may be comparable as measures of atmospheric pressure, certain corrections must be applied.

1. *Correction for Temperature.* As mercury expands with heat, it follows that a column of warm mercury exerts less pressure than a column of the same height at a lower temperature; and it is usual to reduce the actual height of the column to the height of a column at the temperature of freezing water which would exert the same pressure.

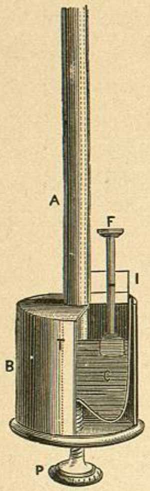

Fig. 113.
Float Adjustment.

Let h be the observed height at temperature $t°$ Centigrade, and $h_{\circ}$ the height reduced to freezing-point. Then, if m be the coefficient of expansion of mercury per degree Cent., we have

$$h_{\circ}(1+m\,t)=h, \text{ whence } h_{\circ}=h-h\,m\,t \text{ nearly.}$$

The value of m is $\frac{1}{5550}=\cdot00018018$. For temperatures Fahrenheit, we have

$$h_{\circ}\left\{1+m\,(t-32)\right\}=h,\; h_{\circ}=h-h\,m\,(t-32),$$

where m denotes $\frac{1}{9990}=\cdot0001001$.

But temperature also affects the length of the divisions on the scale by which the height of the mercurial column is measured. If these divisions be true inches at 0° Cent., then at $t°$ the length of n divisions will be $n\,(1+l\,t)$ inches, l denoting the coefficient of linear expansion of the scale, the value of which for brass, the usual material, is ·00001878. If then the observed height h amounts to n divisions of the scale, we have

$$h_{\circ}(1+m\,t)=h=n\,(1+l\,t);$$

whence

$$h_{\circ}=\frac{n\,(1+l\,t)}{1+m\,t}=n-n\,t\,(m-l), \text{ nearly;}$$

that is to say, if n be the height read off on the scale, it must be diminished by the correction $n\,t\,(m-l)$, t denoting the temperature of the mercury in degrees Centigrade. The value of $m-l$ is ·0001614.

For temperatures Fahrenheit, assuming the scale to be of the correct length at 32° Fahr., the formula for the correction (which is still subtractive), is $n\,(t-32)\,(m-l)$, where $m-l$ has the value ·00008967.[1]

[1] The correction for temperature is usually made by the help of tables, which give its amount for all ordinary temperatures and heights. These tables, when intended for

2. *Correction for Capillarity.*—In the preceding chapter we have seen that mercury in a glass tube undergoes a capillary depression: whence it follows that the observed barometric height is too small, and that we must add to it the amount of this depression. In all tubes of internal diameter less than about $\frac{3}{4}$ of an inch this correction is sensible; and its amount, for which no simple formula can be given, has been computed, from theoretical considerations, for various sizes of tube, by several eminent mathematicians, and recorded in tables, from which that given below is abridged. These values are applicable on the assumption that the meniscus which forms the summit of the mercurial column is decidedly convex, as it always is when the mercury is rising. When the meniscus is too flat, the mercury must be lowered by the foot-screw, and then screwed up again.

It is found by experiment, that the amount of capillary depression is only half as great when the mercury has been boiled in the tube as when this precaution has been neglected.

For purposes of special accuracy, tables have been computed, giving the amount of capillary depression for different degrees of convexity, as determined by the sagitta (or height) of the meniscus, taken in conjunction with the diameter of the tube. Such tables, however, are seldom used in this country.[1]

English barometers, are generally constructed on the assumption that the scale is of the correct length not at 32° Fahr., but at 62° Fahr., which is (by act of Parliament) the temperature at which the British standard yard (preserved in the office of the Exchequer) is correct. On this supposition, the length of n divisions of the scale at temperature $t°$ Fahr., is

$$n\left\{1+l\,(t-62)\right\};$$

and by equating this expression to

$$h_{\circ}\left\{1+m\,(t-32)\right\}$$

we find

$$\begin{aligned} h_{\circ} &= n\left\{1-m\,(t-32)+l\,(t-62)\right\} \\ &= n\left\{1-(m-l)\,t+(32m-62l)\right\} \\ &= n\left\{1-\cdot00008967\,t+\cdot00255654\right\}; \end{aligned}$$

which, omitting superfluous decimals, may conveniently be put in the form—

$$n-\frac{n}{1000}(\cdot09\,t-2\cdot56).$$

The correction vanishes when

$$\cdot09\,t-2\cdot56=0;$$

that is, when $t=\frac{256}{9}=28\cdot5$.

For all temperatures higher than this the correction is subtractive.

[1] The most complete collection of meteorological and physical tables, is that edited by Professor Guyot, and published under the auspices of the Smithsonian Institution, Washington.

TABLE OF CAPILLARY DEPRESSIONS IN UNBOILED TUBES.

(To be halved for Boiled Tubes.)

Diameter of tube in inches.	Depression in inches.	Diameter.	Depression.	Diameter.	Depression.
·10	·140	·20	·058	·40	·015
·11	·126	·22	·050	·42	·013
·12	·114	·24	·044	·44	·011
·13	·104	·26	·038	·46	·009
·14	·094	·28	·033	·48	·008
·15	·086	·30	·029	·50	·007
·16	·079	·32	·026	·55	·005
·17	·073	·34	·023	·60	·004
·18	·068	·36	·020	·65	·003
·19	·063	·38	·017	·70	·002

3. *Correction for Capacity.*—When there is no provision for adjusting the level of the mercury in the cistern to the zero point of the scale, another correction must be applied. It is called the correction for *capacity*. In barometers of this construction, which were formerly much more common than they are at present, there is a certain point in the scale at which the mercurial column stands when the mercury in the cistern is at the correct level. This is called the neutral point. If A be the interior area of the tube, and C the area of the cistern (exclusive of the space occupied by the tube and its contents), when the mercury in the tube rises by the amount x, the mercury in the cistern falls by an amount $y=\frac{A}{C}x$; for the volume of the mercury which has passed from the cistern into the tube is $Cy=Ax$. The change of atmospheric pressure is correctly measured by $x+y=\left(1+\frac{A}{C}\right)x$; and if we now take x to denote the distance of the summit of the mercurial column from the neutral point, the corrected distance will be $\left(1+\frac{A}{C}\right)x$, and the correction to be applied to the observed reading will be $\frac{A}{C}x$, which is additive if the observed reading be above the neutral point, subtractive if below.

It is worthy of remark that the neutral point depends upon the volume of mercury. It will be altered if any mercury be lost or added; and as temperature affects the volume, a special temperature-correction must be applied to barometers of this class. The investigation will be found in a paper by Professor Swan in the *Philosophical Magazine* for 1861.

In some modern instruments the correction for capacity is avoided, by making the divisions on the scale less than true inches, in the

ratio $\frac{C}{A+C}$, and the effect of capillarity is at the same time compensated by lowering the zero point of the scale. Such instruments, if correctly made, simply require to be corrected for temperature.

4. *Index Errors.*—Under this name are included errors of graduation, and errors in the position of the zero of the graduations. An error of zero makes all readings too high or too low by the same amount. Errors of graduation (which are generally exceedingly small) are different for different parts of the scale.

Barometers intended for accurate observation are now usually examined at Kew Observatory before being sent out; and a table is furnished with each, showing its index error at every half inch of the scale, errors of capillarity and capacity (if any) being included as part of the index error. We may make a remark here once for all respecting the signs attached to errors and corrections. The sign of an error is always opposite to that of its correction. When a reading is too high the index error is one of excess, and is therefore positive; whereas the correction needed to make the reading true is subtractive, and is therefore negative.

5. *Reduction to Sea-level.*—In comparing barometric observations taken over an extensive district for meteorological purposes, it is usual to apply a correction for difference of level. Atmospheric pressure, as we have seen, diminishes as we ascend; and it is usual to add to the observed height the difference of pressure due to the elevation of the place above sea-level. The amount of this correction is proportional to the observed pressure. The law according to which it increases with the height will be discussed in the next chapter.

6. *Correction for Unequal Intensity of Gravity.*—When two barometers indicate the same height, at places where the intensity of gravity is different (for example, at the pole and the equator), the same mass of air is superincumbent over both; but the pressures are unequal, being proportional to the intensity of gravity as measured by the values of g (§ 91) at the two places.

If h be the height, in centimetres, of the mercurial column at the temperature 0° Cent., the absolute pressure, in dynes per square centimetre, will be $gh \times 13{\cdot}596$; since 13·596 is the density of mercury at this temperature.

205. Other kinds of Mercurial Barometer.—The *Siphon Barometer*, which is represented in Fig. 114, consists of a bent tube, generally of uniform bore, having two unequal legs. The longer leg, which must be more than 30 inches long, is closed, while the shorter leg is open. A sufficient quantity of mercury having been introduced to fill the longer leg, the instrument is set upright (after boiling to expel air), and the mercury takes such a position that the difference of levels in the two legs represents the pressure of the atmosphere.

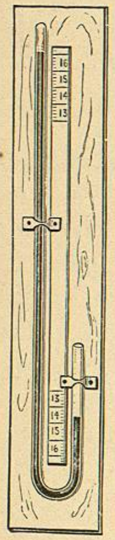

Fig. 114. Siphon Barometer.

Supposing the tube to be of uniform section, the mercury will always fall as much in one leg as it rises in the other. Each end of the mercurial column therefore rises or falls through only half the height corresponding to the change of atmospheric pressure.

In the best siphon barometers there are two scales, one for each leg, as indicated in the figure, the divisions on one being reckoned upwards, and on the other downwards, from an intermediate zero point, so that the sum of the two readings is the difference of levels of the mercury in the two branches.

Inasmuch as capillarity tends to depress both extremities of the mercurial column, its effect is generally neglected in siphon barometers; but practically it causes great difficulty in obtaining accurate observations, for according as the mercury is rising or falling its extremity is more or less convex, and a great deal of tapping is usually required to make both ends of the column assume the same form, which is the condition necessary for annihilating the effect of capillary action.

Wheel Barometer.—The wheel barometer, which is in more general use than its merits deserve, consists of a siphon barometer, the two branches of which have usually the same diameter. On the surface of the mercury of the open branch floats a small piece of iron or glass suspended by a thread, the other extremity of which is fixed to a pulley, on which the thread is partly rolled. Another thread, rolled parallel to the first, supports a weight which balances the float. To the axis of the pulley is fixed a needle which moves on a dial. When the level of the mercury varies in either direction, the float follows its movement through the same distance; by the action of the counterpoise the pulley turns, and with it the needle, the extremity of which points to the figures on the dial, marking the barometric heights. The mounting of the dial is usually placed

in front of the tube, so as to conceal its presence. The wheel barometer is a very old invention, and was introduced by the celebrated Hooke in 1683. The pulley and strings are sometimes replaced by a rack and pinion, as represented in the figure (Fig. 115).

Besides the faults incidental to the siphon barometer, the wheel

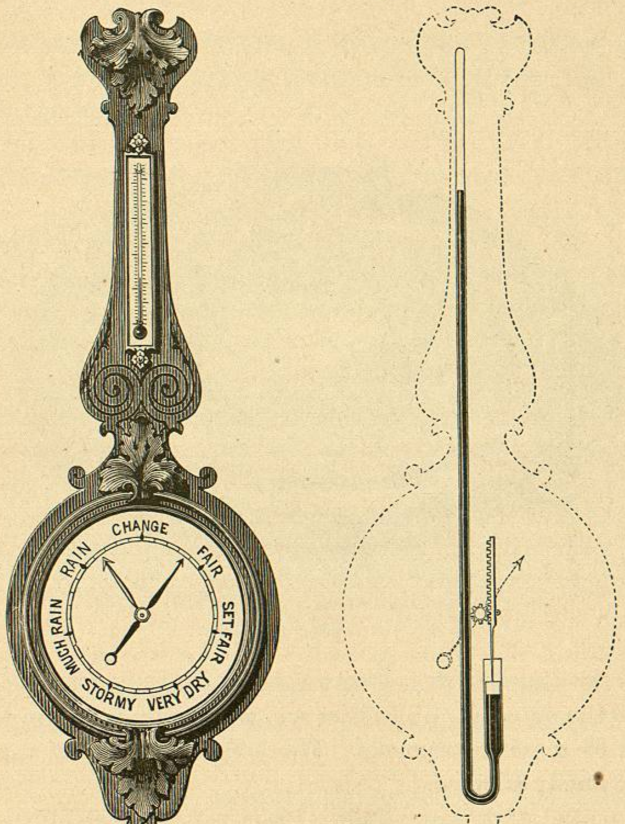

Fig. 115.—Wheel Barometer.

barometer is encumbered in its movements by the friction of the additional apparatus. It is quite unsuitable for measuring the exact amount of atmospheric pressure, and is slow in indicating changes.

Marine Barometer.—The ordinary mercurial barometer cannot be used at sea on account of the violent oscillations which the mercury would experience from the motion of the vessel. In order to meet this difficulty, the tube is contracted in its middle portion nearly to capillary dimensions, so that the motion of the mercury in either direction is hindered. An instrument thus constructed is called a marine barometer. When such an instrument is used on land it is always too slow in its indications.

206. Aneroid Barometer (α, νηρος).—This barometer depends upon the changes in the form of a thin metallic vessel partially exhausted

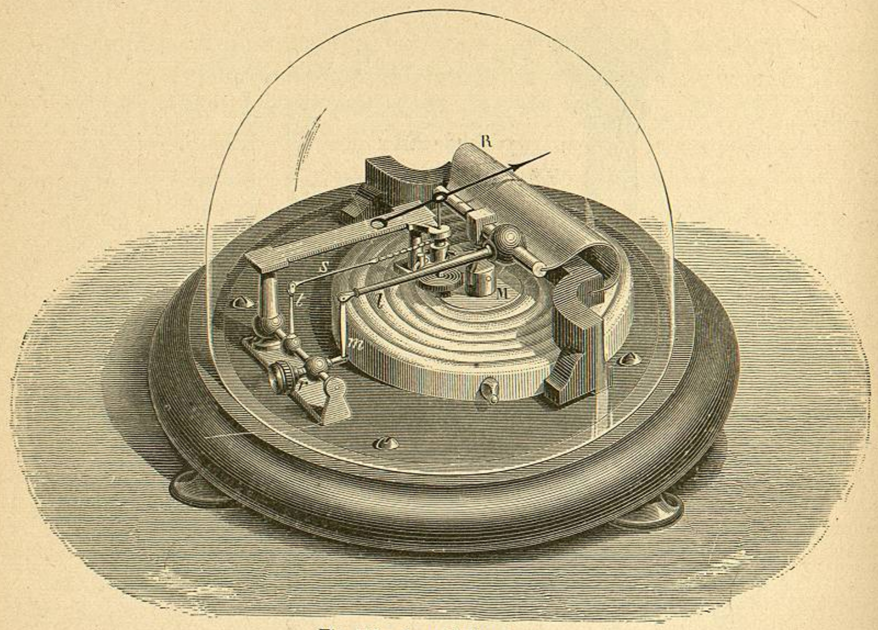

Fig. 116.—Aneroid Barometer.

of air, as the atmospheric pressure varies. M. Vidie was the first to overcome the numerous difficulties which were presented in the construction of these instruments. We subjoin a figure of the model which he finally adopted.

The essential part is a cylindrical box partially exhausted of air, the upper surface of which is corrugated in order to make it yield more easily to external pressure. At the centre of the top of the box is a small metallic pillar M, connected with a powerful steel spring R. As the pressure varies, the top of the box rises or falls, transmitting its movement by two levers *l* and *m*, to a metallic axis *r*. This latter carries a third lever *t*, the extremity of which is attached to a chain *s* which turns a drum, the axis of which bears the index needle. A spiral spring keeps the chain constantly stretched, and thus makes the needle always take a position corre-

sponding to the shape of the box at the time. The graduation is performed empirically by comparison with a mercurial barometer. The aneroid barometer is very quick in indicating changes, and is much more portable than any form of mercurial barometer, being both lighter and less liable to injury. It is sometimes made small enough for the waistcoat pocket. It has the drawback of being affected by temperature to an extent which must be determined for each instrument separately, and of being liable to gradual changes which can only be checked by occasional comparison with a good mercurial barometer.

In the *metallic barometer*, which is a modification of the aneroid, the exhausted box is crescent-shaped, and the horns of the crescent separate or approach according as the external pressure diminishes or increases.

207. Old Forms Revived.—There are two ingenious modifications of the form of the barometer, which, after long neglect, have recently been revived for special purposes.

Counterpoised Barometer.—The invention of this instrument is attributed to Samuel Morland, who constructed it about the year 1680. It depends upon the following principle:—If the barometric tube is suspended from one of the scales of a balance, there will be required to balance it in the other scale a weight equal to the weight of the tube and the mercury contained in it, minus the upward pressure due to the liquid displaced in the cistern.[1] If the atmospheric pressure increases, the mercury will rise in the tube, and consequently the weight of the floating body will increase, while the sinking of the mercury in the cistern will diminish the upward pressure due to the displacement. The beam will thus incline to

[1] A complete investigation based on the assumption of a constant upward pull at the top of the suspended tube shows that the sensitiveness of the instrument depends only on the internal section of the upper part of the tube and the external section of its lower part. Calling the former A and the latter B, it is necessary for stability that B be greater than A (which is not the case in the figure in the text) and the movement of the tube will be to that of the mercury in a standard barometer as A is to B – A. The directions of these movements will be opposite. If B – A is very small compared with A, the instrument will be exceedingly sensitive; and as B – A changes sign, by passing through zero, the equilibrium becomes unstable.

A curious result of the investigation is that the level of the mercury in the cistern remains constant.

In the instrument represented in the figure, stability is probably obtained by the weight of the arm which carries the pencil.

In King's barograph, B is made greater than A by fixing a hollow iron drum round the lower end of the tube.

the side of the barometric tube, and the reverse movement would occur if the pressure diminished. For the balance may be substituted, as in Fig. 117, a lever carrying a counterpoise; the variations of pressure will be indicated by the movements of this lever.

Such an instrument may very well be used as a *barograph* or recording barometer; for this purpose we have only to attach to the lever an arm with a pencil, which is constantly in contact with a sheet of paper moved uniformly by clock-work. The result will be a continuous trace, whose form corresponds to the variations of pressure. It is very easy to determine, either by calculation or by comparison with a standard barometer, the pressure corresponding to a given position of the pencil on the paper; and thus, if the paper is ruled with twenty-four equidistant lines, corresponding to the twenty-four hours of the day, we can see at a glance what was the pressure at any given time. An arrangement of this kind has been adopted by the Abbé Secchi for the meteorograph of the observatory at Rome. The first successful employment of this kind of barograph appears to be due to Mr. Alfred King, a gas engineer of Liverpool, who invented and constructed such an instrument in 1853, for the use of the Liverpool Observatory, and subsequently designed a larger one, which is still in use, furnishing a very perfect record, magnified five-and-a-half times.

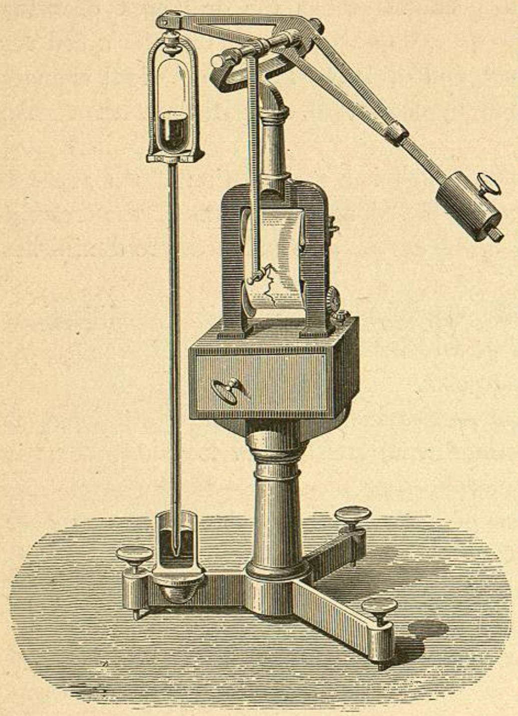
Fig. 117.—Counterpoised Barometer.

Fahrenheit's Barometer.—Fahrenheit's barometer consists of a tube bent several times, the lower portions of which contain mercury; the upper portions are filled with water, or any other liquid, usually

coloured. It is evident that the atmospheric pressure is balanced by the sum of the differences of level of the columns of mercury, diminished by the sum of the corresponding differences for the columns of water; whence it follows that, by employing a considerable number of tubes, we may greatly reduce the height of the barometric column. This circumstance renders the instrument interesting as a scientific curiosity, but at the same time diminishes its sensitiveness, and renders it unfit for purposes of precision. It is therefore never used for the measurement of atmospheric pressure; but an instrument upon the same principle has recently been employed for the measurement of very high pressures, as will be explained in Chap. xix.

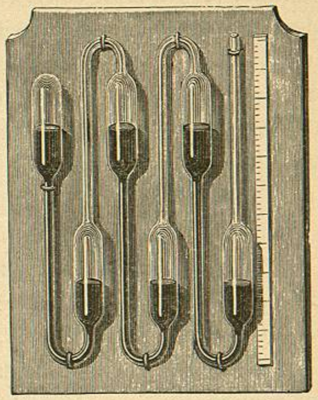
Fig. 118.—Fahrenheit's Barometer.

208. Photographic Registration.—Since the year 1847 various meteorological instruments at the Royal Observatory, Greenwich, have been made to yield continuous traces of their indications by the aid of photography, and the method is now generally employed at meteorological observatories in this country. The Greenwich system is fully described in the *Greenwich Magnetical and Meteorological Observations* for 1847, pp. lxiii.–xc. (published in 1849).

The general principle adopted for all the instruments is the same. The photographic paper is wrapped round a glass cylinder, and the axis of the cylinder is made parallel to the direction of the movement which is to be registered. The cylinder is turned by clock-work, with uniform velocity. The spot of light (for the magnets and barometer), or the boundary of the line of light (for the thermometers), moves, with the movements which are to be registered, backwards and forwards in the direction of the axis of the cylinder, while the cylinder itself is turned round. Consequently (as in Morin's machine, Chap. vii.), when the paper is unwrapped from its cylindrical form, there is traced upon it a curve of which the abscissa is proportional to the time, while the ordinate is proportional to the measure of the movement which is the subject of measure.

The barometer employed in connection with this system is a large siphon barometer, the bore of the upper and lower extremities of its arms being about 1·1 inch. A glass float in the quicksilver of the 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