THURSDAY, JANUARY 3, 1878

THE LAST OF THE GASES

THE year 1877 will ever be memorable in the history of scientific progress, its close having been marked by a brilliant series of researches which have ended in an absolute demonstration of the fact that molecular cohesion is a property of all bodies without any exception whatever.

This magnificent work divides itself into two stages, which we shall refer to separately: first the liquefaction of oxygen, and then, following close upon this, the liquefaction of hydrogen, nitrogen, and atmospheric air.

In the liquefaction of oxygen, which we announced last week as having been accomplished by M. Pictet of Geneva, we have not only an instance of the long time we may have to wait, and of the great difficulties which have to be overcome, before a theoretical conclusion is changed into a concrete fact—something definite acquired to science; but also another instance of a double discovery, showing that along all the great lines of thought opened up by modern investigation and modern methods, students of science are marching at least two abreast.

It appears that as early as December 2 M. Cailletet had succeeded in liquefying oxygen and carbonic oxide at a pressure of 300 atmospheres and at a temperature of $-29°$ C. This result was not communicated to the Academy at once, but was consigned to a sealed packet on account of M. Cailletet being then a candidate for a seat in the Section of Mineralogy. Hence, then, the question of priority has been raised, but it is certain that in the future the work will be credited to both, on the ground that the researches of each were absolutely independent, both pursuing the same object, creating methods and instruments of great complexity. We regret, therefore, that M. Jamin, at the sitting of the Academy to which we have referred, seemed to strain the claims of M. Cailletet by stating that to obtain the gas non-transparent was the same as to obtain it liquefied. We are beginning to know enough of the various states of vapour now not to hazard such an assertion as this. This remark, however, rather anticipates matters, and indeed, as we shall show afterwards, M. Cailletet need not himself be very careful of the question of priority—even if it were ever worth caring for except to keep other people honest.

Owing to the double discovery and the curious incident to which we have referred, the meeting of the Academy on the 24th ult. was a very lively one, as not only was the sealed packet and a subsequent communication from M. Cailletet read, but M. Pictet had sent a long letter to M. Dumas giving full details of his arrangements. MM. Dumas, H. St. Claire Deville, Jamin, Regnault and Berthelot all took part in the discussion, the former admirably putting the work in its proper place by the following quotation from Lavoisier:—

"... Considérons un moment ce qui arriverait aux différentes substances qui composent le globe, si la température en était brusquement changée. Supposons, par exemple, que la terre se trouvât transportée tout à coup dans une région beaucoup plus chaude du système solaire, dans une région, par exemple, où la chaleur habituelle serait fort supérieure à celle de l'eau bouillante; bientôt l'eau, tous les liquides susceptibles de se vaporiser à des degrés voisins de l'eau bouillante, et plusieurs substances metalliques même, entreraient en expansion et se transformeraient en fluides aériformes, qui deviendraient parties de l'atmosphère.

"Par un effet contraire, si la terre se trouvait tout à coup placée dans des régions très froides, par exemple de Jupiter et de Saturne, l'eau qui forme aujourd'hui nos fleuves et nos mers, et probablement le plus grand nombre de liquides que nous connaissons, se transformeraient en montagnes solides.

"L'air dans cette supposition, ou du moins une partie des substances aériformes qui le composent, cesserait, sans doute, d'exister dans l'état de fluide invisible, faute d'un degré de chaleur suffisant; il reviendrait donc à l'état de liquidité, et ce changement produirait de nouveaux liquides dont nous n'avons aucune idée."

When Faraday in the year 1823 (at the age of 31) began the researches indicated in the last paragraph quoted by M. Dumas, and first liquefied chlorine and then several other gases, he had no idea that he had been anticipated, as he had been, by Monge and Clouet, who condensed sulphurous acid before the year 1800, and by Northmore, who liquefied chlorine in 1805. If the great experimenter were among us now how delighted he would be to see one of the greatest ironmasters of France employing the enormous resources at his disposal at Châtillon-sur-Seine, and a descendant of the Pictet, the firm friend of his great friend De la Rive (who was the first to whom he communicated his liquefaction of chlorine), thus engaged in carrying on the work which he made his own.

The methods employed by MM. Pictet and Cailletet are quite distinct and are the result of many years' preparatory study, as testified by M. H. St. Claire Deville and M. Regnault. It is difficult to know which to admire most, the scientific perfection of Pictet's method or the wonderful simplicity of Cailletet's. It is quite certain that the one employed by the latter will find frequent use in future experiments. We may briefly refer to both these methods.

M. Cailletet's apparatus has already been briefly alluded to in these columns. It consists essentially of a massive steel cylinder with two openings; through one hydraulic pressure is communicated. A small tube passes through the other, the sides of which are strong enough to withstand a pressure of several hundred atmospheres, and which can be inclosed in a freezing mixture. It opens within the cylinder into a second smaller cylinder serving as a reservoir for the gas to be compressed. The remainder of the space in the large cylinder is occupied by mercury. M. Cailletet's process consists in compressing a gas into the small tube, and then by suddenly placing it in communication with the outer air, producing such a degree of cold by the sudden distention of the confined gas that a large portion of it is condensed, a process perfectly analagous to that used to prepare solid carbonic acid by the rapid evaporation of the liquefied gas.

In M. Cailletet's experiment with oxygen it was brought to a temperature of $-29°$ C. by the employment of sulphurous acid and a pressure of 300 atmospheres; the gas was still a gas. But when allowed to expand suddenly, which, according to Poisson's formula, brings it down to 200 degrees below its starting-point, a cloud was at once formed. The same result has since been obtained without the employment of sulphurous acid, by giving the gas time to cool after compression. M. Cailletet has not yet obtained, at all events, so far as we yet know, oxygen in a liquid form, as M. Pictet has done; on being separated from its enormous pressure it has merely put on the appearance of a cloud.

M. Pictet's arrangements are more elaborate. He uses four vacuum- and force-pumps, similar to those which were recently exhibited in the Loan Collection of Scientific Apparatus for making ice, driven by an engine of 15-horse power. Two of these are employed in procuring a reduction of temperature in a tube about four feet long containing sulphurous acid. This is done in the following way: the vacuum pump withdraws the vapour from above the surface of the liquid sulphurous acid in the tube, which, like all the others subsequently to be mentioned, is slightly inclined so as to give the maximum of evaporating surface. The force-pump then compresses this vapour, and sends it into a separate reservoir, where it is again cooled and liquefied; the freshly-formed liquid is allowed to return under control to the tube first referred to, so that a complete circulation is maintained. With the pumps at full work there is a nearly perfect vacuum over the liquid and the temperature falls to − 65° or − 70° C.

M. Pictet uses this sulphurous acid as a cold-water jacket, as we shall see. It is used to cool the carbonic acid after compression, as water is used to cool the sulphurous acid after compression.

This is managed as follows:—In the tube thus filled with liquid sulphurous acid at a temperature of − 60° C. there is another central one of the same length but naturally of smaller diameter. This central tube M. Pictet fills with liquid carbonic acid at a pressure of four or six atmospheres. This is then let into another tube four metres long and four centimetres in diameter. When thus filled the liquid is next reduced to the solid form and a temperature of − 140° C., the extraction of heat being effected as before by the pump, which extracts three litres of gas per stroke and makes 100 strokes a minute.

Now it is the turn of the oxygen.

Just as the tube containing carbonic acid was placed in the tube containing sulphurous acid, so is a tube containing oxygen inserted in the long tube containing the now solidified carbonic acid. This tube is five metres long, fourteen millimetres in exterior diameter, and only four in interior diameter—the glass is very thick. The whole surface of this tube, except the ends which project beyond the ends of the carbonic acid tube, is surrounded by the frozen carbonic acid.

One end of this tube is connected with a strong shell containing chlorate of potash, the other end is furnished with a stop-cock.

When the tube was as cold as its surroundings, heat was applied to the chlorate, and a pressure of 500 atmospheres was registered; this descended to 320. The stop-cock was then opened, and a liquid shot out with such violence that none could be secured, though we shall hear of this soon.

Pieces of lighted wood held in this stream spontaneously inflamed with tremendous violence.

In this way, then, has oxygen been liquefied at last. But this result has no sooner filled us with surprise than it has been completely eclipsed. On the last day of December, a week after the meeting of the Academy to which we have referred, M. Cailletet performed a series of experiments in the laboratory of the École Normale at Paris, in the presence of Berthelot, Boussingault, St. Claire Deville, Mascart, and other leading French chemists and physicists, using the same method as that formerly employed for oxygen and he then and there liquefied hydrogen, nitrogen, and air!

M. Cailletet first introduced pure nitrogen gas into the apparatus. Under a pressure of 200 atmospheres the tube was opened, and a number of drops of liquid nitrogen were formed. Hydrogen was next experimented with, and this, the lightest and most difficult of all gases, was reduced to the form of a mist at 280 atmospheres. The degree of cold attained by the sudden release of these compressed gases is scarcely conceivable. The physicists present at the experiment estimated it at − 300° C.

Although oxygen and nitrogen had both been liquefied, it was deemed of interest to carry out the process with air, and the apparatus was filled with the latter, carefully dried and freed from carbonic acid. The experiment yielded the same result. On opening the tube a stream of *liquid air* issued from it resembling the fine jets forced from our modern perfume bottles.

These more recent results are all the more surprising as, at an earlier stage, hydrogen, at a pressure of 300 atmospheres, has shown no signs of giving way.

These brilliant and important results, though, as we have said, they give us no new idea on the constitution of matter, open out a magnificent vista for future experiment. First, we shall doubtless be able to study solid oxygen, hydrogen, and air, and if MM. Pictet and Cailletet succeed in this there will then be the history to write of the changes of molecular state, probably accompanied by changes of colour, through which these elemental substances pass in their new transformations.

There is a distinct lesson to be learnt from the sources whence these startling *tours de force* have originated. The means at the command of both MM. Cailletet and Pictet arise from the industrial requirements of these gentlemen, one for making iron, the other for making ice.

Why then in England, the land of practical science, have we not more men like MM. Cailletet and Pictet to utilise for purposes of research the vast means at their disposal, or at all events to allow others to use them?

It is also clear that to cope with modern requirements our laboratories must no longer contain merely an antiquated air-pump, a Leyden jar, and a few bottles, as many of them do. The professor should be in charge of a work- instead of an old curiosity-shop, and the scale of his operations must be large if he is to march with the times—times which, with the liquefaction of the most refractory gases, mark an epoch in the history of science.

HUXLEY'S PHYSIOGRAPHY

Physiography: an Introduction to the Study of Nature. By T. H. Huxley, F.R.S. (London: Macmillan and Co., 1877.)

AMONG educational works which are calculated to afford real assistance to the teacher in his all-important labours, we may recognise two distinct classes. One