ARTICLE III.

NATURAL THEOLOGY: THEORY OF HEAT.

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PART 1.—THEORY OF HEAT IN ITS RELATION TO WATER.

THE welfare of man is more closely dependent on the agency and laws of heat than on any other physical force. It concerns his most constant and imperative necessities. Houses and clothing are needful mainly because they protect us from cold. Food is required to produce the vital heat which is the condition of comfort and the source of motion, while it is itself produced by the heat of the sun. All the phenomena of climate and of the weather are controlled by the laws of heat. Every motion on the earth (except that of aerolites and the tides), and every dynamic power which man can create or direct, is ultimately the work of heat.[1]

As this agent relates to the more simple and tangible wants of man, we may expect that its laws will give very plain indications of the character of their Author. As it affects the material conditions of man at so many points, we should look for very copious evidence. This is true to such an extent that this Article will be confined to a single subdivision of the subject; namely, some proofs of the knowledge and goodness of God derived from the laws of heat as related to water.

1. The boiling-point of water affords proofs of the wisdom and goodness of God.

There is no physical necessity that this should occur at two hundred and twelve degrees of the Fahrenheit scale. As far as we know it might have been made the same with the boiling-points of oil of turpentine, alcohol, or ether. We shall see the benevolence of the present adjustment by noticing some of the consequences which would follow if any change were made.

[1] See Heat considered as a Mode of Motion: By John Tyndall, F.R.S., (New York: D. Appleton and Co., 1863), pp. 446, 447.

The amount of vapor given off at ordinary temperatures by any liquid depends on the temperature at which it boils. If the boiling-point of water were the same as that of alcohol, the vapor given off by the ocean would be two and a half times as much as at present.[1] Such an excess of aqueous vapor would produce continual rains and inundations, and would make the air too damp for animal, and too cloudy for vegetable, life. If water boiled at the same temperature as ether, the vapor rising from the ocean would be more than twenty-five times as much as at present.[1] In such a state of things no man could see the sun on account of the clouds; the rain would be so excessive as to tear up the soil and wash away plants; inundations would be constant, and navigation would be impossible in the inland torrents which would take the place of our rivers. In winter the snow of one day might bury the houses.

If, on the other hand, water boiled at the same temperature with oil of turpentine, the vapor given off by the ocean would be less than one fourth of its present amount.[1] In this case rain would be a rarity like an eclipse of the sun, the dryness of the desert of Sahara would be equalled in a large part of the globe, which would therefore be bare of vegetation, and incapable of sustaining animal life. Plants would be scorched by unclouded sunshine, springs and rivulets would be dry, and inland navigation would cease; for nearly all the rain would be absorbed by the porous earth.

We see then that the boiling-point of water has been adjusted to various relations. It is adjusted to the capacity of space to contain aqueous vapor in a transparent state; if it were higher than two hundred and twelve degrees the earth

[1] See Elements of Chemistry, Theoretical and Practical. By William Allen Miller, M.D., LL.D., Part i. Chemical Physics (From the Third London edition. New York: John Wiley, 1864), table p. 274. The tension of the vapor of water at 68° F. (the most suitable temperature mentioned), is 0.686; of the vapor of turpentine, 0.168; of the vapor of alcohol, 1.732; and of the vapor of ether, 17.117. $\frac{.168}{.686} = \frac{1}{4}$ nearly; $\frac{1.732}{.686} = 2\frac{1}{2}$ nearly; $\frac{17.117}{.686} = 25$ nearly. The density of aqueous vapor is assumed constant.

would be scorched by an unclouded sun; if it were lower, it would droop under continual shade. It is suited to the demand of plants for water; if it were higher, they would suffer from drouth; if it were lower, they would be torn up by floods. It is in harmony with the texture of the soil; if it were higher, the earth would absorb all the rain which falls; if it were lower, the soil would often be washed away by the surface torrents after a shower. It is adapted to the elevation of the continents above the sea; if it were higher, rivers with their present inclination would be so shallow as to be often dry; if it were lower, most rivers would be so deep as to be torrents, while the land would be covered with floods.[1]

But some one objects: "We have no right to assert that the constitution of water has been adjusted to the other objects to which it is related. This may have been fixed first, and other things adjusted to it." Certainly; but the fact of *adjustment* remains. Whether the key or the lock be made first, we equally see the skill of their maker in the accuracy of their mutual adaptation.

It may be said: "If the boiling-point of water had been higher or lower, other things would have been so arranged that these injurious consequences should be avoided. Plants might have been made so as to require less moisture, and thus no evil would have followed."

This objection assumes what we are attempting to prove: If the Author of nature is wise and good he will in some way avoid the evils mentioned above. Then the question comes: Is he wise and good? This we can answer by looking at the nature of the contrivances he uses. We examine the delicate mechanism of a chronometer; we are told that if a certain part were the hundredth of an inch shorter, a slight jar might stop its motion at any time, while if the same part were as much longer, excessive friction would destroy all accuracy. We remember that if the chronometer either stops or is in

[1] On this topic the following may be consulted with advantage: Tyndall on Heat, p. 130; Miller, Chemical Physics, p. 272 seq.; Nichol, Cyclopaedia of the Physical Sciences, p. 208.

error, the ship may be lost; and we cannot avoid the conclusion that some skilful artist both knew of these evils and made choice of the means of preventing them. If the boiling-point of water were slightly different, the evils mentioned above would follow. They have been avoided, and we cannot resist the conclusion that the present adjustment was adopted by one who knew what would be the evils of any other, and who chose to avoid them. Then he is wise and good.

2. The adjustments of the freezing-point of water exhibit the wisdom and goodness of God.

No physical necessity is known by virtue of which water must freeze at thirty-two degrees, and not rather thirty degrees higher or lower. The results which would come from a change in either direction show that the selection of the present freezing-point, rather than any other, is a mark of benevolence.

If the freezing-point of water were raised ten degrees, in Massachusetts very few weeks of the year would be free from frost. The climate of Okak, "where the missionaries inform us that on the first of May, 1837, their yard was covered with snow to the depth of from five to eight yards, and in August it snowed anew,"[1] would almost be equalled in some parts of New England. This state of things may not imply a degree of cold injurious to animal life, as the winter might on the whole be no colder than now; but it would destroy vegetation, partly by frequent frosts, which would cut down individual plants, and partly by the shortness of the summer, which would prevent whole species from maturing seed. Rivers would be closed to navigation much longer than now, and the salt water of our harbors would often freeze.

If, on the other hand, the freezing-point of water were lower by thirty degrees, the consequences would be yet more serious. Ice keeps the water under it at a temperature a little above thirty-two degrees. If water could cool down to zero before receiving this protection, the polar seas would become immense reservoirs of perpetual cold which aqueous

[1] Quoted in Nichol, Cyclopaedia of the Physical Sciences, p. 401, *b*.

and aerial currents would diffuse through the temperate zones. Snow would not fall to protect the roots of plants till most of them had been destroyed by cold; and most of the snow which now falls without harm to animals would fall as rain at a temperature near zero, and kill every being exposed to it. If the discomforts and blustering winds of our March thaws came at zero, they would be unendurable.

Thus the freezing-point of water is adjusted to the mean temperature of spring and summer, being far enough below it to save plants from destructive frosts. It is also adapted to the length of summer and autumn, permitting the plants of each latitude to mature their seed. It is in harmony with the capacity for endurance possessed by animals, saving them from the consequences of a rain or a thaw at zero.

Does one believe that this adjustment is the result of accident or chance? He should believe that two and two are four by accident, that every event has a cause by accident. Such a belief is an accident which happens to no sane mind. Does one think that possibly an ignorant contriver stumbled on so happy a medium? Ignorance would stumble on something as inept as this opinion. Does any one doubt whether, after all, a malevolent being may not have chosen so beneficent a relation of means to ends? Only malignity towards infinite benevolence can sanction a mode of reasoning so at variance with all our laws of thought. We cannot resist the tendency of our minds to infer that this particular adjustment was made because its consequences were known and its benefits regarded as desirable. Then its Author is wise and good.

3. The high specific heat of water affords further proof of the wisdom and goodness of God.

The specific heat of any substance is the quantity of heat required to raise its temperature one degree, taking for our unit the quantity of heat expended in warming the same weight of water one degree. As a stiff and a flexible bow require very different amounts of strength to bend them equally, different bodies require very different amounts of heat to warm the same weight equally.

It is a fact which has elicited much attention, that the specific heat of water is greater than that of any other known substance. The heat which would warm one pound of water eighteen degrees and one half, would raise the temperature of a pound of lead from thirty-two degrees to its melting-point.[1] The heat which would warm a pound of water thirty-one degrees, would make a pound of gold red-hot.[2] The heat which would boil three pounds of ice-water would melt nineteen pounds of ice-cold lead.[3]

Were the specific heat of water small, the extremes of summer and winter would be too excessive.

Through its enormous power of storing up heat, the ocean acts the part of a balance-wheel, preventing sudden or great variations of temperature. A part of the sea, three hundred and twenty-five feet deep, having the same area as Massachusetts, contains so much heat that by cooling one degree it would warm all the air over that State forty degrees.[4] If the specific heat of water were the same as that of mercury, forty degrees would be reduced to less than one and one third,[5] and the effect of the ocean in moderating the extremes of heat and cold would be but a thirtieth of its present amount. How important this influence is, may be inferred from a comparison of two places, one of which feels its full power, while the other receives a smaller share. The eastern coast

[1] Fusing point of lead [Miller, Chemical Physics, p. 248], 620° F.; specific heat [*id.* p. 241], 0.0314, water being the standard; $[620° - 32°] \times .0314 = 18.46°$.

[2] Lowest temperature at which metals become luminous [Miller, p. 121], 977°; specific heat of gold [*id.* p. 242], 0.03244; $[977° - 32°] \times .03244 = 30.66°$.

[3] Fusing point of lead [Miller, p. 248], 620°; specific heat [*id.* p. 241], 0.03140; latent heat of fusion [*id.* p. 247], 9.65°; $\frac{212° - 32°}{(620° - 32°) \times 0.03140 + 9.65°} = \frac{19 \text{ lbs.}}{3 \text{ lbs.}}$ nearly.

[4] Corrected height of barometer at Cambridge, Mass. [Guyot, Tables Meteorological and Physical, third edition, series D, folio 85], 30.010; specific gravity of mercury at 32° [Lardner, Hand-book of Natural Philosophy; Hydrostatics, Pneumatics, and Heat (London, 1858), p. 65], 13.598; specific heat of air [Miller, p. 237], 0.2375; $\frac{325 \times 12 \text{ in.}}{30.01 \text{ in.} \times 13.598 \times 0.2375} \times 1° = 40.24°$.

[5] Specific heat of mercury [Miller, p. 241], 0.03192; $40.24° \times .03192 = 1.28°$.

of Iceland is only twenty degrees colder in January than in July;[1] the surrounding water stores up in summer the heat which would be injurious, and returns it to the air in winter when it is needed. But Jakoutsk, in the interior of Siberia, farther from the compensating power of the ocean, suffers a variation of more than a hundred and fourteen degrees in the mean temperatures of those months.[2] No man can tell from what extremes more terrible than this even Jakoutsk is saved by the large specific heat of water. If this were the same as that of lead, or one thirty-second part of its present amount, this compensating power of the ocean would be so small as to be of no avail. The winter of New England would too closely resemble that of Jakoutsk, where mercury is frozen more than three months of the year, and the summer that of Soudan, where sealing-wax melts and ether boils in the shade.

Were the specific heat of water small, bodies of water on the earth would receive too much heat in summer.

Green River in Williamstown has a temperature during August of sixty-nine and a half degrees.[3] Shallow pools become somewhat warmer than this. If water had the same specific heat as lead, a thirty-second part[4] of its present amount, the heat which warms a river three degrees would be sufficient to warm it ninety-six degrees. Small rivers would therefore become too hot for animal life during August. They would almost boil away on a hot day. The amount of vapor given off would be excessive; fogs would be constant, and the miasma resulting would be intolerable and destructive. This vapor would come down in torrents of rain, as we have indicated above, tearing up the earth, sweeping off vegetation, and destroying the works of man.

[1] Nichol, Cyclopaedia of the Physical Sciences, p. 727, and Johnston's Physical Atlas, Isothermal Charts and accompanying text.

[2] 114.26°, Dove, Report of British Association, Meeting at Oxford, 1847, p. [76] (following p. 376); Nichol and Johnston, loc. cit.

[3] From Manuscript Observations by Professor Dewey, Library of Williams College.

[4] Specific heat of lead [Miller, p. 241], 0.03140 = $\frac{1}{32}$ nearly.

From this survey it would seem, therefore, that the specific heat of water has been adjusted to other parts of the system to which it is related. It is adjusted to the specific heat and to the weight of the atmosphere, and the variations of the seasons are not too excessive. It is adapted to the conditions of comfort for animal life, and the changes from heat to cold are neither too large nor too rapid. It is in harmony with the amount of heat received by the earth from the sun, and therefore water does not become too hot in August. It is suited to the amount of water on the land, so that lakes do not become so nearly dry as to cause miasma. It is adapted to the consistence of the soil; rains are not so copious as to wash it away. It is adjusted to the laws of vision, and fogs do not render eyes useless. If such thoughtful and benevolent provisions do not prove that their cause is wise and good, nothing can be proved.

4. The high latent heat of water affords proof of the wisdom and goodness of God, perhaps more strikingly than the preceding.

In melting any solid a certain quantity of heat is expended, not in making it warmer, but in causing a purely *mechanical* change, in forcing asunder the particles of the body. This heat is said to become latent. The latent heat of melted ice is enormous. To melt a cubic yard of ice already at the temperature of thirty-two degrees, requires all the heat produced by burning a bushel of charcoal.[1] This heat would raise seven hundred and five pounds of cast iron from thirty-two degrees to its melting-point.[2] To melt a ton of ice already at thirty-two degrees, demands as much heat as would raise fifteen hundred and twenty-six pounds of copper,[3]

[1] Miller, p. 246; applies *to dry* charcoal.

[2] Fusing-point of cast iron [Miller, p. 248], 2786°; specific heat [*id.* p. 241], 0.11379; latent heat of water at 32° [*id.* p. 247], 142.65°; weight of cubic yard of most compact ice, about 1550 lbs.; $\frac{142.65^\circ}{(2786^\circ - 32^\circ) \times .11379} \times 1550$ lbs. = 705.6 lbs. As specific heat increases with temperature, this is somewhat too large.

[3] Specific heat of copper [Miller, p. 241], 0.09515; fusing-point [*id.* p. 248], 1996°; $\frac{142.65^\circ}{(1996^\circ - 32^\circ) \times .09515} \times 2000$ lbs. = 1526.7 lbs.

or four thousand four hundred and thirty-two pounds of gold,[1] or fifteen thousand four hundred and fifty-two pounds of lead[2] each from thirty-two degrees to its melting-point. All this heat is expended without warming the ice a thousandth of a degree.

If the latent heat of water were small, the cold of winter would be too great.

When water freezes, its latent heat is communicated to the air, which is at this time colder than the ice. The amount of heat thus given off is very great. The freezing of Lake Superior two and a half feet thick would be sufficient to warm all the air over the lake forty-one degrees.[3] The air is warmed just as much as it would be by an equal area covered nine and three quarter inches deep with red-hot cannon balls.[4] Thus in colder climates water becomes a very powerful equalizing agent; when the air is colder than thirty-two degrees, the water by freezing gives out this latent heat, and prevents the air from becoming too cold. The heat of summer and the cold of winter are thus made to counteract each other. But if water had the same latent heat as mercury, this equalizing effect would be only one twenty-eighth of its present amount, and the cold of winter would be too extreme.

If the latent heat of water were small, the transitions from autumn to winter and from winter to spring would be destructively sudden.

[1] Specific heat of gold [Miller, p. 242], 0.03244; fusing-point [*id.* p. 248], 2016°; $\frac{142.65}{(2016^\circ - 32^\circ) \times .03244} \times 2000$ lbs $= 4432.8$ lbs.

[2] Specific heat of lead [Miller, p. 241], 0.03140; fusing-point [*id.* p. 248], 620°; $\frac{142.65^\circ}{(620^\circ - 32^\circ) \times .0314} \times 2000$ lbs. $= 15452.4$ lbs.

[3] Combining data given in note 4, page 657, and note 2, page 659, with the specific gravity of ice [Miller, p. 100], 0.923, we have $\frac{30 \text{ in.} \times .923 \times 142.65}{30.01 \text{ in.} \times 13.596 \times .2375} \times 1^\circ = 40.76^\circ$.

[4] Combining data given in notes 2, page 657, 2, page 659, and 3, page 660, with the specific gravity of cast iron [Lardner, p. 65], 7.20 and the formula for solidity of spheres, we have $\frac{142.65^\circ \times .923}{.11379 \times (977^\circ - 32^\circ) \times 7.20 \times .5236} \times 30$ in. $= 9.74$ in.

When a ton of water freezes it gives out enough heat to raise one hundred and forty-three tons of water one degree.[1] Till this heat is carried away by the air no more water can freeze. This takes time; hence congelation is retarded, and transitions to greater cold are made more uniform. It is a fact of common observation that near a river the weather is always milder while it is freezing than afterwards. In the same way when a ton of ice melts, it absorbs enough heat to cool one hundred and forty-three tons one degree; till this amount is replaced by the sun and air, no more ice can thaw. The changes from water to ice and the reverse are therefore produced as slowly as is necessary to secure a sufficient interval between radical changes in the seasons, and to preserve vegetation from too rapid freezing. Trees are found by lumbermen in Maine frozen so hard that they cannot easily be cut till they thaw. They can endure such cold because the process of freezing is so gradual that the organs of the tree have time to adjust themselves to it. But if water had the same latent heat as mercury, this retarding influence would be only one twenty-eighth as much as at present, and trees in northern latitudes would freeze with such rapidity as to be riven in pieces.

If the latent heat of water were small, the transition from winter to spring would bring destructive floods.

Were the latent heat of water the same as that of mercury, the amount of heat which thaws half an inch of ice or six inches of snow would thaw fourteen inches or fourteen feet. One sunny day in spring might do much more than this, and every spring would bring such floods that no work of man could be placed near a river, for it would be undermined, crushed, or carried away. No meadow could be cultivated, for it would be alternately torn up and covered with boulders, gravel, and sand. The tremendous flood caused by an eruption of lava which covered a deep snow lying on the sides of Etna, or a similar deluge in Quito, which filled up valleys with six hundred feet of mud, stopped the course of rivers

[1] Latent heat of fusion of ice [Miller, p. 247], 142.65°.

and made new lakes,[1] are hints of what we might expect every spring, if the latent heat of water were like that of mercury, and the ice and snow which now melt in twenty-eight days should therefore melt in one sunny afternoon.

We see, then, that the latent heat of water has been carefully adjusted to other parts of a system on which the welfare of sentient beings depends. It is adjusted to the amount and to the specific heat of the air; it is large enough to warm the atmosphere as much as is needed to make the winter tolerable. It harmonizes with the structure of plants, changes between seasons are not too sudden, trees do not freeze fast enough to destroy them. It is adjusted to the amount of snow, and hence to the amount of vapor which produced that snow, to the length, size, and inclination of rivers, and to the amount of heat received from the sun, so that we are delivered from an annual inundation on an immense scale.

Was it accident or necessity by which the latent heat of water was thus adjusted to the welfare of organic life? An accident or a necessity so thoughtful, so benevolent, deserves a far nobler name.

5. Further proof of the divine wisdom and goodness is seen in the law of expansion of water.

Most substances expand with heat. Some, on the contrary, contract with heat and expand when cooled, like india-rubber.[2] Some expand in one direction and at the same time contract in another, like Iceland spar.[3] Some substances have a point of maximum density; whether they are warmed above or cooled below that point, they expand in volume and become specifically lighter. Rose's fusible metal is an instance.[4]

Here it is obvious that there is a wide range of selection.

[1] Lyell's Principles of Geology (New York, 1865), pp. 411, 412, and pp. 469, 470.

[2] Tyndall, Heat, etc., pp. 101, 102.

[3] Tyndall, Heat, p. 100; Miller, pp. 187; 211, 212.

[4] Thomson, Outlines of Chemistry, etc., p. 27.

Water might uniformly expand with heat, it might uniformly contract with heat, or it might have a point of maximum density; and this point might occur at any number of degrees above or below the freezing-point.

If the first of these laws of expansion were adopted for water, rivers would freeze solid in winter.

Water, as it cools at the surface, becomes heavier and sinks. If this process went on down to thirty-two degrees, the lower strata would become coldest, and would freeze first. The freezing of the upper strata would be progressively easier, and the whole would become solid. This would destroy all the life contained in our lakes and rivers. Ice forming in channels would be as destructive to shipping as are sunken rocks, while it would be far more difficult to avoid.

If the first of these laws of expansion were adopted in the case of water, rivers would not thaw in spring.

Should ice form on the ground, under the current of a river, it would remain there, kept down by adhesion and by the superincumbent pressure. In spring the sun could not melt it; his rays could not penetrate the water above it. The warm winds could not melt it; they cannot touch it. The warmer water of the surface could not melt it with sufficient rapidity. Thus no rivers in this latitude would melt till summer or autumn, while many would be always frozen.

If the first of these laws of expansion were adopted, the banks of our rivers would be barren and uninhabitable.

Ice-houses may be filled with solid ice in a few cold days by letting water fall slowly on the surface of the ice already formed. There is scarcely any limit to the thickness which ice will attain when kept covered with a thin stratum of water. Were the first of these laws of expansion adopted, so that ice began to form under water rather than at the surface, as indicated above, the channel of a river would soon be filled with ice, the stream being still fed by springs would overflow its banks, this inundation quickly freezing would force the water to rise still higher, freezing as it rose. Thus nearly all the water which now during the winter runs under the ice of our rivers to the sea would lie in a solid form on their banks. The waters of spring flowing over this mass would protect it from melting. In this way large rivers in northern latitudes might become perpetual glaciers, while the meadows around small streams, now the most fertile parts of the land, would be made the most barren by the ice which would remain till summer or autumn.

We thus see that the first law of expansion would bring disastrous consequences. But if the second were adopted equal disasters would follow.

If water, like india-rubber, uniformly contracted with heat, the surface of the ocean would always be the coldest, for the warmer strata would sink. Much of the present animal life in the sea could no longer exist in this case, for it could endure neither the cold of the surface nor the pressure at a depth. The cold of the surface of the ocean would also lessen evaporation, and the consequent dryness of the land would be fatal to many species of plants, and dangerous to man.

If now the third law is adopted, most of its possible adjustments fail to obviate these evils.

There is no physical necessity that the point of maximum density of water should occur a few degrees above its freezing-point. It might be forty-five degrees below the point of congelation as in fusible metal;[1] it might be as many degrees above. But if the maximum density of water should occur at sixty or seventy degrees, all the evils of adopting the second law of expansion would remain; if it were below the freezing-point, the effects of the first law would still be felt. This point is therefore carefully adjusted to the wants of organic life by placing it higher than the freezing-point, but higher by only the four hundred and eightieth part of the measured range of temperature, so as to avoid all the evils which would be the result of the first or second laws of expansion. Lakes do not become solid, for when the upper stratum of water has cooled to thirty-nine degrees it no longer sinks, and the inferior strata can assume a lower tem-

[1] Thomson, Outlines of Chemistry, etc., p. 27.

perature than this only by conduction, which in water is a very slow process. A coating of clay and sand five eighths of an inch thick will contain melted iron for twenty minutes without becoming too warm for the hand.[1] Water is a yet poorer conductor of heat,[2] and therefore in winter it cools from the surface with great difficulty. But when the temperature of the air is above thirty-nine degrees, the warmer stratum is at the surface, and evaporation is unchecked.

One point is to be noticed. This protection against becoming solid, which lakes and rivers need, would be useless or hurtful in the case of the ocean. Currents carry to equatorial climates the cold strata which sink from the surface. Hence that adjustment of molecular forces on which the temperature of maximum density depends, is so modified by the addition of salt that it occurs below the freezing-point.[3] For this reason not much ice is formed upon the surface of sea water, and ascending currents of warmer water are thus permitted to exert an important ameliorating influence on climate.

Thus it is seen in how many respects the expansion of water has been so adjusted as to promote the comfort of sentient beings. It harmonizes with the condition of lakes and rivers; if fresh water had no point of maximum density, they would become solid in the winter, and would not thaw in summer. It is suited to the conditions of organic life; if this point of maximum density were much higher, many species of salt-water fish would become extinct; if it were seven degrees lower, fresh-water fish would die. It is adjusted to the convenience of agriculture; if the point of maximum density were seven degrees lower, our most fertile and most conveniently situated meadows would be covered with ice till harvest time. It is adapted to the demands of

[1] Nichol, Cyclopaedia of the Physical Sciences, p. 167.

[2] Lardner, Hand-book, etc., p. 356.

[3] Temperature of congelation [Miller, p. 200], 27.4°; of maximum density, [ib.] 25.38°.

vegetation; if water contracted for many degrees above the freezing-point, rain would be too scanty.

It is therefore evident that of the three laws of expansion which might be given to water, only the last is consistent with the comfort of sentient beings, while of the many variations of this which are possible, only one is useful. No greater range for selection and adjustment occurs in any human mechanism whatever. No human work can less reasonably be ascribed to accident or necessity. No human contrivance more imperatively demands that we refer it to the skill and goodness of a designing mind.

6. Further proof of the wisdom and benevolence of God may be derived from the sudden expansion of water at the moment of becoming solid.

Some liquids in the act of congealing undergo a sudden contraction. It is for this reason that silver and copper cannot be made to take the exact shape of the mould in which they are cast.[1] Some liquids pass to the solid state with no appreciable change of bulk. Sulphuric acid is an instance.[2] Some liquids, on the contrary, suddenly expand as they become solid. It is on account of such an expansion that cast iron and type metal take an accurate impression of a mould.[3]

Water, in freezing suddenly, expands about one twelfth of its bulk with almost irresistible force.[4] By the freezing of half a pint of water in a cavity, a large anvil has been burst with such violence as to hurl a sledge hammer several yards.

If water did not thus expand in freezing, the effects on rivers and lakes would be disastrous.

Were ice heavier than water it would sink immediately after its formation. If it were neither heavier nor lighter it would soon contract as its temperature falls; it would then have a larger specific gravity and would sink. The channels

[1] Lardner, p. 304; Miller, p. 100.

[2] Lardner, p. 304.

[3] Lardner, p. 304; Miller, p. 100.

[4] Miller, p. 100 (cf. Lardner, p. 303).

of rivers would thus be filled up, and the stream overflowing its banks would cover them with ice. This, being under water, would not readily thaw in spring, as has been mentioned before. In this case, also, icebergs floating from the polar seas would not rise above the surface of the ocean, and would thus give ships no warning of their approach. In the waters of warmer latitudes they would sink; having so nearly the same specific gravity with water, they would easily be carried about by currents at the bottom of the sea. No science or seamanship could avoid such movable rocks and shoals, while no art could ensure the safety of an oceanic telegraph under the influence of such destructive agents. The channels of our rivers would be closed to navigation for part of the year by the same cause. It may readily be seen that the same results would follow if the expansion of water in solidifying were so small as not to produce a buoyancy which compels ice to float in water, whatever may be their relative temperatures.

Did not water thus expand in freezing, the soil would be less fertile.

The expansion of moist earth in solidifying extends to every particle, breaking up hard clods, and thus rendering the soil more fertile by making it so soft that the roots of young plants can easily penetrate it. Although this influence may be unnecessary in warmer climates, yet wherever the severity of the winter materially shortens the season of vegetable growth, it is of great importance. Further than this,—much of the soil of every zone was produced from the solid rock by this agency. Water penetrating the substance of the rock is frozen; by its expansion it rends off flakes of disintegrated material, which quickly crumble to arable earth. Every one has noticed with what ease pebbles may be picked from the surface of conglomerate; the fact is owing to this agency. The softer rocks which can be reduced to soil by other means do not yield all the elements necessary to healthful vegetable life. No quartz could be decomposed by sun and rain, but this element is indispensable to the growth of wheat. If, then, it were not for this power which can break down any rock that absorbs moisture, much of the fertility of the soil would be wanting.

The sudden expansion of water in the act of freezing, then, gives evidence of that careful adjustment to its place in the world which has been seen in its other qualities. It is suited to the condition of lakes and rivers; were it not for this provision they would freeze nearly solid, would cover their banks with ice, would remain frozen through the spring, and would be made innavigable. It harmonizes with the chemical constitution of plants, by providing them with those elements which are essential to them. It is adjusted to the mechanical conditions of vegetable life; it softens the earth so that the rootlets of plants can penetrate the soil.

If all liquids expanded at the moment of congelation we might have supposed that the injurious consequences described had been prevented by the necessary limitations of the nature of matter. This is so far from being the fact that we find a range of selection as wide as that occurring in the adjustment of any human mechanism whatever. From this variety we are compelled to believe that nothing but knowledge and goodness can have selected the only suitable law.

7. The fact that water is a non-conductor of heat likewise indicates the divine wisdom and goodness.

It is so poor a conductor that the heat received at the surface of the ocean is not conveyed downwards, but retained at the surface, thus promoting evaporation. If it were not for this provision, the amount of rain would be too scanty.

The non-conducting power of water is in curious harmony with its solvent power. Much of the usefulness of water as a detergent depends on the fact that its solvent power is increased by heat. If this higher solvent power were possessed at a lower temperature, the water of rivers and lakes and of our wells would resemble that of mineral springs in the amount of saline and earthy matter held in solution by it; were it a good conductor of heat, at the temperature at which it has this high solvent power its domestic use would be difficult, as the hand could not endure contact with it.

The non-conducting power of water has more important relations to vegetable life. The roots of biennial and perennial plants lose their vitality if exposed to a cold excessively below the freezing-point. Hence soon after they are frozen and fitted for their season of rest snow covers them with a non-conducting garment, while the gentle warmth which the summer sun imparted to the soil is slowly conducted back to the surface.[1] Part of this protecting power of snow is due to its texture, but part it possesses in common with water. Were it not for this protection the consequences to vegetation in the higher latitudes would be disastrous.

To the same property of water is it due that the thickness of ice on our lakes and rivers is kept within bounds. When a layer of ice twelve inches thick is formed, in order that another inch may be added, an amount of heat must be given out through each square foot of surface which would warm twenty-four pounds of lead from thirty-two degrees to a temperature above its fusing-point.[2] Through such a poor conductor as ice, this takes place slowly. Had ice the conducting power of lead or of gold, our rivers would freeze nearly solid. The evil results of such a state of things require no further description, and both the knowledge which could anticipate them, and the goodness which chose to prevent them are proved, if anything can be proved.

8. One proof of the divine wisdom and goodness is seen in a curious adjustment between the attraction of the particles of water for each other and their attraction for atmospheric air.

Water at ordinary temperatures holds in solution a small amount of air. If this be expelled, water may be heated even a hundred and forty-eight degrees above its boiling-

[1] Somerville, Connection of the Physical Sciences, (London) p. 288.

[2] Uniting the data used in note 3, page 657, the latent heat of water, 142.65° and the weight of a cubic foot of ice, 57.5 lbs. nearly, we have

$$\frac{142.65^\circ}{(620^\circ - 32^\circ) \times .03140 \times 9.65^\circ} \times \frac{57.5}{12} \text{ lbs.} = 24.31 \text{ lbs.}$$

point.[1] At this temperature a slight jar will cause a violent explosion; for in a fraction of a second the water is converted into two hundred and sixty times its own volume of steam.[2] The homogeneity of the fluid prevents it from boiling at the proper temperature; if air is dissolved in water it is no longer homogeneous; some particles of water are ready to separate into steam, and the process once commenced goes on quietly. The tremendous attraction of particles of water for each other is necessary for several reasons; but unless this attraction can be quietly destroyed, water is useless for culinary purposes. Therefore, besides all the other qualities which fit water for its place, this, whose minuteness almost eludes our notice, is indispensable, and the Author of these qualities has the wisdom and goodness to add this.

9. The wisdom and benevolence of God are seen in the fact that the latent heat of aqueous vapor is very great.

In converting any liquid into vapor a certain amount of heat disappears, being transformed into the force which separates the particles of the liquid. This is called latent heat. The latent heat of aqueous vapor is very great. To convert one pound of water into vapor without raising its temperature the hundredth of a degree demands an amount of heat which would make nine pounds of iron red-hot.[3] The rain which covers an acre one inch deep, in its conversion into vapor absorbs enough heat to raise three hundred and eighty-five tons of iron to its melting-point.[4]

The latent heat of aqueous vapor is not only absolutely but

[1] "Even as high as 360° [F.] in an open glass vessel." Miller, pp. 256, 257.

[2] Latent heat of steam at 212° [Miller, p. 260], 966.6°; expansion of water in becoming vapor at 212° [ib.], 1695 volumes; $\frac{360° - 212°}{966.6°} \times 1696 = 259.68$.

[3] Using data in notes 2, pages 657, 659, and 670, $\frac{966.6°}{(977° - 32°) \times .11379} \times 1 \text{ lb.} = 8.99 \text{ lbs.}$

[4] Latent heat of aqueous vapor at 66° [Lardner, p. 346], 1067.4; fusing-point of iron [Miller, p. 248], 2786°. This amount of rain weighs about 113 tons. Combining these data with the specific heat of iron $\frac{1067.4°}{(2786° - 32°) \times .11379} \times 113.07 \text{ tons} = 385.14 \text{ tons.}$

relatively very great. Comparing equal weights it is more than twice that of any other liquid known. The advantages which come from this provision cannot be estimated too highly.

It is by this provision that rain is diffused through the temperate zones.

It is somewhat difficult to distil mercury, because the vapor condenses so easily that it falls back as a mercurial rain almost as soon as it leaves the surface of the liquid. The latent heat of its vapor is so small that it is quickly lost. It is by giving to the vapor of water a latent heat absolutely and relatively very great that rain and moisture are conveyed to all parts of the earth. If water were like mercury in this respect, winds could carry their stores of rain but a few leagues, and coasts receiving moist winds from the ocean would be deluged with rains like those of Cherrapoongee at the mouth of the Ganges, where forty-four feet have fallen in six months, and even thirty inches in twenty-four hours.[1] Such a denudation of the soil would be caused that our fertile coasts would become barren moorlands, and many harbors would be destroyed. Lands more remote from the sea would suffer like the west declivity of the Andes, the winds which should bring it rain having lost every drop in passing over the eastern slope. New England would be dry like the great African desert, for no clouds could transport aqueous vapor to so great a distance from its source. Great Britain, too, would suffer; her rains are produced in the Caribbean Sea, and unless the vapor of water had a latent heat nearly eight times as large as that of oil of turpentine[2] it would never cross the ocean, but would precipitate itself on the Atlantic.

It is by this provision that tropical regions are kept so cool as to be habitable.

The heat which becomes latent in the vapor of water would make the same weight of water red-hot if kept under

[1] Lyell, Principles of Geology, p. 260.

[2] Miller, p. 265.

pressure.[1] All this heat is carried away, and the remaining water left cool. At the equator so immense an amount of heat is made latent by evaporation and transferred beyond the tropics, that in July the temperature of the hottest parts of Mexico is only sixteen degrees greater than that of Andover. The heat which otherwise would make the tropical zone like the Australian desert, where if a match falls on the ground it instantly ignites,[2] becomes latent, and is transferred to regions where its power for good is as great as would be its influence for evil were it not removed.

It is by this provision that heat is carried from tropical to extra-tropical regions.

One pound of aqueous vapor gives out in condensing, as much heat as nine pounds of red-hot iron give out in cooling to zero.[3] A rain covering the ground one inch deep brings to every acre heat enough to make one-thousand one hundred and twenty-two tons of iron red-hot.[4] A rain of this depth covering the State of Massachusetts is sufficient to warm all the superincumbent atmosphere eleven degrees.[5] A snow of the same weight, about twelve inches in depth, would warm the air more than twelve degrees.[6] Every one has noticed that it does not snow in very cold weather; this is largely owing to the fact that the condensation of vapor which precedes its fall has already warmed the atmosphere.

Many facts show how important an ameliorating influence is thus exerted on cold climates. It is necessary that there be

[1] Sum of latent and sensible heat of steam [Miller, p. 266], 1178.6° F. Solids become luminous at 977° F. [*id.* p. 121].

[2] Dove, Distribution of Heat, Note on p. 22.

[3] From previous data; $\frac{1067.4^\circ}{977^\circ \times .11379} \times 1 \text{ lb.} = 9.6 \text{ lbs.}$

[4] From previous data; $\frac{1067.4^\circ}{(977^\circ - 32^\circ) \times .11379} \times 113 \text{ tons} = 1122 \text{ tons.}$

[5] From previous data; $\frac{1 \text{ in.}}{30.01 \text{ in.} \times 13.598 \times .2375} \times 1067.4^\circ = 11.01^\circ.$

[6] Latent heat of aqueous vapor at 32° [Miller, p.266], 1091.7°; combining previous data we obtain $\frac{1 \text{ in.}}{30.01 \text{ in.} \times 13.598 \times .11379} \times (1091.7^\circ + 142.65^\circ) = 12.74^\circ.$

cold climates; for if the sun directly warmed all parts of the earth alike, there would be no winds, and no rain except on the ocean. It is also necessary that such climates be warmed indirectly, or many of them would be unfit for civilized life. We can estimate the amount of heat thus imparted to temperate and frigid zones by comparing the amount received at more and at less favored places. The Faroe Islands have a mean temperature thirty-one degrees higher than Jakoutsk in the same latitude. The islands are visited by the sea breezes before their vapor has been condensed, and has thus given out its store of latent heat, while Jakoutsk receives only the residual amount after the moist winds from the Caribbean have warmed nearly a whole continent. In January, when the winds are more thoroughly despoiled of their treasures of heat before reaching Siberia, Jakoutsk has a temperature below the freezing-point of mercury, while the Islands, though lying within two hundred and forty miles of the frigid zone, have a temperature above the freezing-point of water. Yet the size of the Siberian rivers shows that the ameliorating effect of the condensation of vapor is very great, even in that climate, and the difference between a more and a less favored place may serve as a hint of the importance of the total effect.

To the high latent heat of aqueous vapor is it due that rain visits every part of the earth which needs it. To the same adjustment it is owing that these cooling influences within the tropics, these warming processes in colder climates, and these equalizing results in all climates are possible. Were it not for this careful adaptation, many parts of the globe now affording pleasant homes for man would be too cold in winter, too hot in summer, or too hostile to vegetable life to support him except under intolerable conditions. Were the latent heat of the vapor of water the same with that of the vapor of the oil of turpentine, Massachusetts would have a climate in winter like that of Jakoutsk, where mercury remains frozen three months in the year, and New Orleans would have a climate nearly like the Australian desert mentioned above, or like the sandy parts of Southern Arabia, a country "of which Hagi Ishmael says, 'the earth is of fire and the wind flame.'"

If the fly-wheel of a steam-engine were not large, it would move so irregularly as to inflict injury. If the axis were not strong it would break. The constitutional tendencies of our minds compel us to refer these adaptations of size and strength to the intention of the maker. They are not the result of accident, nor the work of an ignorant or malicious designer. In the same way the laws and the constitutional tendencies of our minds demand an intelligent cause for such skilful adaptations as these, and a benevolent cause for adjustments so benign.

10. The high radiating power of aqueous vapor exhibits the same wisdom and goodness which are seen in the other properties of water.

The fact that the vapor of water has a very high latent heat has been mentioned, and some of the advantages of such an arrangement have been noticed. But some of the more important of these would be lost unless another careful adjustment of the qualities of water were made. Before vapor can be condensed into rain its latent heat must be given off in some way. No other method sufficing, it must escape by radiation; unless, then, water has a power of radiating heat commensurate with its power of rendering it latent, rain would be too scanty, for the vapor of water could not condense. Accordingly we find that the radiating power of aqueous vapor is enormous; therefore, at the proper time, it easily loses its latent heat, and is precipitated as rain. One pound of vapor, before it becomes liquid, must give off, to bodies nearly as warm as itself, enough heat to render nine pounds of iron red-hot; if it parted with its heat as slowly as does polished silver, rains would be almost unknown, and plants would receive but an insufficient moisture from dew. But no one contrivance of the Author of nature is thus rendered nugatory by the want of another; this result was anticipated; those means were chosen which would avoid these evils, and the skill and benevolence of God are again both illustrated and proved. This was no result of a constitution made necessary by fate, for it contains every mark of design which the most ingenious human mechanism ever displayed.

11. The power which aqueous vapor possesses of absorbing radiant heat adds further proof of the divine wisdom and goodness.

Some substances permit rays of heat to pass through them, as light passes through glass. Some are opaque to heat, while others, unlike both the former, suffer certain rays of heat to penetrate them, but stop others, as red glass permits the passage of red rays of light, but intercepts others.[1]

Now if the vapor of water were transparent to rays of heat, the mechanism of the winds would be hopelessly disordered.

It is well known that winds are due to the fact that the lower strata of the atmosphere becomes warmer and therefore lighter than those immediately above them. Hence they rise, and the surrounding air rushing in to fill the partial vacuum causes all the phenomena of the winds. Heat must be communicated to the air either by conduction, convection, or radiation; the first is not practicable, for air is a non-conductor; the second is insufficient, and only the third remains. But air itself can absorb but a minute fraction of radiant heat,[2] and unless some new provision is made, even the heat which might be imparted by conduction or convection would be lost by radiating ineffectively into empty space. But without winds both animal and vegetable life would be in danger; for on them depend the purity of the air and the diffusion of rain. Now in the lower strata of the air there is a small fraction of aqueous vapor, about a two-hundredth part of the entire atmosphere,[3] and this minute fraction absorbs more than sixty times as much radiant heat as the whole remaining air.[4] Here is the source of the winds; if the vapor of water were transparent to rays of heat, the

[1] Miller, p. 226; Tyndall, Heat, etc., *passim*.
[2] Tyndall, p. 362 et seq.
[3] Tyndall, p. 390.
[4] Tyndall, p. 398.

atmosphere would fail to fulfil two of its most important offices.

If aqueous vapor were transparent to radiant heat the extremes of day and night would be intolerable.

By day the surface of the earth receives heat from the sun, while at night it is cooled by radiating heat into a space whose temperature is far below zero. Unless something be thrown over the earth as a cloak protecting it from this cold, absorbing and retaining the heat which is radiated by the earth, on every evening in this latitude the thermometer would fall probably below the freezing-point, and nearly all vegetable life would be destroyed.[1] Now the air cannot protect us, for heat passes through it more readily than light through glass. But the small fraction of aqueous vapor contained in air has a power of absorbing radiant heat many thousand times greater than air possesses. So immense is this power that Tyndall estimates that more than ten per cent of the heat escaping from the earth is stopped by the infinitesimal amount of vapor contained by the air within ten feet of the ground.[2] A hint of the value of such protection is given us by those climates where the air is comparatively dry. In the great African desert, where the heat of the day is such that ether will boil in the shade, the unchecked radiation of night is such that water will freeze.[3] In the Australian desert where a match dropped on the sand by day will instantly inflame, the same thing is true.[4] These terrible extremes are due to the fact that the air is comparatively dry; were it entirely so they would be intolerably greater. Such extremes would be felt all over the earth did the vapor of water allow free passage to rays of heat.

These are evils which would follow were aqueous vapor transparent to radiant heat. But if it were opaque, the earth would be unfitted for organic life.

[1] Tyndall, p. 405.

[2] Tyndall, p. 398.

[3] Tyndall, p. 405; Rede Lecture on Radiation, by Tyndall (New York, 1865), p. 85.

[4] Dove, Distribution of Heat, p. 22.

Our globe is warmed by heat which passes through the entire atmosphere. The atmosphere always contains aqueous vapor; if this were opaque to radiant heat it would intercept the sun's rays. Becoming itself warm, it would radiate this heat, but only half of it would reach us, the remainder being radiated away from the earth. There would be no insupportable extremes now, for both day and night would feel a similar intensity of cold. The upper strata of the air, first receiving the sun's heat, would be warmer than the lower, and there could be no winds. The earth being cool, evaporation would be too scanty to supply rain, and would merely fill the atmosphere with enough vapor to intercept most of the sun's heat, and make the whole world like the frigid zones.

But if watery vapor must not be transparent to rays of heat, nor yet opaque; if it must not permit them a free passage, but must on no account intercept them; it must have some very peculiar relation to radiant heat. Accordingly we find that its power of absorbing heat is elective. It absorbs with tremendous energy all the heat radiating from a body at a low temperature; it is utterly powerless to stop rays of intense heat.[1] The intense heat of the sun passes freely through the air and the vapor contained in it, and warms the earth. The warm earth then radiates a heat of low intensity, the vapor in the atmosphere stops this almost as abruptly as an iron door intercepts light. Thus "the atmosphere acts the part of a ratchet wheel in mechanics; it allows of motion in one direction, but prevents it in another."[2] It keeps the heat of the earth from passing out, but permits the sun's heat to enter.

As far as we know, watery vapor might sustain either of these three relations to radiant heat. The selection of one of these laws rather than another seems to be as purely a matter of intelligent adjustment as the making the lever of a watch thirty hundredths of an inch in length, rather than

[1] Tyndall, Heat, etc., p. 320.
[2] Tyndall, Glaciers of the Alps (Boston, 1861), p. 243.

twenty-nine or thirty-one. In the latter case we are certain that a mind directed the manufacture which knew the evils to be avoided, and chose to prevent them. The argument in the former is no more abstruse, nor the conclusion less certain.

In this survey of the relations of water to heat we have seen that the temperatures of its boiling and freezing points, and the amounts of its specific and of its latent heat are exactly adapted to its place in the system on which the welfare of organic life depends. Its laws of expansion while remaining a fluid and while becoming solid, as well as its non-conducting power and its attraction for atmospheric air, are further instances of the same adaptation. Lastly, in the state of vapor, its high latent heat, its great radiating power, and the peculiar properties of its power of absorbing radiant heat, exhibit the most subtile ingenuity of contrivance, and produce the most important and advantageous results. Thus all the qualities of water agree in proving the wisdom and goodness of their Author. All the laws of logical thought compel us to the same conclusion. All the constitutional tendencies of our minds conspire to give intensity to this conviction, to exalt our idea of his character, and to deepen our reverence.

But the concurrence of all these arguments is a new and independent argument. The combination of separate indications has the force, not of their sum, but of their product. If only one grain of gold were to be found in the soil of California, it must have a source, and the auriferous quartz is proved to exist. But if we cannot turn our eyes downwards without seeing gold, if we cannot find a single grain without perceiving another touching it and a score surrounding it, the evidence is as much more luminous than before as is day than night. So if water were adjusted to the welfare of sentient beings in but one of the modes discussed above, the ingenuity of the contrivance and the benevolence of the result would sufficiently indicate the character of its cause. If we should find not another atom of proof in all nature, no candid mind could reject this. But if we find so many lines of proof converging and concentrating themselves around one point, and so much evidence condensed in the texture of a single substance, and compressed as if there were not room in nature to contain all the testimony to the character of God unless space is *economized*, the force of our conviction will be irresistible.

And yet the evidences of benevolent design which have been mentioned are but a small part of those concealed in the constitution of water. Nothing has been said of its relations to other departments of natural philosophy; nothing of its chemical properties; nothing of its adaptation to vegetable life; nothing of its adjustments to animal life and comfort, except as it more remotely affects them through the agency of heat. But it is in the line of its more immediate relations to organic existence that this substance affords the most copious and convincing proofs of the divine wisdom and goodness.

These pages, too, are but a hint of the contribution which the somewhat recent science of heat is ready to make for the uses of natural theology. The very nature of the agent called caloric, and the mechanism provided for its distribution, both stand prepared to contribute an argument which shall combine all the fascination of a fairy tale with all the majesty and more than the authority of law. The relations between heat and the processes of the arts, its relations to organic life and all its relations to the other substances which occur in nature, are also ready with a rich harvest; and here is but a handful from one corner of the field.

These qualities of water indicate the infinity of some of the attributes of God. They *prove* that his knowledge, for instance, transcends any limits which we can define or even imagine, but they *indicate* that it has *no* limits. In the same way, they prove that his power extends beyond any boundary which the human intellect can assign or even conceive, but they as clearly indicate that it has absolutely *no* boundary and *no* limit; that this attribute is infinite.

The qualities of water indicate the infinity of some of the divine attributes by the wealth of contrivance which they display. They impress us as the work of a being who can afford to be lavish of his skill. We cannot but feel that one whose knowledge was less than infinite would husband his resources, would prudently economize his stores.

They indicate this infinity also by the number of the relations to which they are adjusted. For instance, the boiling-point of water sustains relations to every species of plant and animal on the globe, to the structure of every soil and every rock on its surface, to the elevation of its mountains, to the slope of its continents, to the conducting power and temperature of its interior, to the temperature and distance of the sun, and to the shape of the earth's orbit. In every one of these countless relations, all is harmony. Yet this one is but a minute fraction of the sum of those adjustments by which water is suited to its place in nature, and among them all there is no clash, no discord, nothing but harmony. We cannot resist the conviction that he who can form a plan so intricate and so vast in its details, and can execute a plan so vast in its proportions and so comprehensive in its results, can make and can carry out any plan whatever. We are forced, by a necessity which no sane mind which is aware of the facts can evade, to believe that in those attributes displayed in this part of his works, God is infinite.