Of the *self-registering barometers*, the best are those which accomplish this object by photography. This is done by concentrating the rays of a gas flame by means of a lens, so that they strike the top of the mercurial column. A sheet of prepared paper is attached to a frame placed behind a screen, with a narrow vertical slit in the line of the rays. The mercury being opaque throws a part of the paper in the shade, while above the mercury the rays from the flame pass unobstructed to the paper. The paper being carried steadily round on a drum at a given rate per hour, the height of the column of mercury is photographed continuously on the paper. From the photograph the height of the barometer at any instant may be taken. *King's, Hardy's, Hough's, Hipp's*, and *Thorell's self-registering barometers* may also be referred to as giving continuous records of the pressure. In all continuously registering barometers, however, it is necessary, as a check, to make eye-observations with a mercury standard barometer hanging near the registering barometer from four to eight times daily.

Materials. In constructing the best barometers three materials are employed, viz. :—(1) brass, for the case, on which the scale is engraved ; (2) glass, for the tube containing the mercury ; and (3) the mercury itself. Brass is the best material for the case and scale, inasmuch as its co-efficient of expansion is well known, and is practically the same though the alloy be not in all cases exactly alike. It is evident that if the co-efficient of expansion of mercury and brass were the same, the height of the mercury as indicated by the brass scale would be the true height of the mercurial column. But this is not the case, the co-efficient of expansion for mercury being considerably greater than that for brass. The result is that if a barometer stand at 30 inches when the temperature of the whole instrument, mercury and brass, is 32°, it will no longer stand at 30 inches if the temperature be raised to 69°; in fact, it will then stand at 30·1 inches. This increase in the height of the column by the tenth of an inch is not due to any increase of pressure, but altogether to the greater expansion of the mercury at the higher temperature, as compared with the expansion of the brass case with the engraved scale by which the height is measured. In order, therefore, to compare with each other with exactness barometric observations made at different temperatures, it is necessary to reduce them to the heights at which they would stand at some uniform temperature. The temperature to which such observations are now almost everywhere reduced is 32° Fahr.

The following is Schumacher's formula for computing the corrections for barometers, whose heights are noted in English inches, for temperature t, according to Fahrenheit's scale :—

$$x = -h\frac{m(t-32°)-s(t-62°)}{1+m(t-32°)},$$

where h = height of barometer,
m = expansion of mercury for 1° Fahr. = 0·0001001,
s = expansion of brass for 1° Fahr. = 0·00001041.

The standard temperature of the English yard being 62° and not 32°, it will be found in working out the corrections from the above formula that the temperature of no correction is not 32° but 28°·5. If the scale be engraved on the glass tube, or if the instrument be furnished with a glass scale or with a wooden scale, different corrections are required. These may be worked out from the above formula by substituting for the co-efficient of the expansion of brass that of glass which is assumed to be 0·00000498, or that of wood, which is assumed to be 0. Wood, however, should not be used, its expansion with temperature being unsteady, as well as uncertain.

If the brass scale be attached to a wooden frame and be free to move up and down the frame, as is the case with many siphon barometers, the corrections for brass scales are to be used, since the zero-point of the scale is brought to the level of the lower limb ; but if the brass scale be *fixed* to a wooden frame, the corrections for brass scales are only applicable provided the zero of the scale be fixed at (or nearly at) the zero line of the column, and be free to expand upwards. In siphon barometers, with which an observation is made from two readings on the scale, the scale must be free to expand in one direction. Again, if only the upper part of the scale, say from 27 to 31 inches, be screwed to a wooden frame, it is evident that not the corrections for brass scales, but those for wooden scales must be used. No account needs to be taken of the expansion of the glass tube containing the mercury, it being evident that no correction for this expansion is required in the case of any barometer the height of which is measured from the surface of the mercury in the cistern.

In fixing a barometer for observation, it is indispensable that it be hung in a perpendicular position, seeing that it is the *perpendicular distance* of the surface of the mercury in the cistern and that of the top of the column which is the true height of the barometer. Hence it is desirable that the barometer swing in position ; or if this be attended with risk or inconvenience, it must be seen that it be clamped or permanently fixed in a position exactly vertical. The surface of the mercurial column is convex, and in noting the height of the barometer, it is not the chord of the curve,—an error not unfrequently made,—but its tangent which is taken. This is done by setting the straight lower edge of the vernier, an appendage with which the barometer is furnished, as a tangent to the curve. The vernier is made to slide up and down the scale, and by it the height of the barometer may be read true to 0·002 or even to 0·001 inch. See VERNIER. Position of barometer.

In hanging a barometer the following points should be attended to :—(1), That it be hung so that the mercurial column be quite perpendicular ; (2), that the scale be about 5 feet high, for facility of reading ; (3), that the whole instrument, particularly the scale and the cistern, be hung in a good light ; and (4), that it be hung in a position in which it will be exposed to as little fluctuation of temperature as possible. A wall heated by a flue, and positions which expose the instrument to the heat of the sun or to that of a fire, are very objectionable. It is to be kept in mind that no barometric observation can be regarded as good unless the *attached thermometer* indicates a temperature differing from that of the whole instrument not more than a degree. For every degree of temperature the attached thermometer differs from the barometer, the observation will be faulty to the extent of about 0·003 inch, which in discussions of diurnal range, barometric gradients, lunar range, and many other questions, is a serious amount.

Before being used, barometers should be thoroughly examined as to the state of the mercury, the size of cistern (so as to admit of low readings), and their agreement with some known standard instrument at different points of the scale. The pressure of the atmosphere is not expressed by the weight of the mercury sustained in the tube by it, but by the perpendicular height of the column. Thus, when the height of the column is 30 inches, it is not said that the atmospheric pressure is 14·7 lb on the square inch, or the weight of the mercury filling a tube at that height whose transverse section equals a square inch, but that it is 30 inches, meaning that the pressure will sustain a column of mercury of that height.

The height of the barometer is expressed in English inches in England and America. In France and most European countries, the height is given in millimètres, a millimètre being the thousandth part of a mètre, which equals 39·37079 English inches. Up to 1869 the barometer Barometric readings. was given in half-lines in Russia, which, equalling the twentieth of an English inch, were readily reduced to English inches by dividing by 20. The metric barometric scale is now used in Russia. In a few countries on the Continent the French or Paris line, equalling 0·088814 inch, still continues to be used. Probably millimètre and English inch scales will soon be exclusively in use. The English measure of length being a standard at 62° Fahr., the old French measure at 61°·2, and the metric scale at 32°, it is necessary, before comparing observations made with the three barometers, to reduce them to the same temperature, so as to neutralize the inequalities arising from the expansion of the scales by heat.

The barometer is a valuable instrument as an indicator of coming weather, provided its readings be interpreted with intelligence. High pressures generally attend fine weather, but they not unfrequently accompany wet stormy weather ; on the other hand, low pressures, which usually occur with wet and stormy weather, not unfrequently accompany fine mild weather, particularly in winter and in the northern parts of Great Britain. The truth is, the barometer merely indicates atmospheric pressure directly, whilst it indicates weather only inferentially. The chief points to be attended to are its fluctuations taken in connection with the wind and the state of the sky, but above all, the readings of the barometer as compared with those at neighbouring places, since it is *difference* of pressure, or the amount of the barometric gradient, which determines the strength of the wind and the weather generally.

Barometrical Measurements of Heights.

The decisive experiment by which Pascal established the reality of atmospheric pressure suggested to him the method of measuring heights by means of the barometer. The first attempts to effect this were necessarily rude and inaccurate, since they went on the assumption that the lower mass of air is of uniform density. The discovery, however, of the actual relation subsisting between the density of air and its elasticity by Boyle in England, and about the same time by Mariotte in France, laid a sure foundation for this branch of atmospheric physics —the relation being that, at the same temperature, the pressure of a gas is exactly proportional to its density.

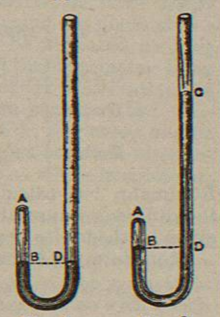

Fig. 1. Fig. 2.

The truth of this law may be shown by the following experiment. Take a glass tube, of equal bore throughout, closed at one end, and bent in the form of a siphon (fig. 1), and let us suppose that it contains in the closed limb a portion of air AB, shut off from the atmosphere by mercury filling the lower portion of the tube, and that the enclosed portion of air exists at the ordinary pressure of the atmosphere or 30 inches. In this case the mercury in each limb, being subject to the same pressure, will stand at the same level. If we now pour mercury into the long limb (fig. 2) till the level in this limb stands 30 inches above the level in the closed limb, the additional mercury will tend to compress the air in A′B′ with a pressure equal to that exerted by a column of 30 inches of mercury. In the latter case, therefore, the air is subjected to a pressure of two atmospheres, or 60 inches, while in the former it was only subjected to a pressure of one atmosphere or 30 inches. It will be found that the space A′B′ under the pressure of two atmospheres is only half the space AB where the pressure is only one atmosphere. If mercury had been

filled in till the difference of level of the mercury in the two limbs was 60 inches, or a pressure of three atmospheres, the space occupied by the air in the closed limb would have been only a third of the original space when the pressure was only that of one atmosphere. Generally, Boyle's law or Mariotte's law is this :—The volume of a gas varies inversely as the pressure. Since the same quantity of air has been experimented with, it follows that the density is doubled with a pressure of two atmospheres, and trebled with that of three, and hence the pressure of a gas is proportional to its density.

This law, however, only holds provided the temperature is the same. The familiar illustration of a bladder, partially filled with air, expanding on being placed near a fire, shows that if the pressure remains the same,—the pressure in this case being that of the atmosphere,—the gas will occupy a larger space if its temperature be raised. If the temperature be increased and the air be confined so as to occupy the same space, the pressure will be increased.

The relation between the temperature and pressure of gases was first discovered by Gay-Lussac; and more recently our knowledge of this branch of the subject has been greatly enlarged by the beautiful and accurate experiments of Regnault. From those experiments it has been concluded that the co-efficient which denotes increase of elasticity for 1° Fahr. of air whose volume is constant equals ·002036 ; and that the co-efficient which denotes increase of volume for 1° Fahr. of air whose elasticity is constant equals ·002039. It may further be added that the co-efficient of expansion for carbonic acid gas, hydrogen, and all other gases, is as nearly as possible the same.

When a fluid is allowed to evaporate in the exhausted receiver of an air-pump, vapour rises from it until its pressure reaches a certain point, after which all further evaporation is arrested. This point depends on the nature of the fluid itself and on the temperature, and it indicates the greatest vapour pressure possible for the fluid at the particular temperature. Regnault has shown the amount of the vapour pressure of water at different temperatures, thus—

Temp. Fahr. °	Max. Pressure of Vapour. Inch.	Temp. Fahr °	Max. Pressure of Vapour Inch.
0	0·044	50	0·361
10	0·068	60	0·518
20	0·108	70	0·733
30	0·165	80	1·023
40	0·248	90	1·410

If gases of different densities be put into the same vessel it is found that they do not arrange themselves according to their densities, but are ultimately diffused through each other in the most intimate manner. Each gas tends to diffuse itself as in a vacuum, the effect of the presence of other gases being merely to retard the process of their mutual diffusion. As regards the atmosphere, evaporation goes on until the maximum vapour pressure for the temperature has been attained, at which point the air is said to be saturated, and whilst the temperature remains the same further evaporation is arrested. Thus, at a temperature of 50° evaporation goes on until the vapour pressure reaches 0·361 inch, but if the temperature were raised to 60° the process of evaporation would be renewed, and go on till the vapour pressure rose to 0·518 inch. If at a vapour pressure of 0·518 inch the temperature were to fall from 60° to 50°, the air would no longer be capable of retaining the whole of the aqueous vapour in suspension, but the surplus part would be condensed and fall as rain. In the change from the aeriform to the liquid state a quantity of latent heat is given out. The yet uncertain effect of these changes, particularly the change of form from the aeriform to the liquid state, on the pressure, temperature, and movements of the air, renders it peculiarly desirable that barometeric observations for the determination of heights should not be made when clouds are forming or rain is falling.

Dalton has shown[1] that air charged with vapour is specifically lighter than when it wants the vapour; in other words, the more vapour any given quantity of air has in it the less is its specific gravity; and Sir William Thomson has shown[2] that the condensation of vapour in ascending currents of air is the chief cause of the cooling effect being so much less than that which would be experienced by dry air. From these ascertained effects of aqueous vapour in modifying the pressure and temperature of the atmosphere, the importance in the barometric measurement of heights of full and accurate observations of the hygrometry of the atmosphere and of the weather will be apparent.

Since the equilibrium of the vapour atmosphere is being constantly disturbed by every instance of condensation, by the ceaseless process of evaporation, and by every change of temperature, and since the presence of oxygen and nitrogen greatly obstructs the free diffusion of the aqueous vapours, it follows that Dalton's law of the independent pressure of the vapour and the dry air does not absolutely hold good. From the constant effort of the vapour to attain to a state of equilibrium there is, however, a continual tendency to approach this state. Since the equal diffusion of the dry air and the vapour is never reached, observations can only indicate local humidity, and therefore as regards any considerable stratum of air can only be regarded as approximate. Though particular observations may often indicate a humidity wide of the mark, yet in long averages a close approximation is reached, except in confined localities which are exceptionally damp or dry. Hence in observations for the determination of heights, the results of a long-continued series of observations should be employed, and those hours should be chosen whose mean is near the daily mean.

The most recent results arrived at by Regnault are the best, but it is to be regretted that the whole subject of the hygrometry, both as regards the methods of observation and the methods of discussing the observations, is still in an unsatisfactory state. This consideration, taken in connection with our defective knowledge of the relation of aqueous vapour to radiant heat, of the mode of its diffusion both vertically and horizontally, and of the influence exerted by its condensation into cloud and rain, and with our ignorance of the merely mechanical effects of ascending, descending, and horizontal currents of air in increasing or diminishing barometric pressure, renders it evident that heights deduced from barometric observations can only be regarded as approximate. It is much to be desired, in stating results, that the limit of error were taken into account, and the nearest round number in accordance therewith should alone be given as the calculated result. Thus, it is a mistake to give as the height of a place 1999 feet when the calculation is based wholly on barometric observations, and the limit of error amounts to 30 feet or more. The height 2000 should be given as the result.

The correction for decrease of gravity at the higher station, as compared with the force of gravity at the lower station or at sea-level, must also be taken into account. Its amount is small, being, roughly speaking, only about 0·001 inch per 400 feet. Since the force of gravity is diminished in proportion to the square of the distance from the centre of gravity, the rate of its decrease with the height varies in different latitudes. Places at the equator being farther from the earth's centre than places at the poles, it follows that the force of gravity diminishes at a less rapid rate as we ascend at the equator than it does at the poles. Now, since at the equator gravity diminishes less rapidly with the height, the air at any given height will exert a higher pressure there than anywhere else on the globe at the same height as compared with what it does at the sea-level of the latitude. Hence a subtraction requires to be made at the equator, and the amount to be subtracted diminishes as we proceed into higher latitudes, till it falls to zero at latitude 45°, where the force of gravity is assumed to be the mean. For higher latitudes an addition is required which constantly increases till it reaches the maximum at the poles. This correction is also small, being for 1000 feet less than 0·001 inch in Great Britain, and less than 0·003 at the equator and the poles.

Various formulæ for the barometrical measurement of heights, based on these principles, have been given by Laplace and others, not a few of them being unnecessarily refined and intricate when the real character of the data is taken into consideration. The following formula by Rühlmann[3] is given as the simplest and best, being based on the most recent results which have been arrived at:—

$$h = 18400{\cdot}2\left(1{\cdot}00157 + 0{\cdot}003675\frac{t'+t''}{2}\right)$$
$$\left(1 + 0{\cdot}378\frac{\frac{\sigma'}{b'}+\frac{\sigma''}{b''}}{2}\right)(1 + 0{\cdot}002623\cos. 2\phi)$$
$$\left(1 + \frac{2z+h}{6378150}\right)\log.\frac{b'}{b''} \quad . \quad . \quad . \quad . \quad . \quad (1),$$

in which h is the difference in mètres of level between the two stations; t' and t'' the temperature centigrade of the air at the two stations; b' and b'' the heights of the barometer in millimètres, corrected for temperature and for all instrumental errors; σ' and σ'' the elastic force of vapour; ϕ the mean of the latitudes of the two stations; and z the height of the lower station above the sea. Making—

$$A = \log.\left\{18400{,}2(1{\cdot}00157 + 0{\cdot}003675)\frac{t'+t''}{2}\right\},$$
$$C = \log.\left\{1 + \frac{0{\cdot}378}{2}\left(\frac{\sigma'}{b'}+\frac{\sigma''}{b''}\right)\right\},$$
$$D = \log.\{1 + 0{\cdot}002623\cos. 2\phi\},$$
$$E = \log.\left\{1 + \frac{2z+h}{6378150}\right\}.$$

Rühlmann has calculated the values A, C, D, and E for the different values of the respective arguments, which are given in the tables appended to the work.

From formula (1) we obtain—

$$\log. h = \log.\{\log. b' - \log. b''\} + (A + C + D + E) \quad . \quad . \quad . \quad (2).$$

It is assumed that the whole stratum of air between the two heights is in a state of rest, and that the means of the temperature and humidity observed at the two stations are the means respectively of the stratum of air between them.

If great accuracy is desired, both barometers must be read from the zeros of their scales, and the observations must be corrected for all merely instrumental errors, and must be made strictly at the same time or times, seeing that a very small error, arising either from imperfect observations, or from their not being comparable, produces a comparatively large error in the calculated results.

In deducing heights from *long-continued observations* it should be ascertained that the barometers and observations are good, and observations should if possible be used which have been made at the same hours of the day and during the same years. Observations at different hours of the day are not comparable, since, owing to our imperfect knowledge of the differences of daily barometric range, the necessity for the application of any so-called corrections for daily range must necessarily lead to error. The comparison should also only be between observations made during the same years, since the means of different years often differ widely from each other. Thus the difference of height between two places at which barometrical observations were made, from 1830 to 1859 and from 1850 to 1869 respectively, could be more accurately ascertained from the ten years' averages from 1850 to 1859 during which observations were made at both places, than from the longer averages of thirty and twenty years. Inattention to this point has often led to error, especially in cases where at one of the places only a few years were available. To secure greater accuracy, the calculations should be made on the mean for the year, the two extreme months, January and July, and that month during which the distribution of pressure is most uniform over the region where the places are situated. Owing to the great differences in the distribution of atmospheric pressure in different parts of the globe (see ATMOSPHERE), comparison of the observations at the higher station with those at more than one lower station is in some cases indispensable. Thus, if it were desired to compute the height of Dovre, in Norway, barometrically, it should be compared both with Christiania and with Christiansund on the west coast; for if compared with Christiania alone the calculated height would be too high, and if with Christiansund too low, the reason being that the mean annual pressure diminishes from Christiania to Christiansund. The same remark applies to a large portion of Hindustan and to many other regions of the globe.

[1] *Meteorological Observations and Essays*, 2d ed., p. 100.
[2] *Mem. Lit. and Phil. Soc Manchester*, vol. ii. 3d series, p. 131.
[3] *Die Barometrischen Höhenmessungen und ihre Bedeutung für die Physik der Atmosphäre*, von Dr Richard Rühlmann, Leipsic, 1870.

The more special precautions to be taken in deducing heights from one or a few observations, that is, from such data as travellers observe, are these:—that the observations be made in as settled weather as possible, at those hours of the day, at least, at which observations are made at the nearest meteorological stations, and be repeated as long as possible from day to day; that the barometer hang perpendicularly and in shade; and that the observations be not made till the whole instrument has acquired the temperature of the surrounding air. For, for every degree which the temperature indicated by the attached thermometer differs from the temperature of the whole instrument, there is an error of about 0·003 inch.

From their portability and handiness the aneroid barometer, and the thermometer for ascertaining the point at which water boils, are of great use in determining heights,—the thermometer, if properly managed, being the more accurate of the two. Since, owing to the sluggishness with which the aneroid often follows the changes of pressure, especially low pressures, its readings should not be recorded till it has hung for some hours at the place of observation, and if this be not possible, the time which elapsed from arriving at the place and making the observations should be stated. It may not be unnecessary to add that every opportunity which presents itself should be taken of comparing it with a standard mercurial barometer, owing to the variations, irregular or permanent, to which aneroids are subject, and that the instrument should always be read in one position, since the difference between the reading in a horizontal position and the reading in a vertical position is often considerable.

At a pressure of 29·905 inches distilled water boils at 212°. The temperature of the boiling point varies with the nature of the vessel. Thus, if the interior of the glass vessel be varnished with shell-lac, the temperature may rise to 221°; and if iron filings be dropped into the water, the temperature is lowered. But in all these cases the temperature of the vapour arising from the water is as nearly as possible the same. Hence in making observations with the thermometer for hypsometrical purposes, the instrument is not plunged into the water, but the whole instrument, bulb and stem, are by an apparatus used for the purpose plunged into the vapour arising from the boiling water. The degrees on the thermometer used are greatly enlarged, thus admitting of a minute subdivision of the scale and, consequently, of very precise readings. The following are a few of the barometric heights corresponding to different temperatures at which distilled water boils, taken from Regnault's tables revised by Moritz:—

Boiling Point. °	Barometer. Inches.	Boiling Point. °	Barometer. Inches.
211	29·331	205	25·990
210	28·751	204	25·465
209	28·180	203	24·949
208	27·618	202	24·442
207	27·066	201	23·943
206	26·523	200	23·453

The temperature of the vapour of the boiling water being observed, the pressure is ascertained from the table, whence the height may be calculated, just as in the case of pressures obtained by means of a mercurial barometer.

The remark made by Sir John Leslie many years ago still holds good, that it is preposterous, in the actual state of physical science, to effect any high refinement in the formula for computing barometrical heights. What is required on the part of the computer of heights from barometrical observations is carefully to weigh the *limits of error* due to the instrument and methods of observations, to the hour of the day and the month of the year (see ATMOSPHERE, p. 28), and to the degree of unsettledness of the weather at the time the observations were made, and to give effect to these in the calculated results. From inattention to these simple considerations a large proportion of important heights given in works of travel and of physical geography are very erroneously stated, and consequently require careful revision.

For very rough approximations to the real height from observations of pressure and temperature, Sir G. B. Airy has prepared a table showing the differences of level corresponding to differences of pressure. It is from this table that the heights corresponding to pressures engraved on many aneroids are usually taken. The heights read off from the pressures should be corrected for observations of temperature carefully taken at the upper and lower stations, the mean of these two observations being assumed as the mean of the stratum of air occupying the interval between the two heights. (A. B.)

BARON. The origin and primary import of this term have been much contested. Menage derives it from the Latin *baro*, a word which we find used in classical Latin to signify "a simple" or "foolish man" (*Cic. Fin.*, ii. 23). Another form of the same word appears to be *varo*, to which Lucilius gives the meaning "a stupid man," "a blockhead," Forcellini observing that its primary sense is "a block of tough, hard wood." But with greater probability Graff derives the word baron from the old German *Bar = Mann, freier Mann*. The word seems related to the Spanish *varon*, which means "a male," "a noble person," and its root may be found in the Sanskrit *vêra*. Like the Greek *ἀνήρ* and the Latin *vir*, the word *baron* signifies man in general and also a *husband*—the old legal expression *baron* and *feme* being equivalent to our ordinary phrase "man and wife."

In modern English usage the term is particularly applied to a member of the lowest order of the peerage, but in ancient records (as Lord Coke observes) the barony included all the (titular) nobility of England, because all noblemen were barons though they might possess a higher dignity also; and the great council of peers, in which were included dukes, marquesses, and earls, as well as barons, was styled simply the "Council de Baronage." In like manner w-