manner with dry air in the globe at pressures H′ and h'. Then the relative density of the gas will be

$$\frac{w}{w'}\,\frac{H'-h'}{H-h}.$$

We must now describe a special precaution which was employed by Regnault (and still earlier by Dr. Prout) to avoid errors in weighing arising from the varying weight of the external air displaced by the globe.

A second globe (Fig. 40) of precisely the same external volume as the first, made of the same glass, and closed air-tight, was used as a counterpoise. The equality of external volumes was ensured in the following way. The globes were filled with water, hung from the two scales of a balance, and equilibrium was brought about by putting a sufficient quantity of some material into one scale. Both globes, thus hanging from the scales in equilibrium, were then immersed in water, and if this operation disturbed the equilibrium it was known that the external volumes were not equal. Let p be the weight which must be put into one scale to restore equilibrium; then this weight of water represents the difference of the two external volumes; and the next operation was to prepare a small piece of glass tube closed at the ends which should lose p when weighed in water. The larger of the two globes was used for containing the gases to be weighed, and the smaller globe along with this piece of tube constituted the counterpoise. Since the volume of the gas globe was exactly the same as that of the counterpoise, the pressure of the external air had no tendency to make either preponderate, and variations in the condition of this air, whether as regards pressure, temperature, or humidity, had no disturbing effect.

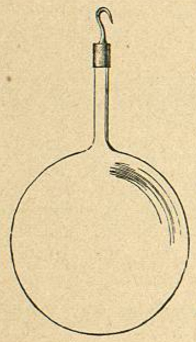

Fig. 40.
Compensating Globe.

54. Absolute Densities.—In order to convert the preceding relative determinations into absolute determinations, it is only necessary to know the precise internal volume of the globe at the temperature 0° C. In order to determine this with the utmost possible exactness the following operations were performed.

The globe was first weighed in air, with its stop-cock open, the temperature of the air and the height of the barometer being noted.

It was then filled with water, special precautions being taken to expel every particle of air; and was placed for several hours in the midst of melting ice, to insure its being filled with water at 0° C.

The stop-cock was then closed, and the globe was left for two hours in a room which had a very steady temperature of 6°. It was then weighed in this room, the height of the barometer being at the same time observed. The difference between this weight and that of the globe before the introduction of the water, was the weight of the water *minus* the weight of the same volume of air, subject to a small correction for change of density in the external air between the two weighings, which, with the actual heights of the barometer and thermometer, was insensible.

The weight of water at 0° which the globe would hold at 0° was therefore known; and hence the weight of water at 4° (the temperature of maximum density) which the globe would hold at 0° was calculated, from the known expansion of water. This weight, in grammes, is equal to the capacity in cubic centimetres.

The result thus obtained was that the capacity of the globe at 0° was 9881 cubic centimetres; and the weight of the dry air which filled it at 0° and a pressure of 760^{mm} was 12·778 grammes. Hence the weight (or mass) of 1 cubic centimetre of such air is ·0012932 gramme.

This experiment was performed at Paris, where the value of g (the intensity of gravity) is 980·94; and since the density of mercury at 0° is 13·596, the pressure of 76 centimetres of mercury was equivalent to

$$76 \times 13{\cdot}596 \times 980{\cdot}94 = 1{\cdot}0136 \times 10^6$$

dynes per square centimetre.

If we divide the density just found by 1·0136, we obtain the density of air at 0° and a pressure of a million dynes per square centimetre, which is a convenient standard for general reference; we have thus

$$\cdot 0012932 \div 1{\cdot}0136 = \cdot 0012759.$$

A litre or cubic decimetre contains 1000 cubic centims. Hence the weight of a litre of air in the standard condition adopted by Regnault is 1·2932 gramme.

The following table gives the densities of several gases at 0° C. at a pressure of 760 millimetres of mercury at Paris.

Name of Gas.	Relative Density.	Mass of a Litre in Grammes.
Air	1	1·2932
Oxygen	1·10563	1·4298
Hydrogen	·06926	·08957
Nitrogen	·97137	1·25615
Chlorine	2·4216	3·1328
Carbonic oxide	·9569	1·2344
Carbonic acid	1·52901	1·9774
Protoxide of nitrogen	1·5269	1·9697
Binoxide of nitrogen	1·0388	1·3434
Sulphurous acid	2·1930	2·7289
Cyanogen	1·8064	2·3302
Marsh-gas	·559	·727
Olefiant gas	·985	1·274
Ammonia	·5967	7697

55. Draught of Chimneys.—The expansion of air by heat produces the upward current in chimneys, and an approximate expression for the velocity of this current may be obtained by the application of Torricelli's theorem on the efflux of fluids from orifices (see Part I.).

Suppose the chimney to be cylindrical and of height h. Let the air within it be at the uniform temperature t' Centigrade, and the external air at the uniform temperature t. According to Torricelli's theorem, the square of the linear velocity of efflux is equal to the product of $2g$ into the head of fluid, the term *head of fluid* being employed to denote the *pressure* producing efflux, *expressed in terms of depth of the fluid.*

In the present case this head is the difference between h, which is the height of air within the chimney, and the height which a column of the external air of original height h would have if expanded upwards, by raising its temperature from t to t'. This latter height is $h\frac{1+\alpha t'}{1+\alpha t}$; α denoting the coefficient of expansion ·00366; and the head is

$$h\frac{1+\alpha t'}{1+\alpha t}-h=\frac{h\alpha\,(t'-t)}{1+\alpha t}.$$

Hence, denoting by v the velocity of the current up the chimney, we have

$$v^2=\frac{2gh\alpha\,(t'-t)}{1+\alpha t}.$$

This investigation, though it gives a result in excess of the truth, from neglecting to take account of friction and eddies, is sufficient to explain the principal circumstances on which the strength of draught depends. It shows that the draught increases with the height h of the chimney, and also with the difference $t'-t$ between the internal and external temperatures.

The draught is not so good when a fire is first lighted as after it has been burning for some time, because a cold chimney chills the air within it. On the other hand, if the fire is so regulated as to keep the room at the same temperature in all weathers, the draught will be strongest when the weather is coldest.

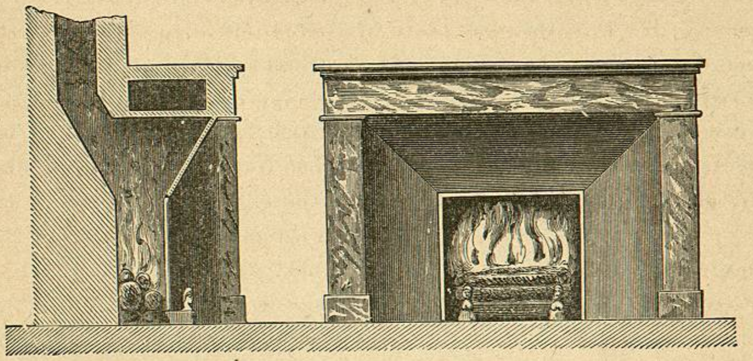

Fig. 41.—Rumford's Fireplace.

The opening at the lower end of the chimney should not be too wide nor too high above the fire, as the air from the room would then enter it in large quantity, without being first warmed by passing through the fire. These defects prevailed to a great extent in old chimneys. Rumford was the first to attempt rational improvements. He reduced the opening of the chimney and the depth of the fireplace, and added polished plates inclined at an angle, which serve both to guide the air to the fire and to reflect heat into the room (Fig. 41).

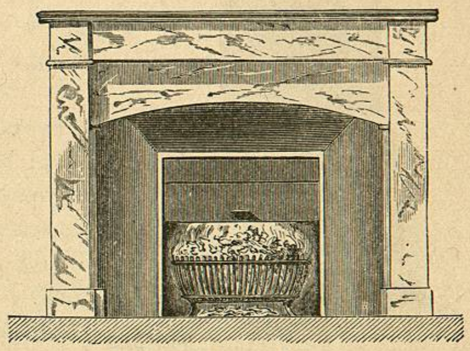

Fig. 42.—Fireplace with Blower.

The blower (Fig. 42) produces its well-known effects by compelling all air to pass through the fire before entering the chimney. This at once improves the draught of the chimney by raising the temperature of the air within it, and quickens combustion by increasing the supply of oxygen to the fuel.

56. Stoves.—The heating of rooms by open fireplaces is effected almost entirely by radiation, and much even of the radiant heat is wasted. This mode of heating then, though agreeable and healthful, is far from economical. Stoves have a great advantage in point of economy; for the heat absorbed by their sides is in great measure given out to the room, whereas in an ordinary fireplace the greater part of this heat is lost. Open fireplaces have, however, the advantage as regards ventilation; the large opening at the foot of the chimney, to which the air of the room has free access, causes a large body of air from the room to ascend the chimney, its place being supplied by fresh air entering through the chinks of the doors and windows, or any other openings which may exist.

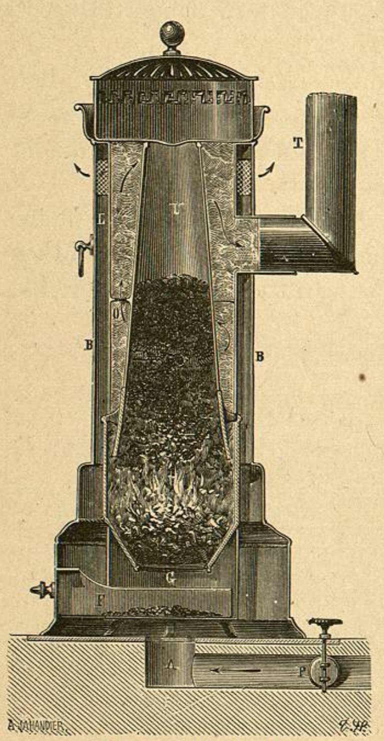

Fig. 43.—Ventilating Stove.

Stoves are also liable to the objection of making the air of the room too dry, not, of course, by removing water, but by raising the temperature of the air too much above the dew-point (Chap. xi.). The same thing occurs with open fireplaces in frosty weather, at which time the dew-point is unusually low. This evil can be remedied by placing a vessel of water on the stove. The reason why it is more liable to occur with stoves than with open fireplaces, is mainly that the former raise the air in the room to a higher temperature than the latter, the defect of air-temperature being in the latter case compensated by the intensity of the direct radiation from the glowing fuel.

Fire-clay, from its low conducting power, is very serviceable both for the backs of fireplaces and for the lining of stoves. In the former situation it prevents the wasteful escape of heat backwards into the chimney, and keeps the back of the fire nearly as hot as the centre. As a lining to stoves, it impedes the lateral escape of heat, thus answering the double purpose of preventing the sides of the stove from overheating, and at the same time of keeping up the temperature of the fire, and thereby promoting complete combustion. Its use must, however, be confined to that portion of the stove which serves as the fire-box, as it would otherwise prevent the heat from being given out to the apartment.

The stove represented in Fig. 43 belongs to the class of what are called in France *calorifères*, and in England *ventilating stoves*, being constructed with a view to promoting the circulation and renewal of the air of the apartment. G is the fire-box, over which is the feeder U, containing unburned fuel, and tightly closed at top by a lid, which is removed only when fresh fuel is to be introduced. The ash-pan F has a door pierced with holes for admitting air to support combustion. The flame and smoke issue at the edge of the fire-box, and after circulating round the chamber O which surrounds the feeder, enter the pipe T which leads to the chimney. The chamber O is surrounded by another inclosure L, through which fresh air passes, entering below at A, and escaping into the room through perforations in the upper part of the stove as indicated by the arrows. The amount of fresh air thus admitted can be regulated by the throttle-valve P.