leaves, like those seen upon the windows during frost. In this experiment, the solar heat, instead of uniformly melting the mass of ice, which it would certainly do if the mass were amorphous, acts successively upon the different crystals of which it is built up, affecting them in the reverse order of their formation. There are thus produced a number of spaces of regular shape, containing water, and producing comparatively dark images upon the screen. In the centre of each there is generally a bright spot, which corresponds to an empty space, depending on the fact that the water occupies a smaller volume than the ice from which it has been produced.

84. Supersaturation.—The proportion of solid matter which a liquid can hold in solution varies according to the temperature; and as a general rule, though not by any means in all cases, it increases as the temperature rises. Hence it follows, that if a saturated solution be left to itself, the effect of evaporation or cooling will be gradually to diminish the quantity of matter which can be held in solution. A portion of the dissolved substance will accordingly pass into the solid state, assuming generally a crystalline form. This is an exceedingly common method of obtaining crystals, and is known as the *humid way.*

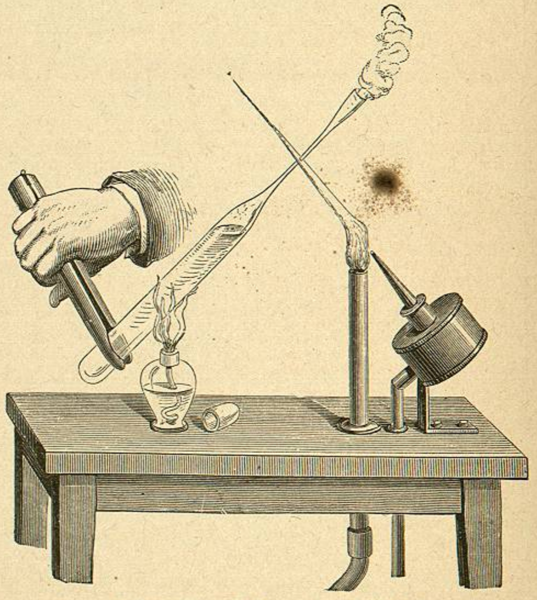
Fig 49.—Preparation of Supersaturated Solution of Sulphate of Soda.

In connection with this process a phenomenon occurs which is precisely analogous to the cooling of a liquid below its freezing-point. It may be exemplified by the following experiment.

A tube drawn out at one end (Fig. 49) is filled with a warm concentrated solution of sulphate of soda The solution is boiled, and while ebullition is proceeding freely, the tube is hermetically sealed; by this means the tube is exhausted of air. The solution when left to itself cools without the solid being precipitated, although the liquid is *supersaturated.* But if the end of the tube be broken off, and the air allowed to enter, crystallization immediately commences at the surface, and is quickly propagated through the whole length of the tube; at the same time, as we should expect, a considerable rise of temperature is observed. If the phenomenon does not at once occur on the admission of the air, it can be produced with certainty by throwing a small piece of the solid sulphate into the solution.

85. Change of Volume at the Moment of Congelation. Expansive Force of Ice.—In passing from the liquid to the solid state, bodies generally undergo a diminution of volume; there are, however, exceptions, such as ice, bismuth, and cast-iron. It is this property which renders this latter substance so well adapted for the purposes of moulding, as it enables the metal to penetrate completely into every part of the mould. The expansion of ice is considerable, amounting to about $\frac{1}{12}$; its production is attended by enormous mechanical force, just as in the analogous case of expansion by heat.


Fig. 50.—Bursting of Iron Tube by Expansion of Water in Freezing.

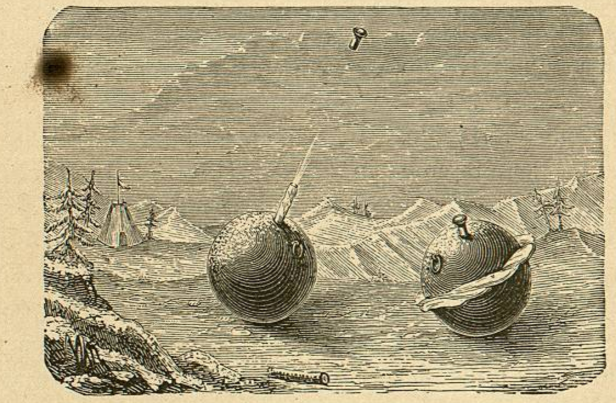
Fig. 51.—Experiment of Major Williams.

Its effect in bursting water-pipes is well known. The following experiment illustrates this expansive force. A tube of forged iron (Fig. 50) is filled with water, and tightly closed by a screw-stopper. The tube is then surrounded with a freezing-mixture of snow and salt. After some time the water congeals, a loud report is often heard, and the tube is found to be rent.

The following experiment, performed by Major Williams at Quebec, is still more striking. He filled a 12-inch shell with water and closed it with a wooden stopper, driven in with a mallet. The shell was then exposed to the air, the temperature being −28° C. (−18° F.). The water froze, and the bung was projected to a distance of more than 100 yards, while a cylinder of ice of about 8 inches in length was protruded from the hole. In another experiment the shell split in halves, and a sheet of ice issued from the rent (Fig. 51).

It is the expansion and consequent lightness of ice which enables it to float upon the surface of water, and thus afford a protection to animal life below.

86. Effect of Pressure on the Melting-point.—Professor James Thomson was led by theoretical considerations to the conclusion that, in the case of a substance which, like water, expands in solidifying, the freezing (or melting) point must of necessity be lowered by pressure, and that a mixture of ice and ice-cold water would fall in temperature on the application of pressure. His reasoning[1] consisted in showing that it would otherwise be possible (theoretically at least) to construct a machine which should be a perpetual source of work without supply; that is, what is commonly called a perpetual motion.

The matter was shortly afterwards put to the test of experiment by his brother, Lord Kelvin, who compressed, in an Œrsted's piezometer, a mixture of ice and water, in which was inserted a very delicate thermometer protected from pressure in the same manner as the instrument represented in Fig. 15 (§ 12). The thermometer showed a regular fall of temperature as pressure was applied, followed by a return to 0° C. on removing the pressure. Pressures of 8·1 and 16·8 atmospheres (in excess of atmospheric pressure) lowered the freezing-point by ·106 and ·232 of a degree Fahr. respectively as indicated by the thermometer, results which agree almost exactly with Prof. J. Thomson's prediction of ·0075 of a degree Cent., or ·0135 of a degree Fahr. per atmosphere.

Mousson has since succeeded in reducing the melting-point several degrees by means of enormous pressure. He employed two forms of apparatus, by the first of which he melted ice at the temperature of −5° C., and kept the water thus produced for a considerable time

---

[1] *Transactions Royal Society, Edinburgh.* January, 1849.—*Cambridge and Dublin Math. Journal.* November, 1850.

at this temperature. This apparatus had windows (consisting of blocks of glass) in its sides, through which the melting of the ice was seen. His second form of apparatus, which bore a general resemblance to the first, is represented in the annexed figure. It consisted of a steel prism with a cylindrical bore, having one of its extremities closed by a conical stopper strongly screwed in, the rest of the bore being traversed by a screw-piston of steel. The apparatus was inverted, and nearly filled with water recently boiled, into which a piece of copper was dropped, to serve as an index. The apparatus, still remaining in the inverted position, was surrounded by a freezing-mixture, by means of which the water was reduced to ice at the temperature of −18° C. The stopper was then screwed into its place, and the apparatus placed in the erect position. The piston was then screwed down upon the ice with great force, the pressure exerted being estimated in some of the experiments at several thousand atmospheres. The pressure was then relaxed, and, on removing the stopper, the copper index was found to have fallen to the bottom of the bore, showing that the ice had been liquefied.

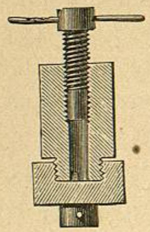

Fig. 52.
Mousson's Apparatus.

Experiments conducted by Bunsen and by Hopkins have shown that wax, spermaceti, sulphur, stearin, and paraffin—substances which, unlike ice, expand in melting—have their melting points *raised* by pressure, a result which had been predicted by Lord Kelvin.

87. Effect of Stress in general upon Melting and Solution.—In the experiments above described, the pressure applied was hydrostatical, and was therefore equal in all directions. But a solid may be exposed to pressure in one direction only, or to pull in one or more directions, or it may be subjected to shearing, twisting, or bending forces, all these being included under the general name of *stress*.

Reasoning, based on the general laws of energy, leads to the conclusion that stress of any kind other than hydrostatic, applied to a solid, must lower its melting-point. To quote Professor J. Thomson (*Proc. Roy. Soc.* Dec. 1861), "Any stresses whatever, tending to change the form of a piece of ice in ice-cold water, must impart to the ice a tendency to melt away, and to give out its cold, which will tend to generate, from the surrounding water, an equivalent quantity of ice free from the applied stresses," and "stresses tending to change the form of any crystals in the saturated solutions from which they have been crystallized must give them a tendency to dissolve away, and to generate, in substitution for themselves, other crystals free from the applied stresses or any equivalent stresses."[1] This conclusion he verified by experiments on crystals of common salt. He at the same time suggested, as an important subject for investigation, the effect of hydrostatic pressure on the crystallization of solutions, a subject which was afterwards taken up experimentally by Sorby, who obtained effects analogous to those above indicated as occurring in connection with the melting of ice and wax.

88. **Bottomley's Experiment.**—Mr. J. T. Bottomley has devised an instructive experiment on the effect of applying stress to ice. A block of ice is placed on two supports with a little space between them, and a stout copper wire with heavy weights at its two ends is slung across it. The wire gradually makes its way through the block—occupying, perhaps, an hour or two in its passage—and at last drops upon the floor; but the block is not cut in two; the cut which the wire makes is filled up by the formation of fresh ice as fast as the wire advances. The pressure of the wire lowers the melting-point of the ice in front, and causes it to melt at this lowered melting-point. The wire itself acquires, by contact with the melting ice, a temperature below zero, and the escaping water freezes at the back of the wire.

89. **Regelation of Ice.**—Faraday in 1850 called attention to the fact that pieces of moist ice placed in contact with one another will freeze together even in a warm atmosphere. This phenomenon, to which Tyndall has given the name of *regelation*, admits of ready explanation by the principles just enunciated. Capillary action at the boundaries of the film of water which connects the pieces placed in contact, produces an effect equivalent to attraction between them, just as two plates of clean glass with a film of water between them seem to adhere. Ice being wetted by water, the boundary of the connecting film is concave, and this concavity implies a diminution of pressure in the interior. The film, therefore, exerts upon the ice a pressure less than atmospheric; and as the remote sides of the

---

[1] Professor Thomson draws these inferences from the following principle, which appears axiomatic:—If any substance or system of substances be in a condition in which it is free to change its state [as ice, for example, in contact with water at 0° C., is free to melt], and if mechanical forces be applied to it in such a way that the occurrence of the change of state will make it lose the potential energy due to these forces without receiving other potential energy as an equivalent; then the substance or system will pass into the changed state.

blocks are exposed to atmospheric pressure, there is a resultant force urging them together and producing stress at the small surface of contact. Melting of the ice therefore occurs at the places of contact, and the cold thus evolved freezes the adjacent portions of the water film, which, being at less than atmospheric pressure, will begin to freeze at a temperature a little above the ordinary freezing-point.

As regards the amount of the force urging the pieces together, if two flat pieces of ice be supported with their faces vertical, and if they be united by a film from whose lower edge water trickles away, the hydrostatic pressure at any point within this film is less than atmospheric by an amount represented, in weight of water, by the height of this point above the part from which water trickles. If, for simplicity, we suppose the film circular, the plates will be pressed together with a force equal to the weight of a cylinder of water whose base is the film and whose height is the radius.

90. **Apparent Plasticity of Ice. Motion of Glaciers.**—A glacier may be described in general terms as a mass of ice deriving its origin from mountain snows, and extending from the snow-fields along channels in the mountain sides to the valleys beneath.

The first accurate observations on the movements of glaciers were made in 1842, by the late Professor (afterwards Principal) J. D. Forbes, who established the fact that glaciers descend along their beds with a motion resembling that of a pailful of mortar poured into a sloping trough; the surface moving faster than the bottom and the centre faster than the sides. The chief motion occurs in summer. He summed up his view by saying, "A glacier is an imperfect fluid, or a viscous body which is urged down slopes of a certain inclination by the mutual pressure of its parts."

This apparent viscosity is explained by the principles of § 87. According to these principles the ice should melt away at the places where stress is most severe, an equivalent quantity of ice being formed elsewhere. The ice would thus gradually yield to the applied forces, and might be moulded into new forms, without undergoing rupture. Breaches of continuity might be produced in places where the stress consisted mainly of a pull, for the pull would lower the freezing-point, and thus indirectly as well as directly tend to produce ruptures, in the form of fissures transverse to the direction of most intense pull. The effect of compression in any direction would, on the other hand, be, not to crack the ice, but to melt a portion of its interior sufficient to relieve the pressure in the particular part affected, and to transfer the excess of material to neighbouring parts, which must in their turn give way in the same gradual manner.

In connection with this explanation it is to be observed that the temperature of a glacier is always about 0° C., and that its structure is eminently porous and permeated with ice-cold water. These are conditions eminently favourable (the former, but not the latter, being essential) to the production of changes of form depending on the lowering of the melting-point by stresses.

This explanation is due to Professor J. Thomson[1] (*British Association Report*, 1857). Professor Tyndall had previously attempted to account for the phenomena of glacier motion by supposing that the ice is fractured by the forces to which it is subjected, and that the broken pieces, after being pushed into their new positions, are united by regelation. In support of this view he performed several very interesting and novel experiments on the moulding of ice by pressure, such as striking medals of ice with a die, and producing a clear transparent cake of ice by powerfully compressing broken pieces in a boxwood mould (Fig. 53).

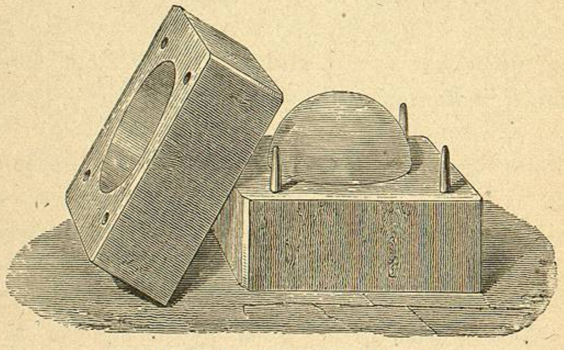

Fig. 53.—Ice Moulded by Pressure.

Interesting experiments on the plasticity of ice may be performed by filling an iron shell with water and placing it in a freezing-mixture, leaving the aperture open. As the water freezes, a cylinder of ice will be gradually protruded. This experiment is due to Mr. Christie. Principal Forbes obtained a similar result by using a very strong glass jar; and by smearing the interior, just below the neck, with colouring matter, he demonstrated that the external layer of ice which was first formed, slid along the glass as the freezing proceeded, until it was at length protruded beyond the mouth.

In the experiments of Major Williams, described in § 85, it is probable that much of the water remained unfrozen until its pressure was relieved by the bursting of the shells.

---

[1] If it should be objected that the lowering of the melting-point by stress is too insignificant to produce the vast effects here attributed to it, the answer is that, when ice and water are present together, the slightest difference is sufficient to determine which portion of the water shall freeze, or which portion of the ice shall melt. In default of a more powerful cause, those portions of ice which are most stressed will melt first.