225. Compressed-air Manometer.—This instrument, which may assume different forms, sometimes consists, as in Fig. 126, of a bent tube AB closed at one end *a*, and containing within the space A*a* a quantity of air, which is cut off from external communication by a column of mercury. The apparatus has been so constructed, that when the pressure on B is equal to that of the atmosphere, the mercury stands at the same height in both branches; so that, under these circumstances, the inclosed air is exactly at atmospheric pressure. But if the pressure increases, the mercury is forced into the left branch, so that the air in that branch is compressed, until equilibrium is established. The pressure exerted by the gas at B is then equal to the pressure of the compressed air, together with that of a column of mercury equal to the difference of level of the liquid in the two branches. This pressure is usually expressed in atmospheres on the scale *ab*.

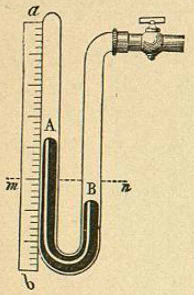

Fig. 126.—Compressed-air Manometer.

The graduation of this scale is effected empirically in practice, by placing the manometer in communication with a reservoir of compressed air whose pressure is given by an open mercurial gauge, or by a standard manometer of any kind.

If the tube AB be supposed cylindrical, the graduation can be calculated by an application of Boyle's law.

Let l be the length of the tube occupied by the inclosed air when its pressure is equal to that of one atmosphere; at the point to which the level of the mercury rises is marked the number 1. It is required to find what point the end of the liquid column should reach when a pressure of n atmospheres is exerted at B. Let x be the height of this point above 1; then the volume of the air, which was originally l, has become $l-x$, and its pressure is therefore equal to $\mathrm{H}\frac{l}{l-x}$, H being the mean height of the barometer. This pressure, together with that due to the difference of level $2x$, is equivalent to n atmospheres. We have thus the equation—

$$\mathrm{H}\frac{l}{l-x}+2x=n\mathrm{H},$$

whence

$$2x^2-(n\mathrm{H}+2l)x+(n-1)\mathrm{H}l=0.$$

$$x=\frac{n\mathrm{H}+2l\pm\sqrt{(n\mathrm{H}+2l)^2-8(n-1)\mathrm{H}l}}{4}.$$

We thus find two values of x; but that given by taking the positive

sign of the radical is inadmissible; for if we put $n=1$, we ought to have $x=o$, which will not be the case unless the sign of the radical is negative.

By giving n the successive values $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, &c., in this expression for x, we find the points on the scale corresponding to pressures of one atmosphere and a half, two atmospheres, &c.

As the pressure increases, the distance traversed by the mercury for an increment of pressure equal to one atmosphere becomes continually less, and the sensibility of the instrument accordingly decreases. This inconvenience is partly avoided by the arrangement shown in Fig. 127. The branch containing the air is made tapering so that, as the mercury rises, equal changes of volume correspond to increasing lengths.

226. Metallic Manometers.—The fragility of glass tubes, and the fact that they are liable to become opaque by the mercury clinging

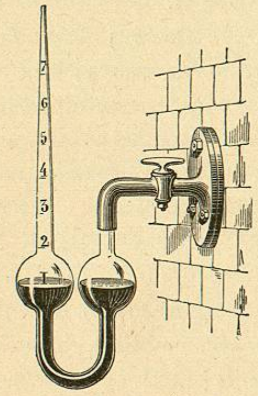
Fig. 127.—Compressed-air Manometer.

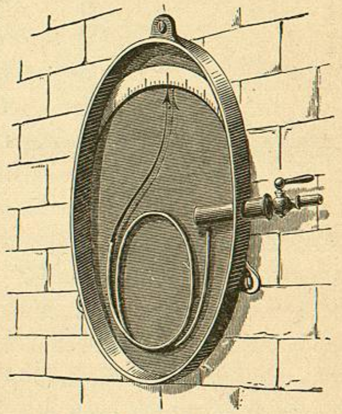
Fig. 128.—Bourdon's Pressure gauge.

to their sides, are serious drawbacks to their use, especially in machines in motion. Accordingly, metallic manometers are often employed, their indications depending upon changes of form effected by the pressure of gas on its containing vessel. We shall here mention only Bourdon's gauge (Fig. 128). It consists essentially of a copper tube of elliptic section, which is bent through about 540°, as represented in the figure. One of the extremities communicates by a stop-cock with the reservoir of steam or compressed gas; to the other extremity is attached a steel needle which traverses a scale. When the pressure is the same within and without the tube the end of the needle stands at the mark 1; but if the pressure within the tube increases, the curvature diminishes, the free extremity of the tube moves away from the fixed extremity, and the needle traverses the scale.

227. Mixture of Gases.—When gases of different densities are inclosed in the same space, experiment shows that, even under the most unfavourable circumstances, an intimate mixture takes place, so that each gas becomes uniformly diffused through the entire space. This fact has been shown by a decisive experiment due to Berthollet. He took two globes (Fig. 129) which could be screwed together, and placed them in a cellar. The lower globe was filled with carbonic acid, the upper globe with hydrogen. Communication was established between them, and after some time it was ascertained that the gases had become uniformly mixed; the proportions being the same in both globes. Gaseous diffusion is a comparatively rapid process. The diffusion of liquids, when not assisted by gravity, is, on the other hand, exceedingly slow.

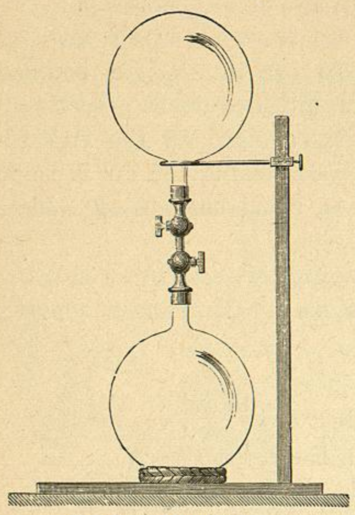

Fig. 129.—Mixture of Gases.

If several gases are inclosed in the same space, each of them exerts the same pressure as if the others were absent, in other words, the pressure exerted by the mixture is equal to the sum of the pressures which each would exert separately. This is known as "Dalton's law for gaseous mixtures." The separate pressures can easily be calculated by Boyle's law, when the original pressure and volume of each gas are known.

For example, let V and P, V′ and P′, V″ and P″ be the volumes and pressures of the gases which are made to pass into a vessel of volume U. The first gas exerts, when in this vessel, a pressure equal to $\frac{VP}{U}$, the second a pressure equal to $\frac{V'P'}{U}$, the third a pressure equal to $\frac{V''P''}{U}$, and so on, so that the total pressure M is equal to $\frac{VP}{U} + \frac{V'P'}{U} + \frac{V''P''}{U}$, whence $MU = VP + V'P' + V''P''$.

This law can easily be verified by passing different volumes of

gas into a graduated glass jar inverted over mercury, after having first measured their volumes and pressures. It may be observed that Boyle's law is merely a particular case of this. It is what this law becomes when applied to a mixture of two portions of the same gas.

228. Absorption of Gases by Liquids and Solids.—All gases are to a greater or less extent soluble in water. This property is of considerable importance in the economy of nature; thus the life of aquatic animals and plants is sustained by the oxygen of the air which the water holds in solution. The *volume* of a given gas that can be dissolved in water at a given temperature is generally found to be approximately the same at all pressures,[1] and the ratio of this volume to that of the water which dissolves it is called the *coefficient of solubility, or of absorption.* At the temperature 0° Cent., the coefficient of solubility for carbonic acid is 1, for oxygen ·04, and for ammonia 1150.

If a mixture of two or more gases be placed in contact with water, each gas will be dissolved to the same extent as if it were the only gas present.

Other liquids as well as water possess the power of absorbing gases, according to the same laws, but with coefficients of solubility which are different for each liquid.

Increase of temperature diminishes the coefficient of solubility, which is reduced to zero when the liquid boils.

Some solids, especially charcoal, possess the power of absorbing gases. Boxwood charcoal absorbs about nine times its volume of oxygen, and about ninety times its volume of ammonia. When saturated with one gas, if put into a different gas, it gives up a portion of that which it first absorbed, and takes up in its place a quantity of the second. Finely-divided platinum condenses on the surface of its particles a large quantity of many gases, amounting in the case of oxygen to many times its own volume. If a jet of hydrogen gas be allowed to fall, in air, upon a ball of spongy platinum, the gas combines rapidly, in the pores of the metal, with the oxygen of the air, giving out an amount of heat which renders the platinum incandescent and usually sets fire to the jet of hydrogen.

Most solids have in ordinary circumstances a film of air adhering

[1] Hence the *mass* of gas absorbed is directly as the pressure.

to their surfaces. Hence iron filings, if carefully sprinkled on water, will not be wetted, but will float on the surface, and hence also the power which many insects have of running on the surface of water without wetting their feet. The film of air in these cases prevents wetting, and hence, by the principles of capillarity, produces increased buoyancy.

CHAPTER XX.

AIR-PUMP.

229. Air-pump.—The air-pump was invented by Otto Guericke about 1650, and has since undergone some improvements in detail which have not altered the essential parts of its construction.

Fig. 130 represents the pattern most commonly adopted in France. It contains a glass or metal cylinder called the barrel, in which a piston works. This piston has an opening through it which is closed at the lower end by a valve S opening upwards. The barrel

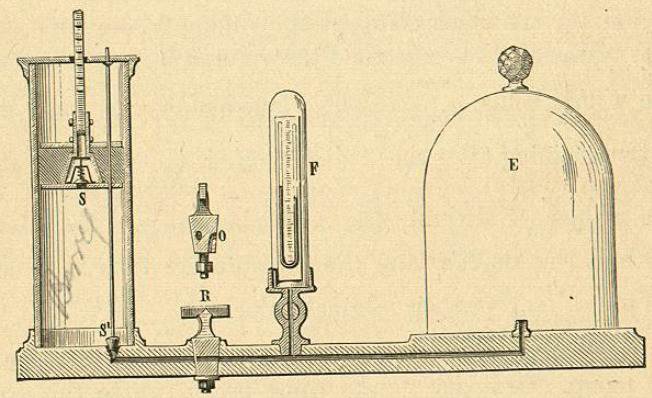

Fig. 130.—Air-pump

communicates with a passage leading to the centre of a brass surface carefully polished, which is called the *plate* of the air-pump. The entrance to the passage is closed by a conical stopper S′, at the extremity of a metal rod which passes through the piston-head and works in it tightly, so as to be carried up and down with the motion of the piston. A catch at the upper part of the rod confines its motion within very narrow limits, and only permits the stopper to rise a small distance above the opening.