CHAPTER XXI.

UPWARD PRESSURE OF THE AIR.

247. The Baroscope.—The principle of Archimedes, explained in Chap. XIII., applies to all fluids, whether liquid or gaseous. Hence the resultant of the whole pressure of the atmosphere on the surface of a body is equal to the weight of the air displaced. The force required to support a body in air, is less than the force required to support it in vacuo, by this amount. This principle is illustrated by the baroscope (Fig. 150).

This is a kind of balance, the beam of which supports two balls of very unequal sizes, which balance each other in the air. If the apparatus is placed under the receiver of an air-pump, after a few strokes of the piston the beam will be seen to incline towards the larger ball, and the inclination will increase as the exhaustion proceeds. The reason is that the air, before it was pumped out, produced an upward pressure, which was greater for the large than for the small ball, on account of its greater displacement; and this disturbing force is now removed.

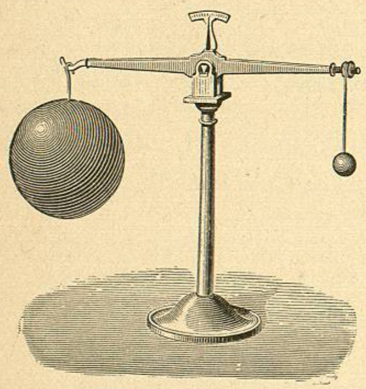

Fig. 150.—Baroscope.

If after exhausting the air, carbonic acid, which is heavier than air, were admitted at atmospheric pressure, the large ball would be subjected to a greater increase of upward pressure than the small one, and the beam would incline to the side of the latter.

248. Balloons.—Suppose a body to be lighter than an equal volume of air, then this body will rise in the atmosphere. For example, if

we fill soap-bubbles with hydrogen (Fig. 151), and shake them off from the end of the tube at which they are formed, they will be seen, if sufficiently large, to ascend in the air. This curious experiment is due to the philosopher Cavallo, who announced it in 1782.[1]

The same principle applies to balloons, which essentially consist of an envelope inclosing a gas lighter than air. In conse-

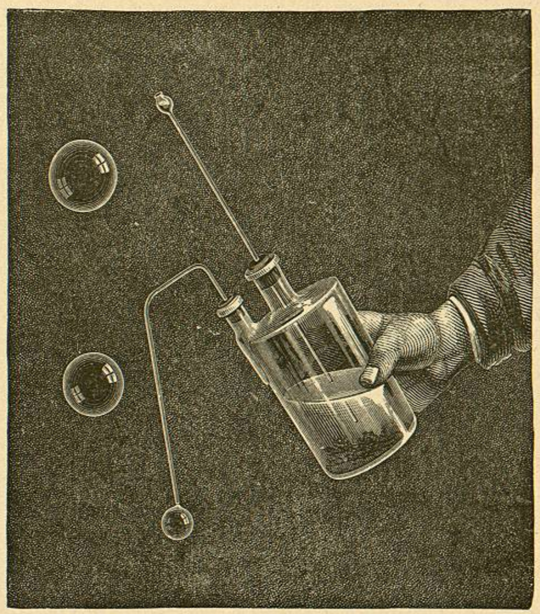

Fig. 151.—Ascent of Soap-bubbles filled with Hydrogen.

quence of this difference of density, we can always, by taking a sufficiently large volume, make the weight of the gas and containing envelope less than that of the air displaced. In this case the balloon will ascend.

The invention of balloons is due to the brothers Joseph and Stephen Montgolfier. The balloons made by them were globe-shaped, and constructed of paper, or of paper covered with cloth, the air inside being rarefied by the action of heat. It is curious to remark

[1] The first idea of a balloon must be attributed to Francisco de Lana, who, about 1670, proposed to exhaust the air in globes of copper of sufficient size and thinness to weigh less, under these conditions, than the air displaced. The experiment was not tried, and would certainly not have succeeded, for the pressure of the atmosphere would have caused the globes to collapse. The theory, however, was thoroughly understood by the author, who made an exact calculation of the amount of force tending to make the globes ascend. —*D.*

that in their first attempts they employed hydrogen gas, and showed that balloons filled with this gas could ascend. But as the hydrogen readily escaped through the paper, the flight of the balloons was short, and thus the use of hydrogen was abandoned, and hot air was alone employed.

The name *montgolfières* is still often applied to fire-balloons. They generally consist of a paper envelope with a wide opening below,

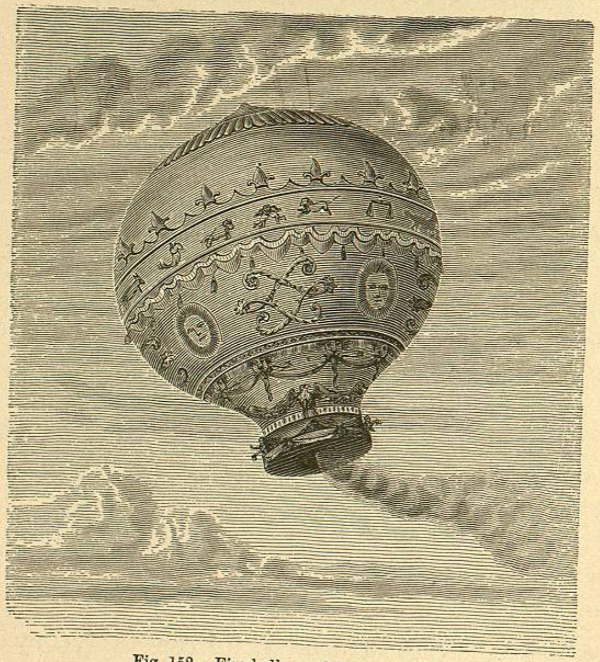

Fig. 152.—Fire balloon of Pilatre de Rozier.

in the centre of which is a sponge held in a wire frame. The sponge is dipped in spirit and ignited, when the balloon is to be sent up.

The first public experiment of the ascent of a balloon was performed at Annonay on the 5th June, 1783. On October 21st of the same year, Pilatre de Rozier and the Marquis d'Arlandes achieved the first aerial voyage in a fire-balloon, represented in our figure.

Charles proposed to reintroduce the use of hydrogen by employing an envelope less permeable to the gas. This is usually made of silk varnished on both sides, or of two sheets of silk with a sheet of india-rubber between. Instead of hydrogen, coal-gas is now generally employed, on account of its cheapness and of the facility with which it can be procured.

249.—The lifting power of a balloon is the difference between its weight and that of the air displaced. It is easy to compare the three modes of inflation in this respect.

A cubic metre of air weighs about	1·300	kilogramme.
A cubic metre of hydrogen	·089	"
A cubic metre of coal-gas .... about	·750	"
A cubic metre of air heated to 200° Cent.	·750	"

We thus see that the lifting power per cubic metre with hydrogen is 1·211, and with coal-gas or hot air about ·500 kilogramme. If, for instance, the total weight to be raised is estimated at 1500 kilogrammes, the volume of a balloon filled with hydrogen capable of raising the weight will be $\frac{1500}{1·210}=1239$ cubic metres. If coal-gas were employed, the required volume would be $\frac{1500}{·550}=2727$ cubic metres.

The car in which the aeronauts sit is usually made of wicker-work or whalebone. It is sustained by cords attached to a net-work (Fig. 153) covering the entire upper half of the balloon, so as to distribute the weight as evenly as possible. The balloon terminates below in a kind of neck opening freely into the air. At the top there is another opening in the inside, which is closed by a valve held to by a spring. Attached to the valve is a cord which passes through the interior of the balloon, and hangs above the car within reach of the hand of the aeronaut.

When the aeronaut wishes to descend, he opens the valve for a few moments and allows some of the gas to escape. An important part of the equipment consists of sand-bags for ballast, which are gradually emptied to check too rapid descent. In the figure is represented a contrivance called a parachute, by means of which the descent is sometimes effected. This is a kind of large umbrella with a hole at the top, from the circumference of which hang cords supporting a small car. When the parachute is left to itself, it opens out, and the resistance of the air, acting upon a large surface, moderates the rate of descent. The hole at the top is essential to safety, as it affords a regular passage for air which would otherwise escape from time to time from under the edge of the parachute, thus producing oscillations which might prove fatal to the aeronaut.

Balloons are not fully inflated at the commencement of the ascent; but the inclosed gas expands as the pressure diminishes outside. The lifting power thus remains nearly constant until the balloon has risen so high as to be fully inflated. Suppose, for instance, that the atmospheric pressure is reduced by one-half, the volume of the balloon will then be doubled; it will thus displace a volume of air twice as great as before, but of only half the density, so that the buoyancy will remain the same. This conclusion, however, is not quite exact, because the solid parts of the balloon do not expand like the gas, and the weight of air displaced by them accordingly diminishes as the balloon rises. If the balloon continues to ascend after it is completely inflated, its lifting power diminishes rapidly, becoming zero when a stratum of air is reached in which the weight of the volume displaced is equal to that of the balloon itself. It is carried past this stratum in the first instance in virtue of the velocity which it has acquired, and finally comes to rest in it after a number of oscillations.

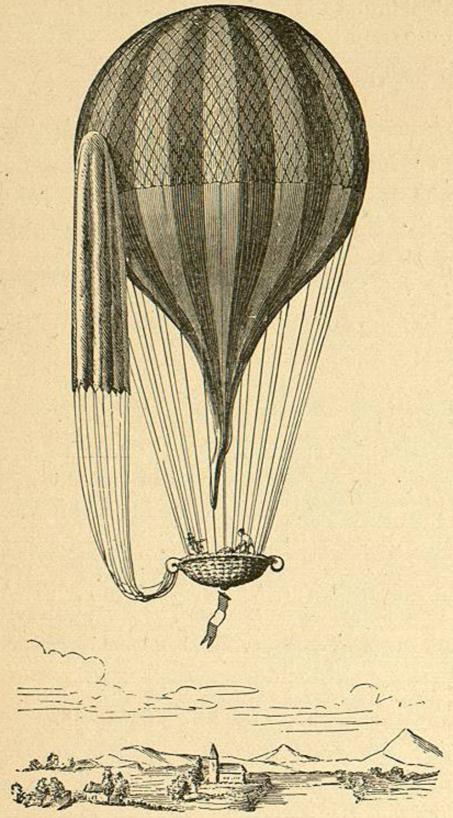

Fig. 153.—Balloon with Car and Parachute.

250. Height Attainable.—The pressure of the air in the stratum of equilibrium can be calculated as follows:

Let V be the volume of gas which the balloon can contain when fully inflated.

v the volume, and w the weight, of the solid parts, including the aeronauts themselves.

δ the density of the gas at the standard pressure and temperature, and D the density of air under the same conditions.

Then if P denote the standard pressure, and p the pressure in the stratum of equilibrium, the density of the gas when this stratum

has been reached will be $\frac{p}{P}\delta$, and the density of the air will be $\frac{p}{P}D$. Equating the weight of the air displaced to that of the floating body, we have

$$\frac{p}{P}(V+v)D = \frac{p}{P}V\delta + w,$$

whence p can be determined.

251. Effect of the Air upon the Weight of Bodies.—The upward pressure of the air impairs the exactness of weighings obtained even with a perfectly true balance, tending, by the principle of the baroscope, to make the denser of two equal masses preponderate. The stamped weights used in weighing are, strictly speaking, standards of mass, and will equilibrate any equal masses in vacuo; but in air the equilibrium will be destroyed by the greater upward pressure of the air upon the larger and less dense body. When the specific gravities of the weights and of the body weighed are known, it is easy from the apparent weight to deduce the true weight (that is to say, the mass) of the body.

Let x be the real weight (or mass) of a body which balances a standard weight of w grammes when the weighing is made in air. Let d be the density of the body, δ that of the standard weight, and a the density of the air. Then the weight of air displaced by the body is $\frac{a}{d}x$, and the weight of air displaced by the standard weight is $\frac{a}{\delta}w$. Hence we have

$$x - \frac{a}{d}x = w - \frac{a}{\delta}w,$$

$$x = w\frac{1-\frac{a}{\delta}}{1-\frac{a}{d}} = w\left\{1 + a\left(\frac{1}{d} - \frac{1}{\delta}\right)\right\} \text{ nearly.}$$

Let us take, for instance, a piece of sulphur whose weight has been found to be 100 grammes, the weights being of copper, the density of which is 8·8. The density of sulphur is 2.

We have, by applying the formula,

$$x = 100\left\{1 + \frac{1}{770}\left(\frac{1}{2} - \frac{1}{8{\cdot}8}\right)\right\} = 100{\cdot}05 \text{ grammes.}$$

We see then that the difference is not altogether insensible. It varies in sign, as the formula shows, according as d or δ is the greater. When the density of the body to be weighed is less than that of the weights used, the real weight is greater than the apparent weight; if the contrary, the case is reversed. If the body to be weighed were of the same density as the weights used, the real and apparent weights would be equal. We may remark, that in determining the *ratio* of the weights of two bodies of the same density, by means of standard weights which are all of one material, we need not concern ourselves with the effect of the upward pressure of the air; as the correcting factor, which has the same value for both cases, will disappear in the quotient.

CHAPTER XXII.

PUMPS FOR LIQUIDS.

252. Machines for raising water have been known from very early ages, and the invention of the common pump is pretty generally ascribed to Ctesibius, teacher of the celebrated Hero of Alexandria; but the true theory of its action was not understood till the time of Galileo and Torricelli.

253. **Reason of the Rising of Water in Pumps.**—Suppose we take a tube with a piston at the bottom (Fig. 154),and immerse the lower end of it in water. The raising of the piston tends to produce a vacuum below it, and the atmospheric pressure, acting upon the external surface of the liquid, compels it to rise in the tube and follow the upward motion of the piston. This upward movement of the water would take place even if some air were interposed between the piston and the water; for on raising the piston, this air would be rarefied, and its pressure no longer balancing that of the atmosphere, this latter pressure would cause the liquid to ascend in a column whose weight, added to the pressure of the air below the piston, would be equal to the atmospheric pressure. This is the principle on which water rises in pumps. These instruments have a considerable variety of forms, of which we shall describe the most important types.

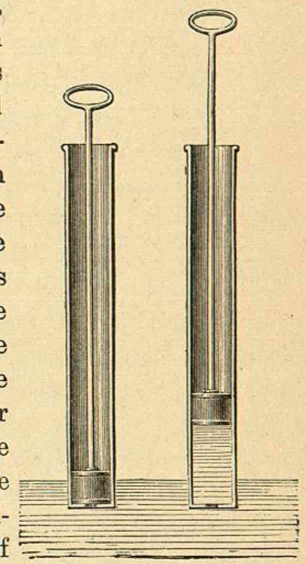

Fig. 154.—Principle of Suction-pump.

254. **Suction-pump.**—The suction-pump (Fig. 155) consists of a