ON THE PLASTICITY OF GLACIER AND OTHER ICE.[1]

THE nature of the motion of glaciers has been the subject of an immense number of observations by Forbes, Agassiz, Schlagintweit, Tyndall, &c., and the following facts amongst others have been established.[2] (1) The velocity decreases gradually and continuously from the centre to the sides, where it is sometimes almost imperceptible, though in other cases it reaches one-third of its value at the centre. (2) The motion is in general continuous from day to day, and even from hour to hour. (3) The motion is generally most rapid at the hottest time of the year, and slowest at the coldest, the ratio being often 4 to 1. But the effect of temperature is at present by no means properly worked out.

One main result of these observations may be summed up in the statement that a glacier moves like a plastic body. The most natural conclusion would be that ice is plastic. But this conclusion was for a long time almost universally rejected. Hand specimens of ice show no sign of plasticity to casual observation, and no doubt few people realized what very slow yielding under stress would account for the observed motion. So the rigidity of ice was treated as an obvious fact. At any rate I have not come across any mention of careful experiments which failed to show plasticity within a few degrees of the melting-point. As will be seen below, however, such results might readily have been obtained on suitable ice.

True plasticity, then, being rejected, some other explanation had to be found. The one generally adopted is due to James Thomson. He proved theoretically that the freezing-point of water is lowered by pressure at the rate of 0°·0075 C. per atmosphere. This was afterwards verified experimentally by Sir Wm. Thomson. The former held further that any kind of stress lowers the freezing-point. Now glaciers are believed to be throughout at or very near the temperature 0° C. Thus the ice should melt at places where the stress is most severe, and an equal quantity should be formed elsewhere. There are at least two difficulties in this explanation. In the first place, the melting must absorb heat, and the work done by pressure in the contraction of volume is quite an insignificant source of heat. So the temperature would be immediately lowered, and the process be brought to a standstill, before it had well commenced, unless heat were supplied by conduction. When we remember that, even when the stress is most severe, the melting-point is only lowered a few hundredths of a degree, and that there must be considerable distances between points of great stress when the ice melts, and points of little stress when it forms, it is difficult to believe that sufficient heat can be conveyed from one to the other to produce much effect. Some rough experiments I have made show ice to be a far worse conductor than any rock, and nearly as bad as wood. In the second place, it has yet to be proved that the mass of the glacier is permeated by water. Recent experiments by Prof. Forel (*Arch. des Sciences Phys.*, Geneva, July 1887) go far to show that the capillary fissures containing water are confined to the surface layer.

But the point which I especially desire to bring out is that this explanation is confessedly only a way out of a dilemma. If glacier ice can be shown in the laboratory to be plastic, the dilemma no longer exists, and there is no necessity to have recourse to any other explanation until it can be proved that the plasticity is insufficient, or otherwise fails to account for the observed facts. The existence of this plasticity in glacier ice we claim to have established in our experiments last winter.

The false plasticity due to melting and regelation is put out of the question by operating at a temperature below even − 0°·1 C., for to lower the melting-point by a tenth of a degree requires a pressure of thirteen atmospheres. If true plasticity is found at lower temperatures, it is impossible to deny its existence at the melting-point itself. And plasticity has been found several degrees below 0° C. by many experimenters, such as Matthews, Bianconi, Aitken, Pfaff, &c.[1] Most of their experiments were made on the bending of bars, in which case the stress is too complicated to furnish any but the vaguest idea of the relation between strain and stress. Further, none of them dealt with glacier ice, for I do not include the experiments of Coutts Trotter, made at 0° C.

Matters were in this state when Dr. Main began his experiments at St. Moritz the winter before last (Roy. Soc. Proc., vol. xlii. p. 329). A winter sojourn in the Engadine affords peculiar facilities for experiments of this nature. During December, January, and February, one can count on almost continuous frost. In a room on the north side of the house, with the window kept permanently open, the temperature seldom rises above the freezing-point. Dr. Main wished not merely to settle the question of the existence of plasticity, but also to determine accurately its amount under various conditions of stress and temperature. He decided to apply tension. This has great advantages over other kinds of stress for purposes of accurate measurement, as it is comparatively easy to isolate from other stresses. Pressure, for instance, applied to the ends of a bar of ice makes it bend, and we have then a complicated set of stresses to deal with. And if the bar be so short and thick that bending is improbable, the contraction to be measured becomes very small. There are, however, certain obvious inconveniences in applying tension, viz. the difficulty of getting a good grip of the ends of the bar of ice, and the constant risk of fracture.

Main used a mould for his ice, which turned out a round bar with a conical enlargement at one end, which would fit into a conical iron collar. A conical piece of ice fitting another collar was frozen to the other end of the bar of ice, and the tension was applied through the two collars. Accurate measurements of the distance between the collars were taken from time to time. In this way he established the existence of plasticity in this kind of ice at all temperatures down to − 6° C. It is to be noticed that the ice cones are subjected to both pressure and shearing stress, and some of the observed extension must have been due to the distortion of these cones; but that nearly all of it was due to pure tension in the bar he found by measuring the distance between marks on pieces of paper gummed on to the bar itself. In this last way he found the bar extended during three days at the rate of 0·02 mm. per hour per length of 10 cm., while the temperature remained below − 2°.

As his health prevented him from spending last winter at St. Moritz, he suggested that I should continue the experiments, kindly putting all his apparatus at my disposal. I should not have been able to carry out such an undertaking had I not been fortunate enough to secure the assistance of an able coadjutor in Mr. Kidd, on whom fell by far the greater part of the labour of experiment. We started, like, I believe, all investigators before us, under the impression that one piece of clear ice would do as well as another, no matter how it had been formed. Thus it was merely owing to the difficulty of obtaining clear ice in the mould that we took our first experimental bar from a different source. We imagined that since Main had established the fact of extension under tension, all that was left was to determine its amount at various temperatures and under various tensions. So we were a good deal surprised by the behaviour of our first bar. It practically refused to stretch. We had taken the pre-

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[1] For full details of the experiments herein described see a Paper by James C. McConnel and Dudley A. Kidd, published in the Royal Society's Proceedings, June 1888.

[2] See Heim's "Gletscherkunde," published by Engelhorn, Stuttgart, 1885.

[1] See NATURE, vol. xxxii. p. 16. and Heim, *loc. cit.* p. 315, who cites a paper by Matthews, *Phil. Mag.*, 1869.

caution of observing the extension of the bar proper by measuring the distance between two needles fixed in the bar near either end. We used a cathetometer in the first instance, but that generally unsatisfactory instrument was particularly untrustworthy in our circumstances, and the small extension we found may have been due to errors of reading. We applied, therefore, a system of light levers to the needles, which would indicate a very minute extension, though it was not well adapted to measure large extensions with accuracy. Under this far more severe test, the bar still maintained its rigid character. Between two of the readings there was a slight extension of 0·044 mm. This we attributed to a sort of surface crack which we found in the bar after the experiment. With this trifling exception, the whole of the lengthening seemed to be caused by a gradual rise of temperature which took place. This supposition gave, indeed, a coefficient quite concordant with the latest results obtained by others. Even without making any allowance for the rise of temperature, the mean rate of extension during six days was less than 0·0002 mm. per hour per length of 10 cm., about 100 times as small as Main had found. This enormous difference had nothing to do with either the temperature or the tension, for the former averaged about the same and the latter was slightly greater in our experiment. The cause evidently was to be sought in the nature of the ice itself, and we were not long in discovering a satisfactory explanation.

Ice is, as is well known, a crystalline body, and its molecular structure is no doubt perfectly regular and definite so far as it is revealed by the polariscope or spectrometer. We have no reason to expect any bending of the optic axis or gradual change of the indices of refraction within any one crystal. Every piece of ice, therefore, is either itself a single uniform crystal, or is built up of pieces, each of which is a single uniform crystal. Thus, bars of ice fall into two classes—homogeneous and heterogeneous. Main's bars were heterogeneous, ours was homogeneous. We concluded, therefore, that *heterogeneous ice is plastic, while homogeneous ice is rigid;* and this conclusion was confirmed by subsequent experiment.

It is generally impossible to tell with the naked eye whether a piece of ice is heterogeneous or homogeneous. But a polariscope settles the question at once. We put together a rude form of polariscope in which the light from a sheet of white paper is reflected at an angle of 57° by a pile of three glass plates towards a Nicol prism held in the same framework. We generally turned the Nicol so as to make the field dark. Looking through the Nicol, and holding a bar of heterogeneous ice between the Nicol and the glass plates, some of the crystals would look dark, some light, and some, perhaps, coloured. If the crystals overlapped and interlaced much, the appearance was very complicated; but in any case it was easy to make out the line where the interface of any two crystals cut the surface of the bar. Our first bar was square, with the optic axis at right angles to two of the sides. It was about an inch thick, and it showed under the polariscope the coloured rings and black cross of a uniaxial crystal very well. And these remained stationary and unbroken while the bar was moved parallel to itself across the field of view, showing that it was a single crystal. To obtain the ice we had put out a large bath of water in, as it happened, comparatively mild weather, and cut the bar from the ice formed at the top. The water was from the ordinary hotel supply, the same as had been used by Main.

Glacier ice, as is well known, is markedly heterogeneous, being composed of irregular lumps accurately fitting each other, each of which is a single crystal. These lumps are called in German *Gletscherkörner*, and in French *grains du glacier;* so in English we may use the term glacier grains. They are found of all sizes, from that of a pea to that of a melon. But the average size diminishes rapidly as we follow a glacier upwards towards its source. At the surface of a glacier the ice is of course quite disintegrated by the sun, and the original structure has vanished, and on the side of a crevasse or in an ice cave where the clear ice is seen, the grains are frequently quite indistinguishable with the naked eye. But, if a fragment of this clear ice be exposed to the sun for a few minutes, the dividing surfaces of the grains come out very clearly through thin films of water being formed. Moreover, in each crystal a number of small disks appear, perhaps the tenth of an inch in diameter, with their planes at right angles to the optic axes. This peculiarity helps to mark off one grain from another.

On account of this structure it was probable that glacier ice would prove to be plastic; but it would have been extremely rash to repeat the mistake into which others had fallen, and deduce the properties of glacier ice from experiments on other ice. Fortunately, it was an easy matter to obtain access to a glacier. For the restaurant at the foot of the Morteratsch Glacier and the road thereto are now kept open in winter, and the distance from St. Moritz is only eight or nine miles. We procured some pieces from the natural ice caves, whence the stream issues at the foot of the glacier, and sawed them into bars at our leisure. We tested three bars, which put beyond a doubt the plasticity of glacier ice under tension. The rate of extension varied, however, in the most extraordinary manner in each bar, not merely with the temperature and the tension, but also with changes in the nature of the bar, due, apparently, to the process of extension itself. To make the results obtained with different bars comparable, I shall give all the rates of extension in millimetres per hour per length of 10 centimetres. The first bar extended at a rate of from 0·013 mm. to 0·022 mm., the variations being attributable to changes of temperature. The second began at a rate of 0·016 mm., and gradually slowed down till it reached at the same temperature a rate of 0·0029 mm., at which point it remained tolerably constant, except for slight temperature fluctuations, until the tension was increased by one-half. This brought the rate at once up to 0·0110 mm. This increased rate in its turn showed a tendency to sink, more or less counterbalanced by a rising temperature. This piece of ice was under tension for twenty-five days, and extended altogether about 3 per cent. of its length. The third piece behaved in a very different manner. It began at the rate of 0·012 mm., increased its speed, with the tension nearly doubled, to 0·026 mm., and stretched faster and faster, with unaltered tension, till it reached the extraordinary speed of 1·88 mm. We put on a check by reducing the tension by one-third, whereupon the speed fell at once to 0·35 mm., and gradually declined to 0·043 mm. The lowest temperature reached during our experiments, except with the intractable bath ice, was with this specimen. For twelve hours the temperature never rose above – 9°, and it probably averaged – 10°·5. The tension happened to be very light—only 1·45 kilos per sq. cm.; but the rate was easily measurable. It was 0·0065 mm. The arrangement of the grains in these bars was too complex for description. The size averaged, perhaps, that of a walnut. Nearly one-third part of the third piece was one crystal, which ran three-quarters of the length between the needles.

Some, though not all, of the ice of the St. Moritz Lake is possessed of a curious structure. It is built up of vertical columns whose sections are of quite irregular shapes. The thickness of each column is not quite uniform; still, the sides are nearly vertical. An average column is about as thick as an ordinary pencil, and in length is only bounded by the depth of the clear ice—*i.e.* a foot or more. Each column is a single crystal, and the optic axes are generally nearly horizontal, though otherwise arranged at random. The columns become visible to the naked eye when the ice begins to melt, and, if this melting is caused by sunshine, they often become quite detached and fall apart. The appearance presented on the lake when the ice melts in the spring is described as very curious. The crackling of the breaking columns, when the loose ice drifts against the shore, can be heard at some distance. It would be interesting to learn if such columns have been noticed in England. (Prof. Heim informs me that he has found a columnar structure in lake ice in the Swiss lowlands, but the optic axes were all vertical.) A few experiments we made on freezing water in a bath led us to attribute this structure to the first layer of ice having been formed rapidly—for example, in air below – 6° C. No doubt the nature of the first crystals formed settles the structure of all the rest of the ice.

This lake ice afforded a capital opportunity for testing our notion that the crystals themselves are rigid, and that the apparent plasticity is due to some action at the interfaces of the different crystals. We first tried a bar whose length was parallel to the columns. This was, really, trying to stretch a bundle of long thin crystals. We were able to measure an extension, but it was excessively small, amounting to about 0·12 mm. on one side of the bar and 0·07 mm. on the other during 208 hours, giving a mean rate per hour per length of 10 cm. of 0·00046 mm. I do not believe that the crystals stretched by even this small amount. For those that were slightly inclined to the direction of pull would be pressed against their neighbours, there would be yielding at the interfaces, and consequent minute lengthening of the bar. We next cut a bar such that the columns ran in a slanting direction across it at an angle of about 45° to the length. The difference was very striking. The new bar stretched at a rate of 0·015 mm. per hour per length of 10 cm.,—more than thirty times as fast.

Towards the end of the winter we determined to try the effect of pressure, and after some thought decided on the following arrangement, which proved in practice very satisfactory. We found in Dr. Main's stock two sheets of thick plate glass, about 25 centimetres by 17. We laid one of these on the table, on it three pieces of ice, and on them the other glass plate. The three pieces were cut as nearly alike as possible, each being about an inch cube. So they were short and thick enough to preclude the likelihood of bending. They were arranged at the angles of an equilateral triangle 9 cm. in the side. Pressure was applied by means of a lever and weight at a point vertically over the centre of this triangle, so the pressure on each block of ice was the same. Measurements of the distance between the plates were taken with calipers at three points at the edge, so selected that it was easy to calculate from the measurements the contraction of each block. Our first experimental result was that the coefficient of friction of ice on glass is very small. The moment the weight was applied, the three pieces of ice shot out on to the floor. Afterwards this inconvenient tendency was held in check by freezing pieces of paper on to the ends of the blocks.

Three pieces of glacier ice showed that this substance is just as amenable to pressure as to tension. The mean rates during five days were respectively 0·035 mm., 0·056 mm., and 0·007 mm. per hour per length of 10 cm. We could not discover any material difference between the three under the polariscope. They were all composed of smallish grains averaging perhaps 7 mm. in diameter, and all three were from the same lump. They were under exactly the same conditions of temperature, and under, at any rate nearly, the same pressure, and yet the second piece gave eight times as much as the third. Of course the arrangement of the interfaces was very complicated in both pieces, and it may have been much less favourable to distortion in the third, but it seems more probable that there was some obscure difference in the state of the interfaces. Bubbles, at any rate, seem to have had no bearing on the matter, for the third piece contained far the most, and the first piece the fewest.

We next tried lake ice with the columns vertical. The mean rate of the three pieces during four days was 0·001 mm. per hour per length of 10 cm. This was only just perceptible to the calipers, and we think it may have been entirely due to the yielding of the films by which the paper was attached or to the same cause as in the case of tension.

Our evidence for the rigidity of an ice crystal rests on three experiments. One of these was on a single crystal of the bath ice, and tension was applied; and the other two on lake ice with the stress applied parallel to the columns: tension in the first case, pressure in the second. These showed that the plasticity of an ice crystal is either non-existent, or is at any rate of a very different order of magnitude from that of ordinary heterogeneous ice. The optic axis in the first case was exactly at right angles to the stress, and in the two latter it was not very far from that position. It would have been perhaps more satisfactory if we had applied stress in other directions. But it seems, *a priori*, very unlikely that any homogeneous substance should be rigid in one direction and plastic in another, and in our Royal Society paper we have given more conclusive reasoning to show that the rigidity must extend to the direction parallel to the axis.

If a bar composed of a number of crystals of irregular shape stretches, while remaining compact, the crystals must necessarily change their shape. It is probable, therefore, that molecules separate themselves from one crystal, and moving across the interface attach themselves to another. But to unravel the laws which govern the direction and rate of the motion of the molecules further experiment is necessary. Mr. Buchanan's experiments, recently described in NATURE (vol. xxxv. p. 608, xxxvi. p. 9), throw some light on the matter. They render it likely that a large part of the soluble impurities in the ice will be collected at the interfaces, and will keep a certain amount of water in the liquid state. This liquid, however, must be a very thin film, for it does not interrupt the optical continuity. If the thickness of the film were not small compared with a mean wave-length of light, there would be reflection, and the interface would be visible to the naked eye. Nevertheless an invisibly thin film might play a very important part in providing a mobile medium for the transmission of the molecules. According to Mr. Buchanan, the amount of liquid present would be roughly inversely proportional to the number of degrees below 0° C. This law is very accurate near 0° C. With any one salt the amount of liquid at low temperatures would be rather greater than is given by the law, but at a certain temperature, the freezing-point of the cryohydrate of that salt, the liquid would completely solidify. According to Guthrie, the cryohydrate of $CaCl_2$ freezes at – 37° C., of NaCl at – 22°, of Na_2SO_4 at as high a point as – 0°·7. If this thin film of liquid be an essentia factor, ice should be perfectly rigid at a temperature low enough to freeze all the cryohydrates. On the other hand, the amount of liquid should become indefinitely great as zero is approached, so that the plasticity might be expected to be very largely increased when the air surrounding the ice rises above zero. We did not find this was the case. In a tension experiment on an icicle, the surrounding air for five hours was at about + 0°·5 C., and yet the rate of extension was not strikingly greater than it had been a few degrees lower.

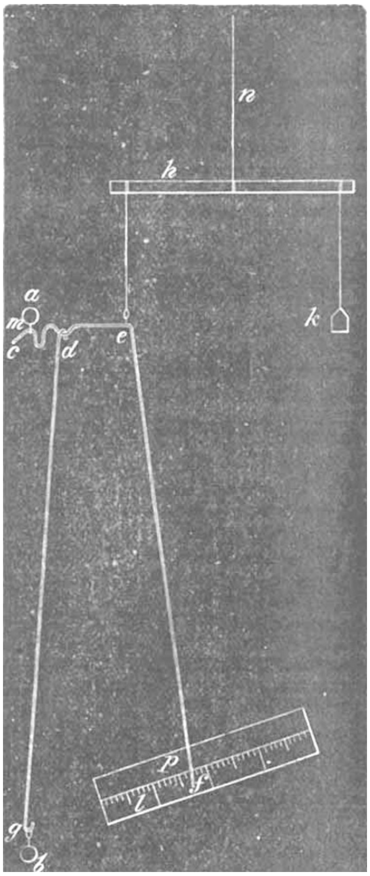
The temperature variations proper were so small compared with the irregular variations spoken of above, that it was difficult to secure any satisfactory measure of them. Still, I have a few figures to offer. In the case of the second piece of glacier ice, while at – 3°·5 the rate was 0·0029 mm., two days before and two days afterwards it was about 0·0020 at – 5°, and a few days earlier 0·0013 at −8°. In the icicle, when the temperature variations seemed paramount, the rate at 2° was 0·0028; and at −0°·2, 0·0034. Under pressure the influence of temperature seems much more powerful. In all three pieces of glacier ice the rate rose at −3° to about ten times its value at −5°.

The effect of a change of tension was very striking. I append a list of all the cases which occurred.

Specimen.	Change of tension: kilos per sq. cm.	Change of rate: mm. per hour per 10 cm.
Glacier ice C	2·55 to 3·85	0·0018 to 0·0110
Glacier ice D	1·45 ,, 2·55	0·0075 ,, 0·026
,, ...	2·55 ,, 1·03	0·105(?) ,, 0·010
,, ...	1·03 ,, 2·50	0·010 ,, 0·228
,, ...	2·50 ,, 1·80	1·88 ,, 0·35

The 0·105 is uncertain owing to an accident. It was certainly not less, and may have been a good deal greater.

I think it will be interesting to describe the system of levers which we found so effective in measuring small extensions. It is shown in the figure. *a* and *b* are sections of the projecting ends of glass needles fixed in the ice from 12 cm. to 20 cm. apart; *cdef* is a bent iron wire, "the indicator," hooked to a wire loop, *m*, securely fastened to *a*; *h* is a wooden lever suspended by a thread *n*, which, owing to the counterpoise *k*, pulls the indicator upwards with a thread fastened to a wire loop at *e*. The indicator is kept from rising by the connecting fibre, a piece of stiff wire hooked at one end to the loop *g*, fastened to *b*, and at the other to a bend d^1 in the indicator. The lower end of the indicator gives the reading on a paper millimetre scale *l*, gummed on to the mirror *p*. The mirror, of course, enables the observer to avoid errors of parallax. The stand of the mirror is glued to the lower collar. To appreciate the action of the levers, regard *a* for the moment as fixed, then lowering *b* through a small distance *r* will move *f* through a distance $s = vr$ at right angles to *mf*, where *v* is the ratio of the distance *mf* to the perpendicular let fall from *m* on the line *gd* produced if necessary. If *md* be the perpendicular to *gd*, when *f* is in the middle of the scale, the multiplier *v* remains practically constant. This precaution was not always taken, but allowance is made for the resulting error. Two lever systems were required, one for the outer ends, and the other for the inner ends of the needles passing through the ice.



In the following table is given a summary of our results:—

SUMMARY. *Extension Experiments.*

Description of specimen.	Duration.	Rate per hour in mm. per length of 10 cm.	Tension, kilos per sq. cm.	Maximum temperature.	Mean temperature.
Bath ice uncorrected for temperature	5½ days	0·00028	4·9	−1·0°	−4·5°
,, corrected for temperature	,,	0·00000	,,	,,	,,
Mould ice	28 hours	0·048	3·8	0·0	−5·0?
Glacier ice A, maximum rate	5 ,,	0·022	1·66	0·0	−2·0
,, minimum rate	4 ,,	0·013	,,	−1·0	−2·5
Glacier ice B, maximum rate	24 ,,	0·016	2·7	−2·5	−3·5
Glacier ice C, ,, ...	23 ,,	0·0068	2·55	−2·5	−4·5
,, minimum rate	3 days	0·0013	,,	−6·0	−9·0
Glacier ice D, maximum rate	10 mins.	1·88	2·50	−2·1	−2·1
,, minimum rate	16 hours	0·0054	1·45	−6·0	−10·0
,, lowest temperature..............	12 ,,	0·0065	,,	−9·0	−10·5
Icicle, maximum rate	5 ,,	0·0041	2·2	0·0	0·0
,, minimum rate	8 ,,	0·0015	,,	−0·7	−1·7
Lake ice, parallel columns	7 days	0·00039	2·1	0·0	−5·5
,, greater tension	2 ,,	0·00076	2·8	−4·0	−5·5
Lake ice, oblique to columns { maximum rate ..	6 hours	0·034	2·75	−5·6	−5·8
Lake ice, oblique to columns { minimum rate ..	16 ,,	0·010	,,	,,	−6·0

Compression Experiments.

Description of specimen.	Duration.	Rate per hour in mm. per length of 10 cm.	Pressure, kilos per sq. cm.	Maximum temperature.	Mean temperature.
Glacier ice E	5 days	0·035	3·2	−2·8	−6·0
Glacier ice F	,,	0·056	,,	,,	,,
Glacier ice G	,,	0·007	,,	,,	,,
Lake ice, parallel to columns { A	3 days	0·002	3·7	−3·9	−6·0
Lake ice, parallel to columns { B	,,	0·0012	,,	,,	,,
Lake ice, parallel to columns { C	,,	0·0018	,,	,,	,,

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[1] This was a deeper bend than is shown in the figure.

Glacier ice C is the same piece as B, cut rather shorter. The rates of extension given here are of course the mean of the rates observed on the two sides of the bar, which were generally far from being equal. Sometimes the greater speed would fluctuate from one side to the other; in other words, the bar would bend first one way then the other. In other cases one side would always extend faster, *e.g.* in glacier ice D the total extension of one face was 2·9 mm., of the other 9·7 mm. The breaking tension we found in the bath ice to be about 8 kilos per sq. cm., but for obvious reasons we did not care to approach this limit too closely. One curious fact deserves notice. The icicle, which was built up of very small crystals, stretched very slowly; while, on the other hand, the most plastic of our pieces of glacier ice contained one very large crystal. This may have been accidental, or it may have been due to the impurities. The fewer the interfaces the greater the quantity of soluble salts at each.

Let us compare the figures in the table with the plasticity actually observed in glaciers. Heim has collected a number of observations on the increase of velocity from the sides to the centre of a glacier. The most rapid increase he mentions among the Alps is on the Rhone glacier on a line 2300 metres above the top of the ice-fall. At 100 metres from the western bank the mean yearly motion from 1874 to 1880 was 12·9 metres, at 160 metres from the bank it was 43·25 metres. This gives an increase of velocity in each metre across the glacier of 0·000058 metre per hour. The stretching involved in this distortion is shown in the paper to be greatest in a direction inclined at 45° to the direction of motion, and then to amount to 0·0029 mm. per hour per length of 10 cm. Hence the plasticity we have found in hand specimens is amply sufficient to account for the distortion of a glacier, even without the aid of crevasses.

It may be said that the term plasticity can not be properly applied to the property of ice that I have described, but there is no other convenient word. Further, it is quite possible that sealing-wax and pitch may be built up of microscopic or ultra-microscopic crystals, and that their plasticity is fundamentally similar to that of ice, the difference being merely one of scale. Helmholtz has suggested somewhere that ice, with its definite and easily ascertainable structure, may furnish the clue to the solution of many difficult problems in the properties of matter.

JAMES C. MCCONNEL.

NOTES.

AT the annual meeting of the Paris Academy of Sciences on December 24, the Bordin Prize, awarded for perfecting the theory of the movement of a solid body, was awarded to Madame Sophia Kovalevsky, a professor at Stockholm University, and a lineal descendant of Matthias Corvinus, King of Hungary from 1458 to 1490. In astronomy, the Valz Prize was awarded to Mr. E. C. Pickering, and the Janssen Prize to Dr. William Huggins. The Montyon physiology prize was divided between Mr. Augustus D. Waller and M. Léon Frédéric.

DR. SCHWEINFURTH has removed his residence from Cairo to Berlin. The German Government has placed at his disposal a house for the accommodation of his African collections, which after his life-time will become the property of the State, but in the meantime remains in his charge, the Government meeting all the expenses of their maintenance.

AT present Dr. Schweinfurth is on his way to Arabia Felix for the purpose of making botanical collections in the mountains of Yemen. Judging from what is known of the limited but extremely peculiar flora of Aden, and from the specimens which Major Hunter, the assistant Resident at Aden, has transmitted to Kew from the interior, the results of Dr. Schweinfurth's explorations are likely to be of the very greatest interest.

A NEW part of the "Scientific Results of Prjevalsky's Expeditions" has just been published by Prof. Hertzenstein. It contains a description of the fishes, and is illustrated by eight plates.

DR. FRANÇOIS, of the Science Faculty of Rennes, has been despatched, by the French Minister of Public Instruction, to Tahiti, to investigate thoroughly corals and coral formations there.

IT is intended that the next general meeting of the Association for the Improvement of Geometrical Teaching shall be held at University College, Gower Street, on January 19, 1889. The morning sitting, at which the Reports of the Council and the Committees will be read, and new officers and members elected, will begin at 11 a.m. After an adjournment for luncheon at 1 p.m., members will reassemble at 2 p.m., when an address will be delivered by Prof. Minchin, of Cooper's Hill, on "The Vices of our Scientific Education."

LAST Friday, Mr. Mundella asked the Chancellor of the Exchequer whether he was able to remove the uncertainty and embarrassment of the provincial Colleges by publishing his scheme for grants in aid; and whether, in consideration of the delay which had already taken place, and the pecuniary position of several Colleges, he would provide that the grants should take effect from January 1 next. In reply, Mr. Goschen said he was not able to make any statement as to the particulars of a scheme for grants in aid to University Colleges in the provinces. In any case it would not be possible for the grants to take effect from January 1 next, as they would be included in the Estimates for the financial year 1889-90, nor could the grants be of such amounts as to retrieve the position of any College in serious financial embarrassment. Government grants, though they would be a valuable addition, could in no case be, and were not intended to be, an effective substitute for local contributions, which must always bear the greater share of the burden. With respect to the scheme in general, Mr. Goschen was anxious to state that any delay which had arisen was due entirely to the number and importance of the subjects competing for the attention of the Government during the session. The Government regarded grants to local Colleges as a step of great importance, and possibly of far-reaching effects. It was absolutely impossible to propose a scheme without the most careful consideration of its bearings, more especially the proportions and the conditions on which any assistance from Imperial funds should be given to local institutions for higher-class education. It was not from any neglect of the matter, but rather from their sense of its extreme importance, that the Government had not been able to formulate their proposal, although they hoped to do so at a very early date.

AT a recent meeting of the Senate of the Sydney University it was announced that the Hon. William Macleay, besides presenting to the University his valuable museum of natural history, which comprises specimens from all the Australian colonies, New Guinea, and the various groups of islands in that quarter of the globe, has also given the sum of £6000 to endow a curatorship for that museum.

WE learn from *Science* that Mr. J. W. Osborne, of Washington, the well-known inventor of photo-lithography, has presented to the United States National Museum and to the Art Museum in Boston his large and valuable collection of proofs and specimens illustrative of the development of photo-mechanical printing. All the important and typical processes are fully represented in each by specimens collected by Mr. Osborne in the art centres of Europe and America, and include the works of all who have