

## CHAPTER VIII.

### EVAPORATION AND CONDENSATION.

91. **Transformation into the State of Vapour.**—The majority of liquids, when left to themselves in contact with the atmosphere, gradually pass into the state of vapour and disappear. This phenomenon occurs much more rapidly with some liquids than with others, and those which evaporate most readily are said to be the most volatile. Thus, if a drop of ether be let fall upon any substance, it disappears almost instantaneously; alcohol also evaporates very quickly, but water requires a much longer time for a similar transformation. The change is in all cases accelerated by an increase of temperature; in fact, when we *dry* a body before the fire, we are simply availing ourselves of this property of heat to hasten the evaporation of the moisture of the body. Evaporation may also take place from solids. Thus camphor, iodine, and several other substances pass directly from the solid to the gaseous state, and we shall see hereafter that the vapour of ice can be detected at temperatures far below the freezing-point.

Evaporation, unlike fusion, occurs over a very wide range of temperature. There appears, however, to be a temperature for each substance, below which evaporation, if it exist at all, is insensible to ordinary tests. This is the case with mercury at  $0^{\circ}$  C., and with sulphuric acid at ordinary atmospheric temperatures.

92. **Vapour, Gas.**—The words *gas* and *vapour* have no essential difference of meaning. A vapour is the gas into which a liquid is changed by evaporation. Every gas is probably the vapour of a liquid. The word *vapour* is especially applied to the gaseous condition of bodies which are usually met with in the liquid or solid state, as water, sulphur, &c.; while the word *gas* generally denotes a

body which, under ordinary conditions, is never found in any state but the gaseous.

93. **Pressure of Vapours. Maximum Pressure and Density.**—The characteristic property of gases is the elastic force<sup>1</sup> with which they tend to expand. This may be exemplified in the case of vapours by the following experiment.

A glass globe A (Fig. 54) is fitted with a metal cap provided with two openings, one of which can be made to communicate with a mercurial manometer, while the other is furnished with a stop-cock R. The globe is first exhausted of air by establishing communication through R with an air-pump. The mercury rises in the left-hand and falls in the right-hand branch of the manometer; the final difference of level in the two branches differing from the height of the barometer only by the very small quantity representing the pressure of the air left behind by the machine. The stop-cock R is then closed, and a second stop-cock R' surmounted by a funnel is fixed above it. The hole in this second stop-cock, instead of going quite through the metal, extends only half-way, so as merely to form a cavity. This cavity serves to introduce a liquid into the globe, without any communication taking place between the globe and the external air. For this purpose we have only to fill the funnel with a liquid, to open the cock R, and to turn that at R' backwards and forwards several times. It will be found that after the introduction of a small quantity of liquid into the globe, the mercurial column begins to descend in the left branch of the manometer, thus indicating an increase of elastic force. This elastic force goes on increasing as a greater quantity of liquid is introduced into the globe; and as no liquid is visible in the globe, we must infer that it evaporates as fast as it is introduced, and that the fall of the mercurial column is caused by the elastic force of the vapour thus formed.

This increase of pressure, however, does not go on indefinitely. After a time the difference of level in the two branches of the manometer ceases to increase, and a little of the unevaporated liquid may be seen in the globe, which increases in quantity as more liquid is

<sup>1</sup> The terms "pressure," "tension," and "elastic force" are often used interchangeably to denote the stress existing in a vapour or gas. "Tension" is the ordinary term employed in this sense in French books. The best English authorities upon elasticity, however, employ the two terms "pressure" and "tension" to denote two opposite things; a pressure is a push, and a tension is a pull. Gases and vapours cannot pull, they can only push, and they are constantly pushing in all directions; hence they are never in a state of *tension*, but are always in a state of *pressure*.



introduced. From this important experiment we conclude that there is a limit to the quantity of vapour which can be formed at a given temperature in an empty space. When this limit is reached, the space is said to be *saturated*, and the vapour then contained in it is at *maximum pressure*, and at *maximum density*. It evidently fol-

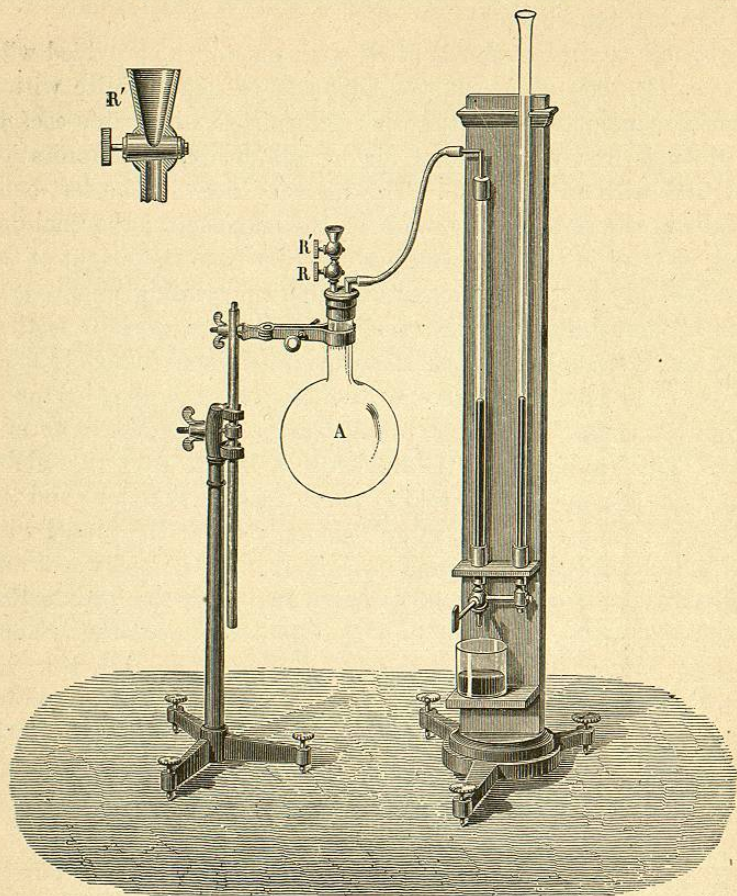


Fig. 54. —Apparatus for studying the Formation of Vapours.

lows from this that if a quantity of vapour at less than its maximum density be inclosed in a given space, and then compressed at constant temperature, its pressure and density will increase at first, but that after a time a point will be reached when further compression, instead of increasing the density and pressure of the vapour, will only cause some of it to pass into the liquid state. This last result may be directly verified by the following experiment. A barometric tube

*a b* (Fig. 55) is filled with mercury, with the exception of a small space, into which a few drops of ether are introduced, care having first been taken to expel any bubbles of air which may have remained adhering to the mercury. The tube is then inverted in the deep bowl *MN*, when the ether ascends to the surface of the mercury, is there converted into vapour, and produces a sensible depression of the mercurial column. If the quantity of ether be sufficiently small, and if the tube be kept sufficiently high, no liquid will be perceived in the space above the mercury; this space, in fact, is not saturated. The pressure of the vapour which occupies it is given by the difference between the height of the column in the tube and of a barometer placed beside it. If the tube be gradually lowered, this difference will at first be seen to increase, that is, the pressure of the vapour of ether increases; but if we continue the process, a portion of liquid ether will be observed to collect above the mercury, and after this, if we lower the tube any further, the height of the mercury in it remains invariable. The only effect is to increase the quantity of liquid deposited from the vapour.<sup>1</sup>

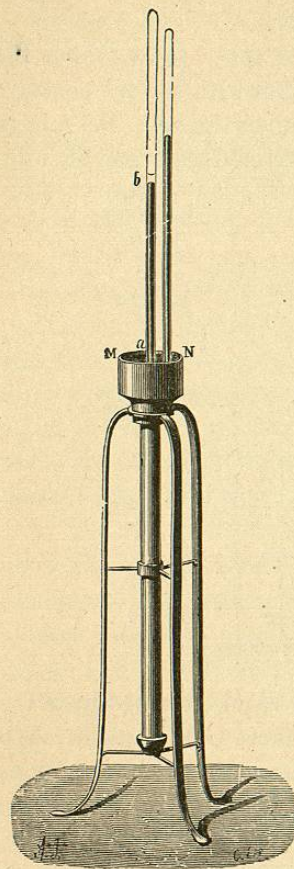


Fig. 55. —Maximum Tension of Vapours.

94. Influence of Temperature on Maximum Density and Pressure.—Returning now to the apparatus represented in Fig. 54, suppose that some of the liquid remains unevaporated in the bottom of the globe, and let the globe be subjected to an increase of temperature. An increase of elastic force will at once be indicated by the manometer, while the quantity of liquid will be diminished. The maximum pressure of a vapour, therefore, and also its maximum density, increase with the temperature; and consequently, in order to saturate

<sup>1</sup> Strictly speaking, there will be a slight additional depression of the mercurial column due to the weight of the liquid thus deposited on its summit; but this effect will generally be very small, owing to the smallness of the quantity of liquid.



a given space, a quantity of vapour is required which increases with the temperature.

Vapour which is at less than the maximum density is called *superheated vapour*; because it can be obtained by giving heat to vapour at maximum density at a lower temperature.

Fig. 56 is a graphical representation of the rate at which the maximum density of aqueous vapour increases with the temperature from  $-20^{\circ}$  to  $+35^{\circ}$  C. Lengths are laid off on the base-line AB, to represent temperatures, and ordinates are erected at every fifth de-

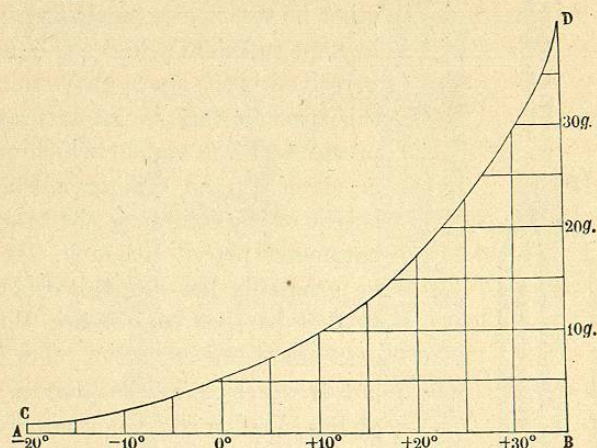


Fig. 56.—Saturation at different Temperatures.

gree, proportional to the masses of vapour required to saturate the same space at different temperatures. The curve CD, drawn through the extremities of these ordinates, is the curve of vapour-density as a function of temperature. The figures on the right hand indicate the number of grammes of vapour required to saturate a cubic metre.

**95. Mixture of Gas and Vapour. Dalton's Laws.**—The experiments with the apparatus of Fig. 54 may be repeated after filling the globe with dry air, or any other dry gas, and the results finally obtained will be the same as with the exhausted globe. If, as before, we introduce successive small quantities of a liquid, it will be converted into vapour, and the pressure will go on increasing till saturation is attained; the elastic force of vapour will then be found to be exactly the same as in the case of the vacuous globe, and the quantity of liquid evaporated will also be the same.

There is, however, one important difference. In the vacuum the complete evaporation of the liquid is almost instantaneous; in a gas,

on the other hand, the evaporation and consequent increase of pressure proceed with comparative slowness; and the difference between the two cases is more marked in proportion as the pressure of the gas is greater.

We may lay down, then, the two following laws (called, from their discoverer, Dalton's laws) for the mixture of a vapour with a gas:—

1. *The mass of vapour which can be contained in a given space is the same whether this space be empty or filled with gas.*

2. *When a gas is saturated with vapour, the actual pressure of the mixture is the sum of the pressures due to the gas and vapour separately; that is to say, it is equal to the pressure which the gas would exert if it alone occupied the whole space, plus the maximum pressure of vapour for the temperature of the mixture.*

This second law comes under the general rule for determining the pressure of a mixture of gases (see Part I.); and the rule still applies to a mixture of gas and vapour when the quantity of the latter falls short of saturation. Each element in a mixture of gases and vapours exerts the same pressure on the walls of the containing vessel as it would exert if the other elements were removed.

It is doubtful, however, whether these laws are rigorously true. It would rather appear from some of Regnault's experiments, that the quantity of vapour taken up in a given space is slightly, though almost insensibly, diminished, as the density of the gas which occupies the space is increased.

**96. Liquefaction of Gases.**—When vapour exists in the state of saturation, any diminution in the volume must, if the temperature is preserved constant, involve the liquefaction of as much of the vapour as would occupy the difference of volumes; and the vapour which remains will still be at the original density and tension. A vapour existing by itself may therefore be completely liquefied by subjecting it to a pressure exceeding, by ever so slight an amount, the maximum tension corresponding to the temperature, provided that the containing vessel is prevented from rising in temperature.

Again, if a vapour at saturation be subjected to a fall of temperature, while its volume remains unchanged, a portion of it must be liquefied corresponding to the difference between the density of saturation at the higher and at the lower temperature. This operation will obviously diminish the pressure, since this will now be the maximum pressure corresponding to the lower instead of to the higher temperature.



There are therefore two distinct means of liquefying a vapour— increase of pressure, and lowering of temperature. They are employed sometimes separately, and sometimes in conjunction.

Fig. 57 represents the apparatus usually employed for obtaining sulphurous acid in the liquid state. The gas, which is generated in a glass globe, passes first into a washing-bottle, then through a drying-tube, and finally into a tube surrounded with a freezing-mixture of snow and salt.

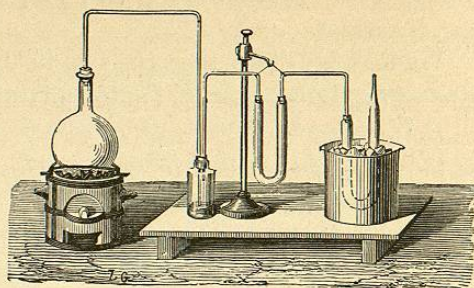


Fig. 57.—Liquefaction of Sulphurous Acid.

Pouillet's apparatus for showing the unequal compressibilities of different gases (see Part I.) serves to liquefy most gases by means of compression. In order to ascertain the pressures at which liquefaction takes place, or, in other words, the maximum pressures of gases, one of the tubes in that apparatus is replaced by a shorter tube, containing air, and serving as a manometer.

By this means Pouillet found that, at the temperature of  $10^{\circ}$  C., sulphurous acid is liquefied by a pressure of  $2\frac{1}{2}$  atmospheres, nitrous oxide by a pressure of 43, and carbonic acid by a pressure of 45 atmospheres.

**97. Faraday's Method.**—Faraday, who was the first to conduct methodical ex-

periments on the liquefaction of gases, employed, in the first instance, the simple apparatus represented in Fig. 58. It con-

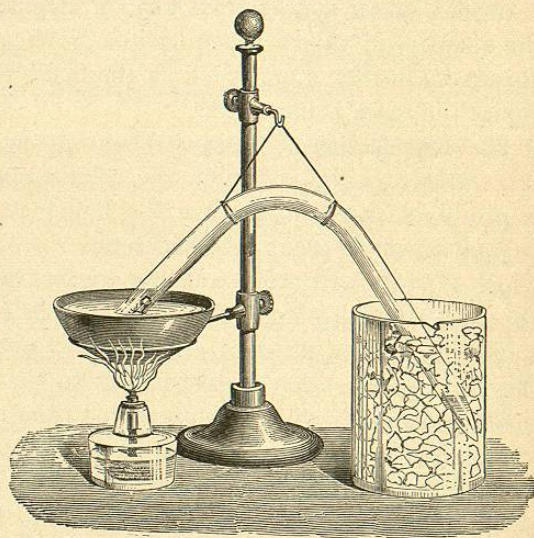


Fig. 58.—Faraday's Apparatus.

sists of a very strong bent glass tube, one end of which contains ingredients which evolve the gas on the application of heat, while the other is immersed in a freezing-mixture. The pressure produced by the evolution of the gas in large quantity in a confined space, combines with the cold of the freezing-mixture to produce liquefaction of the gas, and the liquid accordingly collects in the cold end of the tube.

Thilorier, about the year 1834, invented the apparatus represented in Fig. 59, which is based on this method of Faraday, and is intended for liquefying carbonic acid gas. This operation requires the enormous pressure of about fifty atmospheres at ordinary temperatures. If a slight rise of temperature occur from the chemical actions attending the production of the gas, a pressure of 75 or 80 atmospheres may not improbably be required. Hence great care is necessary in testing the strength of the metal employed in the construction of the apparatus. It was formerly made of cast-iron, and strengthened by wrought-iron hoops; but the construction has since been changed on account of a terrible explosion, which cost the life of one of the operators. At present the vessels are formed of three parts; the inner one of lead, the next *e*, which completely envelops this, of copper, and finally, the hoops *ff* of wrought iron (Fig. 59), which bind the whole together. The apparatus consists of two distinct reservoirs. In the generator *C* is placed bicarbonate of soda, and a vertical tube *a*, open at top, containing sulphuric acid. By imparting an oscillatory movement to the vessel about the two pivots which support it near the middle, the sulphuric acid is gradually discharged, and the carbonic acid is evolved, and becomes liquid in the interior. The generator is then connected with the condenser *C'* by the tube *t*, and the stop-cocks *R* and *R'* are opened. As soon as the two vessels are in communication, the liquid carbonic acid passes into the condenser, which is at a lower temperature than the generator, and represents the cold branch of Faraday's apparatus. The generator can then be disconnected and recharged, and thus several pints of liquid carbonic acid may be obtained.

In the foregoing methods, the pressure which produces liquefaction is furnished by the evolution of the gas itself.

In some other forms of apparatus the pressure is obtained by the use of one or more compression-pumps, which force the gas from the vessel in which it is generated into a second vessel, which is kept cool either by ice or a freezing-mixture. The apparatus of this kind



which is most extensively used is that devised by Bianchi. It consists of a compression-pump driven by a crank furnished with a fly-wheel, and turned by hand.

Faraday, in his later experiments, employed two pumps, the first

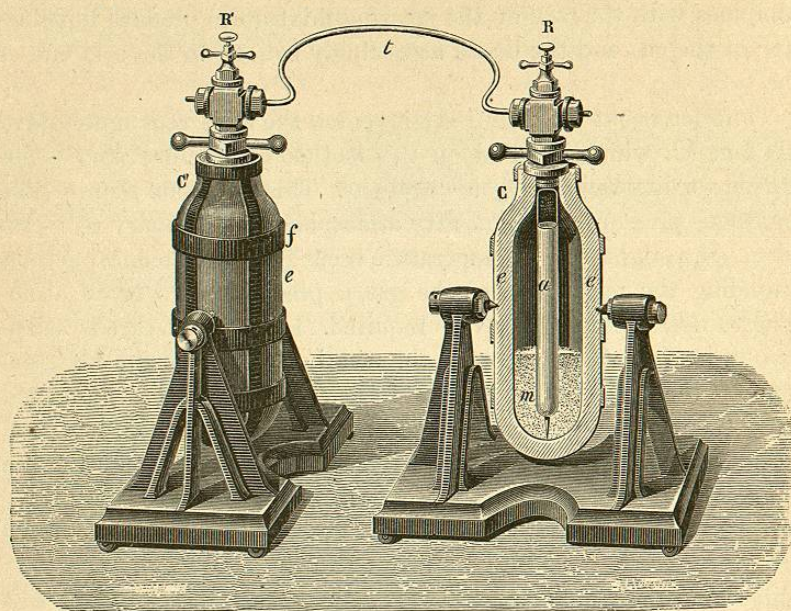


Fig. 59.—Thilorier's Apparatus.

having a piston of an inch, and the second of only half an inch diameter. The first pump in the earlier stage of the operation forced the gas through the second into the receiver. In the later stage the second pump was also worked, so as to force the gas already condensed to 10, 15, or 20 atmospheres into the receiver at a much higher pressure. The receiver was a tube of green bottle-glass, and was immersed in a very intense freezing-mixture, consisting of solid carbonic acid and ether, the cooling effect being sometimes increased by exhausting the air and vapour from the vessel containing the freezing-mixture, so as to promote more rapid evaporation.

**98. Latent Heat of Vaporization. Cold produced by Evaporation.**—The passage from the liquid to the gaseous state is accompanied by the disappearance of a large quantity of heat. Whenever a liquid evaporates without the application of heat, a depression of temperature occurs. Thus, for instance, if any portion of the skin be kept moist with alcohol or ether, a decided sensation of cold is felt. Water

produces the same effect in a smaller degree, because it evaporates less rapidly.

The heat which thus disappears in virtue of the passage of a liquid into the gaseous condition, is called the *latent heat of vaporization*. Its amount varies according to the temperature at which the change is effected, and it is exactly restored when the vapour returns to the liquid form, provided that both changes have been effected at the same temperature. Its amount for vapour of water at the temperature  $100^{\circ}$  C. is  $536^{\circ}$ ; that is to say, the quantity of heat which disappears in the evaporation of a pound of water at this temperature, and which reappears in the condensation of a pound of steam at the same temperature, would be sufficient to raise the temperature of 536 pounds of water from  $0^{\circ}$  to  $1^{\circ}$ .

The latent heat of vaporization plays an important part in the heating of buildings by steam. A pound of steam at  $100^{\circ}$ , in becoming reduced to water at  $30^{\circ}$ , gives out as much heat as about  $8\frac{3}{4}$  lbs. of water at  $100^{\circ}$  in cooling down to the same temperature.

**99. Leslie's Experiment.**—Water can be easily frozen by the cold resulting from its own evaporation, as was first shown by Leslie in a celebrated experiment. A small capsule (Fig. 60) of copper is taken, containing a little water, and is placed above a vessel containing strong sulphuric acid. The whole is placed under the receiver of an air-pump, which is then exhausted. The water evaporates with great rapidity, the vapour being absorbed by the sulphuric acid as fast as it is formed, and ice soon begins to appear on the surface. The experiment is, however, rather difficult to perform successfully. This arises from various causes.

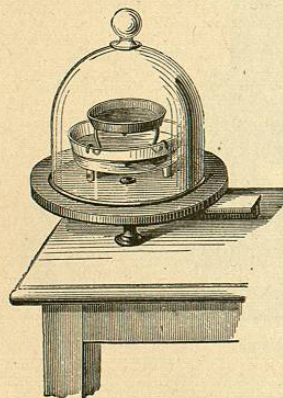


Fig. 60.—Leslie's Experiment.

In the first place, the vapour of water which occupies the upper part of the receiver is only imperfectly absorbed; and, in the second place, as the upper layer of the acid becomes diluted by absorbing the vapour, its affinity for water rapidly diminishes.

These obstacles have been removed by an apparatus invented by M. Carré, which enables us to obtain a considerable mass of ice in a few minutes. It consists (Fig. 61) of a leaden reservoir containing