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After the discussion on Mr. White's paper, the following paper was read by the Secretary in the regrettable absence of the author :—

THE ABNORMAL CONDITIONS OF WATER; AS EVIDENCE OF DESIGN IN NATURE. By Professor EDWARD HULL, LL.D., F.R.S. (*Vice-President*).

WE are every day brought face to face with phenomena of which we are unable to understand the origin and cause, and can only reason on their effects. An instructive and closely reasoned paper was read before the Society recently on the origin of species,* but I fear it left us very much in the same position as did Darwin's celebrated essay, dealing with the same subject; in this case, however, the difficulty was to define what was meant by "a species," while Darwin, if I recollect right, assumes the existence of species.

The phenomena of nature may be conveniently arranged under two heads; those which are normal, and those which are abnormal, or appear to be so. The former are accepted by us without question, and we have theories to account for them which appear satisfactory when tested by experience. Thus when the apple falls from the tree to the ground, we say it is merely the effect of the law of gravitation by which all movable bodies fall in the direction of the centre of the earth; this is supposed to have suggested to Newton the question which gave rise to the discovery of the great universal law: that all bodies attract each other in proportion to their mass, and inversely as the square of the distance. This seems very simple to us now that it has been demonstrated by the great mathema-

* By Rev. John Gerard on February 7th, 1910.

tician; but those who have dipped, however slightly, into the *Principia*, will find that the demonstration was *not* a very simple matter.

But it is the abnormal conditions of phenomena that more especially attract attention, and call for explanation, and I propose in the following paper to deal with two conditions of *water* which *appear* to be quite abnormal. These effects are of transcendent importance, and influence the harmonious working of the physical agencies around us; and yet have scarcely been recognized as being very different from what are regarded as the ordinary or normal results which we are acquainted with when we see that water flows down an inclined plane; or that when boiling it gives off steam. There are, indeed, many remarkable effects produced by water which I should like to have dealt with did time permit, such as its presence in the quartz of granite, and its solvent action on minerals when at high temperature and pressure, whereby these substances have been introduced into mineral veins. But I pass on to the subject more immediately before us, namely, the abnormal conditions under which waters occur; and by "abnormal" I mean differing from those which we should be led to expect by comparison with other natural objects; these conditions resolve themselves under two heads:—

(1) The temperature of water at its maximum density of 39·2° Fahr. (4° Cent.), and
(2) Its incompressibility by which it probably differs from all other substances.

The consequences of these abnormal conditions in the economy of nature are inestimable, and we shall consider them in the above order.

(1) *Maximum Density.*—When water is at a temperature of 212° F. under normal pressure it passes into steam and has a minimum density. Cooling down from this point it contracts or becomes denser as it grows cooler, until it reaches a temperature of 39·2° Fahr. (4° Cent.) where the contraction is arrested; and from this point down to 32° F. (that of freezing) it expands, producing ice, which being lighter than water, floats on its surface. Here it is, therefore, that the abnormal conditions arise, for the condensation might have been supposed to have continued throughout the intermediate seven degrees (from 39·2° to 32° F.) resulting in the formation of ice heavier than water, and consequently sinking down to the bottom of the basin or reservoir. Such, however, we know not to be the case, as eleven

volumes of ice melt into only two volumes of water* at 32° F. The water has, therefore, expanded (or become less dense) between these two definite points of temperature. This is a very remarkable and important fact; and we shall best understand its importance by considering what would have been the physical results had what we may call "the normal law of contraction of volume" been continuous down to 32° F.

(*a*) We may consider the results as regards rivers and lakes and other large areas where the annual mean temperature of the air is below 32° F., such as the lands north of the Arctic Circle—latitude 66·33° N.—especially those at some elevation above the border of the ocean. North of the Arctic Circle the rainfall, instead of flowing off the land into the ocean as rivers, would have been permanent ice-streams; while the lakes would have been converted into solid masses of ice; because the ice once formed would have remained as such, accumulating on the bed of the valley without opportunity of melting. As this process must have been in operation throughout long ages of time it is impossible to imagine what would have been the condition of these regions had ice as it formed at the surface subsided to the bottom.

(*b*) Now extending our purview to the adjoining oceanic regions, is it not clear that the effects would have been similar in kind, though vastly greater in result? The ice as it froze on the surface, being by hypothesis heavier than the underlying water, would have subsided, and this process having proceeded throughout long ages of time must have inevitably resulted in converting what is now oceanic water into solid ice. Can we conceive anything more lamentable than a solid Arctic Ocean? Only where the influence of the Gulf Stream extends, warming the surface waters, and mollifying the climate so that the surface does not freeze throughout the year, would the present conditions have been permanent.

(2) We now come to consider the second abnormal, or exceptionable, condition under which water exists, namely, INCOMPRESSIBILITY and its effects in the arrangement of the *Cosmos.* Water is incompressible; and perhaps it is the only object in nature that is so. Various experiments have been tried in order to compress this liquid without success, and just because it is a liquid. On the other hand, solids are compressible; the contrast being due to the difference in arrangement

* Daniel, *Principles of Physics*, 3rd edit. (1895).

of the molecules in each case. In solids the molecules are not in contact, and consequently pressure only forces them closer to each other, "but in liquids, the molecules are within the spheres of each other's action; and each molecule is free to adjust its mean position under the influence of surrounding molecules." This, at least, is Alfred Daniel's interpretation of the phenomena.*

But whatever be the true explanation of the difference between fluids and solids as regards incompressibility and the reverse—the experiments shown in Bramah's hydraulic press, and by Francis Bacon seem to confirm both the above statements. In the former case a ball of iron was filled with water at 3·9° Cent. and closed. It was then subjected to great pressure; but the water forced itself through the pores of the iron, and appeared on the surface as vapour. In the latter case, a shell of lead was filled with water and compressed; the water oozed through the lead in drops and beads on the surface of the shell, showing that the iron and lead are porous; while the water resisted compression, up to the bursting point of the shell and ball.†

But however the question of incompressibility might be investigated by the aid of experiments in the laboratory it is surely set at rest by observations in the region of physical phenomena itself. It may be impossible to imagine that water like other substances in nature cannot yield to any conceivable force—but for all practical purposes, the fact remains that it is incompressible; as it remains fluid at the lowest depths of the ocean yet touched by the soundings. Depths of 2,000 fathoms and upwards have been sounded in waters of the North Atlantic at a temperature of 2° to 3° C. (37° to 39° Fahr.)‡ and living forms have been brought up from the bottom. What the pressure on the lowest strata of the water may be I cannot venture to say; it must be some thousands of tons per square foot, but it is insufficient to consolidate the water even at a temperature approaching freezing point. Now just imagine for a moment compressible water. What would be the state of the ocean under such conditions even were the degree of compressibility of the slightest? Evidently, that after the weight

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* *Principles of Physics*, p. 254, 3rd edit.

† *Principles*, p. 220; we are not told the amount of pressure, or the thickness of the ball and shell, but we may assume they were both sufficient to satisfy the experimentalists up to bursting point.

‡ Wyville Thomson, *Depths of the Sea*, p. 322, Plate VI.

of a few hundred fathoms of water added to the degree of condensation reached at a rather low temperature, the water would become solid; that is to say, a mass of ice throughout a depth of several thousand feet from the floor. Throughout this zone life would be absent; the currents of the ocean would be restricted to the surface, and the whole physical arrangements now working harmoniously, would be impossible. All this has been rendered impossible owing to the incompressibility of water, in which it differs from all other bodies, and is therefore abnormal.

As a digression for a moment, I may observe that it is owing to this condition or attribute of incompressibility that the flanges of a propeller are so effective in forcing a ship of the largest size at a high speed through the water. When we examine one of the beautiful models of our ocean liners, we are struck by the diminutive size of the propeller at the stern with the huge mass which by its rotation and the slight angle at which the flanges are set to the axis, it is capable of forcing the ship through the ocean at a high speed. We have to recollect, however, that the water when thus acted upon is practically a solid. There is not time for it to give way, and being incompressible it cannot yield to the lateral pressure exercised by the flange, any more than if the waters were solid or nearly so. We shall now return to our subject.

It is to be observed, moreover, that these two attributes of the maximum density and incompressibility work harmoniously together in the physical system of the globe. It is owing to this that the ocean at its profoundest depths is never frozen, though it approaches within a few degrees of the freezing point. The currents of warm water, such as that of the Gulf Stream, which is constantly pouring water at a high temperature into high latitudes, are necessarily replaced by cold polar waters moving slowly in both directions over the bottom of the ocean towards the equatorial regions. If the waters were compressible, or if the conditions regarding density were otherwise from those above described, this circulation of the warm and cold waters would be rendered difficult, if not impeded because the frozen polar waters would not be able to rise to the surface.

As regards lakes; for similar reasons the waters even in deep lakes are never frozen at the bottom; the ice as it forms at the surface owing to the cold of the air, constantly ascends; thus tending to keep the underlying waters in a state of fluidity. The soundings over the Lake of Geneva show that the lowest waters are at a temperature above freezing point. From a depth of 240 feet down to nearly 1,000 there is an unvarying temperature of 34·9° F. (6·6° C.) throughout the year. In the Lake of Constance a temperature of 40·1° F. (4·5° C.) prevails in the deeper parts, and in that of Neuchâtel of 41° F. (5° C.) prevails. The slight excesses in some cases are probably due to the heat of the bottom rocky floor.

I hope I have succeeded in showing that the two conditions under which water exists are apparently abnormal—yet I do not wish to assert that they are on a plane outside the range of the Creator's general work, or plan, in Nature. To my mind the whole mechanism of the world is the outcome of supreme wisdom and mind tending to the harmonious working of the whole, and the instances I have adduced are only parts of the general plan. These are amongst the most evident as indicating DESIGN, and we are therefore more able to investigate their mode of operation.

DISCUSSION.

At the conclusion of the paper the Rev. A. IRVING, D.Sc., B.A., said: Professor Hull's paper on "Abnormal Properties of Water, as Evidence of Design in Nature," deals with a very interesting subject, and one which Canon J. M. Wilson of Worcester, who in his day was a Cambridge Senior Wrangler, handled in a masterly way in a lecture given many years ago to the Literary and Philosophical Society of Nottingham.

(1) The fact that water has its maximum density at 4° C. is one which admits of quite simple demonstration, and I have frequently given the demonstration (by a modification of Hope's method) to classes in years gone by. But not only does water expand on cooling from 4° C. to 0° C., it also further expands in the act of congelation, a fact with which most householders have unpleasant familiarity in severe frosty weather. The force of this expansion is enormous. Some thirty years ago we obtained actual demonstration of this at Wellington College, when a bomb-shell, 9 inches in diameter, with walls of solid cast-iron 1½ inches thick, was burst into three large fragments by simply exposing the shell (after being filled with water at 4° C. and closed with the gun-metal plug) to

the severe frost of a January night. The importance of this in the economy of nature is pointed out by Professor Hull; but I wonder that, as a geologist, he did not lay some stress upon the important work which it does in the degradation of mountains and of sea-cliffs as well as in pulverising the soil during frost, with beneficial results known to every agriculturist.

(2) But another deduction follows from this law, and from the converse fact, that pressure acting hydrostatically upon ice causes it to melt or liquefy. This was splendidly demonstrated years ago by Helmholtz and others.* Now, as pressure upon ice tends to its liquefaction, so pressure upon water at 0° C. prevents its congelation. This is the true explanation of the fact that water can exist in the liquid state at ocean-depths at very low temperature; and we cannot therefore follow Professor Hull, when (in the second part of his paper) he attributes this fact to the incompressibility of water. Pure water is compressible to only about one twenty-thousandth of its bulk; but most water, as it occurs in nature, holds atmospheric or other gases in solution (a fact which is easily demonstrated), and is rather more compressible accordingly. Still, for practical purposes water may be said to be incompressible, and the important results of this have been dealt with by Professor Hull.

(3) In connection with this subject there is however one point which has not been touched upon in the paper, although it must be of philosophical interest to many members of the Victoria Institute. We can follow Professor Hull in pointing to the abnormal behaviour of water in expanding from 4° C. to 0° C., with all its important consequences, as one of the strongest evidences of Creative Design which Physical Science discloses to us, because it is *unique* among liquids. But we must not confound this fact with the other fact, that in the act of congelation it undergoes further expansion, since in this matter it is not unique. Bismuth and cast-iron undergo similar expansion; and in the case of the former, the fact is turned to account in using an alloy of bismuth and lead for casting type-metal, the expansion of one metal compensating for the contraction

* Liquefaction under pressure and regulation is a most important factor in the flow-movement of glaciers. See my paper on "The Mechanics of Glaciers," in the *Quarterly Journal of the Geological Society* (February, 1883).

of the other. Failing to draw this distinction so good a physician as the late Professor Tyndall went out of his way to deal (in some of his writings) feeble blows at the teleologist. It was an instance of dealing blows into the air, *vires in ventos effundere* (Virg.)

Professor HULL's reply.—That water "further expands in the act of congelation," as Dr. Irving points out, is of interest; though I question whether the experiment at Wellington College proves more than that at zero of Cent. the expansion had reached its maximum; and water *being incompressible ex necessitate* burst the bomb.

As regards Dr. Irving's "wonder" that as a geologist I did not enter upon the agency of water in eroding mountains, etc., my reply is that these were outside the range of my subject. My object was to point out the abnormal characteristics of water, and their evidence of Design in Nature. Until I received Dr. Irving's criticism I was not aware that this subject had been treated by a Senior Wrangler of Cambridge, or any other writers; the advantage of this is, that both essays, that of Canon J. M. Wilson and my own, are original.