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On the temperature of optical uniaxiality in Gypsum.

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Introduction.

IN the account of an investigation of the optical properties of gypsum published by one of us (A. E. H. T.) in 1908[1] it was stated, as the result of direct measurement in sodium-light of the optic axial angle of a section-plate perpendicular to the first median line, which was heated in an air-bath, that the substance became uniaxial at 105·2° C. Three other section-plates examined subsequently gave somewhat higher values, the results ranging from 109·5° to 114·2° C. These figures were arrived at after a considerable correction, amounting to as much as 7°, had been applied for conduction along the crystal-holder, the temperatures actually observed being greater by this amount.

Illumination of the plates with light of various colours established the interesting fact that the temperature of uniaxiality varied for different

[1] A. E. H. Tutton, 'The optical constants of gypsum at different temperatures, and the Mitscherlich experiment.' Proc. Roy. Soc. London, 1908, ser. A, vol. lxxxi, pp. 40–57; also with additions in Zeits. Kryst. Min., 1909, vol. xlvi, p. 135.

parts of the spectrum, and attained a maximum in the case of light of wave-length 578 as shown in the following table, where the temperatures given in column A were obtained in the case of a plate cut by Hilger, those in columns B, C, and D referring to plates supplied by Steeg and Reuter.

Wave-length.	A	B	C	D
671 (Li)	104.5°	108.0°	113.0°	110.0°
656 (H_α = C)	104.7	108.5	113.2	110.3
589 (Na = D)	105.2	109.5	114.2	111.3
578	105.5	110.0	114.5	111.5
535 (Tl)	105.1	109.0	114.0	111.0
486 (H_β = F)	104.5	108.0	113.0	110.0
431 (G)	102.5	106.0	111.0	108.0

It will be noticed, moreover, that the plates become uniaxial at the same temperature for wave-lengths 671 and 486, and this is also very approximately true for wave-lengths 589 and 535.

These results were, however, not in accord with those obtained by observations of the refracted images produced by the prism cut by Hilger for the determination of the α and β indices from the same crystal as the plate. On heating this prism the two images corresponding to the indices α and β approached one another, at 80° C. they were separated by 3′ only, and at 90° they appeared to coincide. Between 90° and 100° no change could be detected, but at 105° one image had passed the other and was separated from it to the extent of 2′. These observations indicate that the temperature at which gypsum becomes uniaxial lies between 90° and 100° C. and is certainly lower than 105°, though the change produced by a rise of temperature of two or three degrees was too small to allow of an accurate determination of the temperature of uniaxiality by this method.

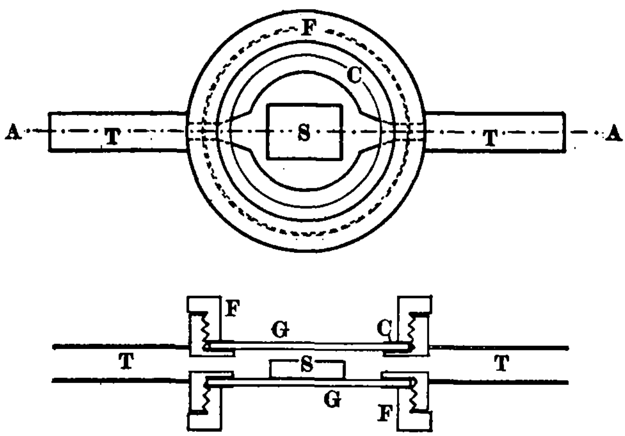
Here the matter rested till in July, 1911, Professor R. Brauns[1] pointed out that it is easy to demonstrate that gypsum becomes optically uniaxial at a temperature well short of 100° C. by simply warming a section on a water-bath and rapidly transferring it for observation to the stage of a polarizing microscope. This simple experiment proved conclusively that the figures published in 1908 were considerably too high, and it became a point of some interest to find as accurately as possible the

[1] R. Brauns, 'Die Aenderung des optischen Achsenwinkels in Gips bei höherer Temperatur.' Centralblatt Min., 1911, pp. 401-405.

temperature at which uniaxiality really occurs. Some experiments with this object were therefore undertaken by one of us (A. H.), and in a verbal communication made to the Mineralogical Society in November, 1911,[1] a temperature of 95° C. was mentioned as an approximate upper limit of the phenomenon. Subsequently some improvements were made in the apparatus, and the final result at which we have arrived is, that for sodium-light gypsum becomes uniaxial at 90·9° C.

Experimental Methods.

As the errors in the results obtained in 1908 appear to be due to the type of air-bath employed, which afforded no security that the temperature of the crystal-section was really that recorded by the thermometers, it was decided to attempt to eliminate this source of uncertainty by



FIGS. 1 and 2.—Hot-water cell for heating gypsum plate on stage of microscope.

immersing the section-plate in a liquid. A small shallow circular brass cell, provided with a glass top and bottom, was therefore constructed and fitted with two brass tubes, one on each side, to act as inlet and outlet for a stream of water saturated with calcium sulphate and heated to any required temperature below 100°, which was conducted through the cell during the observations. The temperature of this water stream was taken immediately before entering and directly after leaving the cell by two thermometers graduated to $\frac{1}{5}$° C. The thermometers were enclosed in the glass tubes by which the hot solution was conducted to

[1] Mineralogical Magazine, vol. xvi, p. xxx; vide Nature, 1911, vol. lxxxviii, p. 105, where owing to a misprint the temperature is given as 25°.

and from the cell, and were therefore wholly immersed in the hot liquid. They were compared with the standards at the National Physical Laboratory, and the corrections found necessary duly applied.

The construction of the cell is indicated in the accompanying diagrams, fig. 1 being a plan, and fig. 2 a vertical section through the line *AA*, both full size. The top and bottom of the cell are formed by the glass plates *G*, which are held in position by the screw flanges *F*. Rings of thin cardboard below the glass keep the cell water-tight, and thin brass washers *C* protect the glass plates from the direct action of the screws. The hot liquid enters and leaves the cell by the tubes *TT*, to which horizontal glass tubes about 1 cm. in internal diameter are connected. These contain the thermometers, which are arranged with their bulbs as near the cell as possible. The section-plate of gypsum perpendicular to the first median line, seen at *S*, is held in position by a small spring (not shown) formed by a coil of thin brass wire.

The cell was adjusted on the stage of the polarizing microscope, and was insulated from the stage of the microscope and protected from radiation by suitable coatings of cardboard and cotton-wool. The tubes containing the thermometers were also protected for the greater part of their length. On allowing the hot calcium sulphate solution, kept stirred in a large copper tank, to run through the cell it was found that the temperature of uniaxiality, as measured by the thermometers immersed in the stream, could easily be kept steady for a time sufficiently prolonged for the changes produced by alteration of the wave-length of the illuminating light to be accurately studied. Occasionally the temperatures indicated by the two thermometers were the same, but usually that first reached by the stream read a little higher than the other. The difference did not, however, generally exceed $\frac{1}{2}°$, and the mean value of the two readings was taken as giving the actual temperature of the section-plate in the cell.

This mode of experimenting possesses some disadvantages, one being the ultimate corrosion of the plate, but in its favour it may be urged that it is hard to conceive that the temperature of the plate can exceed that registered by the first thermometer or be lower than that recorded by the second, and moreover, as the thermometers are wholly immersed, no corrections of uncertain magnitude for the exposed portion of the stem are necessary.[1] As a matter of fact the results obtained on different days and with two different section-plates proved to be very concordant.

[1] If only the bulb and a small portion of the stem were immersed this correction would probably lie between 0·5 and 1·0° C.

The kind of accuracy attained can be estimated from the following series of successive observations of the point of uniaxiality in sodium-light:

Thermometer	I,	90·6°	90·8°	90·6°	90·7°	90·6°	90·5°	90·4° C.
„	II,	90·0	90·3	90·3	90·2	90·1	90·0	90·0 C.

The mean result deduced from these observations is 90·36° C. On introducing the fixed-point corrections which have to be applied to the thermometers we arrive at the temperature 90·9°, the value we consider to be nearest the truth for sodium-light. Four sets of confirmatory observations made on different days, the first with the same section-plate as above, and the other three with a different one, gave the corrected values 90·8°, 90·4°, 90·9°, and 91·0° respectively.

The effect of altering the wave-length of the light employed was also studied, with the result that so far as their relative values are concerned the observations made in 1908 are fully confirmed. Thus it was found that when the temperature of uniaxiality had been reached for red, the crystal was also uniaxial for green, but still distinctly biaxial for intermediate colours. When, however, at a slightly higher temperature it became uniaxial for sodium-light it was noticed that the axes for red and blue had distinctly separated in a plane at right angles to that which they at first occupied. The corrected temperatures actually determined are as follows: in lithium-light, wave-length 671, the crystal becomes uniaxial at 90·2° C. In F-light, green, wave-length 486, at 90·1°, while the maximum temperature observed, 91·0°, corresponds to light of wave-length 570–575. The relations of these values for the different wave-lengths are so close to those shown in the table published in 1908 that the following undoubtedly represents a very close approximation to the truth:

Temperature of optical uniaxiality of gypsum for different wave-lengths.

Wave-length.	Temperature.
671 (Li)	90·2° C.
656 (H_α = C)	90·4
589 (Na = D)	90·9
573	91·0
535 (Tl)	90·8
486 (H_β = F)	90·1

In view of these results it was thought advisable to repeat the measurements of the indices of refraction by the prism method made in 1908, and more especially to study anew the effect of gradually raising the temperature of the prism giving α and β. In the first place, the published values of α, β, and γ at 12° C. were absolutely confirmed. Secondly, it was found that on slowly heating the prism giving α and β the two images of the collimator-slit gradually approached one another. Using sodium-light their separate existence could still be detected at 89° C., but at 91° they coalesced completely. When, however, the temperature had risen to 93° two independent images could once more be recognized. The results obtained in 1908 as well as those just described are therefore amply confirmed. It was, moreover, thought desirable to make a complete set of refractive index determinations at a temperature a little lower than the highest previously employed, and in the table below the values observed at 98° are given, those already determined at 12° and at 105° being quoted for the sake of comparison.

Wave-length.	Index α.			Index β.			Index γ.		
	12°	98°	105°	12°	98°	105°	12°	98°	105° C.
Li	1·5178	1·5162	1·5154	1·5201	1·5166	1·5158	1·5270	1·5247	1·5243
C	1·5184	1·5168	1·5160	1·5207	1·5172	1·5164	1·5276	1·5253	1·5249
Na	1·5207	1·5193	1·5184	1·5230	1·5196	1·5188	1·5299	1·5277	1·5274
573	1·5218	1·5199	1·5190	1·5237	1·5201	1·5194	1·5307	1·5284	1·5280
Tl	1·5231	1·5219	1·5209	1·5255	1·5222	1·5213	1·5325	1·5304	1·5300
F	1·5262	1·5248	1·5239	1·5285	1·5252	1·5243	1·5355	1·5332	1·5330
G	1·5303	1·5294	1·5285	1·5328	1·5299	1·5289	1·5400	1·5379	1·5377

The α and β indices interchange vibration-directions at about 91° C.; the vibration-direction for γ remains for all temperatures that of the first median line lying in the symmetry-plane. A comparison of the values of α and β determined at 98° C. shows that the minimum difference, 0·0002, is attained for light of wave-length 573, while equal differences, 0·0003, are observed in the case of sodium- and thallium-light, and still greater, but also equal differences, 0·0004, are found for lithium- and for F-light.

Conclusions.

The results we have obtained lead us to conclude:

1. That gypsum becomes optically uniaxial in sodium-light at 90·9° C. The point of uniaxiality is reached at the slightly lower temperatures of 90·2° for lithium-light and 90·1° for F-light, while a slightly higher temperature 91·0°, the maximum, is required to produce the uniaxial figure when the crystal-section is examined in light of wave-length 573.

2. That the temperature determinations made in 1908, although considerably too high, are relatively correct among themselves.

3. That the refractive index determinations already published are quite accurate, and both these and the additional values now given agree completely with the conclusions stated in 1 and 2 above.

Since a notice of this work first appeared in 'Nature', Professor E. H. Kraus, of the University of Michigan, has very courteously informed us by letter that he has been occupied with the same problem, and has determined the temperature of uniaxiality in sodium-light as 89·67° C. in the case of a section-plate heated in an oil-bath, while for a section heated in an air-bath the somewhat higher value 91·6° C. was obtained.[1] It is interesting to notice that the temperature was originally given by Mitscherlich as about 73·5° R., which corresponds to 91·9° C.

[1] This work has since been published in detail: E. H. Kraus and L. J. Youngs, 'Über die Änderungen des optischen Achsenwinkels in Gips mit der Temperatur.' Neues Jahrbuch Min., 1912, vol. i, pp. 123–146. It does not appear from the description what correction, if any, was applied for the exposed portions of the stems of the long thermometers employed; and in reply to an inquiry, Professor Kraus has very courteously informed us that, as a matter of fact, no such correction was applied. He believes, however, that under the conditions of the experiments this correction could not in any case have exceeded 0·7° C.