were furnished by Waldemar T. Schaller, U. S. Geological Survey. The crystals used are small, colorless, transparent, prismatic elongated along [001], with large (110).

Weissenberg patterns, using Cu radiation, were prepared for the zero and upper levels around [001] and [010]. The systematic extinctions observed, namely that reflections $(0k0)$ with k even only, and $(h0l)$

[1] Publication authorized by the Director, U. S. Geological Survey.

with h even only are present, lead unequivocally to the space group $P2_1/a$.

For the purpose of obtaining precise lattice constants, Weissenberg patterns of small crystals (about 0.2×0.2×0.4 mm.) around [001] and [010] (Cu radiation) with superimposed powder patterns of silver were prepared. The powder pattern of silver (of precisely known lattice constant) on each colemanite film that was measured enabled a precise camera constant to be assigned to that film. The corrected d-spacings thus obtained from the films were then plotted as a function of $\sin^2\theta$ and the extrapolated values determined in the usual fashion (Bradley and Jay, 1932). A full discussion of the use of the conventional Weissenberg camera in measuring lattice constants of single crystals precisely, with colemanite as an example, will be discussed elsewhere (Christ, in preparation).

The single crystal data for colemanite are collected in Table 1.

TABLE 1. SINGLE CRYSTAL DATA: COLEMANITE—$2CaO\cdot 3B_2O_3\cdot 5H_2O$

Space Group—$P2_1/a(C^5_{2h})$	
$a=8.743\pm0.004$ Å	Z=2
$b=11.264\pm0.002$ Å	density (calc.)=2.419
$c=6.102\pm0.003$ Å	density (meas.)=2.42
$\beta=110°7'\pm5'$	V=564.2 Å^3
$a:b:c=0.7762:1:0.5418$	

(Values based on Cu radiation: $\lambda K\alpha_2=1.54434$, $\lambda K\alpha_1=1.54050$, $\lambda K\beta=1.39217$ Å; Ag: a=4.0861 Å)

Two previous x-ray studies have been made on colemanite by Dér (1941) and Nikolsky (1940). Their results are compared with those obtained in the present study in Table 2.

TABLE 2. COMPARISON OF X-RAY RESULTS

	a	b	c	β	Space Group
Present work	8.743	11.264	6.102	110°7′	$P2_1/a$
Dér (1941)	8.63	11.14	6.11	110°9′*	$P2_1/a$
Nikolsky (1940)	8.74	11.31	6.07	110°9′*	$P2/m$

The lattice constants are given in Å units. The values originally given by Dér and Nikolsky are assumed to be in kX units and are recalculated to Å units above.

* Assumed by Dér and Nikolsky from the morphological measurements.

It may be remarked that the Weissenberg patterns prepared in the present study clearly show the extinctions leading to $P2_1/a$, in agree-

TABLE 3. *X*-RAY POWDER DATA: COLEMANITE—$2CaO \cdot 3B_2O_3 \cdot 5H_2O$

Monoclinic $P2_{1/a}$; $a=8.743$, $b=11.264$, $c=6.102$ Å
$\beta=110;7'$, Z=2

Measured*		Measured*		Calculated	
Cu/Ni	λ=1.5418 Å	Cr/V	λ=2.2909 Å		
I	d_{hkl}	I	d_{hkl}	d_{hkl}	hkl
4	6.66		6.69	6.634	110
		wk.	5.74	5.730	001
50	5.64		5.64	5.632	020
18	5.10		5.09	5.107	011
				5.093	$11\bar{1}$
4	4.65		4.65	4.644	120
36	4.00		4.00	4.017	021
				4.010	$12\bar{1}$
50	3.85		3.85	3.857	210
				3.840	111
36	3.29		3.29	3.295	$22\bar{1}$
100	3.13		3.13	3.137	$13\bar{1}$
				3.141	031
36	2.894		2.895	2.898	201
25	2.805		2.806†	2.807	211
				2.795	$31\bar{1}$
25	2.772		2.761	2.770	230
				2.768	$21\bar{2}$
				2.764	131
				2.758	$23\bar{1}$
9	2.660		2.659	2.663	140
				2.659	310
50	2.550		2.546	2.554	022
				2.547	$22\bar{2}$
18	2.392		2.390	2.399	112
				2.387	$31\bar{2}$
18	2.315		2.314	2.318	141
				2.315	$24\bar{1}$
9	2.196		2.207	2.211	330
2	2.176		2.168	2.172	150
36	2.141		2.142	2.145	$41\bar{1}$
18	2.094		2.090	2.097	051
				2.096	$15\bar{1}$
18	2.067		2.070	2.067	$14\bar{2}$
18	2.045		2.043	2.047	$33\bar{2}$
				2.044	321
				2.043	202
50	2.010		2.011	2.015	$34\bar{1}$
				2.010	212
				2.008	042

TABLE 3—(*Continued*)

Measured*		Measured*		Calculated	
Cu/Ni	λ=1.5418 Å	Cr/V	λ=2.2909 Å		
I	d_{hkl}	*I*	d_{hkl}	d_{hkl}	*hkl*
25	1.969		1.969	1.972	151
				1.970	$25\bar{1}$
18	1.892		1.891	1.894	331
		v wk.	1.887	1.889	$43\bar{1}$
3	1.848		1.848	1.851	142
				1.845	$34\bar{2}$
3	1.814		1.809	1.812	$15\bar{2}$
				1.809	023
9	1.778		1.781	1.779	$13\bar{3}$
				1.779	251
				1.777	$23\bar{3}$
9	1.728	Plus additional weak lines			
9	1.701				
3	1.656				
3	1.627				
9	1.569				
2	1.545				
4	1.481				
4	1.453				
4	1.383				
4	1.344				
Plus additional weak lines.					

* Patterns corrected for shrinkage.
† Doublet.

ment with Dér, and in disagreement with Nikolsky. The space group listed in Dana (1951, p. 349) is incorrect.

The morphology of colemanite has been studied by several investigators; the results of these investigations are summarized by Hutchinson (1912). It suffices here to compare the axial ratio and value of the monoclinic angle obtained in the present study with those obtained by Eakle (1902) and by Jackson (1885) from morphological measurements. The values given by other investigators all lie between those given by Eakle and Jackson.

Present study:	$a:b:c=0.7762:1:0.5418$, $\beta=110°7'$
Eakle:	$a:b:c=0.7768:1:0.5430$, $\beta=110°7'$
Jackson:	$a:b:c=0.7748:1:0.5410$, $\beta=110°9'$

The x-ray powder data for colemanite are collected in Table 3.

In regard to the structure of colemanite it is interesting to note that the calculated volume per oxygen atom is 17.6 Å^3. This is about the value to be expected if the structure is essentially determined by the nearly close-packing of oxygen ions with the boron and calcium ions occupying interstices in the oxygen framework. The perfect cleavage of colemanite parallel to (010) indicates that the oxygen ions are linked by boron ions in sheets parallel to (010). Work on the structure is proceeding.

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