by f. The volume occupied by this air when in the atmosphere, where the temperature is T, is known by the regular formulæ to have been

$$V \cdot \frac{H-f}{H-x} \cdot \frac{1+\alpha T}{1+\alpha t},$$

x denoting the pressure of the aqueous vapour in the atmosphere, and H the total atmospheric pressure as indicated by the barometer; and, since the relative density of steam is ·622, and the weight of a litre of air at temperature 0° C. and pressure 760 mm. is 1·293 gramme, the weight of vapour which this air contained must have been

$$V \cdot \frac{H-f}{H-x} \cdot \frac{1+\alpha T}{1+\alpha t} \times 1{\cdot}293 \times {\cdot}622 \cdot \frac{x}{760} \cdot \frac{1}{1+\alpha T},$$

which must be equal to the known weight w, and thus we have an equation from which we find

$$x = \frac{w\,(1+\alpha t)\,760\,H}{V\,(H-f) \times {\cdot}622 \times 1{\cdot}293 + w\,(1+\alpha t)\,760}.$$

A good approximation will be obtained by writing

$$w = V \times 1{\cdot}293 \times {\cdot}622\,\frac{x}{760},$$

whence

$$x = 945\,\frac{w}{V}.$$

This method has all the exactness of a regular chemical analysis, but it involves great labour, and is, besides, incapable of showing the sudden variations which often occur in the humidity of the atmosphere. It can only give the mean quantity of moisture in a given volume of air during the time occupied by the experiment. Its accuracy, however, renders it peculiarly suitable for checking the results obtained by other methods, and it was so employed by Regnault in the investigations to which we have referred in the foot-note to the preceding section.

155. Weight of a given Volume of Moist Air.—The laws of vapours and the known formulæ of expansion enable us to solve a problem of very frequent occurrence, namely, the determination of the weight of a given volume of moist air. Let V denote the volume of this air, H its pressure, f the pressure of the vapour of water in it, and t its temperature. The entire gaseous mass may be divided into two parts, a volume V of dry air at the temperature t and the pressure $H-f$, whose weight is, by known formulæ,

$$V \times 1{\cdot}293 \times \frac{1}{1+\alpha t} \cdot \frac{H-f}{760},$$

and a volume V of aqueous vapour at the temperature t and the pressure f; the weight of this latter is

$$\frac{5}{8} V \times 1{\cdot}293 \times \frac{1}{1+\alpha t} \cdot \frac{f}{760}.$$

The sum of these two weights is the weight required, viz.

$$V \times 1{\cdot}293 \times \frac{1}{1+\alpha t} \cdot \frac{H - \frac{3}{8}f}{760}.$$

156. Ratio of the Volumes occupied by the same Air when saturated at Different Temperatures and Pressures.—Suppose a mass of air to be in presence of a quantity of water which keeps it always saturated; let H be the total pressure of the saturated air, t its temperature, and V its volume.

At a different temperature and pressure t' and H′, the volume occupied V′ will in general be different. The two quantities V and V′ may be considered as the volumes occupied by a mass of dry air at temperatures t and t' and pressures $H-f$ and $H'-f'$; we have then the relation

$$\frac{V}{V'} = \frac{H'-f'}{H-f} \cdot \frac{1+\alpha t}{1+\alpha t'} \qquad (1)$$

In passing from one condition of temperature and pressure to another, it may be necessary, for the maintenance of saturation, that a new quantity of vapour should be formed, or that a portion of the vapour should be condensed, or again, neither the one nor the other change may take place. To investigate the conditions on which these alternatives depend, let D and D′ be the maximum densities of vapour at the temperatures t and t' respectively. Suppose we have $t'>t$, and that, without altering the pressure f, the temperature of the vapour is raised to t', all contact with the generating liquid being prevented. The vapour will no longer remain saturated; but, on increasing the pressure to f', keeping the temperature unchanged, saturation will again be produced. This latter change does not alter the actual quantity of vapour, and if we suppose its coefficient of expansion to be the same as that of air, we shall have

$$\frac{D}{D'} = \frac{f}{f'} \cdot \frac{1+\alpha t'}{1+\alpha t}, \qquad (2)$$

and, by multiplying together equations (1) and (2), we have

$$\frac{VD}{V'D'} = \frac{H'f - ff'}{Hf' - ff'}. \qquad (3)$$

From this result the following particular conclusions may be deduced:—

1. If $H'f=Hf'$, $VD=V'D'$, that is, the mass of vapour is the same in both cases; consequently, neither condensation nor evaporation takes place.

2. If $H'f>Hf'$, $VD>V'D'$, that is, partial condensation occurs.

3. If $H'f<Hf'$, $VD<V'D'$, that is, a fresh quantity of vapour is required to maintain saturation. In this case the formula (1) can only be applied when we are sure that there is a sufficient excess of liquid to produce the fresh quantity of vapour which is required.

The general formulæ (1), (2), (3) furnish the solution of many particular problems which may be proposed by selecting some one of the variables for the unknown quantity.

157. **Aqueous Meteors.**—The name *meteor*, from the Greek *μετεωρος*, *aloft*, though more especially applied to the bright objects otherwise called shooting-stars and their like, likewise includes all the various phenomena which have their seat in the atmosphere; for example, clouds, rain, and lightning. This use of the word *meteor* is indeed somewhat rare; but the correlative term *meteorology* is invariably employed to denote the science which treats of these phenomena, in fact, the *science of matters pertaining to weather*.

By *aqueous meteors* are to be understood the phenomena which result from the condensation of aqueous vapour contained in the air, such as rain, dew, and fog. This condensation may occur in either of two ways. Sometimes it is caused by the presence of a cold body, which reduces the film of air in contact with it to a temperature below the dew-point, and thus produces the liquefaction or solidification of a portion of its vapour in the form of dew or hoar-frost.

When, on the contrary, the condensation of vapour takes place in the interior of a large mass of air, the resulting liquid or solid *falls* in obedience to gravity. This is the origin of rain and snow.

158. **Cloud and Mist.**—When vapour is condensed in the midst of the air, the first product is usually *mist* or *cloud*, a cloud being merely a mist at a great elevation in the air.

Natural clouds are similar in constitution to the cloudy substance which passes off from the surface of hot water, or which escapes in puffs from the chimney of a locomotive. In common language this substance is often called steam or vapour, but improperly, for steam

is, like air, transparent and invisible, and the appearance in question is produced by the presence of particles of liquid water, which have been formed from vapour by cooling it below its dew-point.

Different opinions have been put forward as to the nature of these particles, the difference having arisen in the attempt to explain their suspension in the atmosphere. Some have endeavoured to account for it by maintaining that they are hollow;[1] but even if we could conceive of any causes likely to lead to the formation of such bubbles, it would furnish no solution of the difficulty, for the air inclosed in a bubble is no rarer, but in fact denser, than the external air (see *Capillarity* in Part I.); the bubble and its contents are therefore heavier than the air which it displaces.

It is more probable that the particles are solid spheres differing only in size from rain-drops. It has been urged against this view, that such drops ought to exhibit rainbows, and the objection must be allowed to have some weight. The answer to it is probably to be found in the excessive smallness of the globules. Indeed, the non-occurrence of bows may fairly be alleged as proving that the diameters of the drops are comparable with the lengths of waves of light.

This smallness of the particles is amply sufficient to explain all the observed facts of cloud suspension, without resorting to any special theory. It probably depends on the same principle as the suspension of the motes which are rendered visible when a beam of sunlight traverses a darkened room. It is true that these motes, which are small particles of matter of the most various kinds, are never seen resting stationary in the air; but neither are the particles which compose clouds. All who have ever found themselves in mountain mists must have observed the excessive mobility of their constituent parts, which yield to the least breath of wind, and are carried about by it like the finest dust. Sometimes, indeed, clouds have the *appearance* of being fixed in shape and position; but this is an illusion due to distance which renders small movements invisible. In many cases, the fixity is one of form and not of material; for example, the permanent cloud on a mountain-top often consists of successive portions of air, which become cloudy by condensation as they pass through the cold region at the top of the mountain, and recover their transparency as they pass away.

[1] Those who adopt this view call them *vesicles* (*vesica*, a bladder), and call mist or cloud *vapour in the vesicular state*.

159. Varieties of Cloud.—The cloud nomenclature generally adopted by meteorologists was devised by Howard, and is contained in his work on the climate of London. The fundamental forms, according to him, are three—*cirrus, cumulus,* and *stratus.*

1. *Cirrus* consists of fibrous, wispy, or feathery clouds, occupying the highest region of the atmosphere. The name *mare's-tails,* which is given them by sailors, describes their aspect well. They are higher than the greatest elevations attained by balloons, and are probably composed of particles of ice. It is in this species of cloud, and its derivatives, that haloes are usually seen; and their observed forms and dimensions seem to agree with the supposition that they are formed by refractions and reflections from ice-crystals.

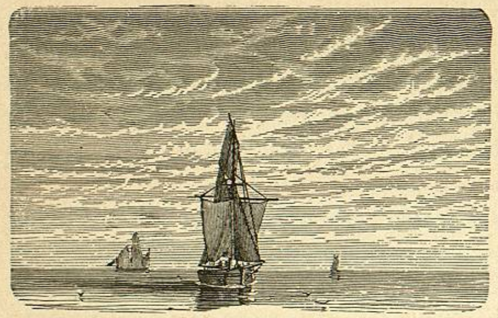

Fig. 96.—Cirrus.

2. *Cumulus* consists of rounded masses, convex above and comparatively flat below. Their form bears a strong resemblance to heaps of cotton wool, hence the name *balls of cotton* and *wool-packs* applied to these clouds by sailors. They are especially prevalent in summer, and are probably formed by columns of ascending vapour which become condensed at their upper extremities.

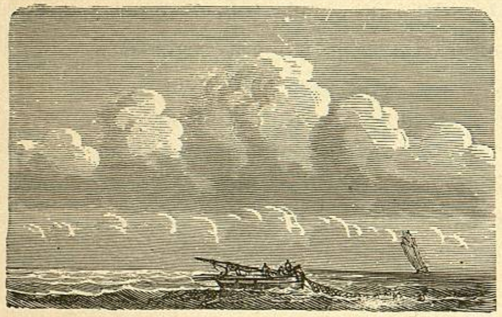

Fig. 97.—Cumulus.

3. *Stratus* consists of horizontal sheets. Its situation is low in the atmosphere, and its formation is probably due to the cooling of the earth and the lower portion of the air by radiation. It is very frequently formed at sunset, and disappears at sunrise.

Of the intermediate forms it may suffice to mention *cirro-cumulus,* which floats at a higher level than cumulus, and consists usually of

small roundish masses disposed with some degree of regularity. This is the cloud which forms what is known as a *mackerel sky.*

As a distinct form not included in Howard's classification, may be mentioned *scud,* the characteristic of which is that, from its low elevation, it *appears* to move with excessive rapidity.

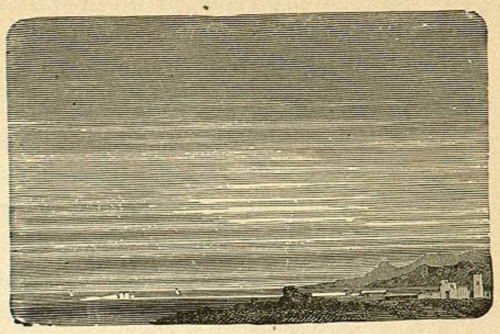

Fig. 98.—Stratus.

Howard gives the name of *nimbus* to any cloud which is discharging rain; and, for no very obvious reason, he regards this rain-cloud as compounded of (or intermediate between) the three elementary types above defined.

The classification of clouds is a subject which scarcely admits of precise treatment; the varieties are so endless, and they shade so gradually into one another.

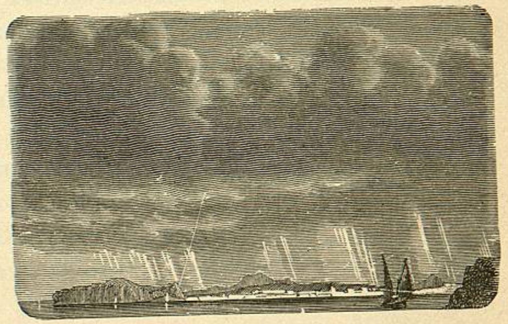

Fig. 99.—Nimbus.

160. Causes of the Formation of Cloud and Mist.—Since clouds are merely condensed vapour, their formation is regulated by the causes which tend to convert vapour into liquid. Such liquefaction implies the presence of a quantity of vapour greater than that which, at the actual temperature, would be sufficient for saturation, a condition of things which may be brought about by the cooling of a mass of moist air in any of the following ways:—

(1.) By radiation from the mass of air to the cold sky.

(2.) By the neighbourhood of cold ground, for example, mountain-tops.

(3.) By the cooling effect of expansion, when the mass of air ascends into regions of diminished pressure. This cooling of the ascending mass is accompanied by a corresponding warming of the air which descends—it may be in some distant locality—to supply its place.

Causes (2) and (3) combine to produce the excessive rainfall which generally characterizes mountainous districts.[1]

It is believed that waterspouts are produced by the rapid ascent of a stream of air up the axis of an aerial vortex.

(4) By the contact and mixture of cooler air.[2] It is obvious, however, that this cooler air must itself be warmed by the process; and as both the temperature and vapour-density of the mixture will be intermediate between those of the two components, it does not obviously follow (as is too often hastily assumed) that such contact tends to produce precipitation. Such is however the fact, and it depends upon the principle that the density of saturation increases faster as the temperature is higher; or, what is the same thing, that the curve in which temperature is the abscissa and maximum vapour-density the ordinate, is everywhere concave upwards.

It will be sufficient to consider the case of the mixing of two equal volumes of saturated air at different temperatures, which we will denote by t_1 and t_2. Let the ordinates AA′, BB′ represent the densities of vapour for saturation at these temperatures, $A'mB'$ being the intermediate portion of the curve, and Cm the ordinate at the middle point of AB, representing therefore the density of saturation for the temperature $\frac{1}{2}(t_1+t_2)$. When the equal volumes are mixed, since the colder *mass* is slightly the greater, the temperature of the mixture will be something less than $\frac{1}{2}(t_1+t_2)$, and, if there were no condensation of vapour, the density of vapour in the mixture would be $\frac{1}{2}(AA'+BB')=Cn$. But the density for saturation is something less than Cm. The excess of vapour is therefore represented by something more than mn. The amount actually precipitated will, however, be less than this, since the portion which is condensed

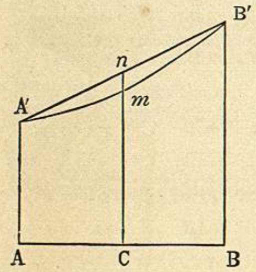

Fig. 100.

[1] The rainiest place at present known in Great Britain is about a mile south of Seathwaite in Cumberland, where the annual rainfall is about 165 inches. The rainiest place in the world is believed to be Cherra Ponjee, in the Khasyah Mountains, about 300 miles N.E. of Calcutta, where the annual fall is about 610 inches.

[2] *Contact* with cooler air may be regarded as equivalent to mixing; for vapour diffuses readily.

gives out its latent heat, and thus contributes to keep up the temperature of the whole.

The cause here indicated combines with (3) to produce condensation when masses of air ascend.

On the surface of the earth mists are especially frequent in the morning and evening; in the latter case extending over all the surface; in the former principally over rivers and lakes. The mists of evening are due simply to the rapid cooling of the air after the heat of the sun has been withdrawn. In the morning another cause is at work. The great specific heat of water causes it to cool much more slowly than the air, so that the vapour rising from a body of water enters into a colder medium, and is there partly condensed, forming a mist, which, however, confines itself to the vicinity of the water, and is soon dissipated by the heat of the rising sun.

161. **Rain.**—In what we have stated regarding the constitution of clouds, it is implied that clouds are always raining, since the drops of which they are composed always tend to obey the action of gravity. But, inasmuch as there is usually a non-saturated region intervening between the clouds and the surface of the earth, these drops, when very small, are usually evaporated before they have time to reach the ground. Ordinary rain-drops are formed by the coalescing of a number of these smaller particles.

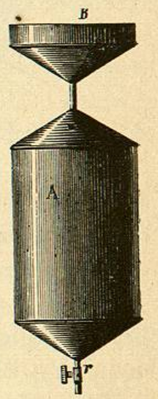

Fig. 101.
Rain-gauge.

By the amount of annual rainfall at a given place is meant the depth of water that would be obtained if all the rain which falls there in a year were collected into one horizonal sheet; and the depth of rain that falls in any given shower is similarly reckoned. It is the depth of the pool which would be formed if the ground were perfectly horizontal, and none of the water could get away. The instrument employed for determining it is called a *rain-gauge*. It has various forms, one of which is represented in the adjoining figure. B is a funnel into which the rain falls, and from which it trickles into the reservoir A. It is drawn off by means of the stopcock r, and measured in a graduated glass.[1]

[1] The best work on the subject of rain and its measurement is Mr. Symons' little treatise [out of print] entitled *Rain*. Mr. Symons, who is at the head of an immense corps of volunteer observers of rain in all parts of the United Kingdom, also publishes an annual volume entitled *British Rainfall*.

The form recommended for use in ordinary localities by Mr. G. J. Symons the best authority on the subject, is called the Snowdon gauge, and is represented in Fig. 102. Its top is a cylinder with a sharp edge. A funnel is soldered to the inside of this cylinder at the distance of about one diameter from the top, and the neck of the funnel descends nearly to the bottom of a bottle which serves as reservoir. A second cylinder, closed below and just large enough for the first to be slipped over it, contains the bottle, and is held in its place by four stakes driven into the ground. The upper cylinder with its attached funnel is slipped over the lower one, and pushed down till its further descent is stopped by the rim of the funnel meeting the edge of the lower cylinder.

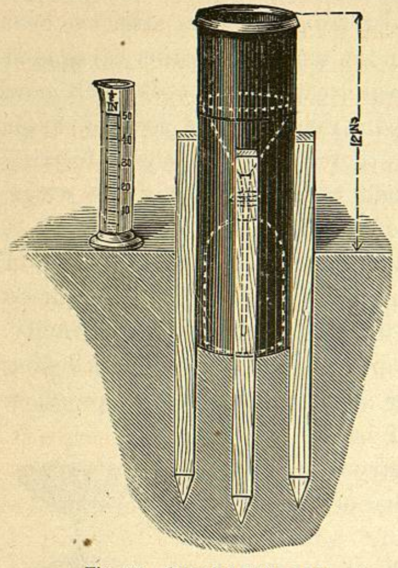

Fig. 102.—Snowdon Rain-gauge.

The height of the receiving surface above the ground is 1 foot, and its diameter 5 inches. The graduated jar reads to hundredths of an inch, and measures up to half an inch. The bottle holds about 3 inches of rain, and in the rare case of a fall exceeding that, the excess is saved by the lower cylinder.

Snow can be measured in either of the following ways:—

(1.) Melt what is caught in the gauge by adding to the snow a previously ascertained quantity of warm water, and then, after deducting this quantity from the total measurement, enter the residue as rain.

(2.) Select a place where the snow has not drifted, invert the upper cylinder with its attached funnel, and, turning it round, lift and melt what is inclosed.

It is essential that the receiving surface should be truly horizontal, otherwise the gauge will catch too much or too little according to the direction of the wind.

The best place for a rain-gauge is the centre of a level and open plot; and the height of its receiving surface should be not less than 6 inches, to avoid in-splashing. The roof of a house is a bad place on account of the eddies which abound there.

A circumstance which has not yet been fully explained is that the higher a gauge is above the ground the less rain it catches. In the case of gauges on the top of poles in an open situation, the amount collected is diminished by $\frac{1}{90}$th part of itself by doubling the height of the receiving surface, as shown by comparing gauges in the same plot of ground at heights ranging from 6 inches to 20 feet.[1]

By means of tipping-buckets and other arrangements, automatic records of rainfall are obtained at the principal observatories.

The mean annual rainfall, according to Mr. Symons, is 20 inches at Lincoln and Stamford; 21 at Aylesbury, Bedford, and Witham; 24 at London and Edinburgh; 30 at Dublin, Perth, and Salisbury; 33 at Exeter and Clifton; 35 to 36 at Liverpool and Manchester; 40 at Glasgow and Cork; 50 at Galway; 64 at Greenock and Inverary; 86 at Dartmoor; 91 on Benlomond; and upwards of 150 inches in some parts of the English lake district.

162. **Snow and Hail.**—Snow is probably formed by the direct passage of vapour into the solid state. Snow-flakes, when examined under the microscope, are always found to be made up of elements possessing hexagonal symmetry. In Fig. 103 are depicted various forms observed by Captain Scoresby during a long sojourn in the Arctic regions.

In these cold countries the air is often filled with small crystals of ice which give rise to the phenomena of haloes and parhelia.

Hail is probably due to the freezing of rain-drops in their passage through strata of air colder than those in which they were formed. Even in fine summer weather, a freezing temperature exists at the height of from 10,000 to 20,000 feet, and it is no unusual thing for a colder stratum to underlie a warmer, although, as a general rule, the temperature diminishes in ascending.

163. **Dew.**—By this name we denote those drops of water which are seen in the morning on the leaves of plants, and are especially noticeable in spring and autumn. We have already seen (§ 157) that dew does not *fall*, as it is not formed in the atmosphere, but in contact with the bodies on which it appears, being in fact due to their cooling after the sun has sunk below the horizon, when they lose heat by radiation to the sky. The lowering of temperature which thus occurs is much more marked for grass, stones, or bare earth than

[1] This appears from the table in Symons on *Rain*, p. 19.

Fig. 103.—Snow-crystals.

for the air, whose radiating power is considerably less. The consequence is a considerable difference of temperature between the surface of the ground and the air at the height of a few feet, a difference which is found by observation to amount sometimes to 8° or 10° C., and it is this which causes the deposition of dew. The surface of the earth, as it gradually cools, lowers the temperature of the adjacent air, which thus becomes saturated, and, on further cooling, yields up a portion of its vapour in the liquid form. If the temperature of the surface falls below 0° C., the dew is frozen, and takes the form of *hoar-frost*.

According to this theory, it would appear that the quantity of dew deposited upon a body should increase with the radiating power of its surface, and with its insulation from the earth or other bodies from which it might receive heat by conduction, both which conclusions are verified by observation.

The amount of deposition depends also in a great measure on the degree of exposure to the sky. If the body is partially screened, its radiation and consequent cooling are checked. This explains the practice which is common with gardeners of employing light coverings to protect plants from frost—coverings which would be utterly powerless as a protection against the cold of the surrounding air. The lightness of the dew on cloudy nights is owing to a similar cause; clouds, especially when overhead, acting as screens.

The deposition of dew is favoured by a slight motion of the atmosphere, which causes the lower strata of air to cool down more rapidly; but if the wind is very high, the different strata are so intermingled that very little of the air is cooled down to its dew-point, and the deposit is accordingly light. When these two obstacles are combined, namely a high wind and a cloudy sky, there is no dew at all.