Notes on the optical characters of the Globules and Spherulites of Lithium Phosphate and some other salts.

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(With Plate V.)

[Read April 18th, 1893.]

IN my paper "On the Micro-chemical Analysis of Rock Making Minerals,"[1] I noticed the abnormal behaviour of globules of lithium phosphate $Li_3PO_4 + H_2O$ in polarised light; the dark cross which ought to remain fixed when the globule is revolved between crossed nicols, opening up, in some cases, into two hyperbolic branches like those of a biaxial crystal in converging polarised light. I find that similar anomalous results may be obtained from the globules yielded by other salts; as for example those of the double sulphates of beryllium and potassium ($BeSO_4K_2SO_4 + 2H_2O$), and of lithium and sodium ($LiNaSO_4$).

Some substances, as for instance granules of starch, present a dark cross when examined under the microscope between crossed nicols, which is explained by the action of the onion-like skins of which the grains are built up upon the rays of light transmitted through them, but this explanation does not apply to the globules under consideration, as there is no reason to suppose that they possess this structure, and if they did it would not explain the opening up of the cross.

Secondly. The peculiarity under discussion does not depend on twinning, to which cause I was at first disposed to attribute it. The opening out of the dark cross appears in some individuals which do not exhibit any trace of twinning; and even in those which seem to be twinned, the opening out of the cross does not bear any fixed relation to the plane of twinning.

Thirdly. It does not appear to be connected with the growth of a globule from two or more different centres. If these centres were so close together that the eye, even aided by the microscope, could not

[1] *Min. Mag.*, Vol X. p. 79.

divide them, the globule would behave as a single individual, and, for all practical purposes, it would have to be regarded as having originated from a single centre. In cases in which the two centres of growth are sufficiently wide apart for the eye to take cognisance of the distance between them, one can readily see that the globule is compounded of two individuals joined together. For instance, in fig. 1, Plate V., a globule is depicted which has originated from two centres near each other. Both halves are normal. A thin line of light interposes between the two halves, and the perpendicular arm of the cross is seen to be twice its normal thickness. We have here two crosses (not a single one) the perpendicular arms of which are parallel to each other. At fig. 2 we have a compound globule made up of two individuals whose centres of growth are somewhat distant from each other. In this case one half is normal (nearly showing a *fixed* cross) and the other is abnormal; that is to say, the cross opens up, when revolved between crossed nicols, into hyperbolic branches. At fig. 3 a compound globule is shown, both halves of which are abnormal. Figs. 1 to 3 (and such instances are numerous) sufficiently show that the phenomenon of the opening out of the cross into hyperbolic branches does not depend on the linking of two globules together. Many globules that exhibit the opening out of the cross are single, and not compound globules, whilst strings of linked globules may be seen in which every member is normal. An instance is shown in the upper part of fig. 12.

Fourthly. The phenomenon is not due to the overlapping of one disk upon another. The effects due to overlapping are illustrated in figs. 4 and 5. We have distortion, but not of the character seen in abnormal globules. In fig. 4 two normal disks have overlapped. In fig. 5 we have one normal and one abnormal disk overlapping.

Fifthly. I have come to the conclusion that the phenomenon above described is really due to molecular strains at the time of crystallisation.

Spherulites are, it is well known, made up of fibrous crystals radiating from a centre. In cases in which each individual crystal has straight extinction a cross is formed, each arm of which corresponds to the plane of one of the crossed nicols, and the cross remains fixed when the spherulite is revolved. In many cases this structure is doubtless present in the globules under consideration, and to it is due, in such cases, the fixed black cross when the globule is revolved between crossed nicols. Sometimes this radiating fibrous structure can be actually made out in the globules by the use of high powers, and they fall within the definition of a spherulite; at other times this structure cannot be seen, and its presence, or the presence of an analogous structure to be presently described, must be inferred from the appearance of the black cross between crossed nicols.

In the spherulite each radiating crystal has length without width; that is to say, the width is inconsiderable as compared with its length. The want of width in each individual is made up for by the number of the individuals. But this arrangement does not always prevail in the rounded crystal aggregates under description. In such a crystal aggregate it is not necessary that each radiating crystal should be a fibre—that it should be without sensible width. Individual crystals may be increased in the direction of their width, and they may be comparatively few in number. A spherulite made up of a set of crystals in the form shown in fig. 6, would show a fixed dark cross if each crystal extinguished parallel and at right angles to a line radiating from the centre of the spherulite that divided the crystal into two halves.

Fig. 11 is a sketch of a spherulite of lithium phosphate under crossed nicols. It is made up of radiating crystals that possess considerable width at the circumference of the spherulite; and on being revolved the cross opens up as shown at fig. 11; that is to say, with the exception of a thin dark line in the centre, the cross opens out very much as in the case of the abnormal spherulites. On a single slide I have numerous other instances almost precisely similar in character, and I think the explanation they suggest is that the opening up of the cross is due to strain. The strained crystals are not absolutely uniform throughout, as far as their optical characters go, and when revolved between crossed nicols the lines of extinction are wavy and irregular and remind the observer forcibly of the well known phenomena of "strain shadows."

That the abnormal appearances discussed above are due to strains at the time of crystallisation may, I think, be seen on an examination of many of the compound rounded crystals of lithium phosphate. In figs. 9, 10, and 12, I have sketched a few illustrations. Rounded compound crystals of a salt, having, presumably, the same chemical composition as lithium phosphate, have grouped themselves round small normal globules of that salt. The small endogenous globules are rarely in the centre of the larger spherulites that surround them, and this, or some other cause not apparent, has set up a condition of strain, the consequence of which is that the cross seen between crossed nicols is very irregular, as represented in the illustrations (figs. 9, 10, and 12). Again in the elongated or oval globules of the double sulphate of beryllium and potassium ($BeSO_4K_2SO_4 + 2H_2O$) the cross opens up (fig. 13) in a way that has a definite and fixed relation to the direction of elongation, and appears to point to a condition of strain. Here the molecular tension that caused the strain was presumably connected with the elongated shape of the globules. Nearly all the elongated globules open up the dark cross, and those that exhibit this phenomenon invariably open up into two hyperbolic branches approximately parallel to the longer axis of the crystal, as shown in fig. 13. Sometimes the lozenge shaped globules are united in the form of a star (embryonic rhombs), as shown in fig. 14. This star gives a dark cross between crossed nicols, each arm of which runs down the centre of each lozenge. On the star being revolved 45° the cross opens out and disappears.

In the spherulites yielded by lithium sodium sulphate ($LiNaSO_4$) different conditions prevail. Some of these spherulites, when examined under crossed nicols, are seen to be compounded of two portions with optical and structural differences between them. One portion, which does not possess a fibrous structure, shows an inner bright cross (*a*, *b*, *c*, *d*, fig. 15) when the planes of the crossed nicols are at 45° to the arms of the cross, as shown in the illustration. (N^1N^1 and N^2N^2 represent the crossed nicols.) Now if a quartz wedge be inserted parallel to (*c*, *d*) the phenomenon of thinning will be *simultaneously* produced in all four arms of the cross, showing that the doubly refracting cross (*a*, *b*, *c*, *d*) is not produced by two crystals (*a*, *b*) and (*c*, *d*) crossing each other; or by four crystals, possessing straight extinction, radiating from a common centre. If either of these two cases represented the structure of the cross the quartz wedge, when introduced parallel to (*c*, *d*), would produce the phenomenon of thinning in two of the arms of the cross (such as (*a*) and (*b*) for example), and the phenomenon of thickening in the other two arms (as (*c*) and (*d*) for example). The four arms of the cross (*a*, *b*, *c*, *d*), therefore, belong to one and the same crystal face, and the extension of this face over the whole area of the spherulite has been prevented by the interposition of *fibrous* crystals at *e*, *f*, *g*, *h*, that follow the ordinary spherulitic structure; that is to say, they radiate from the centre and show the phenomenon of thinning with the quartz wedge either parallel to, or at right angles to, the fibres, and not simultaneously in both directions.

In the case represented by the illustration, fig. 15, the face (probably the basal face) which forms the cross *a*, *b*, *c*, *d*, is elongated in two directions at right angles to each other; but there seems no reason why the elongation should not sometimes be in one direction only and at other times in more than two directions; or why those elongations of the basal face should not take place in azimuths other than those in which the elongation has taken place in the case depicted at fig. 15. Further, there seems no reason why the radiating fibrous crystals, which in fig. 15 are represented as interposing at *e*, *f*, *g*, and *h*, should not accommodate themselves to the developments, or elongations, of the basal plane, and interpose sometimes at one azimuth, and sometimes at another; or why they should not be unduly represented on some occasions and scarcely represented at all on other occasions. Illustrations of all these variations may be seen in some or other of these spherulites. For instance, lithium sodium sulphate ($LiNaSO_4$) belongs to the hexagonal system, but the spherulites of this salt exhibit what is at first sight a very puzzling appearance. Between crossed nicols some are all dark; some exhibit a regular black cross with four arms; some show five, six, or more than six arms. In some instances the arms radiate in a north, south, east, and west directions; in others they radiate irregularly at different azimuths. At the first blush the observer might easily fancy that he was dealing with the intergrowths of a monoclinic and of a hexagonal mineral. The true explanation, I think, is that offered above; namely, that we have somewhat irregular elongations of the basal face at various azimuths intercepted by radiating fibrous crystals lying on one of the pinacoidal faces: that, in short, the combinations presented are a form of twinning.
