12,000 cubic feet capacity. Here the gas is absorbed into the lime (which is obtained from Buxton and prepared on the works), and the bleaching powder of commerce is formed. From the stone tank in the caustic house the solution is run into the caustic pots, of which there are nine, each of 12 tons capacity. In these the liquor is evaporated down to the required density, after which it is filled into drums for the market.

The current, which is the prime agent in the manufacture, is generated by two of Parsons' parallel flow steam turbo-dynamos at 120 volts, each generator being capable of giving off 110 units. On the switchboard are two Weston ammeters for 4,000 amperes each and a Weston voltmeter, besides which there are 10 other ammeters for the circuits. Two horizontal brass bars run the whole length of the board at the back and 10 vertical bars in front, connection being made with massive copper plugs which put the tanks and instruments in circuit. Five cables leave each side of the board to go to each side of the tank house. All cables used are of bare copper, including those which connect the switchboard with the dynamos, which are buried and covered with pitch. The alternate compartments of the decomposing tanks are closed with a lid from which the carbon anode is suspended; the tanks are placed in series with each other, the cells being in parallel. There are five circuits on each side of the tank house, each circuit making a set. Each tank requires about four or five volts to send 700 amperes through it. The connection of the main cable is effected in a very ingenious manner, which, in common with the other details of the process, forms the subject of a patent. The cable is of stranded copper, and at each terminal one strand is taken off to join on to it, and so on to the second, where another strand is jointed on, the cable thus getting smaller and smaller until the last strand is taken off to the last terminal, a considerable saving in copper thus being effected.

The present output of the works is about 100 tons of 35 per cent. bleaching powder and 60 tons of 70 per cent. white caustic soda per week from 60 tons of common salt.—The Electrical Engineer.

NEW EXPERIMENTS ON THE CATHODE RAYS.*

(1) Two hypotheses have been propounded to explain the properties of the cathode rays.

Some physicists think, with Goldstein, Hertz, and Lenard, that this phenomenon is like light, due to vibrations of the ether,† or even that it is light of short wave length. It is easily understood that such rays may have a rectilinear path, excite phosphorescence, and affect photographic plates.

Others think, with Crookes and J. J. Thomson, that these rays are formed by matter which is negatively charged and moving with great velocity, and on this hypothesis their mechanical properties, as well as the manner in which they become curved in a magnetic field, are readily explicable.

This latter hypothesis has suggested to me some experiments which I will now briefly describe, without for the moment pausing to inquire whether the hypothesis suffices to explain all the facts at present known, and whether it is the only hypothesis that can do so. Its adherents suppose that the cathode rays are negatively charged; so far as I know, this electrification has not been established, and I first attempted to determine whether it exists or not.

(2) For that purpose I had recourse to the laws of induction, by means of which it is possible to detect the introduction of electric charges into the interior of a closed electric conductor, and to measure them. I therefore caused the cathode rays to pass into a Faraday's cylinder. For this purpose I employed the vacuum tube represented in Fig. 1. A B C D is a tube

FIG. 1.

with an opening, α , in the center of the face, B C. It is this tube which plays the part of a Faraday's cylinder. A metal thread soldered at S to the wall of the tube connects this cylinder with an electroscope.

E F G H is a second cylinder in permanent communication with the earth, and pierced by two small openings at β and γ ; it protects the Faraday's cylinder from all external influence. Finally, at a distance of about 0.10 m. in front of F G, was placed an electrode, N. The electrode, N, served as cathode; the anode was formed by the protecting cylinder, E F G H; thus a pencil of cathode rays passed into the Faraday's cylinder. This cylinder invariably became charged with negative electricity.

The vacuum tube could be placed between the poles of an electromagnet. When this was excited, the cathode rays, becoming deflected, no longer passed into the Faraday's cylinder, and this cylinder was then not charged; it, however, became charged immediately the electromagnet ceased to be excited.

In short, the Faraday's cylinder became negatively charged when the cathode rays entered it, and only when they entered it; the cathode rays are then charged with negative electricity.

The quantity of electricity which these rays carry can be measured. I have not finished this investigation, but I shall give an idea of the order of magnitude of the charges obtained when I say that for one of my tubes, at a pressure of 20 microns of mercury, and for a single interruption of the primary of the coil, the Faraday's cylinder received a charge of

electricity sufficient to raise a capacity of 600 C. G. S. units to 300 volts.

(3) The cathode rays being negatively charged, the principle of the conservation of electricity drives us to seek somewhere the corresponding positive charges. I believe that I have found them in the very region where the cathode rays are formed, and that I have established the fact that they travel in the opposite direction, and fall upon the cathode. In order to verify this hypothesis, it is sufficient to use a hollow cathode pierced with a small opening by which a portion of the attracted positive electricity might enter. This electricity could then act upon a Faraday's cylinder inside the cathode.

The protecting cylinder, E F G H, with its opening, β , fulfilled these conditions, and this time I therefore employed it as the cathode, the electrode, N, being the anode. The Faraday's cylinder is then invariably charged with positive electricity. The positive charges were of the order of magnitude of the negative charges previously obtained.

Thus, at the same time as negative electricity is radiated from the cathode, positive electricity travels toward that cathode.

I endeavored to determine whether this positive flux formed a second system of rays absolutely symmetrical to the first.

(4) For that purpose I constructed a tube (Fig. 2) similar to the preceding, except that between the

FIG. 2.

Faraday's cylinder and the opening, β , was placed a metal diaphragm pierced with an opening, β' , so that the positive electricity which entered by β could only affect the Faraday's cylinder if it also traversed the diaphragm, β' . Then I repeated the preceding experiments.

When N was the cathode, the rays emitted from the cathode passed through the two openings, α and β , without difficulty, and caused a strong divergence of the leaves of the electroscope. But when the protecting cylinder was the cathode, the positive flux, which, according to the preceding experiment, entered at β , did not succeed in separating the gold leaves except at very low pressures. When an electrometer was substituted for the electroscope, it was found that the action of the positive flux was real but very feeble, and increased as the pressure decreased. In a series of experiments at a pressure of 20 microns, it raised a capacity of 2000 C. G. S. units to 10 volts; and at a pressure of 3 microns, during the same time, it raised the potential to 60 volts.*

By means of a magnet this action could be entirely suppressed.

(5) These results as a whole do not appear capable of being easily reconciled with the theory which regards the cathode rays as an ultra-violet light. On the other hand, they agree well with the theory which regards them as a material radiation, and which, as it appears to me, might be thus enunciated.

In the neighborhood of the cathode, the electric field is sufficiently intense to break into pieces (into ions) certain of the molecules of the residual gas. The negative ions move toward the region where the potential is increasing, acquire a considerable speed, and form the cathode rays; their electric charge, and consequently their mass (at the rate of one valence-gramme for 100,000 coulombs), is easily measurable.

The positive ions move in the opposite direction; they form a diffused brush, sensitive to the magnet, and not a radiation in the correct sense of the word.†

THE LIQUEFACTION OF AIR AND RESEARCH AT LOW TEMPERATURES.‡

By JAMES DEWAR, LL.D., F.R.S.

THE author reviewed all the forms of apparatus that had been used in low temperature research, pointing out that the best and most economical plant for the production of liquid air or oxygen was one based on the general plan of the apparatus used by Pictet in his celebrated experiments on the liquefaction of oxygen in the year 1878. Instead of using Pictet's combined circuits of liquid sulphur dioxide and carbon dioxide maintained in continuous circulation by means of compression, liquefaction, and subsequent exhaustion, it has been found preferable to select ethylene after Cailletet and Wroblewski, for one circuit, and to join with it either nitrous oxide, or better, carbon dioxide. Further, instead of making the oxygen to be liquefied by heating potassium chlorate in an iron bomb directly connected with the refrigerator, and thereby reaching high gas pressures, it has been found more convenient to use gas previously compressed in steel cylinders. The stop cock that Pictet employed to draw off liquid and produce sudden expansion was in his apparatus placed outside the refrigerator proper, but it is now placed inside, so as to be kept cool by the

gases undergoing expansion. This improvement was introduced along with that of isolating the liquid gases by surrounding them with their own vapor in the apparatus made wholly of copper, described and figured in the Proc. Roy. Inst. for 1886. In all continuously working circuits of liquid gases used in refrigerating apparatus the regenerative principle applied to cold first introduced by Siemens, in 1857, and subsequently employed in the freezing machines of Kirk, Coleman, Solvay, Linde, and others has been adopted. Quite independently, Prof. Kamerlingh Onnes, of Leyden, has used the regenerative principle in the construction of the cooling circuits in his cryogenic laboratory (see paper by Dr. H. Kamerlingh Onnes, on the "Cryogenic Laboratory at Leyden, and on the Production of Very Low Temperatures," Amsterdam Akademie, 1894). Apart, therefore, from important mechanical details, and the conduct of the general working, nothing new has been added by any investigator to the principles involved in the construction and use of low temperature apparatus since the year 1878. The Phil. Mag. of February, 1895, contains a fantastic claim put forward by Prof. Olszewski, of Cracow, that because he used in 1890 a steel tube combined with a stopcock to draw off liquid oxygen, he had taught the world, to use his own language, "the method of getting large quantities of liquid gases." But when, in addition, Olszewski alleges, four years after the event, that the experiments made at the Royal Institution since 1891 are chiefly borrowed from Cracow, and that he is entitled to the credit of all low temperature research subsequent to 1891, because of his steel tube and stopcock invention, one can only wonder at the meager additions to knowledge that in our time are unhesitatingly brought forward as original, and more especially that scientific men could be got to give them any currency in this country. Such persons

A, air or oxygen inlet; B, carbon dioxide inlet; C, carbon dioxide valve; D, regenerator coils; E, air or oxygen expansion valve; F, vacuum vessel with liquid oxygen; G, carbon dioxide and air outlet; H, air coil; I, carbon dioxide coil.

FIG. 1.—APPARATUS FOR LIQUEFYING OXYGEN AND OTHER GASES.

should read the late Prof. Wroblewski's pamphlet entitled "Comment l'air a été liquéfié" (Paris, Librairie de Luxembourg, 1885), and make themselves generally acquainted with his work before coming to hasty conclusions on claims of priority brought forward by the professor of chemistry at Cracow.

Liquefying Apparatus.—The author proceeded to describe the construction and show the working of a laboratory apparatus for the production of liquid oxygen and other gases, represented in section (Fig. 1). With this simple arrangement 100 c. c. of liquid oxygen can readily be obtained, the cooling agent being carbon dioxide, at the temperature of -79° , no exhaustion being used. The gaseous oxygen, cooled before expansion by passing through a spiral of copper tube immersed in solid carbon dioxide, passes through a fine screw stopcock under a pressure of 100 atmos., and thence backward over the coils of pipe. The liquid oxygen begins to drop in about a quarter of an hour from starting. The general arrangement of the circuits will be easily understood from the sectional drawing. The pressure in the oxygen cylinders at starting is generally about 150 atmos., and the best results are got by working down to about 100. This little apparatus will enable liquid oxygen to be used for demonstration and research in all laboratories.

Vacuum Vessels.—It has been shown in previous

* Translation of a paper by M. Jean Perrin, read before the Paris Academy of Sciences on December 30, 1895.—From Nature.

† These vibrations might be something different from light; recently M. Jaumann, whose hypotheses have since been criticised by M. H. Poincaré, supposed them to be longitudinal.

* The breaking of the tube has temporarily prevented me from studying the phenomenon at lower pressures.

† This work has been carried out in the laboratory of the Normal School, and in that of M. Pellat at the Sorbonne.

‡ Abstract reprinted from the Proceedings of the Chemical Society, 1896.

papers * that a good exhaustion reduces the influx of heat to one-fifth part of what is conveyed when the annular space in such double walled vacuum vessels is filled with air. If the interior walls are silvered, or excess of mercury is left in the vessel, the influx of heat is diminished to one-sixth part of the amount entering without the metallic coating. The total effect of the high vacuum and silvering is to reduce the ingoing heat to $\frac{1}{30}$ part, or, roughly, $3\frac{1}{2}$ per cent. Vessels constructed with three dry air spaces only reduced the influx of heat to 35 per cent. An ordinary mercury vacuum vessel is therefore 10 times more economical for storing liquid air, apart from considerations of manipulation, than a triple annular spaced air vessel. It has been suggested that the metallic coating of mercury does no good, because Pictet has found that all kinds of matter at low temperatures become transparent to heat. The results above mentioned dispose of this assumption, and direct experiment proves that no increase in the transparency of glass to thermal radiation takes place by cooling to the boiling point of air.

Solid Air.—As Prof. Olszewski has recently alleged that air does not solidify at the lowest pressures (Phil. Mag., February, 1895), the author's former experiments were repeated on a larger scale. If a liter of liquid air is placed in a globular silvered vacuum vessel and subjected to exhaustion, as much as half a liter of solid air can be obtained and maintained in this condition for half an hour. At first the solid is a stiff, transparent jelly, which, when examined in the magnetic field, has the liquid oxygen drawn out of it to the poles. This proves that solid air is a nitrogen jelly containing liquid oxygen. Solid air can only be examined in a vacuum or in an atmosphere of hydrogen, because it instantly melts on exposure to the air, giving rise to the liquefaction of an additional quantity of air. It is strange to see a mass of solid air melting in contact with the atmosphere, and all the time welling up like a kind of fountain.

Samples of Air Liquefied in Sealed Flasks.—In a previous paper "On the Relative Behavior of Chemically Prepared and of Atmospheric Nitrogen," Proc., December, 1894, the plan of manipulating such samples was described. Two flasks of dry air that had stood over phosphoric anhydride were liquefied side by side, the only difference between the samples being that one was free from carbonic acid. The one gave a liquid that was perfectly clear, the other was turbid from the 0.04 per cent. of carbon dioxide. The temperature was now lowered by further exhaustion of the liquid air surrounding the tubes until both liquids became solid. The flasks were then sealed off for the purpose of examining the composition of the air that had not been condensed. The one sample contained oxygen, 21.19 per cent., and the other 20.7 per cent. This is an additional proof to the one previously given, that, substantially, the oxygen and nitrogen in air liquefy simultaneously, even under gradually diminishing pressure, and that in these experiments all the known constituents of air are condensed together. These results finally disproved the view expressed in "A System of Inorganic Chemistry" (1891, p. 70), by Prof. Ramsay, who he says: "Air has been liquefied by cooling to -192° , but as oxygen and nitrogen have not the same boiling points, the less volatile oxygen doubtless liquefies first." In the author's former experiments, the substance now known as argon became solid before nitrogen, but chemical nitrogen and air nitrogen, with its 0.1 per cent. of argon, behaved in substantially the same way on liquefaction.

Liquid Nitric Oxide.—Great interest attaches to the behavior of nitric oxide at low temperatures. Prof. Olszewski has examined the liquid and describes it as colorless. Dr. Scott has prepared in different ways samples of nitric oxide. These have been transferred to liquefaction flasks, where they were left in contact with potash, sulphuric or phosphoric acid, for many days before use. Each of the samples, when cooled, gave a nearly white solid, melting into a blue liquid. The color is more marked at the melting point than at the boiling point. Liquid nitric oxide is not magnetic; neither is the solid phosphorescent. Color in the oxides of nitrogen evidently begins with the second oxide. Solid nitric oxide does not show any chemical action in liquid oxygen, provided the tube containing it is completely immersed; but if the tube full of liquid oxygen is lifted into the air, almost instantly a violent explosion takes place.

Specific Gravities Taken in Liquid Oxygen.—In a good vacuum vessel specific gravities may be taken in liquid oxygen with as great ease as in water.

Some twenty substances were weighed in liquid oxygen, and the apparent relative density of the oxygen determined. The results were then corrected, using Fizeau's values for the variation of the coefficient of expansion of the solids employed, and thereby the real density of liquid oxygen calculated. The resulting value was 1.1375, bar. 766.5, in the case of such different substances as cadmium, silver, lead, copper, silver iodide, calc spar, rock crystal. Direct determinations with an exhausted glass cylindrical vessel displacing about 22 c. c. gave 1.1378. Fizeau's parabolic law for the variation of the coefficient of expansion holds down to -183° . The solid which showed the greatest contraction was a block of compressed iodine, the one that contracted least being a compressed cylinder of silver iodide. Wroblewski gave the density of liquid oxygen at the boiling point as 1.168, whereas Olszewski found 1.124. The variation of density is about ± 0.0012 , for 20 mm. barometric pressure. Much work requires to be done in the accurate determination of the physical constants of liquid gases.

Liquid Air.—A large silver ball weighed in liquid air gave the density of the latter as 0.910, and the corresponding density of nitrogen at its boiling point 0.850. It is difficult to be quite certain that the constituents of liquid air are in the same proportion as the gaseous ones, so that further experiments must be made. Liquid air kept in a silvered vacuum vessel gradually rises in boiling point from the instant of its

collection, the rate of increase during the first hour being nearly directly proportional to the time. As the increase amounted to one degree in ten minutes, the boiling point of oxygen ought to have been reached within two hours. The density of liquid air, however, does not reach that of pure oxygen even after thirty hours' storage. The large apparatus can be arranged to deliver liquid air containing 49 per cent. of oxygen, which gives off gas containing 20 per cent. of oxygen, rising after six hours to 72.6 per cent.

Combustion in Liquid Oxygen.—A small ignited jet of hydrogen burns continuously below the surface of liquid oxygen, all the water produced being carried away as snow. There is a considerable amount of ozone formed, which concentrates as the liquid oxygen evaporates. In the same way graphite or diamond, when properly ignited, burns continuously on the surface of liquid oxygen, producing solid carbonic acid and generating ozone. If liquid oxygen is absorbed in wood charcoal or cotton wool, and a part of the body heated to redness, combustion can start with explosive violence.

Gas Jets Containing Liquid.—The experiments of Joule and Thomson and Regnault on the temperature of gas jets issuing under low pressures are well known. The following observations refer to the pressure required to produce a lowering of temperature sufficient to yield liquid in the gas jet.

The apparatus used in the study of highly compressed gas jets is represented in Fig. 2; where C is a

FIG. 2.

FIG. 3.

FIG. 4.

vacuum tube which holds a coil of pipe about 5 mm. in diameter, along with carbon dioxide or liquid air for cooling the gas before expansion, and A is a small hole in the silver or copper tube about $\frac{1}{8}$ mm. in diameter, which takes the place of a stopcock. When carbon dioxide gas at a pressure of 30 or 40 atmospheres is expanded through such an aperture, liquid can be seen where the jet impinges on the wall of the vacuum tube along with a considerable amount of solid. If oxygen gas escapes from the small hole at the pressure of 100 atmospheres, having been cooled previously to -79° in the vessel, C, a liquid jet is just visible. It is interesting to note in passing that Pictet could get no liquid oxygen jet below 270 atmospheres. This was due to his stopcock being massive and outside the refrigerator. If the oxygen is replaced by air, no liquid jet can be seen unless the pressure is raised to 180 atmospheres. If the carbon dioxide is cooled by exhaustion (to about 1 mm. pressure) or -115° , then liquid air can easily be collected in the small vacuum vessel, D, or if the air pressure is raised above 200 atmospheres, keeping the cooling at -79° as before. The chief difficulty is in collecting the liquid owing to the rapid current of gas. The amount of liquid in the gas jet is small and its collection is greatly facilitated by directing the spray on a part of the metallic tube above the little hole or by increasing resistance to the escaping gas by placing some few turns of the tube, like B in the figure, in the upper portion of the vacuum tube, or generally by pushing in more tube in any form. A vacuum vessel shaped like an egg glass also works well. This practically economizes the cool gas which is escaping to reduce the temperature of the gas before expansion, or, in other words, it is the cold regenerative principle. Coleman pointed out long ago that his air machine could be adapted to deliver air at as low a temperature as has yet been produced in physical research. Both Solvay and Linde have taken patents for the production of liquid air by the application of cold regeneration, but the latter has the credit of having succeeded in constructing an industrial apparatus (the plans of which are not yet published) that is lowered in temperature to -140° , or to the critical point of air in about 15 hours, and from which liquid air containing 70 per cent. oxygen is collected after that time.

For better isolation the pipe can be rolled between two vacuum tubes, the outer one being about 9 in. long and $1\frac{1}{2}$ in. diameter, as shown in Fig. 3. The aperture in the metal pipe has a little piece of glass tube over it which helps the collection of the liquid. With such a simple apparatus and an air supply at 200 atmospheres with no previous cooling, liquid air begins to collect in about five minutes, but the liquid jet can be seen in between two and three minutes. It is not advisable to work below 100 atmospheres.

In Fig. 4 the metallic tube in the vacuum vessel is placed in horizontal rings, leaving a central tube to allow the glass tube C to pass, which is used to cool bodies or examine gases under compression. The inner tube can be filled for an inch with liquid air under a pressure of 60 atmospheres in about three minutes. Generally, in the experiments, about $\frac{1}{2}$ to 4 cubic feet of air passes through the different sized needle holes per minute when the pressure is about 200 atmospheres. As the small hole is apt to get stopped, for general working it is better to use a needle stopcock worked from the outside by a screw passing through the middle of the coil of pipe. A double coil of pipe has advantages in the conduct of some experiments. The efficiency is small, not exceeding the liquefaction of 2 to 5 per cent. of the air passing, but it is a quick method of reaching low temperatures and easy to use for cooling tubes and collecting a few hundred c. c. of liquid air, especially if the compressed air is

delivered at the temperature of -79° before expansion. With larger vacuum vessels and larger regenerative coils no doubt the yield of liquid could be increased. The liquid air resulting from the use of this form of apparatus contains about 50 per cent. of oxygen. If the air is cooled with solid carbonic acid previous to its reaching the vacuum tube coil of pipe, the only change is to reduce the percentage of oxygen to 40. Successive samples of liquid taken during the working had nearly the same composition. If the arrangement shown in Fig. 2 is used with silver tube about $\frac{1}{8}$ in. bore and a foot or two coiled in upper part of the vacuum vessel, liquid air containing 25 per cent. of oxygen was obtained. On the other hand, the percentage of oxygen can be increased by a slight change in the mode of working.

In the above experiments air is taken at the ordinary temperature, which is a little above twice its critical temperature, and is partially transformed in a period of time which, in my experiments, has never exceeded 10 minutes, simply and expeditiously into the liquid state at its boiling point, -194° , or a fall of more than 200° has been effected in this short period of time.

Experiments on Hydrogen.—Wroblewski made the first conclusive experiments on the liquefaction of hydrogen in January, 1884. He found that the gas cooled in a tube to the boiling point of oxygen, and expanded quickly from 100 to 1 atmos., showed the same appearance of sudden ebullition as Cailliet had seen in his early oxygen experiments. No sooner had the announcement been made than Olszewski confirmed the result by expanding hydrogen from 190 atmos., previously cooled with oxygen and nitrogen in a vacuum. Olszewski declared in 1884 that he saw colorless drops, and by partial expansion to 40 atmos. the liquid hydrogen was seen by him running down the tube.

Wroblewski could not confirm these results, his hydrogen being always what he called a "liquide dynamique." He proposed to get "static" liquid hydrogen by the use of hydrogen gas as a cooling agent. From this time until his death, in the year 1888, Wroblewski devoted his time to a laborious research on the isothermals of hydrogen at low temperatures. The data thus arrived at enabled him, by the use of Van der Waal's formula, to define the critical constants of hydrogen, its boiling point, density, etc., and the subsequent experiments of Olszewski have confirmed the accuracy of the results. In a paper published in the Phil. Mag., September, 1884, "On the Liquefaction of Oxygen and the Critical Volumes of Fluids," the suggestion was made that the critical pressure of hydrogen was wrong, and that instead of being 99 atmos. (as deduced by Sarrau from Amagat's isothermals), the gas had probably an abnormally low value for this constant. This view was substantially confirmed by Wroblewski finding a critical pressure of 13.3 atmos., or about one-fourth that of oxygen. The Chemical News (September 7, 1894) contains an account of the stage the author's hydrogen experiments had reached at that date. The object was to collect liquid hydrogen at its boiling point, in an open vacuum vessel, which is a much more difficult problem than seeing the liquid in a glass tube under pressure and at a higher temperature. In order to raise the critical point of hydrogen to about -200° , from 2 to 5 per cent. of nitrogen or air was mixed with it. This is simply making an artificial gas containing a large proportion of hydrogen, which is capable of liquefaction by the use of liquid air. The results are summed up in the following extract from the paper:

"One thing can, however, be proved by the use of the gaseous mixture of hydrogen and nitrogen, viz., that by subjecting it to a high compression at a temperature of -200° and expanding the resulting liquid into air, a much lower temperature than anything that has been recorded up to the present time can be reached. This is proved by the fact that such a mixed gas gives, under the conditions, a paste or jelly of solid nitrogen, evidently giving off hydrogen, because the gas coming off burns fiercely. Even when hydrogen containing only some 2 to 5 per cent. of air is similarly treated, the result is a white, solid matter (solid air) along with a clear liquid of low density, which is so exceedingly volatile that no known device for collecting has been successful."

In Prof. Olszewski's paper "On the Liquefaction of Gas" (Phil. Mag., 1895), after detailing the results of his hydrogen experiments, he says, "The reason for which it has not hitherto been possible to liquefy hydrogen in a static state is that there exists no gas having a density between that of hydrogen and nitrogen, and which might be, for instance, 7-10 (H = 1). Such a gas would be liquefied by means of liquid oxygen or air as cooling agent, and afterward used as a recognized menstuum in the liquefaction of hydrogen."

Science will probably have to wait a very long time before this suggestion of how to get "static" liquid hydrogen is realized. The proposal Wroblewski made in 1884 of using the expansion of hydrogen as a cooling agent to effect the change of state is far more direct and practicable.

Liquid Hydrogen Jet and Solid Oxygen.—Hydrogen, cooled to -194° (80° abs. t.), the boiling point of air, is still at a temperature which is two and a half times its critical temperature, and its direct liquefaction at this point would be comparable to that of air taken at 60° and liquefied by the apparatus just described. Now, air supplied at such a high temperature greatly increases the difficulty and the time required for liquefaction. Still, it can be done, even with the air supply at 100° , in the course of seven minutes, and this is the best proof that hydrogen, if placed under really analogous conditions, at -194° must also liquefy with the same form of apparatus. Hydrogen, cooled to -200° , was forced through a fine nozzle under 140 atmos. pressure, and yet no liquid jet could be seen. If the hydrogen contained a few per cent. of oxygen, the gas jet was visible, and the liquid collected, which was chiefly oxygen, contained hydrogen in solution, the gas given off for some time being explosive.

If, however, hydrogen, previously cooled by a bath of boiling air, is allowed to expand at 200 atmospheres over a regenerative coil similar to that shown in Fig. 2, but longer, a liquid jet can be seen after the circulation has continued for a few minutes along with a liquid which is in rapid rotation in the lower part of the vacuum vessel. The liquid did not accumulate,

* "On Liquid Atmospheric Air," Proc. Roy. Inst., 1893; "Scientific Uses of Liquid Air," ibid., 1894.

† As this is passing through the press, I observe that M. Cailliet, at the last meeting of the French Academy (Comptes Rendus) presented a paper by M. Solvay, of Brussels, in which my device of vacuum vessels is attributed to M. Cailliet, and tacitly accepted by him! In 1873 I had already used a highly exhausted vessel, of similar shape to the vacuum test tube, in calorimetric experiments. See paper on "The Physical Constants of Hydrogenium," Trans. Roy. Soc. Ed., vol. 27.

owing to its low specific gravity and the rapid current of gas. These difficulties will doubtless be overcome by the use of a differently shaped vacuum vessel and by better isolation. The liquid jet can, however, be used as a cooling agent like the spray of liquid air obtained under similar circumstances, and, this being practicable, the only difficulty is one of expense. In order to test, in the first instance, what the hydrogen jet could do in the production of lower temperatures, liquid air and oxygen were placed in the lower part of the vacuum tube just covering the jet. The result was that in a few minutes about 50 c. c. of the respective liquids were transformed into hard white solids resembling avalanche snow, quite different in appearance from the jelly-like mass of solid air got by the use of the air pump. The solid oxygen had a pale, bluish color, showing by reflection all the absorption bands of the liquid. The temperatures reached and other matters will be dealt with in a separate communication. There is no reason why a spray of liquid hydrogen, at its boiling point in an open vacuum vessel, should not be used as a cooling agent in order to study the properties of matter at some 20° or 30° above the absolute zero. The sole difficulty is the cost.

Fluorine.—This is the only widely distributed element that has not been liquefied. Some years ago Wallach and Hensler pointed out that an examination of the boiling points of substituted halogen organic compounds led to the conclusion that, although the atomic weight of fluorine is 19 times that of hydrogen, yet it must in the free state approach hydrogen in volatility. This view is confirmed by the specific refractive index, which Gladstone showed was rather lower than hydrogen. If the chemical energy of fluorine at low temperatures is abolished like that of other active substances, then some kind of glass or other transparent material not so brittle as calcium fluoride could be employed in the form of a tube, and its liquefaction achieved by the use of hydrogen as a cooling agent.

During the conduct of these investigations, able assistance has been rendered by Mr. Robert Lennox, whose name has been so often mentioned in the Royal Institution lectures. Valuable help has also been given by Mr. J. W. Heath, assistant at the Royal Institution.

DISCUSSION.

Prof. Ramsay remarked that Prof. Olszewski had succeeded in liquefying hydrogen, and from unpublished information received from Cracow, he was able to state that a fair amount of liquid had been obtained, not as a froth, but in a state of quiet ebullition, by surrounding a tube containing compressed hydrogen by another tube also containing compressed hydrogen at the temperature of oxygen boiling at a very low pressure. On allowing the hydrogen in the middle jacket suddenly to expand, the hydrogen in the innermost tube liquefied, and was seen to have a meniscus. Its critical point and its boiling point, under atmospheric pressure, were determined by means of a resistance thermometer. There would appear to be no difficulty in distinguishing the meniscus of hydrogen, where the liquid is 50 times as heavy as the gas, for it is perfectly easy to see a meniscus with such a liquid as ether, at temperatures so near the critical point that the liquid has only three or four times the density of the gas.

Mr. Blount said that the first account of the Linde process for liquefying air had been published in the early autumn of 1895, in the form of a paper read by Herr Schrotter, before the Association of German Engineers, at Aachen. Briefly, it consisted in taking advantage of the fact that air, not being a perfect gas, is permanently cooled when allowed to expand through a narrow opening without doing external work. The lowering of temperature was expressed by Joule and

Thomson's formula, $t = \frac{p_2 - p_1}{4} \left(\frac{289}{T_1} \right)^2$, where t is the

fall in temperature in degrees Centigrade, p_2 is the pressure of the air before it passes the opening, p_1 is the pressure of the air after passing the opening, and T_1 is the absolute temperature of the air before passing the opening. The effect was made cumulative by causing the air thus cooled to cool that which was about to pass through the opening. This was effected by the use of two long concentric tubes, the inner conveying the air to be cooled, and the annular space between the two being traversed by the cooling air. Circulation was maintained by means of an ordinary air compressor, and the temperature fell until the critical temperature was reached. A subsidiary compressor supplied fresh air to the cycle to replace that liquefied. The process was interesting, because it differed fundamentally from those usually employed for the liquefaction of difficultly condensable gases, in two respects, viz.: (1) it dispensed with the use of intermediate cooling agents, and (2) it applied a method for the cumulative withdrawal of heat analogous to the converse process of heat regeneration. Trials of the process had been made on a considerable scale, and there appeared to be no difficulty in liquefying air cheaply and in quantity.

Lord Playfair said, as a past president of the society, he was aware that it is not the practice to move a vote of thanks to the reader of a paper, so that he must not conclude with a motion to that effect. But he was sure that he was expressing the sentiments of all present when he said that they were grateful for the admirable exposition and splendid experiments which they had heard and seen. It is known to them all that an undesirable controversy had been going on as to how much originality there is in the researches of Prof. Dewar, whom he had the honor of claiming as an old student and assistant when he was professor in Edinburgh. He had wasted his time in reading these attacks, and they have had no influence on his mind, or rather that they had influenced him to send a subscription to the Royal Institution toward the cost of the apparatus. The diagram of Pictet's apparatus, now shown, certainly gives to the general chemist the most original conceptions as to how the problem of liquefying gases should be attacked. But if Pictet were now with them, and could see the great advances which had been made on his ideas, he would be the first to recognize their importance, and to congratulate Prof. Dewar. It is only

in mythology that Minerva, full grown, and panoplied in complete armor, is born from the brain of Jupiter after a prolonged gestation. In human brains one discovery suggests another, and we proceed to the goal of knowledge step by step. The world now feels that Watt's discoveries, in improving the steam engine, gave an enormous impulse to civilization. But the men of his day were petty enough to deny him merit, and they went to a court of justice to prove that every one of his discoveries had previously been made by other men, and more strange still, the court agreed with them and solemnly declared that Watt had done nothing to improve the steam engine. Every discovery can be connected with previous discoveries. Would the merit of Rayleigh and Ramsay be lessened as the discoverers of argon because Cavendish had it undoubtedly as the residue in his tube in his famous experiment on air? It is to be hoped that Prof. Dewar will go on with his magnificent experiments on the liquefaction of gases, and with the researches which come from them, without caring for the mosquitoes of science which buzz about his ears.

Dr. Armstrong said that, after what had fallen from Lord Playfair, he would venture to express the opinion that the attacks made on Prof. Dewar during the past few months were disgraceful. In these days we should encourage as far as possible all who were engaged in such dangerous and difficult work, not decry their labors. The history of the Royal Institution in the past, in so far as concerned the liquefaction of gases, was a glorious one, and he had no doubt that when the work done there more recently came to be considered without prejudice, it would be regarded as equally important. In fact there was evidence of this already. Prof. Onnes, of Leyden, who, with most limited appliances and means, had already accomplished so much in the field of research at low temperatures—an acknowledged expert in these matters—in a recent publication, in which justice was done to all workers, clearly recognized that much credit was due to Prof. Dewar for his various improvements. He did not consider it necessary to thank Prof. Dewar, but thought that his assistants should not be forgotten. Messrs. Lennox and Heath had done much service in connection with the work generally, and especially in making the present demonstration possible.

Prof. Dewar, in reply, stated that he could have no knowledge of unpublished work on the liquefaction of hydrogen. The mere fact of liquefaction was first

THE CHROMOSCOPE.

definitely given by Wroblewski, although Cailletet had made an earlier experiment of the same kind. His paper contained a quotation from Prof. Olszewski's communication made to the Philosophical Magazine in February, 1895, in which Olszewski distinctly says that he had not succeeded in getting liquid hydrogen in the "static" condition. Further, in a later paper, published in the same journal, for August, 1895, no mention is made of getting a "fair amount of liquid in a state of quiet ebullition" or of seeing a "meniscus." Even the method of working, to which reference has been made, is not mentioned, far less the result of the experiments made by the speaker in 1894. He was unable to understand why such a point should be made of seeing a meniscus, considering that the liquid can be seen. The remarks about the difficulty of separating liquid hydrogen from the gas had reference to a fine rain of fluid in a rapidly rushing stream of gas passing through vacuum vessels, and has no relation whatever to critical point phenomena to which reference had been made. If the liquid oxygen and air jets shown have any resemblance to the Linde apparatus described by Mr. Blount, chemists, for once, may be congratulated that a small laboratory apparatus works in some respects better than a large industrial plant. The Linde apparatus, after working fifteen hours, is capable of reducing the temperature of air to its critical point, whereas in the present small apparatus liquid air is produced in five minutes. Such a process cannot replace the use of "cooling agents" when considerable quantities of liquid air have to be produced in a short period of time, as in ordinary laboratory work. It is a mistake to attribute to Linde the idea of using the "cumulative withdrawal of heat," for the first time, in his apparatus, but he has succeeded in making a workable industrial machine, and that is a very important step. The late Prof. Wroblewski, as early as the year 1884, predicted that liquid air would be the refrigerating agent of the future; his prophecy seems about to be realized.

THE CHROMOSCOPE.

THIS is an improved apparatus by J. B. W. Betts, of Plymouth, Eng., for the production of bands of color by the rotation of certain forms of any size, material or shape. This apparatus is intended for the same purpose as the spectrum top noticed in our columns some time ago. It consists of a wheel connected with an upright, on which designs (of different shapes and marked in different ways with black lines) are fixed. By turning the wheel the design revolves. This action produces bands of color in place of the black lines, and when the motion is reversed the colors of the bands change.

A NEW and hitherto unsuspected cause of fire in factories is reported in the list of fires and losses in September last, issued by the Boston Manufacturers' Mutual Fire Insurance Company. The destruction of the mills of the Warren Manufacturing Company, at Warren, R. I., is said to have been caused by the ignition of the wooden lagging of the high-pressure steam cylinder of a compound steam engine, working under 120 pounds pressure. The circular of the insurance company advises each treasurer and mill owner to protect every engine room with automatic sprinklers without delay.

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