The Forms of Water in Clouds and Rivers, Ice and Glaciers

John Tyndall*

§ 1. *Clouds, Rains, and Rivers.*

1. EVERY occurrence in Nature is preceded by other occurrences which are its causes, and succeeded by others which are its effects. The human mind is not satisfied with observing and studying any natural occurrence alone, but takes pleasure in connecting every natural fact with what has gone before it, and with what is to come after it.

2. Thus, when we enter upon the study of rivers and glaciers, our interest will be greatly augmented by taking into account not only their actual appearances, but also their causes and effects.

3. Let us trace a river to its source. Beginning where it empties itself into the sea, and following it backwards, we find it from time to time joined by tributaries which swell its waters. The river of course becomes smaller as these tributaries are passed. It shrinks first to a brook, then to a stream; this again divides itself into a number of smaller streamlets, ending in mere threads of water. These constitute the source of the river, and are usually found among hills.

---

* The original version appeared in: John Tyndall, *The Forms of Water in Clouds & Rivers, Ice & Glaciers*, London, 1872, pp. 1–34.

4. Thus the Severn has its source in the Welsh Mountains; the Thames in the Cotswold Hills; the Danube in the hills of the Black Forest; the Rhine and the Rhone in the Alps; the Ganges in the Himalaya Mountains; the Euphrates near Mount Ararat; the Garonne in the Pyrenees; the Elbe in the Giant Mountains of Bohemia; the Missouri in the Rocky Mountains, and the Amazon in the Andes of Peru.

5. But it is quite plain that we have not yet reached the real beginning of the rivers. Whence do the earliest streams derive their water? A brief residence among the mountains would prove to you that they are fed by rains. In dry weather you would find the streams feeble, sometimes indeed quite dried up. In wet weather you would see them foaming torrents. In general these streams lose themselves as little threads of water upon the hill sides; but sometimes you may trace a river to a definite spring. The river Albula in Switzerland, for instance, rushes at its origin in considerable volume from a mountain side. But you very soon assure yourself that such springs are also fed by rain, which has percolated through the rocks or soil, and which, through some orifice that it has found or formed, comes to the light of day.

6. But we cannot end here. Whence comes the rain which forms the mountain streams? Observation enables you to answer the question. Rain does not come from a clear sky. It comes from clouds. But what are clouds? Is there nothing you are acquainted with which they resemble? You discover at once a likeness between them and the condensed steam of a locomotive. At every puff of the engine a cloud is projected into the air. Watch the cloud sharply: you notice that it first forms at a little distance from the top of the funnel. Give close attention and you will sometimes see a perfectly clear space between the funnel and the cloud. Through that clear space the thing which makes the cloud must pass. What, then, is this thing which at one moment is transparent and invisible, and at the next moment visible as a dense opaque cloud?

7. It is the *steam* or *vapour of water* from the boiler. Within the boiler this steam is transparent and invisible; but to keep it in this invisible state a heat would be required as great as that within the boiler. When the vapour mingles with the cold air above the hot funnel it ceases to be vapour. Every bit of steam shrinks, when chilled, to a much more minute particle of water. The liquid particles thus produced form a kind of *water-dust* of exceeding fineness, which floats in the air, and is called *a cloud.*

8. Watch the cloud-banner from the funnel of a running locomotive; you see it growing gradually less dense. It finally melts away altogether, and if you continue your observations you will not fail to notice that the speed of its disappearance depends upon the character of the day. In humid weather the cloud hangs long and lazily in the air; in dry weather it is rapidly licked up. What has become of it? It has been reconverted into true invisible vapour.

9. The *drier* the air, and the *hotter* the air, the greater is the amount of cloud which can be thus dissolved in it. When the cloud first forms, its quantity is far greater than the air is able to maintain in an invisible state. But as the cloud mixes gradually with a larger mass of air it is more and more dissolved, and finally passes altogether from the condition of a finely-divided liquid into that of transparent vapour or gas.

10. Make the lid of a kettle air-tight, and permit the steam to issue from the pipe; a cloud is precipitated in all respects similar to that issuing from the funnel of the locomotive.

11. Permit the steam as it issues from the pipe to pass through the flame of a spirit-lamp, the cloud is instantly dissolved by the heat, and is not again precipitated. With a special boiler and a special nozzle the experiment may be made more striking, but not more instructive, than with the kettle.

12. Look to your bedroom windows when the weather is very cold outside; they sometimes stream with water derived from the

condensation of the aqueous vapour from your own lungs. The windows of railway carriages in winter show this condensation in a striking manner. Pour cold water into a dry drinking-glass on a summer's day: the outside surface of the glass becomes instantly dimmed by the precipitation of moisture. On a warm day you notice no vapour in front of your mouth, but on a cold day you form there a little cloud derived from the condensation of the aqueous vapour from the lungs.

13. You may notice in a ball-room that as long as the door and windows are kept closed, and the room remains hot, the air remains clear; but when the doors or windows are opened a dimness is visible, caused by the precipitation to fog of the aqueous vapour of the ball-room. If the weather be intensely cold the entrance of fresh air may even cause *snow* to fall. This has been observed in Russian ball-rooms; and also in the subterranean stables at Erzeroom, when the doors are opened and the cold morning air is permitted to enter.

14. Even on the driest day this vapour is never absent from our atmosphere. The vapour diffused through the air of this room may be congealed to hoar frost in your presence. This is done by filling a vessel with a mixture of pounded ice and salt, which is colder than the ice itself, and which, therefore, condenses and freezes the aqueous vapour. The surface of the vessel is finally coated with a frozen fur, so thick that it may be scraped away and formed into a snow-ball.

15. To produce the cloud, in the case of the locomotive and the kettle, *heat* is necessary. By heating the water we first convert it into steam, and then by chilling the steam we convert it into cloud. Is there any fire in nature which produces the clouds of our atmosphere? There is: the fire of the sun.

16. Thus, by tracing backward, without any break in the chain of occurrences, our river from its end to its real beginnings, we come at length to the sun.

§ 2.

17. There are, however, rivers which have sources somewhat different from those just mentioned. They do not begin by driblets on a hill side, nor can they be traced to a spring. Go, for example, to the mouth of the river Rhone, and trace it backwards to Lyons, where it turns to the east. Bending round by Chambery, you come at length to the Lake of Geneva, from which the river rushes, and which you might be disposed to regard as the source of the Rhone. But go to the head of the lake, and you find that the Rhone there enters it, that the lake is in fact a kind of expansion of the river. Follow this upwards; you find it joined by smaller rivers from the mountains right and left. Pass these, and push your journey higher still. You come at length to a huge mass of ice—the end of a glacier—which fills the Rhone valley, and from the bottom of the glacier the river rushes. In the glacier of the Rhone you thus find the source of the river Rhone.

18. But again we have not reached the real beginning of the river. You soon convince yourself that this earliest water of the Rhone is produced by the melting of the ice. You get upon the glacier and walk upwards along it. After a time the ice disappears and you come upon snow. If you are a competent mountaineer you may go to the very top of this great snow-field, and if you cross the top and descend at the other side you finally quit the snow, and get upon another glacier called the Trift, from the end of which rushes a river smaller than the Rhone.

19. You soon learn that the mountain snow feeds the glacier. By some means or other the snow is converted into ice. But whence comes the snow? Like the rain, it comes from the clouds, which, as before, can be traced to vapour raised by the sun. Without solar fire we could have no atmospheric vapour, without vapour no clouds, without clouds no snow, and without snow no glaciers. Curious then as the conclusion may be, the cold ice of the Alps has its origin in the heat of the sun.

§ 3. *The Waves of Light.*

20. But what is the sun? We know its size and its weight. We also know that it is a globe of fire far hotter than any fire upon earth. But we now enter upon another enquiry. We have to learn definitely what is the meaning of solar light and solar heat; in what way they make themselves known to our senses; by what means they get from the sun to the earth, and how, when there, they produce the clouds of our atmosphere, and thus originate our rivers and our glaciers.

21. If in a dark room you close your eyes and press the eyelid with your finger-nail, a circle of light will be seen opposite to the point pressed, while a sharp blow upon the eye produces the impression of a flash of light. There is a nerve specially devoted to the purposes of vision which comes from the brain to the back of the eye, and there divides into fine filaments, which are woven together to a kind of screen called the *retina.* The retina can be excited in various ways so as to produce the consciousness of light; it may, as we have seen, be excited by the rude mechanical action of a blow imparted to the eye.

22. There is no spontaneous creation of light by the healthy eye. To excite vision the retina must be affected by something coming from without. What is that something? In some way or other luminous bodies have the power of affecting the retina—but *how?*

23. It was long supposed that from such bodies issued, with inconceivable rapidity, an inconceivably fine matter, which flew through space, passed through the pores supposed to exist in the humours of the eye, reached the retina behind, and by their shock against the retina, aroused the sensation of light.

24. This theory, which was supported by the greatest men, among others by Sir Isaac Newton, was found competent to explain a great number of the phenomena of light, but it was not found competent to explain *all* the phenomena. As the skill and knowledge of experimenters increased, large classes of facts were

revealed which could only be explained by assuming that light was produced, not by a fine matter flying through space and hitting the retina, but by the shock of minute *waves* against the retina.

25. Dip your finger into a basin of water, and cause it to quiver rapidly to and fro. From the point of disturbance issue small ripples which are carried forward by the water, and which finally strike the basin. Here, in the vibrating finger, you have a source of agitation; in the water you have a vehicle through which the finger's motion is transmitted, and you have finally the side of the basin which receives the shock of the little waves.

26. In like manner, according to the *wave theory* of light, you have a source of agitation in the vibrating atoms, or smallest particles, of the luminous body; you have a vehicle of transmission in a substance which is supposed to fill all space, and to be diffused through the humours of the eye; and finally, you have the retina, which receives the successive shocks of the waves. These shocks are supposed to produce the sensation of light.

27. We are here dealing, for the most part, with suppositions and assumptions merely. We have never seen the atoms of a luminous body, nor their motions. We have never seen the medium which transmits their motions, nor the waves of that medium. How, then, do we come to assume their existence?

28. Before such an idea could have taken any real root in the human mind, it must have been well disciplined and prepared by observations and calculations of ordinary wave-motion. It was necessary to know how both water-waves and sound-waves are formed and propagated. It was above all things necessary to know how waves, passing through the same medium, act upon each other. Thus disciplined, the mind was prepared to detect any resemblance presenting itself between the action of light and that of waves. Great classes of optical phenomena accordingly appeared which could be accounted for in the most complete and satisfactory manner by assuming them to be produced by waves, and which

could not be otherwise accounted for. It is because of its competence to explain all the phenomena of light that the wave theory now receives universal acceptance on the part of scientific men.

Let me use an illustration. We infer from the flint implements recently found in such profusion all over England and in other countries, that they were produced by men, and also that the Pyramids of Egypt were built by men, because, as far as our experience goes, nothing but men could form such implements or build such Pyramids. In like manner, we infer from the phenomena of light the agency of waves, because, as far as our experience goes, no other agency could produce the phenomena.

§ 4. *The Waves of Heat which produce the Vapour of our Atmosphere and melt our Glaciers.*

29. Thus, in a general way, I have given you the conception and the grounds of the conception, which regards light as the product of wave-motion; but we must go farther than this, and follow the conception into some of its details. We have all seen the waves of water, and we know they are of different sizes—different in length and different in height. When, therefore, you are told that the atoms of the sun, and of almost all other luminous bodies, vibrate at different rates, and produce waves of different sizes, your experience of water-waves will enable you to form a tolerably clear notion of what is meant.

30. As observed above, we have never seen the light-waves, but we judge of their presence, their position, and their magnitude, by their effects. Their lengths have been thus determined, and found to vary from about $\frac{1}{30000}$th to $\frac{1}{60000}$th of an inch.

31. But besides those which produce light, the sun sends forth incessantly a multitude of waves which produce no light. The largest waves which the sun sends forth are of this non-luminous character, though they possess the highest heating power.

32. A common sunbeam contains waves of all kinds, but it is possible to *sift* or *filter* the beam so as to intercept all its light, and to allow its obscure heat to pass unimpeded. For substances have been discovered which, while intensely opaque to the light-waves, are almost perfectly transparent to the others. On the other hand, it is possible, by the choice of proper substances, to intercept in a great degree the pure heat-waves, and to allow the pure light-waves free transmission. This last separation is, however, not so perfect as the first.

33. We shall learn presently how to detach the one class of waves from the other class, and to prove that waves competent to light a fire, fuse metal, or burn the hand like a hot solid, may exist in a perfectly dark place.

34. Supposing, then, that we withdraw, in the first instance the large heat-waves, and allow the light-waves alone to pass. These may be concentrated by suitable lenses and sent into water without sensibly warming it. Let the light-waves now be withdrawn, and the larger heat-waves concentrated in the same manner; they may be caused to boil the water almost instantaneously.

35. This is the point to which I wished to lead you, and which without due preparation could not be understood. You now perceive the important part played by these large darkness-waves, if I may use the term, in the work of evaporation. When they plunge into seas, lakes, and rivers, they are intercepted close to the surface, and they heat the water at the surface, thus causing it to evaporate; the light-waves at the same time entering to great depths without sensibly heating the water through which they pass. Not only, therefore, is it the sun's fire which produces evaporation, but a particular constituent of that fire, the existence of which you probably were not aware of.

36. Further, it is these selfsame lightless waves which, falling upon the glaciers of the Alps, melt the ice and produce all the rivers flowing from the glaciers; for I shall prove to you presently that the

light-waves, even when concentrated to the uttermost, are unable to melt the most delicate hoar-frost; much less would they be able to produce the copious liquefaction observed upon the glaciers.

37. These large lightless waves of the sun, as well as the heat-waves issuing from non-luminous hot bodies, are frequently called obscure or invisible heat.

We have here an example of the manner in which phenomena, apparently remote, are connected together in this wonderful system of things that we call Nature. You cannot study a snow-flake profoundly without being led back by it step by step to the constitution of the sun. It is thus throughout Nature. All its parts are interdependent, and the study of any one part *completely* would really involve the study of all.

§ 5. *Experiments to prove the foregoing Statements.*

38. Heat issuing from any source not visibly red cannot be concentrated so as to produce the intense effects just referred to. To produce these it is necessary to employ the obscure heat of a body raised to the highest possible state of incandescence. The sun is such a body, and its dark heat is therefore suitable for experiments of this nature.

39. But in the atmosphere of London, and for experiments such as ours, the heat-waves emitted by coke raised to intense whiteness by a current of electricity are much more manageable than the sun's waves. The electric light has also the advantage that its dark radiation embraces a larger proportion of the total radiation than the dark heat of the sun. In fact, the force or energy, if I may use the term, of the dark waves of the electric light is fully seven times that of its light-waves. The electric light, therefore, shall be employed in our experimental demonstrations.

40. From this source a powerful beam is sent through the room, revealing its track by the motes floating in the air of the room; for

were the motes entirely absent the beam would be unseen. It falls upon a concave mirror (a glass one silvered behind will answer) and is gathered up by the mirror into a cone of reflected rays; the luminous apex of the cone, which is the *focus* of the mirror, being about fifteen inches distant from its reflecting surface. Let us mark the focus accurately by a pointer.

41. And now let us place in the path of the beam a substance perfectly opaque to light. This substance is iodine dissolved in a liquid called bisulphide of carbon. The light at the focus instantly vanishes when the dark solution is introduced. But the solution is intensely transparent to the dark waves, and a focus of such waves remains in the air of the room after the light has been abolished. You may feel the heat of these waves with your hand; you may let them fall upon a thermometer, and thus prove their presence; or, best of all, you may cause them to produce a current of electricity, which deflects a large magnetic needle. The magnitude of the deflection is a measure of the heat.

42. Our object now is, by the use of a more powerful lamp, and a better mirror (one silvered in front and with a shorter focal distance), to intensify the action here rendered so sensible. As before, the focus is rendered strikingly visible by the intense illumination of the dust particles. We will first filter the beam so as to intercept its dark waves, and then permit the purely luminous waves to exert their utmost power on a small bundle of gun-cotton placed at the focus.

43. No effect whatever is produced. The gun-cotton might remain there for a week without ignition. Let us now permit the unfiltered beam to act upon the cotton. It is instantly dissipated in an explosive flash. This experiment proves that the light-waves are incompetent to explode the cotton, while the waves of the full beam are competent to do so; hence we may conclude that the dark waves are the real agents in the explosion.

44. But this conclusion would be only probable; for it might be urged that the *mixture* of the dark waves and the light-waves is

necessary to produce the result. Let us then, by means of our opaque solution, isolate our dark waves and converge them on the cotton. It explodes as before.

45. Hence it is the dark waves, and they only, that are concerned in the ignition of the cotton.

46. At the same dark focus sheets of platinum are raised to vivid redness; zinc is burnt up; paper instantly blazes; magnesium wire is ignited; charcoal within a receiver containing oxygen is set burning; a diamond similarly placed is caused to glow like a star, being afterwards gradually dissipated. And all this while the *air* at the focus remains as cool as in any other part of the room.

47. To obtain the light-waves we employ a clear solution of alum in water; to obtain the dark waves we employ the solution of iodine above referred to. But as before stated (32), the alum is not so perfect a filter as the iodine; for it transmits a portion of the obscure heat.

48. Though the light-waves here prove their incompetence to ignite gun-cotton, they are able to burn up black paper; or, indeed, to explode the cotton when it is blackened. The white cotton does not absorb the light, and without absorption we have no heating. The blackened cotton absorbs, is heated, and explodes.

49. Instead of a solution of alum, we will employ for our next experiment a cell of pure water, through which the light passes without sensible absorption. At the focus is placed a test-tube also containing water, the full force of the light being concentrated upon it. The water is not sensibly warmed by the concentrated waves. We now remove the cell of water; no change is visible in the beam, but the water contained in the test-tube now boils.

50. The light-waves being thus proved ineffectual, and the full beam effectual, we may infer that it is the dark waves that do the work of heating. But we clench our inference by employing our opaque iodine filter. Placing it on the path of the beam, the light is entirely stopped, but the water boils exactly as it did when the full beam fell upon it.

51. The truth of the statement made in paragraph (34) is thus demonstrated.

52. And now with regard to the melting of ice. On the surface of a flask containing a freezing mixture we obtain a thick fur of hoar-frost. Sending the beam through a water-cell, its luminous waves are concentrated upon the surface of the flask. Not a spicula of the frost is dissolved. We now remove the water-cell, and in a moment a patch of the frozen fur as large as half-a-crown is melted. Hence, inasmuch as the full beam produces this effect, and the luminous part of the beam does not produce it, we fix upon the dark portion the melting of the frost.

53. As before, we clench this inference by concentrating the dark waves alone upon the flask. The frost is dissipated exactly as it was by the full beam.

54. These effects are rendered strikingly visible by darkening with ink the freezing mixture within the flask. When the hoar frost is removed, the blackness of the surface from which it had been melted comes out in strong contrast with the adjacent snowy whiteness. When the flask itself, instead of the freezing mixture, is blackened, the purely luminous waves being absorbed by the glass, warm it; the glass reacts upon the frost, and melts it. Hence the wisdom of darkening, instead of the flask itself, the mixture within the flask.

55. This experiment proves to demonstration the statement in paragraph (36): that it is the dark waves of the sun that melt the mountain snow and ice, and originate all the rivers derived from glaciers.

There are writers who seem to regard science as an aggregate of facts, and hence doubt its efficacy as an exercise of the reasoning powers. But all that I have here taught you is the result of reason, taking its stand, however, upon the sure basis of observation and experiment. And this is the spirit in which our further studies are to be pursued.

§ 6. *Oceanic Distillation.*

56. The sun, you know, is never exactly overhead in England. But at the equator, and within certain limits north and south of it, the sun at certain periods of the year is directly overhead at noon. These limits are called the Tropics of Cancer and of Capricorn. Upon the belt comprised between these two circles the sun's rays fall with their mightiest power; for here they shoot directly downwards, and heat both earth and sea more than when they strike slantingly.

57. When the vertical sunbeams strike the land they heat it, and the air in contact with the hot soil becomes heated in turn. But when heated the air expands, and when it expands it becomes lighter. This lighter air rises, like wood plunged into water, through the heavier air overhead.

58. When the sunbeams fall upon the sea the water is warmed, though not so much as the land. The warmed water expands, becomes thereby lighter, and therefore continues to float upon the top. This upper layer of water warms to some extent the air in contact with it, but it also sends up a quantity of aqueous vapour, which being far lighter than air, helps the latter to rise. Thus both from the land and from the sea we have ascending currents established by the action of the sun.

59. When they reach a certain elevation in the atmosphere, these currents divide and flow, part towards the north and part towards the south; while from the north and the south a flow of heavier and colder air sets in to supply the place of the ascending warm air.

60. Incessant circulation is thus established in the atmosphere. The equatorial air and vapour flow above towards the north and south poles, while the polar air flows below towards the equator. The two currents of air thus established are called the upper and the lower trade winds.

61. But before the air returns from the poles great changes have occurred. For the air as it quitted the equatorial regions was laden with aqueous vapour, which could not subsist in the cold polar

regions. It is there precipitated, falling sometimes as rain, or more commonly as snow. The land near the pole is covered with this snow, which gives birth to vast glaciers in a manner hereafter to be explained.

62. It is necessary that you should have a perfectly clear view of this process, for great mistakes have been made regarding the manner in which glaciers are related to the heat of the sun.

63. It was supposed that if the sun's heat were diminished, greater glaciers than those now existing would be produced. But the lessening of the sun's heat would infallibly diminish the quantity of aqueous vapour, and thus cut off the glaciers at their source. A brief illustration will complete your knowledge here.

64. In the process of ordinary distillation, the liquid to be distilled is heated and converted into vapour in one vessel, and chilled and reconverted into liquid in another. What has just been stated renders it plain that the earth and its atmosphere constitute a vast distilling apparatus in which the equatorial ocean plays the part of the boiler, and the chill regions of the poles the part of the condenser. In this process of distillation *heat* plays quite as necessary a part as *cold,* and before Bishop Heber could speak of 'Greenland's icy mountains,' the equatorial ocean had to be warmed by the sun. We shall have more to say upon this question afterwards.

Illustrative Experiments.

65. I have said that when heated, air expands. If you wish to verify this for yourself, proceed thus. Take an empty flask, stop it by a cork; pass through the cork a narrow glass tube. By heating the tube in a spirit-lamp you can bend it downwards, so that when the flask is standing upright the open end of the narrow tube may dip into water. Now cause the flame of your spirit-lamp to play against the flask. The flame heats the glass, the glass heats the air; the air expands, is driven through the narrow tube, and issues in a storm of bubbles from the water.

66. Were the heated air unconfined, it would rise in the heavier cold air. Allow a sunbeam or any other intense light to fall upon a white wall or screen in a dark room. Bring a heated poker, a candle, or a gas flame underneath the beam. An ascending current rises from the heated body through the beam, and the action of the air upon the light is such as to render the wreathing and waving of the current strikingly visible upon the screen. When the air is hot enough, and therefore light enough, if entrapped in a paper bag it carries the bag upwards, and you have the Fire-balloon.

67. Fold two sheets of paper into two cones and suspend them with their closed points upwards from the end of a delicate balance. See that the cones balance each other. Then place for a moment the flame of a spirit-lamp beneath the open base of one of them; the hot air ascends from the lamp and instantly tosses upwards the cone above it.

68. Into an inverted glass shade introduce a little smoke. Let the air come to rest, and then simply place your hand at the open mouth of the shade. Mimic hurricanes are produced by the air warmed by the hand, which are strikingly visible when the smoke is illuminated by a strong light.

69. The heating of the tropical air by the sun is *indirect.* The solar beams have scarcely any power to heat the air through which they pass; but they heat the land and ocean, and these communicate their heat to the air in contact with them. The air and vapour start upwards charged with the heat thus communicated.

§ 7. *Tropical Rains.*

70. But long before the air and vapour from the equator reach the poles, precipitation occurs. Wherever a humid warm wind mixes with a cold dry one, rain falls. Indeed the heaviest rains occur at those places where the sun is vertically overhead. We must enquire a little more closely into their origin.

71. Fill a bladder about two-thirds full of air at the sea level, and take it to the summit of Mont Blanc. As you ascend, the bladder becomes more and more distended; at the top of the mountain it is fully distended, and has evidently to bear a pressure from within. Returning to the sea level you find that the tightness disappears, the bladder finally appearing as flaccid as at first.

72. The reason is plain. At the sea level the air within the bladder has to bear the pressure of the whole atmosphere, being thereby squeezed into a comparatively small volume. In ascending the mountain, you leave more and more of the atmosphere behind; the pressure becomes less and less, and by its expansive force the air within the bladder swells as the outside pressure is diminished. At the top of the mountain the expansion is quite sufficient to render the bladder tight, the pressure within being then actually greater than the pressure without. By means of an air-pump we can show the expansion of a balloon partly filled with air, when the external pressure has been in part removed.

73. But why do I dwell upon this? Simply to make plain to you that the *unconfined air*, heated at the earth's surface, and ascending by its lightness, must expand more and more the higher it rises in the atmosphere.

74. And now I have to introduce to you a new fact, towards the statement of which I have been working for some time. It is this:— *The ascending air is chilled by its expansion*. Indeed this chilling is one source of the coldness of the higher atmospheric regions. And now fix your eye upon those mixed currents of air and aqueous vapour which rise from the warm tropical ocean. They start with plenty of heat to preserve the vapour as vapour; but as they rise they come into regions already chilled, and they are still further chilled by their own expansion. The consequence might be foreseen. The load of vapour is in great part precipitated, dense clouds are formed, their particles coalesce to rain-drops, which descend daily in gushes so profuse that the word 'torrential' is

used to express the copiousness of the rain-fall. I could show you this chilling by expansion, and also the consequent precipitation of clouds.

75. Thus long before the air from the equator reaches the poles its vapour is in great part removed from it, having redescended to the earth as rain. Still a good quantity of the vapour is carried forward, which yields hail, rain, and snow in northern and southern lands.

Illustrative Experiments.

76. I have said that the air is chilled during its expansion. Prove this, if you like, thus. With a condensing syringe, you can force air into an iron box furnished with a stopcock, to which the syringe is screwed. Do so till the density of the air within the box is doubled or trebled. Immediately after this condensation, both the box and the air within it are *warm*, and can be proved to be so by a proper thermometer. Simply turn the cock and allow the compressed air to stream into the atmosphere. The current, if allowed to strike a thermometer, visibly chills it; and with other instruments the chill may be made more evident still. Even the hand feels the chill of the expanding air.

77. Throw a strong light, a concentrated sunbeam for example, across the issuing current; if the compressed air be ordinary humid air, you see the precipitation of a little cloud by the chill accompanying the expansion. This cloud-formation may, however, be better illustrated in the following way:—

78. In a darkened room send a strong beam of light through a glass tube three feet long and three inches wide, stopped at its ends by glass plates. Connect the tube by means of a stopcock with a vessel of about one-fourth its capacity, from which the air has been removed by an air-pump. The exhausted cylinder of the pump itself will answer capitally. Fill the glass tube with humid air; then simply turn on the stopcock which connects it with the exhausted vessel. Having more room the air expands, cold accompanies the expansion, and, as a consequence, a dense and brilliant cloud

immediately fills the tube. If the experiment be made for yourself alone you may see the cloud in ordinary daylight; indeed, the brisk exhaustion of any receiver filled with humid air is known to produce this condensation.

79. Other vapours than that of water may be thus precipitated, some of them yielding clouds of intense brilliancy, and displaying iridescences, such as are sometimes, but not frequently, seen in the clouds floating over the Alps.

80. In science what is true for the small is true for the large. Thus by combining the conditions observed on a large scale in nature we obtain on a small scale the phenomena of atmospheric clouds.

§ 8. *Mountain Condensers*.

81. To complete our view of the process of atmospheric precipitation we must take into account the action of mountains. Imagine a south-west wind blowing across the Atlantic towards Ireland. In its passage it charges itself with aqueous vapour. In the south of Ireland it encounters the mountains of Kerry: the highest of these is Magillicuddy's Reeks, near Killarney. Now the lowest stratum of this Atlantic wind is that which is most fully charged with vapour. When it encounters the base of the Kerry mountains it is tilted up and flows bodily over them. Its load of vapour is therefore carried to a height, it expands on reaching the height, it is chilled in consequence of the expansion, and comes down in copious showers of rain. From this, in fact, arises the luxuriant vegetation of Killarney; to this, indeed, the lakes owe their water supply. The cold crests of the mountains also aid in the work of condensation.

82. Note the consequence. There is a town called Cahirciveen to the south-west of Magillicuddy's Reeks, at which observations of the rainfall have been made, and a good distance farther to the north-east, right in the course of the south-west wind, there is another town, called Portarlington, at which observations of rainfall have also been made. But before the wind reaches the latter station

it has passed over the mountains of Kerry and left a great portion of its moisture behind it. What is the result? At Cahirciveen, as shown by Dr. Lloyd, the rainfall amounts to 59 inches in a year, while at Portarlington it is only 21 inches.

83. Again, you may sometimes descend from the Alps when the fall of rain and snow is heavy and incessant, into Italy, and find the sky over the plains of Lombardy blue and cloudless, the wind at the same time *blowing over the plain towards the Alps.* Below the wind is hot enough to keep its vapour in a perfectly transparent state; but it meets the mountains, is tilted up, expanded, and chilled. The cold of the higher summits also helps the chill. The consequence is that the vapour is precipitated as rain or snow, thus producing bad weather upon the heights, while the plains below, flooded with the same air, enjoy the aspect of the unclouded summer sun. Clouds blowing *from* the Alps are also sometimes dissolved over the plains of Lombardy.

84. In connection with the formation of clouds by mountains, one particularly instructive effect may be here noticed. You frequently see a streamer of cloud many hundred yards in length drawn out from an Alpine peak. Its steadiness appears perfect, though a strong wind may be blowing at the same time over the mountain head. Why is the cloud not blown away? It *is* blown away; its permanence is only apparent. At one end it is incessantly dissolved, at the other end it is incessantly renewed: supply and consumption being thus equalized, the cloud appears as changeless as the mountain to which it seems to cling. When the red sun of the evening shines upon these cloud-streamers they resemble vast torches with their flames blown through the air.

§ 9. *Architecture of Snow.*

85. We now resemble persons who have climbed a difficult peak, and thereby earned the enjoyment of a wide prospect. Having

made ourselves masters of the conditions necessary to the production of mountain snow, we are able to take a comprehensive and intelligent view of the phenomena of glaciers.

86. A few words are still necessary as to the formation of snow. The molecules and atoms of all substances, when allowed free play, build themselves into definite and, for the most part, beautiful forms called crystals. Iron, copper, gold, silver, lead, sulphur, when melted and permitted to cool gradually, all show this crystallizing power. The metal bismuth shows it in a particularly striking manner, and when properly fused and solidified, self-built crystals of great size and beauty are formed of this metal.

87. If you dissolve saltpetre in water, and allow the solution to evaporate slowly, you may obtain large crystals, for no portion of the salt is converted into vapour. The water of our atmosphere is fresh though it is derived from the salt sea. Sugar dissolved in water, and permitted to evaporate, yields crystals of sugar-candy. Alum readily crystallizes in the same way. Flints dissolved, as they sometimes are in nature, and permitted to crystallize, yield the prisms and pyramids of rock crystal. Chalk dissolved and crystallized yields Iceland spar. The diamond is crystallized carbon. All our precious stones, the ruby, sapphire, beryl, topaz, emerald, are all examples of this crystallizing power.

88. You have heard of the force of gravitation, and you know that it consists of an attraction of every particle of matter for every other particle. You know that planets and moons are held in their orbits by this attraction. But gravitation is a very simple affair compared to the force, or rather forces, of crystallization. For here the ultimate particles of matter, inconceivably small as they are, show themselves possessed of attractive and repellent poles, by the mutual action of which the shape and structure of the crystal are determined. In the solid condition the attracting poles are rigidly locked together; but if sufficient heat be applied the bond of union is dissolved, and in the state of fusion the poles are pushed so far asunder as to be practically

out of each other's range. The natural tendency of the molecules to build themselves together is thus neutralized.

89. This is the case with water, which as a liquid is to all appearance formless. When sufficiently cooled the molecules are brought within the play of the crystallizing force, and they then arrange themselves in forms of indescribable beauty. When snow is produced in calm air, the icy particles build themselves into beautiful stellar shapes, each star possessing six rays. There is no deviation from this type, though in other respects the appearances of the snow-stars are infinitely various. In the polar regions these exquisite forms were observed by Dr. Scoresby, who gave numerous drawings of them. I have observed them in mid-winter filling the air, and loading the slopes of the Alps. But in England they are also to be seen, and no words of mine could convey so vivid an impression of their beauty as the annexed drawings of a few of them, executed at Greenwich by Mr. Glaisher.

90. It is worth pausing to think what wonderful work is going on in the atmosphere during the formation and descent of every snow-shower: what building power is brought into play! and how imperfect seem the productions of human minds and hands when compared with those formed by the blind forces of nature!

91. But who ventures to call the forces of nature blind? In reality, when we speak thus we are describing our own condition. The blindness is ours; and what we really ought to say, and to confess, is that our powers are absolutely unable to comprehend either the origin or the end of the operations of nature.

92. But while we thus acknowledge our limits, there is also reason for wonder at the extent to which science has mastered the system of nature. From age to age, and from generation to generation, fact has been added to fact, and law to law, the true method and order of the Universe being thereby more and more revealed. In doing this science has encountered and overthrown various

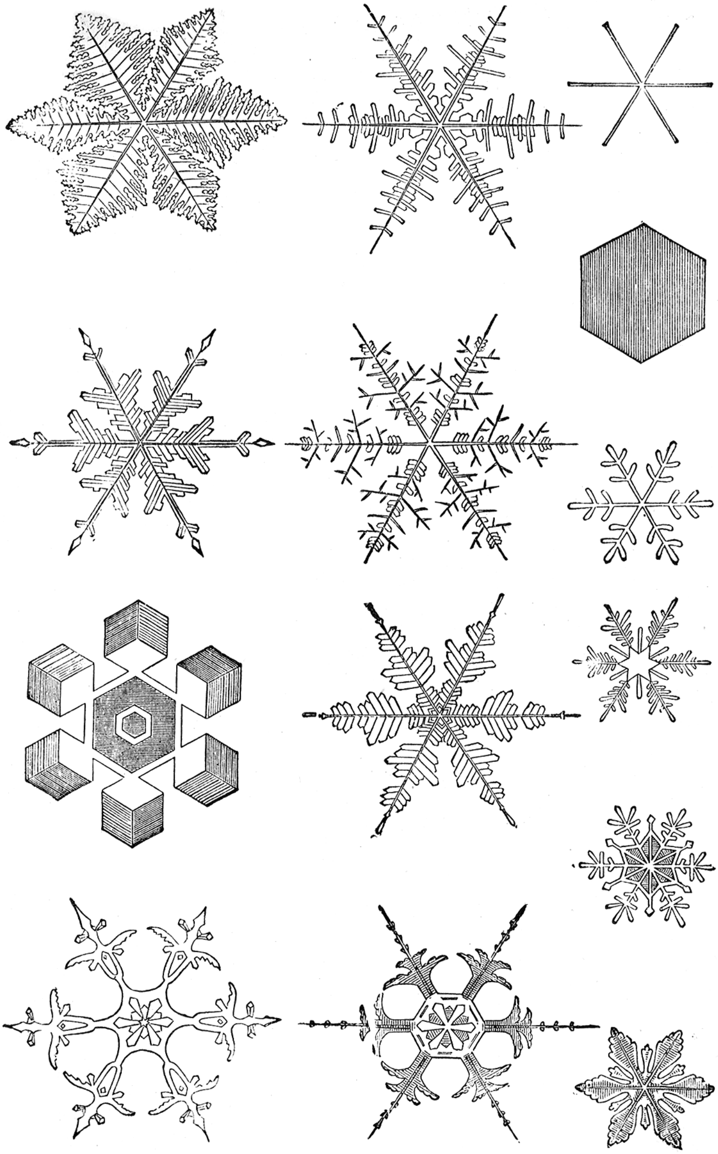
forms of superstition and deceit, of credulity and imposture. But the world continually produces weak persons and wicked persons; and as long as they continue to exist side by side, as they do in this our day, very debasing beliefs will also continue to infest the world.

§ 10. *Atomic Poles.*

93. 'What did I mean when, a few moments ago (88), I spoke of attracting and repellent poles?' Let me try to answer this question. You know that astronomers and geographers speak of the earth's poles, and you have also heard of magnetic poles, the poles of a magnet being the points at which the attraction and repulsion of the magnet are as it were concentrated.

94. Every magnet possesses two such poles; and if iron filings be scattered over a magnet, each particle becomes also endowed with two poles. Suppose such particles devoid of weight and floating in our atmosphere, what must occur when they come near each other? Manifestly the repellent poles will retreat from each other, while the attractive poles will approach and finally lock themselves together. And supposing the particles, instead of a single pair, to possess several pairs of poles arranged at definite points over their surfaces; you can then picture them, in obedience to their mutual attractions and repulsions, building themselves together to form masses of definite shape and structure.

95. Imagine the molecules of water in calm cold air to be gifted with poles of this description, which compel the particles to lay themselves together in a definite order, and you have before your mind's eye the unseen architecture which finally produces the visible and beautiful crystals of the snow. Thus our first notions and conceptions of poles are obtained from the sight of our eyes in looking at the effects of magnetism; and we then transfer these



SNOW CRYSTALS.

D

notions and conceptions to particles which no eye has ever seen. The power by which we thus picture to ourselves effects beyond the range of the senses is what philosophers call the Imagination, and in the effort of the mind to seize upon the unseen architecture of crystals, we have an example of the 'scientific use' of this faculty. Without imagination we might have *critical* power, but not *creative* power in science.