draft is used, and this means a saving of heat which would otherwise be uselessly dissipated. Mechanical or artificial draft thus presents to us a method of economically furnishing the air supply to furnaces and producing a more efficient combustion temperature, while it also renders possible further economies due to retarding the movement and escape of hot gases and to preliminary heating of the air supply by waste heat or otherwise."

PREPARATION AND COMPRESSION OF PURE GASES FOR EXPERIMENTAL WORK.*

By R. S. HUTTON and J. E. PETAVEL.

INTRODUCTION.—Having been engaged for some time past on experimental research dealing with the effect

which we have been able to obtain by direct experiment, references are given to several of the more important published accounts dealing with the manufacture on the full commercial scale. For some chemical purposes, the gases would be passed straight from the generator for use in the chemical process for which they were required; on the other hand, it is frequently necessary for convenience to store the gas for subsequent use; in fact, where the experiments are at all general in character, it is advisable to have a stock of different gases constantly available. This involves the erection of compressing and storing plant even where high pressure *per se* does not play a part in the work. Our account, therefore, includes a de-

latter method is of the two by far the more important for large-scale working, such as for inflating balloons. In this case some 10,000 cubic feet of gas may be required to fill a single balloon, an operation which has to be effected within a short space of time. The process has also been employed for many years at the Royal Institution for the manufacture of hydrogen in connection with the liquefaction experiments, and at a more recent date by Morris W. Travers at University College, London (Phil. Mag., 1901, [6], 1, 411). A plant on these lines has been recently constructed by Messrs. Lennox, Benton & Reynolds, Ltd., capable of delivering some 800 cubic feet of hydrogen per hour. The receiver is a copper cylinder about 6 feet high

FIG. 1.—HYDROGEN GENERATOR PLANT.

(Scale, 1/2 inch to foot.)

A, acid reservoir; B, cooling tank; C, generator proper; D and E, washing towers; b, valve regulating admission of acid; g, sight feed for ditto; K, outlet for gas; c and d, valves regulating water admission to washing towers; e and f, sight feeds for ditto; H, cast-iron tank acting as seal to the cylinders and into which spent acid flows; K, outlet for gas.

of high gaseous pressures upon electric furnace reactions, the necessity arose of preparing, compressing, and storing several gases which were either not available commercially, or which could not thus be obtained in the desired state of purity. Although a very great deal of information had been published relating to the production of the various gases in sufficient quantities for ordinary laboratory experiments, such methods cannot be easily applied when the required scale of working is considerably larger. On the other hand, the commercial manufacture in some cases has been most carefully worked out, but the plant required is too large and costly to be practical for temporary use. The object of the present paper is to describe how, with little more than such apparatus as should be available in any chemical laboratory, the preparation of a number of gases can be carried out at a trifling cost and with due consideration as to their purity. It will be noticed that the equipment is so devised as to be available for use in the different cases with but little modification. Those

FIG. 2.—EXPERIMENTAL HYDROGEN GENERATOR.

Constructed throughout of lead. Height, 2 feet 6 inches; diameter, 1 foot.

who look for any novelty in the principles of the methods adopted will, we fear, be disappointed; we venture, however, to think that to the increasing number of workers, who either for commercial or scientific purposes require, like ourselves, pure gases in considerable quantities, the information which we offer will be of some value. The apparatus has been devised for gas generation and purification at a rate of about 1 liter per second (130 cubic feet per hour). Hydrogen, nitrogen, carbon monoxide, and ethylene are dealt with in detail. Apart from the information

*From the Journal of the Society of Chemical Industry.

FIG. 3.—DIAGRAM OF NITROGEN PLANT.

a, Air-inlet tap from blower; A, gage indicating rate of flow of air; B, reservoir of ammonia liquor; C, graduated tube for measuring rate of flow of ammonia; b, tap for filling tube C with ammonia; c, tap for regulating admission of ammonia; E, iron gas-pipe filled with copper turnings; R, furnace; built up of loose firebricks, and heated with large Fletcher furnace

scription of a small plant which we have found satisfactory for these purposes.

Hydrogen: Commercial Manufacture and Applications.—Hydrogen is at present principally employed for inflating military balloons, autogenous welding, and lead-burning (Zeits. f. Elektrochem., 1895, 2, 204), and is manufactured in considerable quantities for these purposes. The older and purely chemical methods of generation based on the action of acids or steam on metals are being to a large extent displaced, where a continuous supply is required, by electrolytic processes, the working cost of the latter being considerably lower. Suitable electrolytic cells can now be installed at a reasonable expense. The plant for the chemical manufacture by the action of acids on metals is of two principal types. The first, a develop-

tuyere F; G, condenser with water-inlet cock d; H, condensed ammonia receiver with draw-off e; J, water washer, through which water or acid could be passed; inlet cocks at g or h, outlet at f; L, acid washer; M, quartz tower scrubber; N and P, two caustic soda towers with draw-off cocks at l and m; Q, manometer; n, exit to gasometer and compressor.

and 1 foot diameter, and contains a charge of 4 hundredweights of granulated zinc. As will be seen by the diagram, Fig. 1, the actual generator is mounted in the center between two washing towers, each 8 feet high. The three cylindrical towers, which are open at the bottom, are supported in a cast-iron tank, which forms a water seal and collects the spent acid. The towers are surmounted by two superimposed tanks, the lower one containing a lead coil immersed in water to act as cooling chamber, the upper one, lead-lined, acting as acid reservoir. A spray of water keeps the flints in the two washing towers moist. The rate of flow of the acid is observed through a sight feed. An apparatus of a similar type, the design of Ch. Renard, has been adopted by the French army for field use. The employment of zinc has, however, the serious disadvantage that the gas often contains suffi-

FIG. 3A.—NITROGEN PLANT.

scribed later. The second type is designed to give for a limited time a very large quantity of gas, and in principle consists in employing a tall cylindrical receiver filled with metal turnings or granulated metal, the outflow of gas being regulated by the amount of acid which is allowed to flow into the top of the cylinder, the spent acid being run off at the bottom. This

cient arsenic to be dangerous if dealt with in any quantity.* Moreover, the gas generated by the action

*Numerous attempts have been made to remove the arsenic from the gas, among which passage through a heated tube or a solution of a permanganate should be mentioned. Recently Ch. Renard has carried out some experiments on the use of liquid air for condensing the arseniuretted hydrogen in connection with the aeronautical department of the French

of acids on ordinary spelter or metallic iron is liable to be considerably more dense than pure hydrogen. (W. Dürer, Zeits. f. Elektrochem., 1901, 8, 3.) Of other chemical processes, the heating of zinc-dust and soda-lime briquettes is employed in the German army in a portable equipment for balloon inflation, while the reaction between heated iron and steam has recently been applied by the Industrial Engineering Company, who regenerate the iron with producer-gas,

FIG. 4.—DIAGRAM OF CARBON MONOXIDE PLANT.

E, bolt head containing boiling H_2SO_4 ; T, thermometer; B, reservoir for formic acid; d, cock for regulating supply from B; G, gage on main gas-pipe before washing apparatus; F, electric heating furnace; a, inlet cock from compressed air; C, tube acting as constant pressure valve, keeping a pressure equal to 2 or 3 feet of water on upper surface of liquids in flasks A and B; A, reservoir of caustic soda solution connected with washing tower K (Fig. 3); b, regulating cock for same.

and have thus brought this method into a convenient and practical form. The electrolytic manufacture of hydrogen is coming much to the front; in this case, whereas the first cost is relatively high, the working expenses, whenever the plant can be run continuously, are generally lower than for the chemical method. Numerous types of plant have been designed, the principal requirements being a low working voltage and the effectual separation of the hydrogen and oxygen; the latter, particularly where the gases have to be compressed, being of the utmost importance from the point of view of safety. The electrolytic methods will be found described in monographs by Victor Engelhardt and P. Schoop (V. Engelhardt, Die Elektrolyse des Wassers (Halle: W. Knapp, 1902); P. Schoop, Die Industrielle Elektrolyse des Wassers (Stuttgart: F. Enke, 1901)); suffice it to say that in principle they can be grouped under three types:

- (1) The Schmidt and Ch. Renard systems employ iron electrodes in alkaline solutions, the electrodes being separated by diaphragms of asbestos.
- (2) The Schoop system, in which each cylindrical electrode is surrounded by tubular diaphragms, has the advantage of absolute safety from any danger of admixture of the gases, but involves some loss of power through additional resistance. In this case lead electrodes are employed in an acid electrolyte.
- (3) The Garuti, Siemens Brothers, and Schuckert

FIG. 5.—CONE CONNECTIONS.

A, flexible copper tubing; B, cone; C, nut by which cone is pressed home; screwed "1/2-inch gas"; D, standard connection forming part of cylinders, valves, or compressor.

plants employ metallic diaphragms and generally work with alkaline electrolytes.

At the present time almost all the European military authorities have adopted one or other of these electrolytic plants for balloon purposes, but in Germany the government makes use largely of the waste hydrogen evolved in the electrolytic alkali industry, an example which will, no doubt, be widely followed in the future, when it is considered that, even at a moderate estimate, some 240,000 cubic feet of hydro-

gen are going to waste daily in this way (cf. Zeits. f. Elektrochem., 1895, 2, 290). At least three large installations (Buffa, Bull. de l'Assoc. des Ing. Electr. [Liège], 1900, 11, 305), those at Brussels, Lucerne, and Rome, exist on the Continent for putting on the market compressed hydrogen obtained by the Garuti process, a notable economy resulting from the fact that the oxygen, which is also compressed, finds a still more ready sale. A complete consideration of the question of cost would carry us too far, but full details will be found in the monographs referred to. Suffice it to say that, with spelter at £21 a ton, a cost of at least some 35s. is incurred in zinc alone per 1,000 cubic feet of hydrogen obtained, whereas by several of the electrolytic processes the same amount of hydrogen can be obtained for 157 kilowatt hours, which, even at 1d. per unit, a high estimate for power generation when used continuously, only amounts to 13s. 1d. It should be borne in mind that the oxygen produced simultaneously is also of considerable commercial value. Thus where an uninterrupted supply of gas is required throughout the entire year, the electrolytic methods offer considerable advantages. Owing, however, to the much smaller capital outlay, the older chemical process is preferable when the hydrogen is required occasionally only, but in large quantities. Several years ago Dewar showed, as a lecture experiment, how coal-gas could be freed from methane and other hydrocarbons by cooling it to a sufficiently low temperature. Recently d'Arsonval (Ann. Chim. et Phys., 1902, [7], 26, 446) has proposed this as a method of obtaining hydrogen; the process has, however, not yet proved of any commercial value.

Experimental Plant.—In considering the type of apparatus suitable for experimental work, it must be borne in mind that the plant should be capable of producing gas at a comparatively high rate, at least for a limited number of hours. As will be more fully explained in describing the compressing plant, it is advisable to make the gas in sufficient quantities to supply the pump at its normal rate of working, which in our case was 100 to 130 cubic feet per hour. Under all conditions where the cost of a large-capacity gasometer is not prohibitive, it would doubtless be more convenient to generate the gas slowly and continuously, and then compress it, whenever the gasometer was filled. With such an arrangement it would have been more convenient even in the laboratory to use the electrolytic process. Preliminary experiments made in this direction showed that a satisfactory electrolytic cell could be easily and cheaply fitted up. This was effected by lining the sides of an ordinary stoneware mixing-pan with sheet lead, and using as a cathode a spiral coil of lead tube, covered with an inverted bell jar. From the top of this the gas is drawn off. To equip a plant to make gas at the rate mentioned above was, however, too costly for a temporary outfit. The preparation from Brunner-Mond zinc and 20 per cent arsenic-free sulphuric acid was therefore resorted to, spelter of this quality being found to give gas of high purity. Sufficiently finely granulated zinc can be obtained by pouring the molten metal into water from a height of about three feet. Three lead generators were used of the ordinary type employed for lead-burning, as shown in Fig. 2. These were arranged in parallel, and so connected that, while two were in actual use, the third was cut off, to allow the gas to displace the partially-spent acid, after which it was reconnected and one of the others turned off. By working in this manner, the required rate of generation could be maintained. The gas was found to need no purification, but was led, through two towers containing solid caustic soda, direct to the gasometer and compressor. Analysis proved the purity to be 99.8 per cent hydrogen.

Nitrogen: Commercial Manufacture and Applications.—Already at the present time nitrogen is coming into use in several of the cyanide processes, an application which will doubtless increase largely so soon as a satisfactory and economical method of generation has been devised. For, despite the apparent simplicity of the process, no very economical method of effecting the separation from the oxygen of the air is available. The older method of passing air over heated iron or copper is chiefly employed technically. In those cases where a large supply of nitrogen is needed, it would be advisable to carefully consider the employment of the waste gases from gas engines and sulphuric acid plants, which are available in quantity and contain a much reduced percentage of oxygen. It must also be borne in mind that similar gases are passed to waste in the course of manufacture of oxygen by Brin's process; while, provided any of the proposed methods of extraction of oxygen from liquid air by fractional distillation become of permanent commercial value, they will prove of direct assistance for the problem under consideration. As will be seen below, pure nitrogen can be prepared at moderate cost by an adaptation of the Harcourt method (Lupton, Chem. News, 1876, 33, 90; R. Marston, Eng. Pat. 19,074 of 1900), consisting in burning out the oxygen of the air by the hydrogen contained in ammonia. Finally, the laboratory process of generation from ammonium nitrite (K. T. Fischer and H. Alt, Ann. der Phys., 1902, [4], 9, 1149; von Knorre, Chem. Ind., 1902, 25, 531 and 550) is out of question for large scale working, owing to the prohibitive cost of material. At the recent International Chemical Congress, R. Knietsch (Chem.-Zeit., 1903, [48], 586) proposed passing air and excess of hydrogen over warmed platinized asbestos; and at the same meeting a few details were given of the process of Messrs. Elkan, of Berlin, who supply the compressed gas in cylinders.

Experimental Plant.—From preliminary trials the Harcourt method seemed to be the only one which could be fitted up in a limited space with ordinary apparatus and suitable to produce gas at a moderate cost. The plant is shown in Figs. 3 and 3a. An iron gas-pipe about 5 feet long and 2 inches internal diameter was filled with copper turnings, connections being made at one end for the introduction of air, supplied by a blower, and of the required quantity of ammonia

ence of hydrogen would be of no disadvantage. For the guidance of any one employing the method in this form, we might state that in one operation some 200 cubic feet were compressed, about 9 liters of 0.880 ammonia being passed through the apparatus; the flow of gas was regulated from time to time so as to supply the pump continuously at its normal rate of working. The cost of the ammonia for 1,000 cubic feet of nitrogen would be about 17s. 6d., or half this amount if the excess of ammonia is efficiently recovered.

Carbon Monoxide: Experimental Plant.—For most chemical processes pure carbon monoxide is rarely required, some form of producer or water gas being generally employed. Where, however, the pure gas is a necessity, the manufacture of formates by the recent synthetical Goldschmidt process renders it possible to obtain it at a reasonable cost and in an extremely simple manner. The actual apparatus used is shown in diagram (Fig. 4), and consists of a bolt head, *E* (9 liters), half filled with sulphuric acid (sp. gr. 1.73). The heating was performed, either by an electric resistance furnace as represented, or by an ordinary gas furnace; the former is preferable, when working with combustible gases, where electric current is available. An electric furnace of the kind can be built up temporarily at trifling cost. The outer walls are constructed of loose firebricks; the electrodes consist of two flat pieces of boiler plate, the space between which is filled with ground coke. An electric current passing through the coke heats this up to any desired temperature. In the present case the iron plates were each 11 inches square, the distance between them being 14 inches; the layer of coke, *G*, about 40 pounds, being 7 inches deep. This gave a resistance when cold of 13 ohms and about 1.5 ohms when heated up to the working temperature. When generating gas at full rate, over 4 kilowatts are required to maintain the temperature. The reservoir, *B*, contains a supply of technical 90 per cent formic acid, from which the carbon monoxide is generated. This reservoir is kept slightly above atmospheric pressure by being connected to a supply of compressed air, thus enabling the acid to be easily forced over. The formic acid is delivered below the surface of the boiling sulphuric acid in the bolt head, the flow being regulated by the cock, *d*. The temperature, which, when the formic acid is added, of course, tends to fall, is maintained throughout the run at about 150 deg. to 170 deg. C. In this way, with a limited amount of sulphuric acid the process can be run continuously. The gas is purified in the apparatus shown in Fig. 3, the only modification being that the bottle, *L*, is in this case filled with 20 per cent caustic soda solution, and a similar solution is also allowed to drip into the quartz tower, *K* (Fig. 3), from the supply bottle, *H* (Fig. 4). Nearly the full theoretical yield of gas is obtained, about 133 pounds of 90 per cent formic acid being required per 1,000 cubic feet, costing 50s. The purity of the gas thus prepared was over 99 per cent.

Ethylene: Experimental Plant.—Up to recent years ethylene has been used in considerable quantities in connection with the production of liquid air; the apparatus which we have already described for carbon monoxides can, without modification, be employed for this preparation. There is not, however, the same latitude with regard to temperature and rate of production as in the former case. It is essential that the sulphuric acid should be kept between 160 deg. and 165 deg. C., since, even at a few degrees above this, carbonization commences, accompanied by production of sulphurous acid and carbon monoxide; at a temperature below 160 deg. C. the yield falls very rapidly, almost all the alcohol being transformed into ether. The sulphuric acid used in the bolt-head should be of such dilution as to boil at 160 deg. C. Methylated spirit is admitted through a perforated lead tube (see Fig. 4). At first scarcely any ethylene is evolved, but as part of the water in the acid becomes displaced by the alcohol, the temperature being kept constant, the rate of production gradually increases, and, after about half an hour, becomes fairly steady. A constant evolution of gas can be maintained under these conditions for any length of time, but the flow of gas is only about one-tenth of what the same-sized apparatus would produce in the case of carbon monoxide. The yield obtained was not much more than half the theoretical. An addition of ferrous sulphate to the sulphuric acid has been proposed by R. N. Lennox as insuring against carbonization and evolution of sulphurous acid. This addition seems to be a considerable improvement on the original process. The acid mixture is made with concentrated sulphuric acid (sp. gr. 1.84) and sufficient saturated ferrous sulphate solution to bring the boiling point down to 160 deg. C.

Another method proposed by Newth (G. S. Newth, J. Chem. Soc., 1901, 79, 915), which consists in employing syrupy phosphoric acid in place of sulphuric acid, was tried in the same apparatus. The temperature should be kept between 200 deg. and 220 deg. C.; there is no carbonization, but a considerable amount of ether is collected. The yield in this case was even lower than with the sulphuric acid method, but the process can be worked quite continuously, and the quantity of phosphoric acid required is not large.

Notes on Various Other Gases.—The foregoing deals with the preparation of such gases as cannot easily be obtained commercially. With regard to many other gases similar methods could of course be adopted, but producing them on the scale with which we have been dealing would hardly repay the trouble involved, in those cases where they are already on the market. Further, for such gases as sulphurous acid,

chlorine, and ammonia, a special pump would be necessary; and even before oxygen could be compressed, much time would have to be spent in carefully removing all traces of organic matter from the pump cylinders, connections, and gages.

Oxygen, nitrous oxide, carbonic acid, sulphurous acid, and ammonia can readily be obtained from the various companies in this country who make a specialty of their manufacture. Where a compressed gas is not required, oxygen in a similar way to acetylene can be produced by the action of water on one of its solid compounds. A French company has recently put on the market a mixture of sodium peroxide and bleaching powder, under the name of "oxylith," which yields oxygen of satisfactory purity. The cost of the gas produced by this method (5s. 9d. per 20 cubic feet) would, however, be prohibitive where a large quantity is required. So far as acetylene is concerned, it will be recalled that, as a result of the exhaustive investigations which followed on numerous and disastrous accidents, Berthelot and Vieille showed that it is highly dangerous to compress this gas above four atmospheres. The gas, however, can now be stored in cylinders, filled with some porous material saturated with acetone, this liquid absorbing about twenty-four times its own volume of gas per atmosphere pressure (A. Janet, *Génie Civil*, 1903, 43, 180). In Germany (O. N. Witt, *Die Chemische Industrie des deutschen Reiches im Beginne des 20. Jahrhunderts*, pp. 100-105) considerable use has been made in recent years of liquid chlorine, which is produced by several companies, and notably by the Badische Anilin Company, and can be obtained retail (e. g., Kahlbaum, Berlin) for 1s. 6d. per pound in bombs of 20 pounds or over. Methyl chloride (2s. per pound, Douane, Paris), phosphene (Kahlbaum, 6s. per pound), and ethyl chloride (2s. per pound) can all be obtained commercially, and find uses particularly in the color industries and for refrigeration.

Compression and Storage of Gases.—The portion of the subject which we have to deal with now is of rather a special nature. Much of the information given below will be well known to those few who have been connected with commercial gas-compression plants; but now that pumps can be obtained at a moderate cost and of sufficiently simple construction to give no trouble for continuous working, there is no reason why the great convenience of storing gas in the compressed state should not be more generally made use of. For work of this kind, the smallest convenient plant comprises:

(1) Compressor capable of dealing with 60 to 130 cubic feet per hour, and of working up to 120 or 200 atmospheres.

(2) A small gas-holder (10 to 20 cubic feet capacity), which is used, not to store the gas, but to act as an equalizer between the pump and generating apparatus. It being assumed that, wherever possible, the gas is made and pumped at the same rate.

(3) A stock of weldless steel gas cylinders.

As a general guidance with regard to cost, the price of the compressor may range from £60 to £100, and the gasometer from £10 to £20. For most purposes it is convenient not to exceed the commercial pressure of 120 atmospheres. For this pressure, gas cylinders, ready fitted with valves, can be obtained at about 1s. per cubic foot of gas stored, when purchased in small quantities; or at half this price when bought on a larger scale. For higher pressures, the cylinders have to be made to order, and are correspondingly more expensive. Another £10 to £20 should be allowed for the purchase of two or three pressure-gages, a dozen cone connections, eight or ten high-pressure valves, and the capillary copper tubing which serves to conduct the gas from the compressor into the receivers. Weldless copper tubing of 1/8-inch bore and 1/4-inch external diameter is both strong and large enough for this purpose, and can be readily obtained from any copper tube manufacturer. This size has the further advantage, when annealed, of being quite flexible, and can thus be bent, whenever used, to the most convenient shape. The ends of each length of such tubing are soldered into brass or gun-metal cones, as shown in Fig. 5. These are screwed to the cylinder or pump valves by a nut which surrounds them. In a plant of the kind it is advisable to keep to a standard size, "half-inch gas" being most convenient for this purpose.

An ordinary air-pump is, of course, not suitable for dealing with combustible gases. The cylinders of the compressor should be entirely closed, the piston-rods passing through properly-made stuffing-boxes. The smaller compressors are usually of the tandem two-stage type, the low-pressure cylinder compressing to about seven atmospheres, the gas being then passed through a cooling coil into the high-pressure cylinder, which forces it up to the full pressure. The high-pressure cylinder delivers its gas, through another copper coil immersed in a cooling tank, into a small gas cylinder, which serves to separate the water used to lubricate the pump. At the bottom of this separator is a valve for withdrawing the water. If the pump is required to suck in its supply of gas under a partial vacuum, the low-pressure inlet valve should be arranged so as to be mechanically lifted at the top of each stroke. The water for lubricating the cylinders is fed through a sight feed, and for a compressor of the size we are dealing with, a single drop per two or three revolutions is an ample supply. The clearances should, in both cylinders, be about 1-32 inch, or at any rate not exceed 1-16 inch, in order that, at the highest working pressures, the pump may deliver its full volume, and not compress and expand the same gas.

The following precautions are of the highest importance from the point of view of safe and satisfactory performance:

(1) The greatest care must be taken never to allow much more than the above-mentioned quantity of lubricating water to enter, as with such small clearances this water carried into the high-pressure cylinder would be unable to pass through the narrow outlet valve and would burst the cover or bend the crankshaft.

(2) If the apparatus is to be used for air, or more especially for oxygen, it is of vital importance that no oil should be employed, either in the pump cylinders or in any of the valves, connections, or gages. Many disastrous explosions have resulted from the neglect of these precautions. The water may, however, if desired, be replaced for lubrication by glycerine, which forms an excellent substitute for oil for this purpose.

(3) Each time before running the pump, it is advisable to turn it through one or two revolutions by hand to insure that it is working freely. If the gas to be pumped is combustible, before connecting to the gas-holder the pump should be run for a minute or two with the inlet cock closed, and the end of the delivery pipe placed under water. In this case, if the stuffing boxes and connections are satisfactorily tight, the pump will be running under a vacuum and should deliver absolutely no gas.

(4) The purity of any combustible gas must of course be properly ascertained, as any admixture with air would lead to serious explosions.

(5) It is very advisable to adopt the excellent system, employed by all the gas-compressing companies, of distinguishing between combustible and non-combustible gases, by invariably storing the former in cylinders characterized by a bright red color, and fitted with left-handed connections. Even where this is done it is advisable before connecting a partially-filled cylinder with the pump to test its contents at a flame.

(6) All storage cylinders, connections, and other apparatus, with the exception of gages, should be occasionally tested hydraulically to double the maximum working pressure.

So far as the actual compressing is concerned, a clear idea will be obtained from the diagrammatic sketch (Fig. 6). The gas passes from the purifying apparatus shown in Fig. 3 to the gasometer, *A* (Fig. 6), from which the two-stage compressor, driven by an electric motor, forces it into the water separator, *F*. At its exit from this separator the gas is sufficiently dry for almost any purpose for which it may be required, since the percentage of aqueous vapor in a gas at 100 atmospheres is only 1-100 of its amount at ordinary pressure. When the gas is being made at the normal rate the valve *k* is kept open, the valve *m* closed, and the gas passed directly into a storage cylinder such as *L* or *K*, or, in the case of our own work, direct into the pressure furnace, *M*. These were situated in the room on the next floor of the building to the compressor. A high-pressure connection is also led direct to a duplicate gage *g*, by which the pump pressure can be independently read. When necessary the gas can be blown off from the valves *q* on the upper floor, or *o* on the lower; *o* being connected to a pipe leading outside the building, for use with poisonous gases such as carbon monoxide. If, for any reason, the supply of gas falls below the normal rate, the valves *m* and *l* are partially opened, *n* being kept closed; a part of the gas delivered by the pump then returns to the gasometer, and is compressed again, thus avoiding the necessity of either stopping the pump or working it under a partial vacuum. When dealing with gases which can only be conveniently kept closed. This last method of working is of course necessary to give up any idea of continuous pumping. In these cases the gasometer is allowed to fill slowly; the pump is then started, and stopped a few minutes afterward, so soon as all the gas has been pumped. The storage cylinder is thus filled step by step up to any desired pressure. It is not possible to restart the pump against a high pressure; the gas contained in the water separator, *F*, must therefore be blown off, and since, at a high pressure, the volume thus returned to so small a gasometer would take up a large part of its capacity, it is preferable to employ an auxiliary cylinder, *G*, which takes the major part of the contents of *F*, the residue only being returned to the gasometer by the valves *k*, *m*, and *l*. The contents of *G* can be returned to the gasometer and pumped during the course of the next run through the valves *n* and *l*, *m* being kept closed. This last method of working is of course somewhat complicated, but has proved very useful in a few cases where it was practically impossible to produce the gas at the normal rate. For those purposes where it is required to study some chemical reaction or to purify a gas when under high pressure, a gas cylinder with a removable cover is employed. The ordinary cone joint as shown in Fig. 5 works satisfactorily to close the opening of any tube up to one-inch bore. Above this size it is necessary to resort to some form of spigot joint, such as is shown in Fig. 7. One or two turns of lead wire about the same diameter as the groove are inserted in it, the ends of the lead being beveled so as to overlap each other. The cover is then forced home by means of the bolts provided for the purpose, and, crushing the lead outward and upward, forms a gas-tight joint. When making such a joint for the first time, exceptional care must be taken that the nuts are pulled down evenly, as otherwise the cover may be strained or, being out of true, the joint will not be gas-tight. When the cover has once been fitted correctly, it can be removed and replaced some hundred times before it is necessary to add fresh lead packing. We have used joints of this kind up to a foot diameter, which have always worked satisfactorily.

Above this diameter the weight of the cover and the size of bolts required become somewhat unmanageable when designed for pressures of 100 or 200 atmospheres. —Electrochemical Laboratory, The University, Manchester.

DIAMONDS AND THE DIAMOND INDUSTRY.*

In 1475 Louis de Berquem invented the great art of diamond polishing, and in 1476 established at Antwerp the earliest known works for the purpose of cutting and polishing diamonds. The disturbed state of that part of Flanders drove the diamond industry to Amsterdam, where it flourished uninterruptedly for upward of three centuries. It was not until the independence of Belgium was established in 1830 that Antwerp began to recover its position as the headquarters of the diamond industry. After the discovery in 1870 of diamond mines in Cape Colony, the wages earned by skilled workmen at Antwerp increased to so great an extent that some of the workmen are said to have earned wages amounting to as much as from £40 to £48 a week. Since that time the diamond trade of Antwerp has continued to increase in importance, and it now equals that of Amsterdam. The whole European diamond trade is centered in these two towns.

Diamond cutting is divided into three separate and distinct processes—(1) cleaving, (2) brutage, (3) cutting and polishing. Cleaving is the act of dividing the layers or scales which form the crystal, an operation which can only be performed in one manner on account of the flaky formation of the diamond. The stones have to be divided in accordance with the running grain of carbon of which they are composed, and any attempt to divide them in another way would result in their being split and destroyed. A diamond is cleft as follows:

The rough stone is placed in a small metal receptacle, with the side of the diamond which it is desired to cut facing downward. Over this receptacle is placed a shaped mold which is securely attached to it. Into the top of this mold is then poured liquid aluminium, which runs into the shape of the mold and, after being cooled, securely holds the diamond in the required position. The mold is then removed and the stone remains fixed in the aluminium ready to be applied to the cutting tool. The machine used for the cleaving is a small circular saw of about four to five inches in diameter, which rotates at a high rate of speed and is driven in the ordinary way by a leather belt from the running machinery. The saw itself is made of fairly soft copper with a prepared edge. To prepare the cutting edge of the circular saw it is necessary for it to go through a special process by which diamond dust mingled with oil is forced into its edge. "Diamond cuts diamond" as, after the preparation of the saw, its cutting edge is embedded with minute grains of diamond dust. The diamond is then applied to the saw in a similar manner to that in which wood is placed against a circular saw in a mill, with the slight difference that the diamond is held immovable in an instrument overhanging the saw which presses it gently against the blade. It frequently takes two weeks continual work to cleave a diamond, the duration of the time depending entirely on the hardness of the substance of the stone to be cut. The most difficult stones to cut are those of double formation, the grain of which is interlaced, thereby creating greater resistance. The machine used was invented some years ago in America by a Belgian who was at the time working in the United States. Before its invention diamond dust for the finishing process was often most difficult to obtain, and manufacturers had frequently to grind fragments of inferior diamonds by means of a hardened steel pestle and mortar, but nowadays the supply of diamond dust is always abundant, not only "for the requirements of the factories, but even to be disposed of for use in other industries, such as glass-cutting." Before the coming into use of the machine referred to, the whole of the process of "brutage" had to be performed by hand, and was most monotonous and tiring work, the shaping of larger stones in particular necessitating a great loss both in time and labor.

The second process in the preparation of a diamond is its primary formation before it is ready for the first cutting and polishing, and the operation is carried out by means of mechanically rubbing one stone against another until the desired formation is achieved. Before the "brutage" takes place the stones are received either in their rough state, save that they have been washed clean, or else from the cleaning department in so many small pieces. The mode of procedure is as follows: Two diamonds may be taken of similar size and equally hard in substance. Each stone is fitted into a brass or other metal cap by melting cement in a gas flame, which is then dropped into the aperture of the cap, the diamond being fixed in the cement, which is afterward cooled and set by being plunged into cold water. Thus, two diamonds of equal dimensions are firmly fixed each in a separate metal cap or holder. One of these stones is then attached, by means of the cap which holds it, to a rotary machine, the stone forming the revolving center. The other stone is fitted to a long handle or holder, and is placed against the revolving stone in the required position in a similar manner to that in which the tool is applied when cutting wood or metal in a lathe. The diamond dust which is produced by the rubbing of the

stones together falls into a copper box called an "eglisoir," or diamond dust box, which is placed immediately below the diamonds being worked. This dust is carefully preserved, and it is eventually used in the third operation of cutting and polishing.

Cutting and polishing is the third and last operation in the preparation of a diamond previous to its sale. In this process the stone, which has been roughly shaped by the second operation, is placed in position at the required angle in a copper holder with which it is firmly pressed by means of a forked clamp, which is pressed against the stone and locked into position with a key. Great skill is required on the part of the workman in fixing the diamond into the holder. Many stones of one-eighth of an inch and less in diameter, weighing between 1 and 2 grains, have as many as 50 to 100 facets or separate cut faces, each at a different angle. Continual practice, however, facilitates this operation, and a skilled workman can immediately place the stone in the holder at the required angle ready for the cutting of another facet. When the stone is ready in the holder it is placed against a revolving disk of soft steel rotating in a horizontal position at a speed of some 3,000 revolutions a minute, and is left there until the required facet is cut and polished. The surface of this disk is prepared with a mixture of diamond dust and purified olive oil, which is rubbed into the steel, and it is this dust, which comes in the form of waste from the second operation of "brutage," that effects the polishing of the stones.

In olden times diamond cutters contented themselves with cutting as large a number as possible of small facets on the surface of a stone, regardless of regularity, and without taking into account its form or size, but it is now recognized that to obtain the best results and sparkling glitter, a diamond must be cut in a regular form, so that one surface may reflect on another, thereby showing forth the hidden light and beauty of the stone. There are two common forms of cutting diamonds, it may almost be said there are only two forms, the brilliant and the rose, the brilliant for stones of a certain uniform thickness, and the rose for flatter stones and layers which have been cut from other and larger diamonds. The cutting of a brilliant is a process which best shows forth the lights and reflections contained in a diamond. A perfectly formed brilliant should have the proportions in depth from the upper surface or summit to the lower point called the pyramid or pavilion of two-thirds of the diameter of the stone at the belt or middle. The summit, or crown, of a brilliant should have 32 facets, and in addition one large central facet called the table. From the side of the pyramid it should have 24 facets and one small facet at the lower point called the "colette," making in all 58 facets, and not, as has sometimes been stated, 64 facets. These facets should be calculated, divided, and regularly cut in such a manner that those cut on the pavilion of a diamond may reflect the light on to the facets cut on a summit, and vice versa, thus showing forth in as high a degree as possible the sparkle and glitter of the gem. All diamonds are cut in a series of stars, one being formed over the other. On looking through the flat surface, or table of a properly cut brilliant the "colette" or lowest point should appear to be directly in the center of the table. In the regular cutting of these facets depends the whole beauty of a diamond, and in their formation lies the secret and difficulty of the diamond trade. The rose is a more useful form of cutting diamonds, of less value and thinner formation, and is cut with one large facet at the base and 24 triangular facets on the summit. The thicker stones cut in this manner, with 24 facets, are called on the Continent "Roses Couronnées." Those which are only cut with twelve or six facets are known by the name of "Roses d'Anvers," and form one of the chief specialties of Antwerp. The quality and value of a diamond may be roughly determined by examining it against the light. In a stone of inferior value there appear to be many lines or scratches, whereas the more perfect stone is recognized by its purity and lack of marks in the grain, and also by its regularity of formation.

The bulk of the diamonds worked in Belgium and the Netherlands originate from British possessions, or mines owned by British subjects. The diamonds, after being cleaned and weighed in their country of origin, are sent to merchants in London, where they are sorted and put up for sale. The stones are then invariably purchased by foreign merchants who have their factories abroad. Thus although the stones come first to the United Kingdom, they are afterward conveyed abroad to be cut and prepared, and then in many cases returned to the United Kingdom to be sold by retail dealers. By this practice the whole of the diamond industry, with its profits, is lost to the United Kingdom. It can hardly be said that low wages prevent British competition in the diamond industry. The average wages paid to diamond workers in Antwerp range from £2 12s. to £2 16s. per week. The diamond cutters are paid from £2 8s. to £3 4s. per week, the shavers from £4 per week upward, and the sorters are paid wages varying from £1 5s. to £2 per week. The workers employed in all the branches of the industry at Antwerp, number from 4,000 to 5,000, including some 70 women employed on the lighter work. No precautions are, or can be taken, to guard against dishonesty in the workers, but cases of dishonesty practically never occur. It is difficult to state the names of the countries to which diamonds cut at Antwerp are sent, or the value of

the stones exported, as no statistics on the subject are published. A diamond is so small an object, and one of so great value, that practically all the diamonds exported are sent out of the country without the knowledge of the customs officials. In the customs returns for 1903, is a note which states that owing to the existing conditions of the export of cut diamonds it is impossible to give details of their value, but that from information received, it is estimated that the value of the exports during that year amounted to £3,340,000. Precious stones are admitted free of duty in Belgium, and there seems to be no sufficient reason why this valuable industry should not be carried on in the United Kingdom. It ought to be possible for the British workman to learn the art of diamond cutting in spite of the secrecy adopted by the diamond cutters as to their method of cutting.—Journal of the Society of Arts.

A NOVEL FLOATING EXPOSITION.

THE Export Shipping Company, of New York, advises the Department of Commerce and Labor that the company has decided to adopt a suggestion made by an officer of the department in an article appearing in the Geographic Magazine in 1901. It is proposed to equip a large steamer and furnish space thereon to American manufacturers to make a display of their products and then send them around the world on a 60,000-mile trip, to consume about fifteen months. In answer to numerous inquiries received by the Bureau of Manufactures, the following explanation of the enterprise is offered:

The plan is to allow each person who subscribes for 40 square feet of space or more to display his goods and to send on the steamer a representative whose duty it will be to see that the exhibit is properly arranged at each port, to meet the merchants and dealers invited to inspect the exhibits, explain the utility and advantages of the goods, quote prices delivered in the country of consumption, terms under which goods are sold, appoint agents, extend the sale of the goods, ascertain what the markets of the country demand, the competition to be met, etc. This representative shall also satisfy himself by a personal investigation that any agent so appointed to represent his principal shall be of good character and financially able to meet his obligations. If the standing of agents is carefully gone into there should be no objection to extending ordinary business credit, and no more risk in doing so than is experienced in granting time payments to domestic customers.

The undertaking is likely to create wide interest in the commercial world, and its progress will be watched keenly by the various trade journals and newspapers, so that every merchant in the countries visited will be familiar with the fact that the exposition is to call at his port. In these circumstances it will not be a hard matter to induce him to visit the ship. The date of arrival in the ports will be advertised, and all interested will be advised to obtain tickets of admission at the newspaper offices, the chamber of commerce, the American consulate, or at the office of the Export Shipping Company. It is also proposed to print, in the language of each country, a catalogue showing the name of each exhibitor, the name of his representative, the position of the display in the ship, and a full description of the goods exhibited. As in some instances it will not be possible to obtain direct land communication, it will be necessary to bring the visitors off in launches, which will also necessitate serving lunch on the steamer as well as insuring sufficient time for each visitor to examine thoroughly each and every exhibit on the ship. The luncheon should provide a most excellent opportunity for the demonstration of American food products.

All firms participating will be required to conform to reasonable rules, and the representatives on the ship will be afforded opportunity to acquire a knowledge of French, Spanish, and German and are expected to improve it. In this way such representatives will gain knowledge of trade conditions and the ability to answer letters, upon returning home, in the language of the inquiry. If in any cases sufficient sales are not consummated while on the trip to reimburse the participants for their expenditure, at least the seed will be sown in fertile ground, which will bear fruit in years to come. The plan will appeal particularly to firms who already have an export trade and agents in the different countries, as the agents would assuredly be flattered to receive a visit from the representative of the manufacturers, and the opportunity would afford a splendid chance for calling the attention of his customers and others interested to the display, and also allow him to explain on the spot what special facilities or changes in standard goods or manner of putting on sale will lead to an increase in business.

The expense of the trip is to be borne entirely by sale of space on a mutual basis. The available space is 20,000 square feet and the price is fixed at \$50 per square foot. The prospectus of the promoters shows in detail the estimated expenses, and the surplus remaining at the termination of the trip is to be returned to those who participate *pro rata*. It is expected that the net cost of space will not exceed \$35 per square foot of space and \$500 for meals and incidental expenses of the representative. This, on a basis of 40 square feet of space, means that the entire cost for traveling expenses and showing samples will be about \$5 a day.

The exhibits will be cared for and all necessary janitor service, lighting, and a limited amount of power for working exhibits will be furnished without

* The statements of fact made in this paper rest upon the report of British Consul-General Hertslet on the diamond industry of Antwerp, just published (No. 634, Miscellaneous Series).