perature. The results for every tenth degree between 0° and 230° are given in the following table:—

Temperatures Centigrade.	Latent Heat.	Total Heat.	Temperatures Centigrade.	Latent Heat.	Total Heat.
0°	606	606	120°	522	642
10	600	610	130	515	645
20	593	613	140	508	648
30	586	616	150	501	651
40	579	619	160	494	654
50	572	622	170	486	656
60	565	625	180	479	659
70	558	628	190	472	662
80	551	631	200	464	664
90	544	634	210	457	667
100	537	637	220	449	669
110	529	639	230	442	672

To reduce latent heat and total heat from the Centigrade to the Fahrenheit scale, we must multiply by $\frac{9}{5}$. Thus the latent and total heat of steam at 212° F. are 966·6 and 1146·6. Total heat is here reckoned from 32° F. If we reckon it from 0° F., 32 must be added.

The following table taken from the researches of Favre and Silbermann, gives the latent heat of evaporation of a number of liquids at the temperature of their boiling-point, referred to the Centigrade scale:—

	Boiling-point.	Latent Heat.		Boiling-point.	Latent Heat.
Wood-spirit, . . .	66·5°	264	Acetic acid, . . .	120°	102
Absolute alcohol,. .	78	208	Butyric acid, . . .	164	115
Valeric alcohol, . .	78	121	Valeric acid, . . .	175	104
Ether, ...	38	91	Acetic ether, . . .	74	100
Ethal, ...	38	58	Oil of turpentine, .	156	69
Valeric ether, . . .	113·5	113·5	Essence of citron, .	165	70
Formic acid, . . .	100	169			

CHAPTER XI.

HYGROMETRY.

141. **Humidity.**—The condition of the air as regards moisture involves two elements:—(1) the amount of vapour present in the air, and (2) the ratio of this to the amount which would saturate the air at the actual temperature. It is upon the second of these elements that our sensations of dryness and moisture chiefly depend, and it is this element which meteorologists have agreed to denote by the term *humidity;* or, as it is sometimes called, *relative humidity.* It is usually expressed as a percentage.

The words *humid* and *moist,* as applied to air in ordinary language, nearly correspond to this technical use of the word *humidity;* and air is usually said to be dry when its *humidity* is considerably below the average. In treatises on physics, "dry air" usually denotes air whose humidity is zero.

The air in a room heated by a hot stove contains as much vapour weight for weight as the open air outside; but it is drier, because its capacity for vapour is greater. In like manner the air is drier at noon than at midnight, though the amount of vapour present is about the same; and it is for the most part drier in summer than in winter, though the amount of vapour present is much greater.

It is to be borne in mind that a cubic foot of air is able to take up the same amount of vapour as a cubic foot of empty space; and "relative humidity" may be defined as *the ratio of the mass of vapour actually present in a given space, to the mass which would saturate the space at the actual temperature.*

Since aqueous vapour fulfils Boyle's law, these masses are proportional to the vapour-pressures which they produce, and relative humidity may accordingly be defined as *the ratio of the actual* *vapour-pressure to the maximum vapour-pressure for the actual temperature.*

142. Simultaneous Changes in the Dry and Vaporous Constituents.—When a mixture of air and vapour is subjected to changes of temperature, pressure, or volume which do not condense any of its vapour, the two constituents are similarly affected, since they have both the same coefficient of expansion, and they both obey Boyle's law. If the volume of the whole be reduced from v_1 to v_2 at constant temperature, both the densities will be multiplied by $\frac{v_1}{v_2}$, and hence, by Boyle's law, the pressures will also be multiplied by $\frac{v_1}{v_2}$. If, on the other hand, the temperature be altered from t_1 to t_2 without change of volume, both the pressures will be multiplied by $\frac{1+at_2}{1+at_1}$. The ratio of the vapour-pressure to the dry-air pressure remains unchanged in both cases.

If the changes of volume and temperature are effected simultaneously, each of the pressures will be multiplied by $\frac{v_1}{v_2}\frac{1+at_2}{1+at_1}$, and the total pressure will be multiplied by the same factor. If the total pressure remains unchanged, as is the case when there is free communication between the altered air and the general atmosphere, both the dry-air pressure and the vapour-pressure will therefore remain unchanged.

143. Dew-point.—When a mixture of dry air and vapour is cooled down at constant pressure until the vapour is at saturation, the temperature at which saturation occurs is called the *dew-point* of the original mass; and if the mixture be cooled below the dew-point, some of the vapour will be condensed into liquid water or solid ice.

The reasoning of the preceding section shows that the process of cooling down to the dew-point does not alter the vapour-pressure. The *actual vapour-pressure* in any portion of air *is* therefore *equal to the maximum vapour-pressure at the dew-point.*

When air is confined in a close vessel, and cooled at constant volume, its pressure and density at any given temperature, and the pressures and densities of its dry and vaporous constituents, will be less than if it were in free communication with the atmosphere. Hence its vapour will not be at saturation when cooled down to what is above defined as the dew-point of the original mass, but a lower temperature will be requisite.

144. These conclusions can also be established as follows:—

Let P denote the pressure of the mixture,
p „ the pressure of the vaporous constituent,
V „ the volume,
T „ the temperature reckoned from absolute zero on the air thermometer.

Then for all changes which do not condense any of the vapour

$$\frac{VP}{T} \text{ is constant, and } \frac{Vp}{T} \text{ is constant.}$$

When P is also constant, we have $\frac{V}{T}$ constant, and therefore p constant.

On the other hand, when V is constant, p will vary as T, and will diminish as T diminishes.

145. Hygroscopes.—Anything which serves to give rough indications of the state of the air as regards moisture may be called a *hygroscope* (ὑγρος, moist). Many substances, especially those which are composed of organic tissue, have the property of absorbing the moisture of the surrounding air, until they attain a condition of equilibrium such that their affinity for the moisture absorbed is exactly equal to the force with which the latter tends to evaporate. Hence it follows that, according to the dampness or dryness of the air, such a substance will absorb or give up vapour, either of which processes is always attended with a variation in the dimensions of the body. The nature of this variation depends upon the peculiar structure of the substance; thus, for instance, bodies formed of filaments exhibit a greater increase in the direction of their breadth than of their length. Membranous bodies, on the other hand, such as paper or parchment, formed by an interlacing of fibres in all directions, expand or contract almost as if they were homogeneous. Bodies composed of twisted fibres, as ropes and strings, swell under the action of moisture, grow shorter, and are more tightly twisted. The opposite is the case with catgut, which is often employed in popular hygroscopes.

146. Hygrometers.—Instruments intended for furnishing precise measurements of the state of the air as regards moisture are called *hygrometers.* They may be divided into four classes:—

1. Hygrometers of absorption, which should rather be called hygroscopes.
2. Hygrometers of condensation, or dew-point instruments.
3. Hygrometers of evaporation, or wet and dry bulb thermometers.

4. Chemical hygrometers, for directly measuring the weight of vapour in a given volume of air.

147. **De Saussure's Hygrometer.**—The best hygrometer of absorption is that of De Saussure, consisting of a hair deprived of grease, which by its contractions moves a needle (Fig. 88). When the hair relaxes, the needle is caused to move in the opposite direction

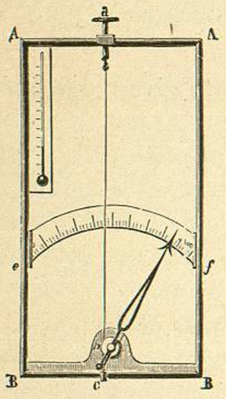

Fig. 88.—De Saussure's Hygroscope.

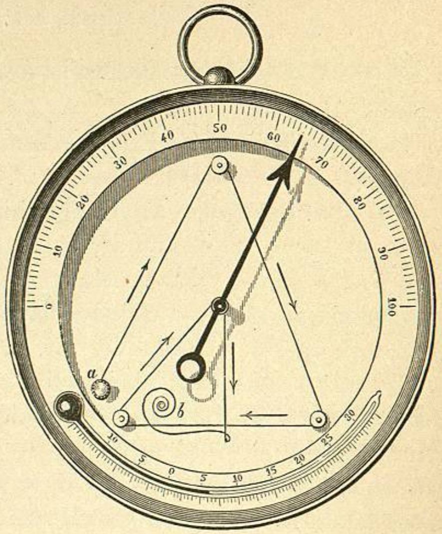

Fig. 89.—Monnier's Hygroscope.

by a weight, which serves to keep the hair always equally tight. The hair contracts as the humidity increases, but not in simple proportion, and Regnault's investigations have shown that, unless the most minute precautions are adopted in the construction and graduation of each individual instrument, this hygrometer will not furnish definite numerical measures.

Fig. 89 represents Monnier's modification of De Saussure's hygrometer, in which the hair, after passing over four pulleys, is attached to a light spring, which serves instead of a weight, and gives the advantage of portability.

These instruments are never employed for scientific purposes in this country.

148. **Dew-point Hygrometers.**—These are instruments for the direct observation of the dew-point, by causing moisture to be condensed from the air upon the surface of a body artificially cooled to a known temperature.

The dew-point, which is itself an important element, gives directly, as we have seen in § 143, the pressure of vapour; and if the temperature of the air is at the same time observed, the pressure requisite for saturation is known. The ratio of the former to the latter is the humidity.

149. **Dines' Hygrometer.**—One of the best dew-point hygrometers is that invented by the late Mr. Dines, shown both in perspective and in section in Figs. 90, 91. Cold water, with ice, if necessary, is put into the reservoir A, and by turning on the tap B this water is allowed to flow through the pipe C into the small double chamber D, the top of which, E, is formed of thin black glass, on which the smallest film of dew is easily perceived. After flowing under the black glass and around the bulb of a thermometer which lies immediately below it, the water escapes through a discharge pipe, and can be received in a vessel, from which it may again be poured into the reservoir A. As soon as any dew is seen on the black glass, the thermometer should be read, and the tap turned off, or partly off, until the dew disappears, when a second reading of the thermometer should be taken.

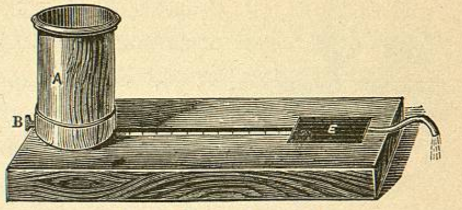

Fig. 90.—Dines' Hygrometer.

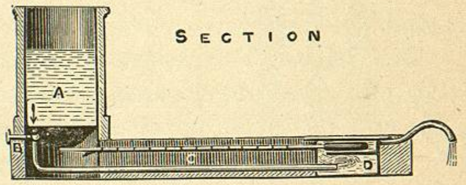

Fig. 91.—Dines' Hygrometer.

The mean of the two will be approximately the dew-point; and in order to obtain a good determination, matters should be so managed as to make the temperatures of appearance and disappearance nearly identical.

150. **Daniell's Hygrometer.**—Daniell's hygrometer has been very extensively used. It consists of a bent tube with a globe at each end, and is partly filled with ether. The rest of the space is occupied with vapour of ether, the air having been expelled. One of the globes A is made of black glass, and contains a thermometer *t*. The method of using the instrument is as follows:—The whole of the liquid is first passed into the globe A, and then the other globe B, which is covered with muslin, is moistened externally with ether.

The evaporation of this ether from the muslin causes a condensation of vapour of ether in the interior of the globe, which produces a fresh evaporation from the surface of the liquid in A, thus lowering the temperature of that part of the instrument. By carefully watching the surface of the globe, the exact moment of the deposition of dew may be ascertained. The temperature is then read on the inclosed thermometer.

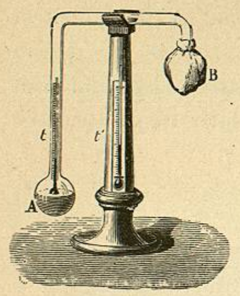

Fig. 92.
Daniell's Hygrometer.

If the instrument be now left to itself, the exact moment of the disappearance of the dew may be observed; and the usual plan is to take the mean between this temperature and that first observed. The temperature of the surrounding air is given by a thermometer t' attached to the stand.

151. **Regnault's Hygrometer.**—Regnault's hygrometer consists (Fig. 93) of a glass tube closed at the bottom by a very thin silver cap D. The opening at the upper end is closed by a cork, through which

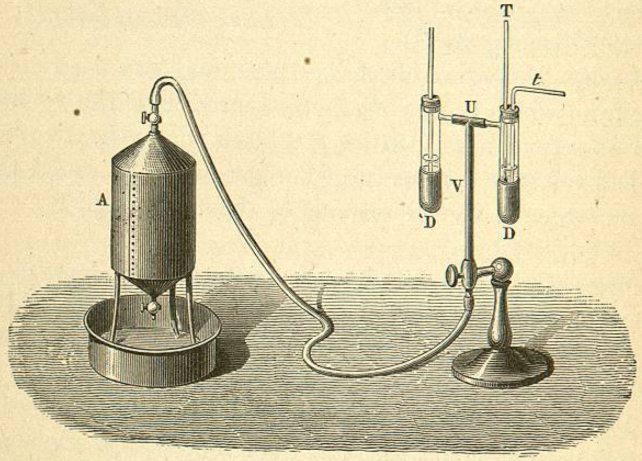

Fig. 93.—Regnault's Hygrometer.

passes the stem of a thermometer T, and a glass tube t open at both ends. The lower end of the tube and the bulb of the thermometer dip into ether contained in the silver cap. A side tube establishes communication between this part of the apparatus and a vertical

tube U V, which is itself connected with an aspirator[1] A, placed at a convenient distance. By allowing the water in the aspirator to escape, a current of air is produced through the ether, which has the effect of keeping the liquid in agitation, and thus producing uniformity of temperature throughout the whole. It also tends to hasten evaporation; and the cold thus produced speedily causes a deposition of dew, which is observed from a distance with a telescope, thus obviating the risk of vitiating the observation by the too close proximity of the observer. The observation is facilitated by the contrast offered by the appearance of the second cap, which has no communication with the first, and contains a thermometer for giving the temperature of the external air. By regulating the flow of liquid from the aspirator, the temperature of the ether can be very nicely controlled, and the dew can be made to appear and disappear at temperatures nearly identical. The mean of the two will then very accurately represent the dew-point.

The liquid employed in Regnault's hygrometer need not be ether. Alcohol, a much less volatile liquid, will suffice. This is an important advantage; for, since the boiling-point of ether is 36° C. (97° F.), it is not easy to preserve it in hot climates.

152. **Wet and Dry Bulb Hygrometer.**—This instrument, which is also called Mason's hygrometer, and is known on the Continent as August's psychrometer, consists (Fig. 94) of two precisely similar thermometers, mounted at a short distance from each other, the bulb of one of them being covered with muslin, which is kept moist by means of a cotton wick leading from a vessel of water. The evaporation which takes place from the moistened bulb produces a depression of temperature, so that this thermometer reads lower than the other by an amount which increases with the dryness of the air. The instrument must be mounted in such a way that the air can circulate

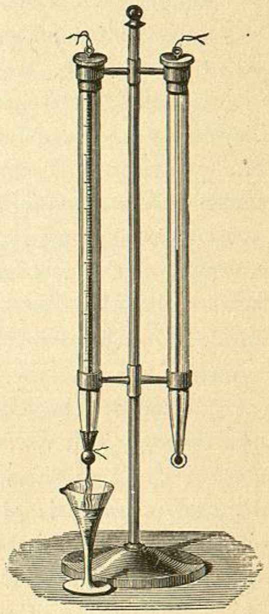
Fig. 94.
Wet and Dry Thermometers.

[1] An aspirator is a vessel into which air is sucked at the top to supply the place of water which is allowed to escape at the bottom; or, more generally, it is any apparatus for sucking in air or gas.

very freely around the wet bulb; and the vessel containing the water should be small, and should be placed some inches to the side. The level of this vessel must be high enough to furnish a supply of water which keeps the muslin thoroughly moist, but not high enough to cause drops to fall from the bottom of the bulb. Unless these precautions are observed, the depression of temperature will not be sufficiently great, especially in calm weather.

In frosty weather the wick ceases to act, and the bulb must be dipped in water some time before taking an observation, so that all the water on the bulb may be frozen, and a little time allowed for evaporation from the ice, before the reading is taken.

The great facility of observation afforded by this instrument has brought it into general use, to the practical exclusion of other forms of hygrometer. As the theoretical relation between the indications of its two thermometers and the humidity as well as the dew-point of the air is rather complex, and can scarcely be said to be known with certainty, it is usual, at least in this country, to effect the reduction by means of tables which have been empirically constructed by comparison with the indications of a dew-point instrument. The tables universally employed by British observers were constructed by Mr. Glaisher, and are based upon a comparison of the simultaneous readings of the wet and dry bulb thermometers and of Daniell's hygrometer taken for a long series of years at Greenwich observatory, combined with some similar observations taken in India and at Toronto.[1]

According to these tables, the difference between the dew-point and the wet-bulb reading bears a constant ratio to the difference between the two thermometers, when the temperature of the dry-bulb thermometer is given. When this temperature is 53° F., the dew-point is as much below the wet-bulb as the wet-bulb is below the temperature of the air. At higher temperatures the wet-bulb reading is nearer to the dew-point than to the air-temperature, and the reverse is the case at temperatures below 53°.

153. In order to obtain a clue to the construction of a rational formula for deducing the dew-point from the indications of this instrument, we shall assume that the wet-bulb is so placed that its temperature is not sensibly affected by radiation from surrounding objects, and hence that the heat which becomes latent by the

[1] The first edition of these Tables differs considerably from the rest, and is never used; but there has been no material alteration since the second edition (1856).

evaporation from its surface is all supplied by the surrounding air. When the temperature of the wet-bulb is falling, heat is being consumed by evaporation faster than it is supplied by the air; and the reverse is the case when it is rising. It will suffice to consider the case when it is stationary, and when, consequently, the heat consumed by evaporation in a given time is exactly equal to that supplied by the air.

Let t denote the temperature of the air, which is indicated by the dry-bulb thermometer; t' the temperature of the wet-bulb; T the temperature of the dew-point, and let f, f', F be the vapour-pressures corresponding to saturation at these three temperatures. Then, as shown in § 143, the tension of the vapour present in the air at its actual temperature t is also equal to F.

We shall suppose that wind is blowing, so that continually fresh portions of air come within the sphere of action of the wet-bulb. Then each particle of this air experiences a depression of temperature and an increase of vapour-pressure as it comes near the wet-bulb, from both of which it afterwards recovers as it moves away and mixes with the general atmosphere.

If now it is legitimate to assume[1] that this depression of temperature and exaltation of vapour-pressure are always proportional to one another, not only in comparing one particle with itself at different times, but also in comparing one particle with another, we have the means of solving our problem; at all events, if we may make the additional assumptions that a portion of the air close to the wet-bulb is at the temperature of the wet-bulb, and is saturated.

On these assumptions the greatest reduction of temperature of the air is $t-t'$, and the greatest increase of vapour-pressure is $f'-F$, and the corresponding changes in the whole mass are proportional to these. The three temperatures t, t', T must therefore be so related, that the heat lost by a mass of air in cooling through the range $t-t'$, is just equal to the heat which becomes latent in the formation of as much vapour as would raise the vapour-pressure of the mass by the amount $f'-F$.

[1] The assumption which Dr. Apjohn actually makes is as follows:—"When in the moist-bulb hygrometer the stationary temperature is attained, the caloric which vaporizes the water is necessarily exactly equal to that which the air imparts in descending from the temperature of the atmosphere to that of the moistened bulb; and the air which has undergone this reduction becomes saturated with moisture" (*Trans. R.I.A.* Nov. 1834).

This implies that all the air which is affected at all is affected to the maximum extent—a very harsh supposition; but August independently makes the same assumption.

Let h denote the height of the barometer, s the specific heat of air, D the relative density of vapour (§ 131), L the latent heat of steam, and let the vapour-pressures be expressed by columns of mercury.

Then the mass of the air is to that of the vapour required to produce the additional tension, as h to D $(f'-F)$, and we are to have

$$LD\,(f'-F)=s\,(t-t')\,h,$$

or

$$f'-F=(t-t')\,h\,.\,\frac{s}{LD}, \qquad (1)$$

which is the required formula, enabling us, with the aid of a table of vapour-pressures, to determine F., and therefore the dew-point T, when the temperatures t, t' of the dry and wet bulb, and the height h of the barometer, have been observed. The expression for the relative humidity will be $\frac{F}{f}$.

Properly speaking, s denotes the specific heat not o' dry air but of air containing the actual amount of vapour, and therefore depends to some extent upon the very element which is to be determined; but its variation is inconsiderable. L also varies with the known quantity t', but its variations are also small within the limits which occur in practice. The factor $\frac{s}{LD}$ may therefore be regarded as constant, and its value, as adopted by Dr. Apjohn[1] for the Fahrenheit scale, is $\frac{1}{2610}$ or $\frac{1}{30}\times\frac{1}{87}$. We thus obtain what is known as *Apjohn's formula*,

$$F=f'-\frac{t-t'}{87}\,.\,\frac{h}{30}. \qquad (2)$$

When the wet-bulb is frozen, L denotes the sum of the latent heats of liquefaction and vaporization, and the formula becomes

$$F=f'-\frac{t-t'}{96}\,.\,\frac{h}{30}. \qquad (3)$$

[1] This value was founded on the best determinations which had been made at the time, the specific heat of air being taken as ·267, the value obtained by Delaroche and Berard. The same value was employed by Regnault in his hygrometrical investigations. At a still later date Regnault himself investigated the specific heat of air and found it to be ·237. When this correct value is introduced into Regnault's theoretical formula (which is substantially the same as Apjohn's), the discrepancies which he found to exist between calculation and observation are increased, and amount, on an average, to about 25 per cent of the difference between wet-bulb temperature and dew-point. The inference is that the assumptions on which the theoretical formulæ are based are not accurate; and the discrepancy is in such a direction as to indicate that diffusion of heat is more rapid than diffusion of vapour.

In calm weather, and also in very dry weather, the humidity, as deduced from observations of wet and dry thermometers, is generally too great, probably owing mainly to the radiation from surrounding objects on the wet-bulb, which makes its temperature too high.

154. Chemical Hygrometer.—The determination of the quantity of aqueous vapour in the atmosphere may be effected by ordinary chemical analysis in the following manner:—

An aspirator A, of the capacity of about 50 litres, communicates at its upper end with a system of U-tubes 1, 2, 3, 4, 5, 6, filled with

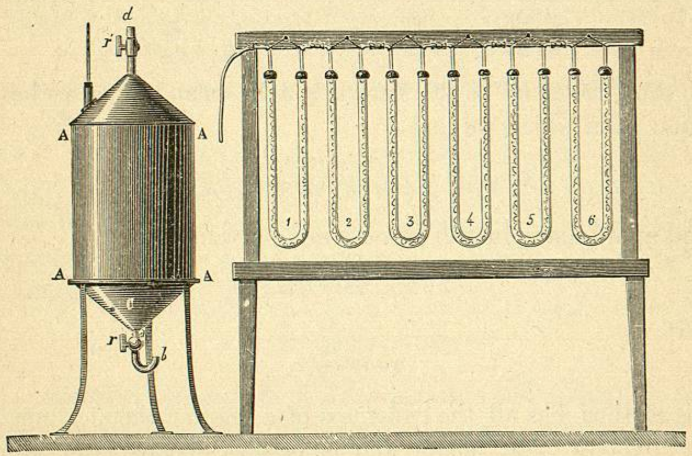

Fig. 95.—Chemical Hygrometer.

pieces of pumice soaked in sulphuric acid. The aspirator being full of water, the stop-cock at the bottom is opened, and the air which enters the aspirator to take the place of the water is obliged to pass through the tubes, where it leaves all its moisture behind. This moisture is deposited in the first tubes only. The last tube is intended to absorb any moisture that may come from the aspirator. Suppose w to be the increase of weight of the first tubes 4, 5, 6; this is evidently the weight of the aqueous vapour contained in the air which has passed through the apparatus. The volume V of this air, which we will suppose to be expressed in litres, may easily be found by measuring the amount of water which has escaped. This air has been again saturated by contact with the water of the aspirator, and the aqueous vapour contained in it is consequently at the maximum pressure corresponding to the temperature indicated by a thermometer attached to the apparatus. Let this pressure be denoted