lower extremity is partially supported by a counterpoise acting on a light lever (which turns on delicate pivots), so that the wire supporting the float is constantly stretched, leaving a definite part of the weight of the float to be supported by the quicksilver. This lever is lengthened to carry a vertical plate of opaque mica with a small aperture, whose distance from the fulcrum is eight times the distance of the point of attachment of the float-wire, and whose movement, therefore (§ 205), is four times the movement of the column of a cistern barometer. Through this hole the light of a lamp, collected by a cylindrical lens, shines upon the photographic paper.

Every part of the cylinder, except that on which the spot of light falls, is covered with a case of blackened zinc, having a slit parallel to the axis of the cylinder; and by means of a second lamp shining through a small fixed aperture, and a second cylindrical lens, a base line is traced upon the paper, which serves for reference in subsequent measurements.

The whole apparatus, or any other apparatus which serves to give a continuous trace of barometric indications, is called a *barograph;* and the names *thermograph, magnetograph, anemograph,* &c., are similarly applied to other instruments for automatic registration. Such registration is now employed at a great number of observatories; and curves thus obtained are regularly published in the Quarterly Reports of the Meteorological Office.

CHAPTER XVIII.

VARIATIONS OF THE BAROMETER.

209. Measurement of Heights by the Barometer.—As the height of the barometric column diminishes when we ascend in the atmosphere, it is natural to seek in this phenomenon a means of measuring heights. The problem would be extremely simple, if the air had everywhere the same density as at the surface of the earth. In fact, the density of the air at sea-level being about 10,500 times less than that of mercury, it follows that, on the hypothesis of uniform density, the mercurial column would fall an inch for every 10,500 inches, or 875 feet that we ascend. This result, however, is far from being in exact accordance with fact, inasmuch as the density of the air diminishes very rapidly as we ascend, on account of its great compressibility.

210. Imaginary Homogeneous Atmosphere.—If the atmosphere were of uniform and constant density, its height would be approximately obtained by multiplying 30 inches by 10,500, which gives 26,250 feet, or about 5 miles.

More accurately, if we denote by H the height (in centimetres) of the atmosphere at a given time and place, on the assumption that the density throughout is the same as the observed density D (in grammes per cubic centimetre) at the base, and if we denote by P the observed pressure at the base (in dynes per square centimetre), we must employ the general formula for liquid pressure (§ 139)

$$P = g\,HD, \text{ which gives } H = \frac{P}{gD}. \qquad (1)$$

The height H, computed on this imaginary assumption, is usually called the *height of the homogeneous atmosphere,* corresponding to the pressure P, density D, and intensity of gravity g. It is sometimes called the *pressure-height.* The *pressure-height* at any point in a liquid or gas is the height of a column of fluid, having the same density as at the point, which would produce, by its weight, the actual pressure at the point. This element frequently makes its appearance in physical and engineering problems.

The expression for H contains P in the numerator and D in the denominator; and by Boyle's law, which we shall discuss in the ensuing chapter, these two elements vary in the same proportion, when the temperature is constant. Hence H is not affected by changes of pressure, but has the same value at all points in the air at which the temperature and the value of g are the same.

211. Geometric Law of Decrease.—The change of pressure as we ascend or descend *for a short distance* in the actual atmosphere, is sensibly the same as it would be in this imaginary "homogeneous atmosphere;" hence an ascent of 1 centimetre takes off $\frac{1}{\mathrm{H}}$ of the total pressure, just as an ascent of one foot from the bottom of an ocean 60,000 feet deep takes off $\frac{1}{60000}$ of the pressure.

Since H is the same at all heights in any portion of the air which is at uniform temperature, it follows that in ascending by successive steps of 1 centimetre in air at uniform temperature, each step takes off the same fraction $\frac{1}{\mathrm{H}}$ of the current pressure. The pressures therefore form a geometrical progression whose ratio is $1-\frac{1}{\mathrm{H}}$. *In an atmosphere of uniform temperature,* neglecting the variation of g with height, *the densities and pressures diminish in geometrical progression as the heights increase in arithmetical progression.*

212. Computation of Pressure-height.—For perfectly dry air at 0° Cent., we have the data (§§ 195, 198),

$$\mathrm{D} = \cdot 0012932 \text{ when } \mathrm{P} = 1013600;$$

which give

$$\frac{\mathrm{P}}{\mathrm{D}} = 783800000 \text{ nearly.}$$

Taking g as 981, we have

$$\mathrm{H} = \frac{783800000}{981} = 799000 \text{ centimetres nearly.}$$

This is very nearly 8 kilometres, or about 5 miles. At the temperature t° Cent., we shall have

$$\mathrm{H} = 799000\,(1 + \cdot 00366\, t). \qquad (2)$$

Hence in air at the the temperature 0° Cent., the pressure diminishes by 1 per cent. for an ascent of about 7990 centimetres or, say, 80 metres. At 20° Cent., the number will be 86 instead of 80

213. Formula for determining Heights by the Barometer.—To obtain an accurate rule for computing the difference of levels of two stations from observations of the barometer, we must employ the integral calculus.

Denote height above a fixed level by x, and pressure by p. Then we have

$$\frac{dx}{\mathrm{H}} = -\frac{dp}{p};$$

and if p_1, p_2 are the pressures at the heights x_1, x_2, we deduce by integration

$$x_2 - x_1 = \mathrm{H}\,(\log_e p_1 - \log_e p_2).$$

Adopting the value of H from (2), and remembering that Napierian logarithms are equal to common logarithms multiplied by 2·3026, we finally obtain

$$x_2 - x_1 = 1840000\,(1 + \cdot 00366\, t)\,(\log p_1 - \log p_2)$$

as the expression for the difference of levels, in centimetres. It is usual to put for t the arithmetical mean of the temperatures at the two stations.

The determination of heights by means of atmospheric pressure, whether the pressure be observed directly by the barometer, or indirectly by the boiling-point thermometer (which will be described in Part II.), is called *hypsometry* (ὕψος, height).

As a rough rule, it may be stated that, in ordinary circumstances, the barometer falls an inch in ascending 900 feet.

214. Diurnal Oscillation of the Barometer.—In these latitudes, the mercurial column is in a continual state of irregular oscillation; but in the tropics it rises and falls with great regularity according to the hour of the day, attaining two maxima in the twenty-four hours.

It generally rises from 4 A.M. to 10 A.M., when it attains its first maximum; it then falls till 4 P.M., when it attains its first minimum; a second maximum is observed at 10 P.M., and a second minimum at 4 A.M. The hours of maxima and minima are called the tropical hours (τρέπω, to turn), and vary a little with the season of the year. The difference between the highest maximum and lowest minimum is called the diurnal[1] *range*, and the half of this is called the *ampli-*

[1] The epithets *annual* and *diurnal*, when prefixed to the words *variation*, *range*, *amplitude*, denote the *period* of the variation in question; that is, the time of a complete oscillation. Diurnal variation does not denote variation from one day to another, but the variation which goes through its cycle of values in one day of twenty-four hours. Annual

tude of the diurnal oscillation. The amount of the former does not exceed about a tenth of an inch.

The character of this diurnal oscillation is represented in Fig. 119. The vertical lines correspond to the hours of the day; lengths have been measured upwards upon them proportional to the barometric heights at the respective hours, diminished by a constant quantity; and the points thus determined have been connected by a continuous curve. It will be observed that the two lower curves, one of which relates to Cumana, a town of Venezuela, situated in about 10° north latitude, show strongly marked oscillations corresponding to the maxima and minima. In our own country, the regular diurnal oscillation is masked by irregular fluctuations, so that a single day's observations give no clue to its existence. Nevertheless, on taking observations at regular hours for a number of consecutive days, and comparing the mean heights for the different hours, some indications of the law will be found. A month's observations will be sufficient for an approximate indication of the law; but observations extending over some years will be required, to establish with anything like precision the hours of maxima and the amplitude of the oscillation.

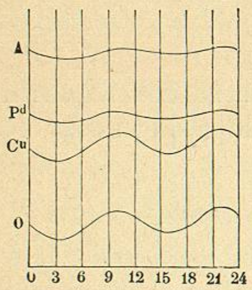

Fig. 119.
Curves of Diurnal Variation.

The two upper curves represent the diurnal variation of the barometer at Padua (lat. 45° 24′) and Abo (lat. 60° 56′), the data having been extracted from Kaemtz's *Meteorology*. We see, by inspection of the figure, that the oscillation in question becomes less strongly marked as the latitude increases. The range at Abo is less than half a millimetre. At about the 70th degree of north latitude it becomes insensible; and in approaching still nearer to the pole, it appears from observations, which however need further confirmation, that the oscillation is reversed; that is to say, that the maxima here are contemporaneous with the minima in lower latitudes.

There can be little doubt that the diurnal oscillation of the barometer is in some way attributable to the heat received from the sun, which produces expansion of the air, both directly, as a mere

range denotes the range that occurs within a year. This rule is universally observed by writers of high scientific authority.

A table, exhibiting the values of an element for each month in the year, is a table of annual (not monthly) variation; or it may be more particularly described as a table of variations from month to month.

consequence of heating, and indirectly, by promoting evaporation; but the precise nature of the connection between this cause and the diurnal barometric oscillation has not as yet been satisfactorily established.

215. Irregular Variations of the Barometer.—The height of the barometer, at least in the temperate zones, depends on the state of the atmosphere; and its variations often serve to predict the changes of weather with more or less certainty. In this country the barometer generally falls for rain or S.W. wind, and rises for fine weather or N.E. wind.

Barometers for popular use have generally the words—

Set fair.	Fair.	Change.	Rain.	Much rain.	Stormy.

marked at the respective heights

30·5	30	29·5	29	28·5	28 inches.

These words must not, however, be understood as absolute predictions. A low barometer rising is generally a sign of fine, and a high barometer falling of wet weather. Moreover, it is to be borne in mind that the barometer stands about a tenth of an inch lower for every hundred feet that we ascend above sea-level.

The connection between a low or falling barometer and wet weather is to be found in the fact that moist air is specifically lighter than dry, even at the same temperature, and still more when, as usually happens, moist air is warmer than dry.

Change of wind usually begins in the upper regions of the air and gradually extends downwards to the ground; hence the barometer, being affected by the weight of the whole superincumbent atmosphere, gives early warning.

216. Weather Charts. Isobaric Lines.—The probable weather can be predicted with much greater certainty if the height of the barometer at surrounding places is also known. The weather forecasts issued daily from the Meteorological Office in London are based on reports received twice a day from about sixty stations scattered over the west of Europe, from the north of Norway to Lisbon, and from the west of Ireland to Berlin. The reading of the barometer reduced to sea-level at each place is recorded on a chart, and curves called *isobaric lines* or *isobars* are drawn through places at which the pressure has given values, proceeding usually by steps of a tenth of an inch. Curves called *isothermal lines* or *isotherms* are also drawn through places of equal temperature. The strength and direction of wind, and the state of weather and of sea are also entered. The charts are compared with those of the previous day, and from the changes in progress the ensuing weather can be inferred with a fair probability of success.

The isobars furnish the most important aid in these forecasts; for from their form and distribution the direction and strength of the wind in each district can be inferred, and to a certain extent the state of the weather generally. As a rule the wind blows from places of higher to places of lower pressure, but not in the most direct line. It deviates more than 45° to the right of the direct line in the northern hemisphere, and to the left in the southern. This is known as Buys Ballot's law, and is a consequence of the earth's rotation.[1]

Very frequently a number of isobars form closed curves, encircling an area of low pressure, to which, in accordance with the above law, the wind blows spirally inwards, in the direction of watch-hands in the southern hemisphere, and against watch-hands in the northern. This state of things is called a *cyclone*. Cyclones usually approach the British Islands from the Atlantic, travelling in a north-easterly direction with a velocity of from ten to twenty miles an hour; sometimes disappearing within a day of their formation, and sometimes lasting for several days. They are the commonest type of distribution of pressure in western Europe, and are usually accompanied by unsettled weather.

The opposite state of things,—that is, a centre of maximum pressure from which the wind blows out spirally with watch-hands in the northern and against watch-hands in the southern hemisphere is called an *anticyclone*. It is usually associated with light winds and fine weather, and is favourable to frost in winter. Anticyclones usually move and change slowly.

The names *cyclone* and *anticyclone* are frequently applied to the distributions of pressure above indicated without taking account of the wind.

The strength of wind generally bears some proportion to the

[1] The influence of the earth's rotation in modifying the direction of winds is discussed in a paper "On the General Circulation and Distribution of the Atmosphere," by the editor of this work, in the *Philosophical Magazine* for September, 1871. Some of the results are stated in the last chapter of Part II. of the present work.

steepness of the barometric gradient, in other words to the closeness of the isobars. Violent storms of wind are usually cyclones, and it was to these that the name was first applied. The phenomenon reaches its extreme form in the tornadoes of tropical regions. The persistence of a cyclone can be explained by the fact that the centrifugal force of the spirally moving air tends to increase the original central depression.

The frontispiece of this volume is a chart of pressure and wind for the United States of America at 4·35 P.M. Washington time on the 15th of January, 1877, when a great storm was raging. The figures marked against the isobars are the pressures to tenths of an inch. They exhibit a very steep gradient on the north-west side of the central depression—a tenth of an inch for about forty-three nautical miles. The direction of the wind is shown by arrows, and the number of feathers on each arrow multiplied by five gives the velocity of the wind in miles per hour. It will be seen that the strongest winds are in or near the region of steepest gradient, and that the directions of the winds are for the most part in accordance with Buys Ballot's law.