PHILOSOPHICAL

TRANSACTIONS.

I. *Additional observations on the optical properties and structure of heated glass and unannealed glass drops. By* David Brewster, *LL. D. F. R. S. Edin. and F. S. A. Edin. In a Letter addressed to the Right Hon. Sir* Joseph Banks, *Bart. K. B. P. R. S.*

Read November 10, 1814.

DEAR SIR,

Edinburgh, April 8, 1814.

IN a former paper on the optical properties of heated glass and unannealed glass drops, I have briefly described the leading phenomena which they exhibit in their action upon polarised light. These experiments I have frequently repeated with the same results, and I have the satisfaction also of stating, that as soon as they were known in France, they were repeated and verified by M. BIOT of the National Institute, to whose active genius this branch of optics owes great obligations.

Having ascertained that glass melted and suddenly cooled, possessed all the optical properties of crystallized bodies, I was anxious to determine if it exhibited any other marks of a crystalline structure. Upon examining the bulb of an unannealed drop AB, Pl. I., fig. 1, by holding it between the eye and a sheet of white paper, I observed a number of lines converging to the vertex *a*, as represented in fig. 2. This structure was more or less apparent in every bulb which I examined, but never appeared in annealed drops. It exhibited itself even on the surface, and seemed to be owing to an imperfect crystalline form, yet it was not marked with sufficient distinctness to entitle me to consider it as the effect of crystallization. In one specimen, however, where the bulb AB remained unshattered, while all the rest of the drop was burst in pieces, the lines diverging from *a* were most distinctly marked, and the bulb was actually cleft in the direction of these lines, so as to produce a real dislocation at the *surface* of the drop. We may therefore consider the drop as possessing that crystalline structure which gives cleavages in the direction of lines diverging from its apex. By examining the fragments of the drop after it is burst, another cleavage is distinctly perceptible: it is parallel to the outer surface, and produces a concentric structure like that of an onion. This cleavage also shows itself in the splinters which are detached from the surface of the drop when it is ground upon freestone. A third cleavage is visible in the direction of lines inclined to the axis of the drop, as represented in fig. 3; but it is not so distinct as the two first.

As it appeared probable that the glass drops possessed a less degree of density than if they had been annealed, I attempted to ascertain this point by measuring their specific gravities in these two different states. The unannealed drops, however, had always one or more vacuities, such as E, F, fig. 1, so that I was able to obtain only approximate results by estimating the magnitude of these cavities.

The following specific gravities were measured by my friend Mr. JARDINE, with his usual correctness.

Unannealed flint glass drop, fig. 1,	-	3.20405
Annealed flint glass from the same pot		3.2763

In order to correct the first of these measures, I moulded a piece of bees' wax into the size and form of the cavities E, F, fig. 1, by examining them under a fluid of the same refractive power as the glass. I then formed the two pieces of wax into a sphere, and thus ascertained, with tolerable accuracy, the weight of a quantity of water of the same magnitude as the cavities. By this means I obtained the following measure,

Corrected specific gravity of the unannealed drop 3.264, a result differing so little from that of the annealed glass, that we may consider them as having nearly the same density.

With the view of obtaining some farther insight into the structure of the crystallized drop, I brought the one, represented in fig. 1, nearly to a red heat. Its shape suffered no change at this temperature, and the vacuities E, F, still remained; but it had now lost the faculty of depolarisation, and the particles had therefore assumed a new arrangement. By increasing the temperature, the cavities E, F, disappeared: the lower side of the drop, upon which it rested, was indented by the bottom of the crucible; but it had in no other respect lost its external shape, the appearance of the cleavage in fig. 2 remaining unaltered. In this state Mr. JARDINE measured the specific gravity of the drop, and found it to be 3.278, which is almost exactly the same as that of the annealed drop.

In order to observe the manner in which the cavities disappeared, I suspended one of the drops by a wire, and viewed it with a telescopic microscope when exposed to a strong heat. Soon after the drop became red hot, the cavities gradually contracted, and at last vanished, the centre of the cavity being the part that was last filled up. The drop had begun to melt at its smaller extremity, but the lines represented in fig. 2 were still visible, the heat probably not having been sufficiently intense to affect its superficial structure.

As the specific gravity of the crystallized drop is nearly the same as that of the annealed drop, the cavities must be produced by the contraction which the internal part experiences in cooling, for the sudden induration of the outer layer prevents the contraction from taking place in any other way. The manner, too, in which the cavities disappear, is a complete proof that they contain no air, and hence we may consider their magnitude, which increases with the size of the drop, as a measure of the contraction which the glass undergoes in its transition from the temperature at which it melts, to the ordinary temperature of the atmosphere.*

I am informed by Dr. HOPE, that he has frequently obtained unannealed drops of crown glass, in which there were no vacuities, and that they all burst spontaneously in the course of a few months. As there is at present no crown glass manufactory in this part of Scotland, I have not been able to make any experiments with drops of this kind; but there is every reason to believe that they would exhibit the same optical properties, as those which are formed of flint

* Upon this supposition, the contraction of glass in bulk, in passing from the first of these states to the second, will be $\frac{1}{45.3}$ or 0.02205.

and bottle glass; and that the contraction of the internal parts, in consequence of which the vacuities are produced, is not necessary to that arrangement of particles upon which these properties depend. In the flint glass drops, such as ABC, fig. 1, there is sometimes only one vacuity, in the thick part at E, and as the slender extremity C is perfectly cold before the vacuity E is formed, and when the glass round E is red hot, it is obvious that the part C has suffered no contraction, and is in the same state as the crown glass drops obtained by Dr. Hope. But the extremity C has a more perfect structure than the bulb AB, as it possesses distinct neutral axes: hence we may infer that the crown glass drops, without vacuities, will exhibit neutral axes in every part of their length; that their structure is more uniform than that of flint and bottle glass drops; and that the difference between the specific gravity of the drop, and that of the annealed crown glass from which it is made, will afford a correct measure of the contraction which the glass experiences, in passing, by a gentle gradation of temperature, from the fluid to the solid state.*

* When a piece of red hot steel is plunged in cold water, it experiences a diminution of density analogous to that which takes place in drops of melted crown glass. Mr. R. Pennington found that a piece of steel, which, when soft, measured 2.769 inches had expanded to 2.7785 inches, after being hardened by immersion, when red hot, into cold water. Mr. Cavallo gives the following measures, without mentioning by whom the experiment was made.

Specific gravity of soft steel hammered - -	7.840
——————— of soft steel hammered, and hardened in water	7.818.

In all these cases the particles are held in a state of unnatural constraint by the sudden induration of the external coat; and therefore it is probable, that neither the glass nor the steel will expand by any moderate accession of temperature. If this conjecture be well founded, it will enable us to supply one of the greatest desiderata in the arts, a *pendulum of invariable length*.

The contraction of the flint glass drops, as computed from the magnitude of the cavities, must always err in defect; but the maximum result obtained from a considerable number of drops may be regarded as a tolerably correct measure of the diminution of density.* For this purpose, those drops should be employed in which the cavities are numerous, and scattered over every part of their length. The largest drops have generally this character, and I have one of these in my possession, in which there are no fewer than *seven* cavities.

A considerable degree of difficulty is experienced in procuring unannealed drops of flint glass. Owing, I presume, to the softness of this kind of glass, the greater number of the drops burst as soon as they are cooled, and from some pots of glass I have been able to procure only four drops out of twenty-four that were plunged into the water. One of these burst in my hand some hours after it was made, without any part of the tail having been previously broken, and another burst on the following day when lying on the table exposed to no change of temperature. The best method of obtaining the drops entire, is to watch the moment when the red heat disappears in the centre of the bulb, and to remove it instantly from the water.

As the minutest fragments of all crystallized bodies have the same action upon light, as the crystals of which they formed a part, I expected a similar property in the fragments

* The specific gravity of the unannealed drop, as corrected in page 3, from an estimate of the size of the cavities, approaches very near to that of the annealed drop. The difference is only 0.012, and would have been considerably less had the cavities been more numerous.

of the shattered drops. One of these, which was about the sixtieth of an inch thick, did not possess the property of depolarisation, and with more than twelve fragments of different thicknesses, below the thirtieth of an inch, I obtained a similar result. A fragment, however, of a crown glass tear, which had burst after being dropped into the water, and which was about two-tenths of an inch thick, depolarised light in every position, but did not exhibit any coloured rings by polarised light.

I have not been able to make a complete series of experiments on the effects of heat upon crystallized bodies, but it will appear from the following experiment that they are not likely to conduct us to new results. I heated to a great degree a fine crystal of spinelle ruby, which has not the property of double refraction, but it did not produce the least change upon a polarised ray. The crystal was $\frac{1}{28}$ of an inch thick; and a piece of crown glass of the same thickness, and brought to the same temperature, depolarised a considerable portion of light.

The effects of heat, as indicated by the preceding experiments, are, perhaps, too imperfectly developed to authorise us to draw those important conclusions, to which they seem so well calculated to conduct us. One of these, however, is so palpable, and so clearly deducible from the phenomena, that it must already have suggested itself, namely, the production of a *new species of crystallization* by the agency of heat alone. When light is transmitted perpendicularly through a plate of glass, the glass exercises no more action upon it, than if it were a mass of water. When the glass, however, is heated, the particles not only expand, but assume a new arrangement, till at a certain temperature the crystallization is complete. As the temperature diminishes, the particles approach one another, and gradually recover their former arrangement. The crystallization which is thus produced in drops of melted glass, is rendered permanent by the sudden immersion of the drop in water, which arrests the particles in that particular position that constitutes the crystalline state of the body. Hence it follows that the particles of glass, when separated to a certain distance by the expansive energy of heat, assume a crystalline arrangement; and, unless they are fixed in this state, by a sudden diminution of temperature, the crystallization is gradually destroyed by the approximation of the particles which takes place during the operation of slow cooling.

During my experiments on depolarisation, which I shall soon have the honour of submitting to your notice, I discovered another species of crystallization, which is the effect of time alone, and which is produced by the slow action of corpuscular forces. This kind of crystallization appears, in general, to accompany the consolidation of many vegetable and animal products, and will probably be found to have had an extensive influence in those vast arrangements which must have attended the formation of our globe.

I have the honour to be,

Dear Sir,

your most obedient humble servant,

DAVID BREWSTER.

To the Right Hon. Sir Joseph Banks, Bart. K. B. P. R.S.

Fig. 1.

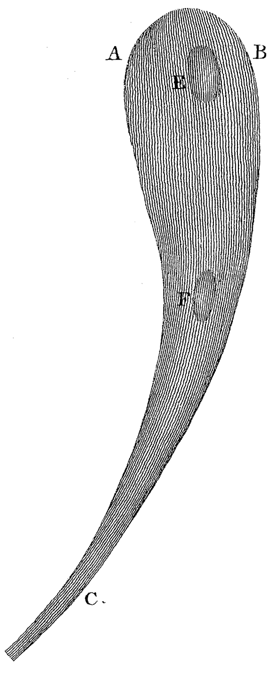

Fig. 2.

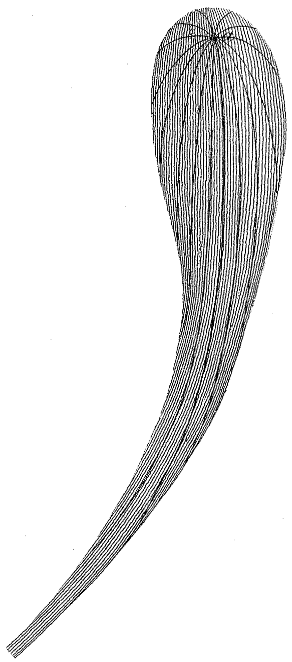

Fig. 3.