

Helium : its Production and Uses.

A LECTURE DELIVERED BEFORE THE CHEMICAL SOCIETY ON
JUNE 17TH, 1920.

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IN 1868 Janssen (*Compt. rend.*, 1868, **67**, 838) drew attention to the existence of certain lines hitherto unobserved in the solar spectrum, which we now know are given by the element helium. In the same year, Frankland and Lockyer (*Proc. Roy. Soc.*, 1868, **17**, 91), from their observations on these spectral lines, were led to announce the existence of an element in the sun which up to that time had not been found on the earth. To this element they gave the name helium.

In 1882 the discovery was made by Palmieri (*Gazzetta*, 1882, **12**, 556) that the helium spectrum could be obtained from rocks and lavas taken from Vesuvius.

In the United States of America, Hillebrand in 1890 (*Bull. U.S. Geol. Survey*, 1890, No. 78, p. 43) succeeded in obtaining a quantity of gas from the mineral uraninite, which from chemical and spectroscopic tests he concluded was nitrogen. This gas we now know was, in fact, helium.

Finally, in 1895, Sir William Ramsay (*Chem. News*, 1895, **71**, 151) discovered that a gas could be obtained from the mineral cleveite. This gas he purified, and, on examining its spectrum, he found it to be the long-sought-for element helium. From 1895 up to the present, investigation has shown that helium is widely diffused throughout the earth. It can be obtained from many types of rocks, minerals, and earths, and it is present in varying amounts in practically all natural gases and spring waters. It is present too in the atmosphere of the earth to the extent of about four parts in one million by volume.

The gases from some springs in France have been shown to contain as much as 5 per cent. of helium. In the Western States of America, especially in Texas, natural gases exist which contain from 1 to 2 per cent. of helium, but within the British Empire no natural gases which have been examined show a helium content as high as 0.5 per cent.

Until the spring of 1918, not more than 3 or 4 cubic metres of helium had, in the aggregate, been collected, and its market price, though variable, was about £300 per cubic foot.

The principal characteristics of helium are:

(1) Its extreme lightness. It is only twice as heavy as hydrogen, the lightest element as yet isolated.

(2) Its absolute inertness. All attempts to effect combinations of helium and the rare gases, neon, argon, krypton, and xenon, as well, with other elements have as yet failed.

(3) Its close approximation to an ideal or perfect gas. It is monatomic, and is liquefiable at a temperature below that of liquid hydrogen. By causing liquid helium to evaporate in a vacuum, Onnes (*Proc. K. Akad. Wetensch. Amsterdam*, 1915, **18**, 493) has succeeded in reaching a temperature within 1° or 2° of the absolute zero.

(4) Its low sparking potential. Electric discharges can be passed through helium more easily than through most other gases.

No element has had a more romantic history than helium, and none is of greater interest to men of science than is this gas at the present time. Its formation as a disintegration product of the radioactive elements, and the identity of the nuclei of helium atoms with α -rays, give it a unique position among the elements.

Intense interest has been aroused by Sir Ernest Rutherford's recent discovery that in the nuclei of helium atoms in the form of α -rays we have a powerful and effective agent for disintegrating and simplifying the nuclei of atoms generally. This discovery points the way to still further progress. In the past, helium has been considered a rare and precious gas. To-day it is being produced in large quantities, and in view of the proposal now being put forward to use this gas in place of hydrogen as a filling for airships, one is apt to consider it to be not so precious as heretofore. It may be, however, that such vast and vitally important directions will suddenly be opened up in which helium can be utilised that the conservation of the gas, while it is still available to us, will become a matter of the first importance.

Shortly after the commencement of the war in 1914, it became evident that if helium were available in sufficient quantities to replace hydrogen in naval and military airships, losses in life and equipment would be very greatly lessened.

The fact that helium is both non-inflammable, non-explosive, and possesses 92 per cent. of the lifting power of hydrogen, makes it a most suitable filling for airship envelopes. By the use of helium, the engines of airships can be placed within the envelope if desired. A further advantage possessed by helium over hydrogen is that the buoyancy may be increased or decreased at will by heating and cooling the gas by electric or other means, which fact may possibly lead to considerable modifications in the technique of airship manœuvring and navigation. Moreover, the loss of gas from diffusion through the envelope is less with helium than with hydrogen to the extent of about 30 per cent.

Although there are indications that proposals had been put forward during the war by men of science in allied and enemy countries, as well as in the British Empire, regarding the development of supplies of helium for aeronautical purposes, it should be stated that the movement that led up to the investigation which it was my privilege to undertake was initiated by Sir Richard Threlfall. The existence in America of supplies of natural gas containing helium in varying amounts was known to him and others, and preliminary calculations as to the cost of production, transportation, etc., which he made led him to believe that there was substantial ground for thinking that helium could be obtained in large quantities at a cost which would not be prohibitive.

His proposals were laid before the Board of Invention and Research of the British Admiralty, and in the autumn of 1915 the author was asked by that Board to determine the helium content of the supplies of natural gas in Canada, and later on of those within the Empire, to carry out a series of experiments on a semi-commercial scale with the helium supplies which were available, and also to work out all technical details in connexion with the production of helium in quantity, as well as those relating to the re-purification, on a large scale, of such supplies as might be delivered and become contaminated with air in service. The present paper aims at giving a brief account of this investigation.

Composition of the Natural Gases Investigated.

In commencing the investigation, a survey was made of all the natural gases available in larger or smaller quantities within the Empire with a view to ascertain their helium content. Natural gases from Ontario and Alberta, Canada, were found to be the richest in helium, and these sources, it was found, could supply from 10,000,000 to 12,000,000 cubic feet of helium per year. The following is a summary of the results obtained from the analyses of a number of the gases investigated. They include, it will be seen, a few samples from outside the Empire. For a complete account of this part of the investigation, the reader is referred to Bulletin No. 31 of the Mines Branch, Department of Mines, Canada, 1920.

(a) *Ontario Gases.*—The analysis made by Profs. Ellis, Bain, and Ardagh (*Report of Bureau of Mines of Ontario, 1914*) of the natural gases supplied to the experimental station, initially set up at Hamilton, Ontario (Blackheath System), is as follows:

Methane	80 per cent.
Ethane	12 "
Nitrogen	8 "

It was found, however, on operating with this gas that the percentage assigned to methane really included a considerable proportion of gasoline, pentane, and butane as well. The helium content of the gas was found to be 0.34 per cent.

(b) *Alberta Gases*.—Gas taken from the mains leading from the Bow Island supply to Calgary was found to be quite free from the heavier hydrocarbons. At times it contained slight amounts of water vapour and occasionally a trace of carbon dioxide as well. Its approximate composition is given under I.

	I.	II.
Helium	0.33 per cent.	0.36 per cent.
Methane	87.6 "	91.6 "
Ethane	0.9 "	1.9 "
Nitrogen	11.2 "	6.14 "
Carbon dioxide	trace	trace
Water vapour	trace	trace

One well in particular, namely, No. 25 Barnwell, which has recently been driven, and now supplies gas to the system, was found to have a product of the composition II.

(c) *New Brunswick Gases*.—Some natural gases obtained from wells struck near Moncton, New Brunswick, Canada, were examined, and found to have the following composition:

Methane	80.0 per cent.
Ethane	7.2 "
Carbon dioxide	None
Oxygen	None
Nitrogen	12.8 per cent.
Helium	0.064 "

(d) *New Zealand Gases*.—A series of samples of the natural gases from the Hanmer, Kotuka, Weber, Blairlogie, and Rotorua supplies in New Zealand were forwarded by Mr. J. S. McLaurin, Dominion Analyst of Wellington, New Zealand, for examination, but were found to have an insignificant helium content, the richest containing not more than 0.077 per cent.

(e) *Italian Gases. Pisa*.—A sample of the natural gas brought by pipe to the city of Pisa, in Italy, was examined, and found to have the following composition:

Methane	80.0 per cent.
Ethane	4.0 "
Carbon dioxide	3.5 "
Nitrogen	11.9 "
Oxygen	0.6 "
Helium	None

(f) *Miscellaneous Analyses*.—An analysis of the natural gas supply from Heathfield, Sussex, England, showed it to have a helium content of but 0.21 per cent. The gas from the King

Spring, Bath, England, was found to contain 0.16 per cent. of helium, and analyses of natural gases obtained from Trinidad and from Peru showed their helium content to be negligible. An interesting observation was made in connexion with natural gases obtained from Pitt Meadows, Fraser River Valley, and Pender Island, in the Gulf of Georgia, British Columbia. Both these gases were found to have a nitrogen content of more than 99 per cent.

Preliminary Experiments.

Soon after taking up the investigation, it was found, as mentioned above, that large supplies of helium were available in the natural gas fields of Southern Alberta, and that a small supply could be obtained from a gas field situated about twenty-five miles to the south-west of the city of Hamilton, in Ontario. In 1917 the Board of Invention and Research decided to endeavour to exploit these sources of supply, and operations were begun by setting up, as already stated, a small experimental station near the city of Hamilton.

At this station, efforts were directed towards constructing a machine which would efficiently and economically separate out the helium from the other constituents present in the natural gas. The carrying out of this work expeditiously was made possible through the hearty co-operation of L'Air Liquide Société of Paris and Toronto, who generously lent, free of cost, a Claude oxygen column and the necessary auxiliary liquefying equipment for the investigation.

By making suitable additions to, and modifications in, this oxygen rectifying column, it was ascertained that the problem of separating, on a commercial scale, the helium which was present in this crude gas to the extent of only 0.33 per cent. was one capable of satisfactory solution. Early in 1918 it was found possible to raise the percentage of helium in the gas to 5.0 by passing it through the special rectifying column once only, and as the gas obtained in this way consisted of nitrogen and helium with a small percentage of methane, it became therefore a comparatively simple matter to obtain helium of a high degree of purity. In one particular set of experiments on this final rectification, helium of 87 per cent. purity was obtained.

Experimental Station at Calgary, Alberta.

In order to operate on the natural gas of the Bow Island system in Southern Alberta, an experimental station was established at Calgary in the autumn of 1918, and, starting with the knowledge

acquired through the preliminary operations at Hamilton, rapid progress was made in developing a rectification and purifying column, together with the requisite auxiliary equipment, which would efficiently and cheaply separate the helium from the natural gas.

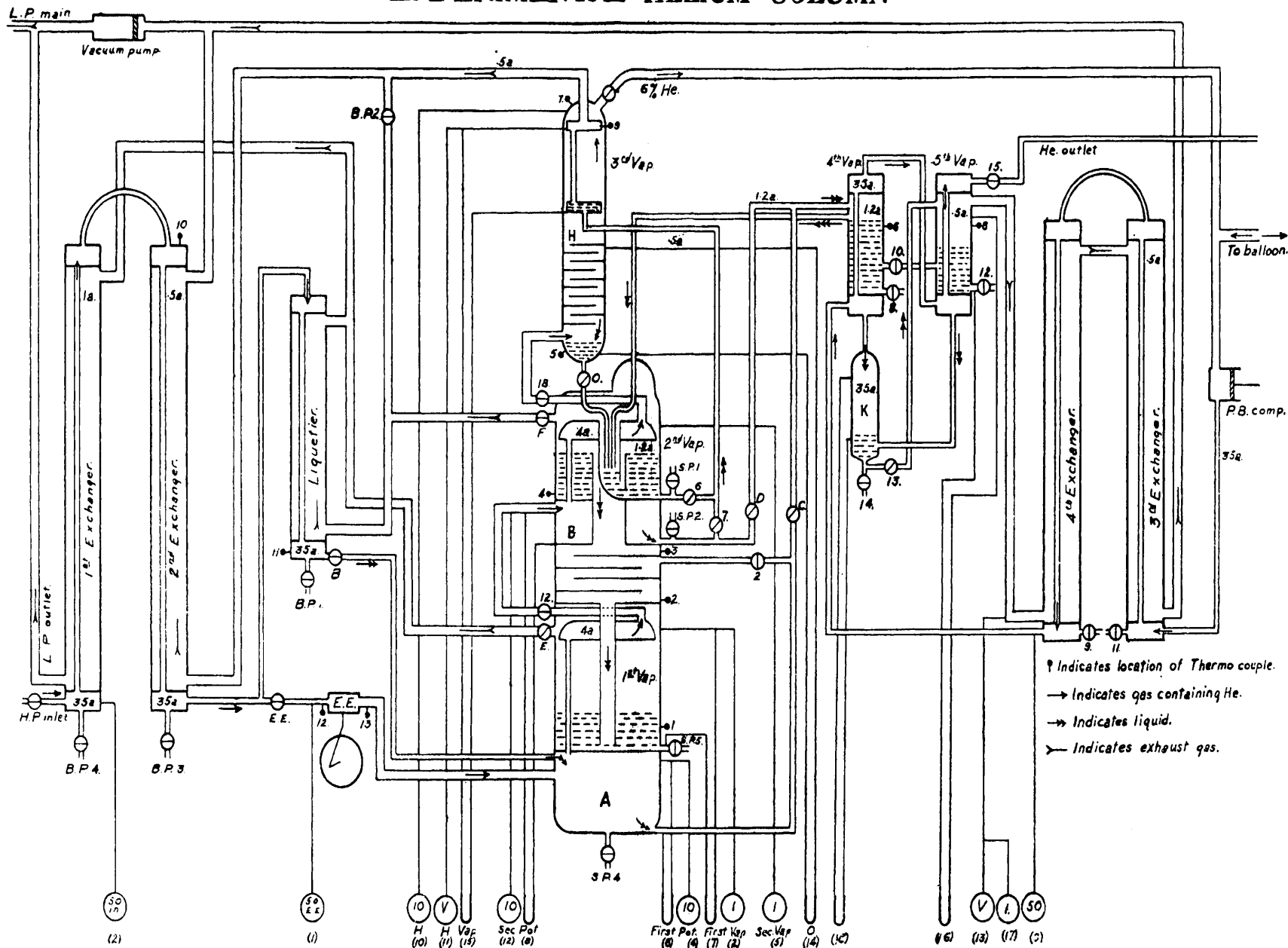
The experimental station at Calgary consisted of a brick building of moderate dimensions, a small brick hut, and a galvanised iron balloon shed, located on the property of the Canadian Western Natural Gas, Light, Heat, and Power Company. The equipment in these buildings included that necessary to furnish an adequate supply of gas, which consisted of the requisite piping, gate valves, pressure-reducing valves, etc., a gasometer and two balloons, a number of gas cylinders, and the rectifying column with its expansion engine, together with the necessary compressors and a complete gas-testing outfit.

Development of the Rectification Column.

In proceeding to develop an equipment for separating the helium from the other constituents of natural gas, three lines of attack appeared to be open, namely, (a) by producing the refrigeration necessary to liquefy all the gases except the helium by the cold obtainable from the natural gas itself, (b) by using external refrigeration entirely, such as that obtainable with ammonia, carbon dioxide, liquid air, liquid nitrogen, etc., and (c) by combining methods (a) and (b).

The last method had been successfully used for the production of helium by the naval authorities of the United States in the Texas field, but from the information supplied it did not appear that this process could be considered to be an economical one.

The preliminary experiments at Hamilton, Ontario, made it abundantly clear that method (a) was very promising and likely to be both efficient and economical. It was therefore adopted. It was evident from the start that to produce an efficient method the main difficulty to overcome would be the securing of a proper balance between the heat exchangers, the liquefier, the vaporisers, and the rectification portions of the machine. A machine was therefore designed, constructed, and supplied with piping which possessed great flexibility, and, in its general scheme, followed the lines of the Claude oxygen-producing column. It is unnecessary to go into details regarding the operation of this machine. It will suffice to say that it was tested under a variety of conditions. Notes were taken of the temperatures reached at different points in the machine under equilibrium conditions when the gas was passed through it in various ways. As a result of this procedure,



it was soon found what parts of the machine could be eliminated and what parts could be modified with advantage. When those changes were made which seemed desirable in the light of the experience gained, it was found that a machine had been evolved which would give highly satisfactory results.

A sketch of the experimental machine as it was finally constructed is shown in Plate I. With this machine, the process of separating the helium consisted of two operations. In the first, the compressed gas was passed through the heat exchangers, thence through the liquefier and the expansion engine to the bottom of the column at *A*. The uncondensed gas passed up through the first vaporiser, then through the valve, No. 12, to *B*. What was still uncondensed passed out through valve No. 18 to the bottom of the rectification column *H* and up over the third vaporiser, where more of the gas was condensed, and the final product, containing from 5 to 6 per cent. of helium, was drawn off. The liquid from *A* was passed through the valve *C* to the fourth vaporiser, from which it would overflow into the second vaporiser. The condensed liquid from *B* could be passed through *D* to the fourth vaporiser or through valve No. 7 to the third vaporiser. Some of the cooling liquid in the second vaporiser could also be passed through valve No. 6 to the third vaporiser when desired. In the second operation, the first product, containing 5 per cent. of helium, the remainder being principally nitrogen with a small percentage of methane, was compressed by a small compression pump to from 20 to 30 atmospheres, and passed through the third and fourth heat exchangers to the fourth vaporiser. Here some of it was condensed by the liquid methane produced in the first operation, and this condensed liquid flowed into the collecting bottle, *K*. The uncondensed gas still at 20 to 30 atmospheres passed, as shown in the sketch, into the fifth vaporiser, where almost all the nitrogen was condensed, and the final product was drawn through valve No. 15. The fifth vaporiser, it will be seen, was supplied with the liquid drawn from the bottle, *K*. It could also be supplied, if desired, by liquid from the fourth vaporiser through the valve No. 10. The level of the bottle was so arranged that there would be about 3 or 4 inches of liquid at the bottom before it showed on the gauge. By keeping the liquid just showing in the gauge, it was possible to prevent the gas from being drawn off with the liquid. In order to keep the temperature in the fifth vaporiser as low as possible, the gas from the evaporating liquid in it was drawn off through the third and fourth heat exchangers by means of a powerful vacuum pump.

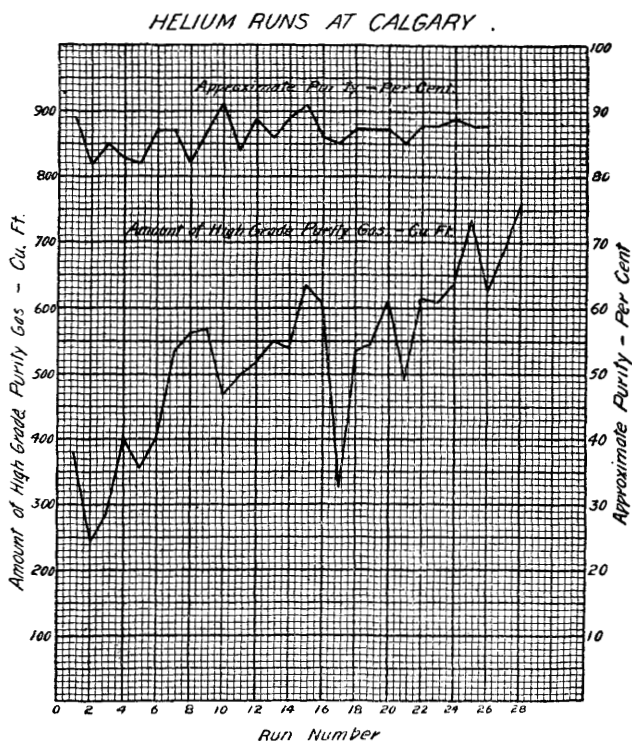
In operating with this machine, it was found that helium of

87 to 90 per cent. purity could be regularly and continuously produced.

Operations.

The experimental machine just described was used continuously for a series of trial runs from December 1st, 1919, to April 17th, 1920. The object of carrying out these trials was to gain as much knowledge as possible of the best running conditions. In the

FIG. 1.



course of the four months' operations, numerous small modifications were made in the apparatus. Losses due to leaks were stopped and valve regulation was greatly improved. As a result of the operations, a steady increase was made in the output of helium of high purity.

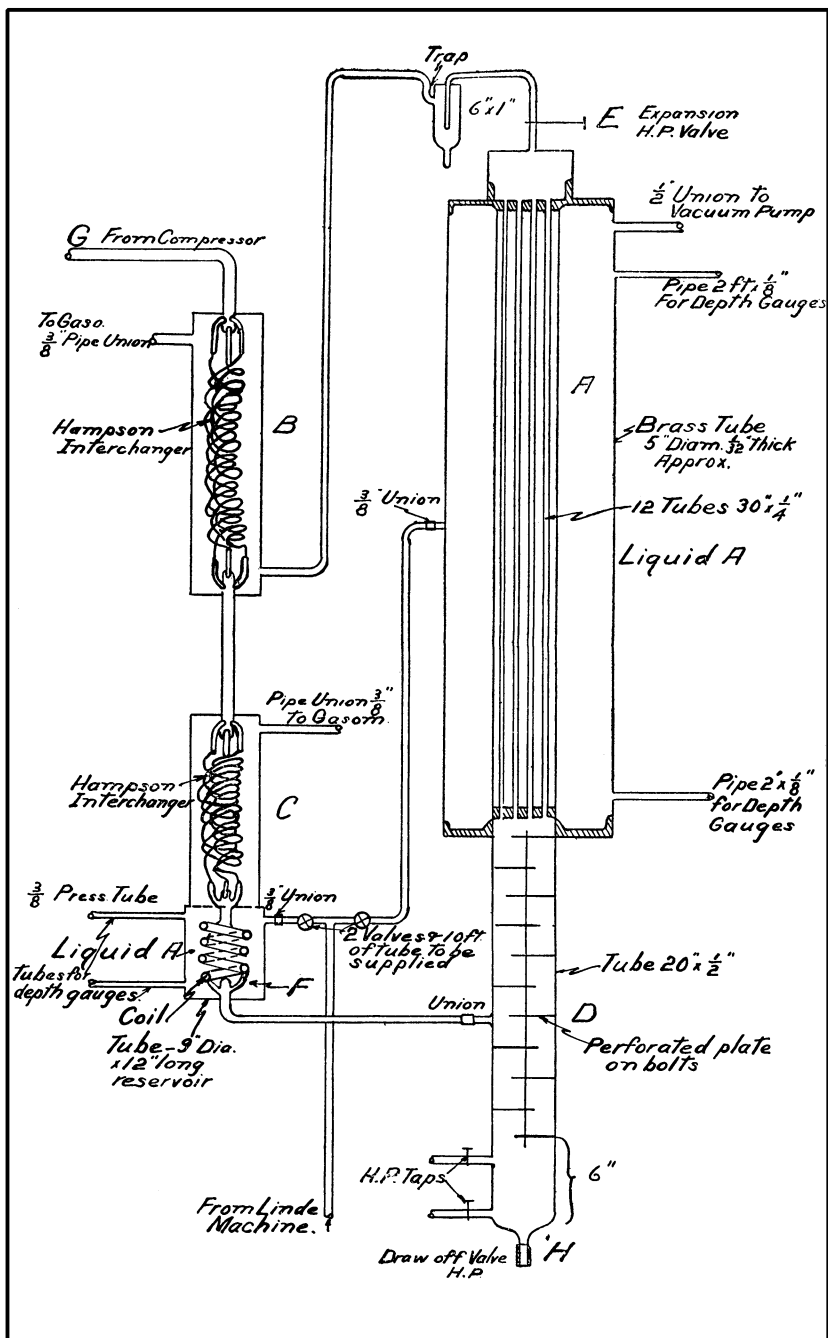
The trials were made in successive runs, as it was necessary to shut down at intervals to refill the desiccators with sodium hydroxide.

In making a run, about 500,000 cubic feet were passed through the machine, and from this amount upwards of 20,000 cubic feet of the gas, containing 5 to 6 per cent. of helium, was obtained. As this low-grade product was made it was stored in a large balloon, and the residual gas was passed back into the mains for use in the city of Calgary. The 5 to 6 per cent. product was compressed to from 20 to 30 atmospheres, and then passed through the fourth and fifth vaporisers, as described above. The amount of final product, of 87 to 90 per cent. purity, obtained in each run rose steadily in the course of the operations from about 300 cubic feet to more than 700 cubic feet per run. From this it will be seen that the efficiency obtained with each of the two operations was about 67 per cent. In special runs made under exceptionally good conditions, a still higher efficiency was obtained. One of the curves given in Fig. 1 shows that the purity of the high-grade final product was steadily maintained in the series of runs, and the other curve exhibits the steady increase made in the production of helium of high-grade purity.

High-grade Purification.

When it was seen that the highest purity obtainable with the experimental machine under actual running conditions was about 90 per cent., steps were taken to design and construct an auxiliary piece of apparatus for raising the purity of the gas up to 99 per cent. or higher. This apparatus is shown in Plate II. *A* and *F* were two receptacles which could be kept partly filled with liquid air or liquid nitrogen. In operating this piece of apparatus, a high vacuum was maintained in *A*, but the liquid in *F* was allowed to evaporate at atmospheric pressure. It was arranged that the gases from both receptacles could be conserved by collecting them in a gasometer, and so rendering them available for use over and over again in closed cycle by the auxiliary liquid air or liquid nitrogen machine. In order to obtain a product of very high purity with this apparatus, the gas containing 87 to 90 per cent. of helium was compressed to 100 atmospheres. It entered the apparatus at *G*, passed through the heat-exchanging coils in *B*, thence through a second heat exchanger in *C*, where it was cooled still further by the vapour from the liquid in *C*. From this it passed through a coil immersed in the liquefied gas in *F*, and thence into the rectification column, *D*. Thence it passed up through a set of tubes in *A*, where its temperature could be lowered to approximately -200° by the surrounding liquid and vapour. As shown in the diagram, the purified gas passed out through a high-pressure valve, *E*, and thence through the exchanger, *B*, to

PLATE II.



a gasometer, where it could be stored prior to being compressed into cylinders. All gases which were condensed in the tubes in *A* or in the column *D* could be run off at *H*. As the pressure of nitrogen is less than half an atmosphere at -200° , it was estimated that, by maintaining the gas containing 87—90 per cent. of helium at 100 atmospheres in the whole apparatus, the final product must necessarily have a purity of more than 99 per cent. As the apparatus was designed, it will be seen that it could be used, not only for obtaining a product of high purity at the works, but also for purifying helium which became contaminated with air by use in balloons in service. Through numerous delays experienced in obtaining delivery of tubing, liquefying equipment, etc., this purifying apparatus has not been given any more than a preliminary trial. From this, however, it is quite evident that it will prove satisfactory in operation. For the purpose of carrying out this scheme of high-grade purification, a liquid-air plant was installed by the University of Toronto. Motors and an electric current supply were furnished by the Hydro Electric Commission of Ontario, and a special financial grant was made by the Honorary Advisory Council for Scientific and Industrial Research of Canada to supplement that made by the Admiralty and the Air Board of Great Britain.

Final Design of Helium-extracting Apparatus.

From the foregoing it will be seen that every step in the production of high-grade helium has been carefully examined and tested. From the experience gained, we have been able to draw up specifications for a commercial plant which will enable one to treat the whole of the natural gas of the Bow Island supply in Alberta. The unit proposed will deal with about 1600 cubic metres or 56,500 cubic feet of gas per hour at normal pressure and temperature. At the altitude of Calgary, this would be equivalent to 62,200 cubic feet per hour. The machine would easily cope with 66,000 cubic feet per hour or 1100 cubic feet per minute. Of these machines, six would deal with 9,500,000 cubic feet of gas per day, and would thus take about the average daily supply available from the field, as based on records of the average yearly consumption. In order to have sufficient machines to operate regularly to capacity, it would probably be advisable to have eight helium columns included in the plant.

The cost of a commercial plant suitable for treating the whole of the supply of the Alberta field would probably be less than £150,000. The amount of helium of upwards of 97 per cent. purity obtainable per year from the field would be about 10,500,000

cubic feet. This is based on the assumption of an efficiency of 80 per cent., which experience has shown is obtainable. As to operating costs, our experience has shown that, allowing for interest on the investment, a ten years' amortisation, salaries, supplies, and running charges, helium can be produced at the Alberta field for considerably less than £10 per 1000 cubic feet. This sum does not, of course, include the cost of purchasing cylinders or of transporting them from and to the works. Neither does it include any compensation to the owners of the field for the supply of gas. The column as finally designed for the production of helium of approximately 97 per cent. purity is shown in Plate III. It is not drawn to scale, but it conforms on general lines to the standard oxygenen-nitrogen machines of L'Air Liquide Société. It consists of :

I. Two exchangers of temperature, one of which, Q , is shown, the two being so arranged that the flow of gas through them can be reversed, as is the present practice in the oxygen and nitrogen machines. The high-pressure gas is in the outer casing, and the return low-pressure gas in the small tubes; the heads are provided with three sections, so that the low temperature of the outgoing gases can be utilised.

II. A liquefier, R . This is the same as the liquefier in the standard machines, but it has only one of the returning gases flowing through it.

III. An expansion engine, S . This engine is of the standard type used in the oxygen and nitrogen machines.

IV. A first vaporiser and pot, U , T . This vaporiser, with pot for collecting liquid, is the same as on the standard nitrogen column.

V. A second vaporiser and pot, W , V . This vaporiser, with the pot, is similar to the second vaporiser now used on the standard nitrogen columns. It should be about one-third the size of the first vaporiser, U .

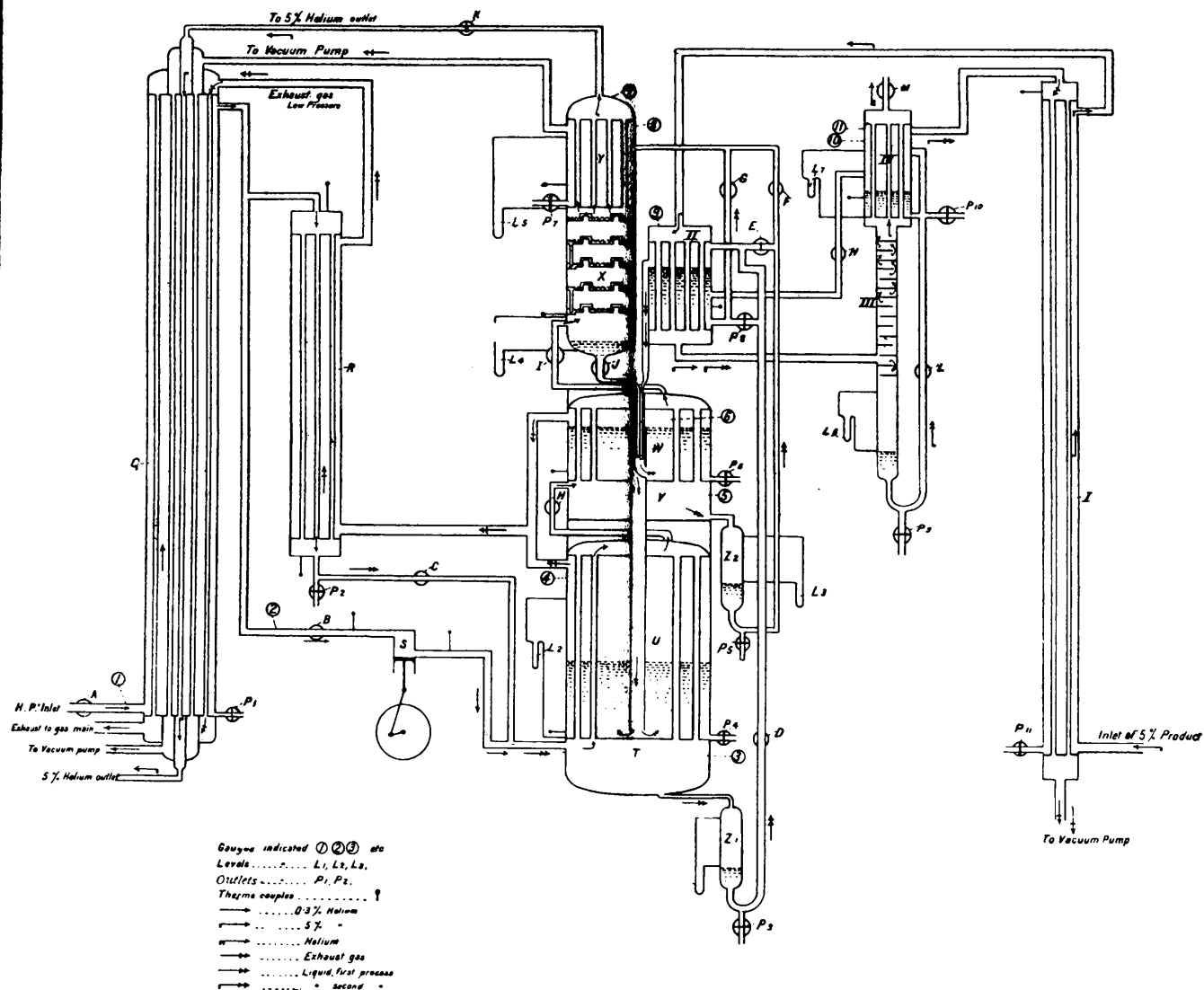
VI. A rectification column, X . This column should stand a pressure of 10 atmospheres and have a collecting basin at the bottom. Its diameter should be about three-eighths of that of the vaporisers U or W . Its length should not exceed 2 feet.

VII. A vaporiser, Y . The diameter of this vaporiser is the same as that of the rectification column, X , and its length should not exceed 2 feet. On this vaporiser, a partial vacuum is maintained.

VIII. Two collecting bottles, Z_1 , Z_2 .

IX. Two exchangers of temperatures, one of which, I , is shown. These are similar to Q , and should be reversible, but their capacity is only 6 per cent. of Q .

HELIUM COLUMN



X. A vaporiser, *II*. This vaporiser should be of the same size as *Y*, and the high-pressure side of it should stand a pressure of 50 atmospheres.

XI. A rectification column, *III*. This column should stand a pressure of 50 atmospheres, and should be about half the diameter of the column *X* and about 3 feet long.

XII. A vaporiser, *IV*. This should be similar to vaporiser *II*, but only half the diameter; on this vaporiser a partial vacuum is maintained.

XIII. The control valves are designated by letters from *A* to *N*, fourteen in all.

XIV. The outlets are designated by P_1 , P_2 , etc., eleven in all.

XV. The gauges are designated by the numbers in parenthesis, thus, (1), (2), etc., eleven in all.

XVI. The levels for showing the depth of liquid are designated by L_1 , L_2 , etc., seven in all.

XVII. The method of connecting up is shown in the figure.

The method of using the column is as follows.

The First Process.—(a) The compressed gas enters the exchangers, *Q*, through valve *A*, and, after passing out of the exchanger at the top, some of it goes through the liquefier, *R*, and the rest of it through the expansion engine, *S*, to the first pot, *T*. In *T* the pressure is about 4 atmospheres, and most of the gas is liquefied in the condenser, *U*. The uncondensed part passes through the valve *H* into *V*, where more of it is liquefied in the condenser, *W*. The still uncondensed gas flows through valve *I* to the bottom of the rectification column, *X*; it passes up through the column, through the condenser *Y*, where more of it is liquefied, and the rest, which now contains about 5 per cent. of helium, passes through valve *K*, where the pressure is reduced to nearly atmospheric, and it passes through the inner section of the exchanger to a gasometer.

(b) The liquid that collects in the pots *T* and *V* is drained into the bottles Z_1 and Z_2 , which are made fairly long, and the bottom limbs of the levels are about 6 inches from the bottom, so that it is possible always to keep liquid in the bottom of the bottles and prevent any uncondensed gas escaping. The liquids from the bottles Z_1 and Z_2 are passed through the valves *D* and *E*, respectively, into the vaporiser, *II*; in addition, the liquid from Z_2 can also be run into the vaporiser, *Y*, through valve *F*. The liquid in the vaporiser *II* overflows into the vaporiser *W*, and it overflows from *W* into the first vaporiser, *U*. Some of the liquid in the vaporiser *II* can be passed through the valve into *Y*. Liquid that condenses in *Y* flows down through the rectification

trays in *X*, and is passed through the valve *J* into the vaporiser *W*.

(c) The gases from the evaporating liquids in the vaporisers *U* and *W* pass directly back to the liquefier, *R*, and from the liquefier to the exchanger, *Q*, as shown in the diagram. The gas evaporated in vaporiser *II* flows with the liquid down into vaporiser *W*. The gas evaporating under vacuum in vaporiser *Y* passes out through the exchanger, *Q*, to the vacuum pump.

The Second Process.—(d) The gas containing helium drawn off in the first process through the valve *K* is re-compressed to 30 atmospheres, and passes through the exchanger *I* to the top of the condenser *II*; it flows down through *II*, where part of it is liquefied, and the liquid and gas pass into the rectification trays, *III*, to the collector at the bottom, the gas passing up through the column to the condenser *IV*, where the rest of the nitrogen is condensed, and the product, containing about 97 per cent. of helium, is drawn off through the valve *M*.

Notes on Special Points.

The vaporiser *Y* is the coldest part of the machine in the first process, owing to the liquid boiling under a partial vacuum. The liquid produced in the condenser runs down through the rectification trays in *X*, and the uncondensed gas from *W* passes up through it. Any helium and most of the nitrogen in the liquid will be recovered, and a large part of the methane in the gas will be condensed. Thus the product drawn off through *K* will contain very little methane.

In the second process, the gas containing 5 per cent. of helium under about 30 atmospheres pressure flows from the top to the bottom of the vaporiser *II*. This vaporiser is filled with the liquid produced in the first process, and is at the temperature of liquid methane (-163°). At this temperature, nitrogen condenses at about 12 atmospheres, and much of it is condensed. The liquid and gas both flow over a few trays, and the helium dissolved in the liquid would be recovered. The uncondensed gas flows up through the trays, and is cooled and partly condensed by the cold liquid from *IV*. The liquid is gradually warmed, and thus any helium in it will be recovered.

Miscellaneous Investigations.

In the course of the investigation on the development of a machine for extracting helium from natural gas, supplies of helium of varying degrees of purity became available. These were highly purified, and were used for the investigation of certain collateral

problems which demanded solution. Among the results obtained, it was found that for aeronautical purposes hydrogen could be mixed with helium to the extent of 15 per cent. without the mixture becoming inflammable or explosive in air. Mixtures containing even as much as 20 per cent. of hydrogen could be burnt or exploded only when treated in an exceptional manner. The permeability of rubbered balloon fabrics for helium was shown to be about 0.71 of its value for hydrogen. For skin-lined fabrics, the permeability to hydrogen and helium was about the same. Thin soap films were found to be about one hundred times more permeable to hydrogen and helium than rubbered balloon fabrics, but untreated cotton fabrics when wetted with distilled water were but feebly permeable to these gases. It was found that rapid estimations of the amount of helium in a gas mixture could be made with a pivoted silica balance, a Shakspear katharometer, or a Jamin interferometer.

The latent heats of methane and ethane have been determined, as has also the composition of the vapour and liquid phases of the system methane-nitrogen. It has also been shown that helium containing as much as 20 per cent. of air, oxygen, or nitrogen can be highly purified in large quantities by simply passing it at slightly above atmospheric pressure through a few tubes of coconut charcoal kept at the temperature of liquid air. In the spectroscopy of the ultraviolet, helium has been found to be exceptionally useful. Arcs in helium between tungsten terminals can be easily established and maintained. In a particular investigation with a vacuum grating spectrograph, it was found that by the use of arcs in helium under 30 cm. pressure, illumination could be maintained continuously for hours, and with such arcs spectra could easily be obtained extending to below 1000 Å.U.

Although it is known that free electrons can exist in highly purified helium to an amount easily measurable, it was found that pure helium under a pressure of more than 80 atmospheres did not exhibit anything in the nature of metallic conduction. Moreover, the mobilities of both positive and negative ions formed by α -rays in helium under this high pressure were found to have about one-third the value expected on the basis of an inverse pressure law.*

* The following is a list of the papers which deal with the subjects mentioned: (1) "Report on some sources of Helium in the British Empire" (McLennan, *Bulletin No. 31, Mines Branch, Department of Mines, Canada*, 1920). (2) "The Estimation of the Helium Content of Gases by the use of a Katharometer" (Murray, *Trans. Roy. Soc., Canada*, 1919, 27). (3) "The Use of the Jamin Interferometer for the Estimation of small amounts of

The Uses of Helium.

The investigation into the problem of producing helium in large quantities was originally undertaken with a view to the utilisation of the gas in aeronautical warfare. The investigation has shown that it can be produced at a cost which is not excessive, but it has also been shown that from the sources in the Empire which are known and have been examined, the supply of helium cannot be greater than about 12,000,000 cubic feet per year. This quantity clearly would be sufficient to keep only a very few of our airships of the larger type in commission, even if the gas were diluted to the extent of 15 per cent. with hydrogen. This amount would, however, suffice to keep a number of the smaller aircraft supplied. Moreover, it might be used to fill fireproof compartments adjacent to the engines if it were ever decided to instal these within the envelopes of our larger airships.

Since it has been demonstrated that helium can be produced in quantity, one is led naturally to consider in what directions one can hope to use the gas other than that originally intended. In industry it may be used as a filling for thermionic amplifying valves of the ionisation type. It may also be used for filling tungsten incandescent filament lamps, especially for signalling purposes where rapid dimming is an essential, and for producing gas arc lamps in which tungsten terminals are used, as in the "Pointolite" type. Both of these varieties of lamps possess the defect, however, of soon becoming dull owing to the ease with which incandescent tungsten volatilises in helium, and deposits on the surface of the enclosing glass bulbs. As regards illumination, helium arc lamps possess an advantage over mercury arc lamps in that the radiation emitted has strong intensities in the red and yellow portion of the spectrum.

Helium or Hydrogen in Air" (McLennan and Elworthy, *ibid.*, p. 19). 4) "The Permeability of Balloon Fabrics to Hydrogen and Helium" (Elworthy and Murray, *ibid.*, p. 37). (5) "Composition of the Vapour and Liquid Phases of the System Methane-Nitrogen" (McTaggart and Edwards, *ibid.*, p. 57). (6) "A Continuous Flow Apparatus for the Purification of Impure Helium Mixtures" (Edwards and Elworthy, *ibid.*, p. 47). (7) "On the Combustibility of Mixtures of Hydrogen and Helium" (Satterly and Burton *ibid.*, p. 211). (8) "On the Latent Heats of Methane and Ethane" (Satterly and Patterson, *ibid.*, p. 123). (9) "On the Mobilities of Ions in Helium at High Pressures" (McLennan and Evans, *ibid.*, 1920). (10) "On the Permeability of Thin Fabrics and Films to Hydrogen and Helium" (McLennan and Shaver, *ibid.*). (11) "Spark Spectra of Various Elements in Helium in the extreme Ultra-violet" (McLennan and Lewis, *ibid.*). (12) "Arc Spectra in vacuo and Spark Spectra in Helium of Various Elements" (McLennan, Young, and Ireton, *ibid.*).

It has been shown by Nutting (*Electrician*, March, 1912) that Geissler tubes filled with helium are eminently suitable, under certain conditions, for light standards in spectrophotometry, but the amount of the gas which could be used in this way is very small.

In spectroscopy, especially for investigations in the ultra-violet region, helium is invaluable. Doubtless its use in this field will be rapidly extended. The use of the gas in physical laboratories generally, and especially where certain investigations on the properties of matter are carried out, will also be greatly increased.

It has recently been proposed to use helium in place of oil for surrounding the switches and circuit-breakers of high-tension electric transmission lines. If the gas should prove suitable for this purpose, large quantities could be utilised, but it has yet to be demonstrated (and it is not clear that it can be) that in this field helium possesses any advantage over the oils now used.

It has been suggested by Elihu Thomson and others that if divers were supplied with a mixture of oxygen and helium, the rate of expulsion of carbon dioxide from the lungs might be increased, and the period of submergence as a consequence be considerably lengthened.

It is probable, however, that in the field of low temperature research helium will immediately find its widest application. For this work, helium is unique in that, when liquefied and possibly solidified, it enables one to reach the lowest temperatures attainable. Every effort should be directed towards the exploitation of its use in this direction.

One point that is important and should not be overlooked is that the supplies of natural gas from which helium can be extracted are being rapidly used up. When our natural gas fields are depleted, it would appear that our main source of supply of helium will have disappeared. Careful consideration should, therefore, be given to the problem of producing helium in large quantities while it is still available, and of storing it up for future use. As already stated, it may be that in the future it will be of paramount importance to have even a moderate supply of the gas available.

A Cryogenic Laboratory.

To chemists and physicists especially, the discovery that helium can be produced in quantity at a moderate cost opens up a vista in the realm of low temperature research of surpassing interest. By means of liquid oxygen, the properties of substances can be studied down to a temperature of -182.5° . Liquid nitrogen provides us with a temperature of -193.5° , and hydrogen, which was

originally liquefied in 1898 by Sir James Dewar, enables us to reach -252.8° . It is but a few years since Onnes, after prolonged effort, secured sufficient helium to enable him to liquefy this gas too. In a brilliantly conceived research, he succeeded in accomplishing this feat in 1908, and in doing it reached a temperature within approximately 1° or 2° of the absolute zero.

The amount of liquid helium which Onnes obtained in his investigation was small, but it sufficed to enable him to show that a number of the elements possessed a remarkable "super-conductivity" at this low temperature. Mercury in particular, at the temperature of liquid helium, possessed an electrical conductivity ten million times greater than at ordinary room temperature, and currents started by induction in a coil of lead wire at the temperature of liquid helium maintained their intensity for more than an hour with but little diminution in magnitude.

The results obtained by Onnes, although limited in number, are of great importance, for they show that if liquid helium were rendered available in quantity, fundamental information of the greatest value on such problems as those connected with electrical and thermal conduction, with specific and atomic heats, with magnetism and the magnetic properties of substances, with phosphorescence, with the origin of radiation, and with atomic structure, could be obtained.

In spectroscopy, supplies of liquid helium would enable us to extend our knowledge of the fine structure of spectral lines, and thereby enable us to obtain clearer ideas regarding the electronic orbits existing in the atoms of the simpler elements. This would lead naturally to clearer views on the subject of atomic structure generally.

In other fields, too, important information could be obtained by the use of temperatures between that of liquid hydrogen and that of liquid helium. What of radioactivity? Would this property be lost by uranium, thorium, radium, and other similar elements at temperatures attainable with liquid helium? Would all chemical action cease at these temperatures? Would photochemical action disappear completely? Would photoelectric action cease or be maintained at such low temperatures?

In the fields of biological and botanical research, information on problems pressing for solution could be gained also. For example, would all life in spores and bacteria be extinguished by subjecting them to temperatures in the neighbourhood of absolute zero?

The list of problems rendered capable of attack by the use of liquid helium might be easily extended; but those cited already

will serve to show that the field is large, and that it is well worth while for us to make a special effort to secure adequate financial support for the equipment and maintenance of a cryogenic laboratory within the Empire.

It is probably beyond the ordinary resources of any university to equip and maintain such a laboratory; but the project is one which merits national and probably imperial support. It should appeal to private beneficence as well, for it is a project deserving strong and sympathetic help.

A properly equipped cryogenic laboratory should include:

- (1) A liquid-air plant of large capacity.
- (2) A liquid-hydrogen plant of moderate capacity.
- (3) A liquid-helium plant of small capacity.
- (4) Machine tools, cylinders, glass apparatus, measuring instruments, etc.

Such an equipment would probably cost more than £10,000.

For building purposes, probably an additional £10,000 or £15,000 would be required.

The staff should include one or two skilled glass-blowers, two or three mechanics and instrument makers, and two or three helpers for running the machinery. To provide this staff and meet charges for light, heat, and power, probably £3,000 a year at least would be needed.

For an administrative and technical staff, probably £2,500 would be necessary.

In addition to the above, special provision would have to be made to secure an adequate supply of helium. If industrial uses can be found for helium and a works were established in Alberta for the production of helium on a large scale, the problem of supply would be solved, for the amount of the gas which would be required for low-temperature research would probably not be more than 20,000 or 30,000 cubic feet a year. In default of a production-works on a large scale being established, it would be necessary to instal a small plant at Calgary for the specific purpose of supplying the cryogenic laboratory with helium. This could easily be done at the present time, as the experimental plant is still in situ. It would require from £3,000 to £4,000 to make the changes in the plant which experience has shown are necessary and to provide the additional auxiliary machinery, tools, etc., required.

If this plant were run for three or four months each year, an adequate supply of helium could be obtained. The expense of running the plant under these conditions would be high, and it would probably be found that it would require from £2,000 to

£3,000 to operate it for a period of three or four months each year. This amount would, of course, have to cover charges for salary of staff, compensation to the owners of the natural gas, light, power, miscellaneous supplies, freight charges on cylinders, etc.

From the above it will be seen that a scheme such as that outlined would require in the aggregate a capital expenditure of about £30,000 for buildings and plant, and the interest on an endowment of about £125,000 for operating and maintaining the cryogenic laboratory together with the supply station.

If a cryogenic laboratory, with its auxiliary supply station, were established along the lines indicated, it would probably be found to be more economical to run the supply station continuously for a number of years, and to store for future use the helium accumulated. In this connexion it should be stated that the experimental plant as it exists would probably not produce more than 100,000 cubic feet of helium per year. The plant could, however, be easily manifolded, and the Governments of Great Britain and Canada might, from the point of view of national safety, legitimately be asked to assume responsibility for operating it.

Much of our knowledge acquired in the field of low temperature research we owe to the brilliant work of such distinguished men as Andrews, Davy, Faraday, and Dewar. The discovery of the rare gases, helium, neon, argon, krypton, and xenon, we owe to Rayleigh, Ramsay, and Dewar. How could we more fittingly perpetuate the work of these great men than by establishing on a permanent basis a cryogenic laboratory for the purpose of making still further progress in the field of low-temperature research—a field in which British scientists have made such brilliant and notable advances?

In conclusion, it should be stated that whilst the investigation just described was financed by the British Admiralty, and in its later stages by the British Air Ministry, valuable assistance was given by L'Air Liquide Société of Paris and Toronto, by the Canadian Pacific Railway Co. of Canada, by the Hydro-Electric Commission of Ontario, and by the University of Toronto. In carrying out the collateral investigations, valuable help was given by Professors E. F. Burton, J. Satterly, H. F. Dawes, and H. A. McTaggart. To Mr. J. Patterson, M.A., whose services were lent by the Director of the Meteorological Office of Canada, much credit is due for working out details of design and construction in connexion with the production of the rectifying column. Mention should also be made of the creditable manner in which the

experimental plant was handled during the trial runs made between December 1st, 1919, and April 17th, 1920, by Mr. R. J. Lang, assisted by Mr. D. S. Ainslie and Mr. H. R. Foreman.

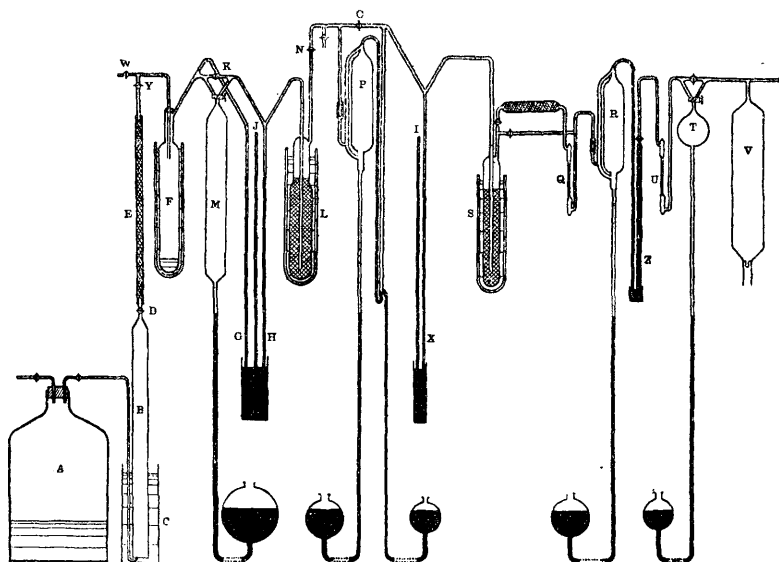
APPENDIX A.

Determinations of Helium Content of Natural Gases.

In determining the helium content of a sample of natural gas, the following procedure was adopted, and the apparatus used is shown in Fig. 2.

A is a glass bottle in which the gas was brought from the field. The gas was forced from *A* into the glass tube *B*, where it collected

FIG. 2.



by water displacement. The capacity of *B* was adjusted to be 1200 c.c. under ordinary conditions of temperature and pressure. The gas was introduced into the apparatus in units of this volume. Before commencing the analysis the charcoal tubes were strongly heated by electric heaters to about 300° to expel absorbed gases, and the whole of the apparatus to the right of the tap was carefully exhausted. All the taps were then turned off. The charcoal on cooling absorbed the remainder of the gas in apparatus, and a good vacuum resulted.

On turning the taps *D* and *Y*, the gas flowed from *B* through a drying tube *E* containing calcium chloride into the condenser *F* of about 400 c.c. capacity, which was immersed in liquid air kept in a Dewar's tube. Condensation of the hydrocarbons occurred at once, the liquid air boiling off rapidly. Comparison of the manometer *G* with the barometer *J* gave the pressure of the uncondensed gases in *F* plus the vapour pressure of the condensed gases.

Usually *B* was filled and emptied five times in quick succession, so that the first charge in *F* was 6000 c.c. of natural gas. After some minutes when the liquid air had ceased from boiling and the manometer was at rest the pressure in *F* was read. Subtracting from this reading the vapour pressure of methane at the temperature of liquid air, we get the pressure of the uncondensable gases in *F*, and knowing the volume of *F* it is an easy matter to find approximately the percentage of uncondensable gases in the sample of natural gas. This analysis, rough though it was, gave useful information as to the suitability of the natural gas for the manufacture of helium on a large scale.

Meanwhile, the tube *L*, of about 300 c.c. capacity, which was full of finely broken cocoanut charcoal, had been immersed in liquid air.

The tap *K* was then opened and the uncondensed gas shared between *F* and *L*. The mercury in the gauge rose quickly, and the liquid air surrounding *L* boiled vigorously, indicating a rapid evolution of heat when the gases are absorbed by charcoal. This was especially noticeable the first time the charcoal was used after being heated. When the gauges were nearly at the same level, *K* was closed, and the remainder of the uncondensed gas in *F* transferred to *L* by means of the large mercury pump *M*. This pump was simply a long wide tube with a two-way tap at the top and a flexible tube and mercury reservoir at the bottom. It was very efficient, and after about five strokes practically all the gas had been transferred to *L*, the pressure in *F* falling to about 3 or 4 cm. The transfer of the gas was especially complete, since at each expansion of the matter in *F* some of the liquid methane would evaporate and sweep out the gas; an excess of pumping is detrimental, as it only transfers methane to *L*, thus tending to clog the charcoal. On standing, the pressure in *L* slowly decreased as absorption reached its maximum amount. Usually, very little except the helium was left unabsorbed in this tube.

When the reading of the gauge *H* was steady, the taps *N* and *O* were opened and the unabsorbed gas was allowed to diffuse over to a second charcoal tube *S* of about 200 c.c. capacity, which was also cooled in liquid air. The tap *O* was then closed, and com-

plete transference of the gas was effected by a mercury pump P of special design. In the early days of the experiment the pump in this position was of the same type as M , but the working and cleaning of the two-way tap proved inconvenient, and it was replaced by the pump shown.

While these operations had been going on any gas left in the apparatus between taps above S and the delivery tube was completely pumped out by the pump R , exhaustion being carried to such an extent that the electric charge had great difficulty in passing through the tube Q .

The gas having remained in the second charcoal tube S for some time and the gauge X attached to this tube having become steady, the taps above S were opened and the gas was pumped through the discharge tube and delivered to the collector Z , which was improvised from a graduated eudiometer by the placing of a tap at the closed end. The phosphoric oxide tube placed to the right of S was only required in the early stages of the experiment, when the charcoal gave off water on heating. A by-pass was placed in between S and the pump R to facilitate the action of the pump.

Before the gas was pumped off, its spectrum was carefully examined by a small, direct-vision spectroscope, and if any but the lines of helium (and mercury) were found, the gas was returned to the charcoal tube, or, in the case of great impurity, exhausted to the air and a fresh start made on a smaller quantity of the original gas. For example, if the natural gas contained large quantities of nitrogen and hydrogen, these may escape absorption, and their presence would be detected at this stage.

The gas obtained in the collector Z was invariably pure helium, and from the readings of its volume and pressure, the volume at atmospheric pressure was calculated.

Tubes similar to V were used for storage, and the pump T was designed to transfer the helium collected in Z over to V until the latter was filled at atmospheric pressure. The tube and pump had previously been exhausted by a mercury pump and a charcoal tube in liquid air (not shown in the figure), and then sealed off just to the right of V .

In making accurate determinations of the helium content of a natural gas, it was found necessary to use, for displacement purposes only, water which had been freed by boiling from occluded air and other gases. Ordinary tap-water or water from rivers was generally found to contain sufficient quantities of air to invalidate the determinations if high accuracy was demanded.

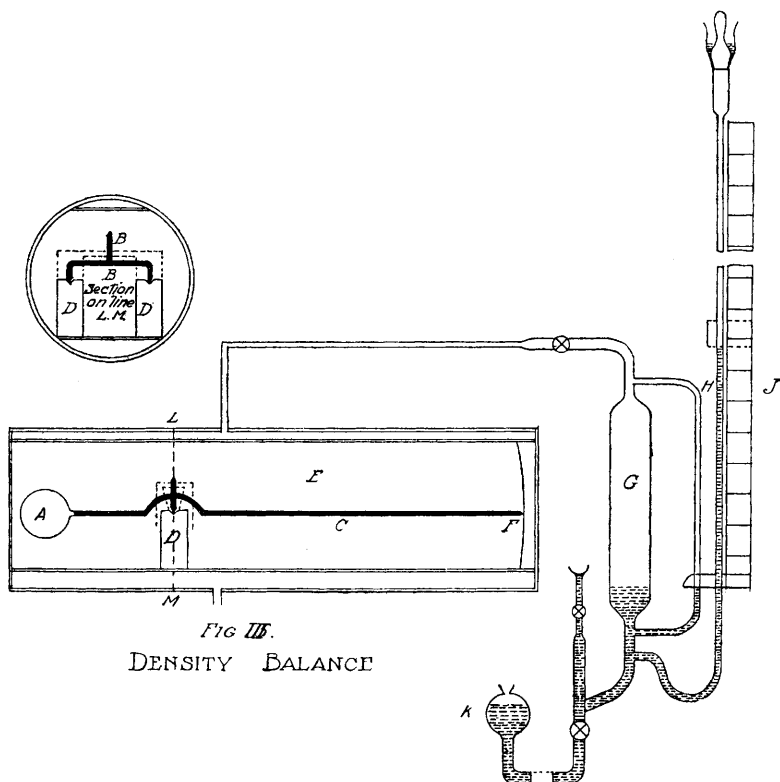
APPENDIX B.

Density Determinations by Balance Method.

For rapid and accurate determinations of gas density, the use of a delicately pivoted silica balance was found to be invaluable.

This type of balance was originally designed and used by Aston

FIG. 3.



(*Proc. Roy. Soc.*, 1913, [A], **89**, 439). A quartz micro-balance of exceedingly high sensitivity had been designed by Steele and Grant (*ibid.*, 1909, [A], **82**, 580), and used by Gray and Ramsay (*ibid.*, 1910, **84**, 536) at an earlier date, and Taylor (*Physical Rev.*, 1917, [N.S.], **10**, 653) has recently published an account of a form of the instrument which enabled him to determine with great exactness the density of helium. Aston's form of the instrument was, however, found to be the most suitable for our purposes. One

method of using the instrument has been described already by R. T. Elworthy (*Bulletin No. 31, Mines Branch, Dept. of Mines, Canada, 1920*), and a second, which has been found very useful, has been worked out for the present investigation by Mr. John Patterson, M.A. It is shown in Fig. 3.

The density balance consisted of a quartz bulb, *A*, 1.25 cm. in diameter, and an arm, *C*, about 10 cm. long, mounted on a rocking arm, *B*. The two points of this arm rested on jewels, and the arm had a protecting case around it, as shown by the dotted lines, so as to prevent the balance from getting out of the jewels. The end of the arm, *C*, was turned at right angles and moved along a scale, which could be easily read to 0.1 mm. In most forms of this instrument, the pressure in the density chamber is adjusted by either exhausting or admitting the gas very slowly until the correct pressure is obtained. This is usually a very troublesome operation, and to overcome it, a reservoir, *G*, was attached to the chamber, which permitted the pressure to be altered by simply raising or lowering the mercury reservoir. The reservoir was provided with a manometer, *H*, with a scale, the zero of which could be set on the lower limb of the manometer and the pressure read directly to 0.1 mm. The manometer, *H*, could be used either for pressures less than atmospheric, in which case the tube, *H*, was free of air, or for pressures greater than an atmosphere, when the seal at the top is taken out. The balance could be calibrated for a standard gas, such as air, by plotting pressures against the scale reading. Then, to obtain the density of a gas, all that was necessary was to wash out the density chamber thoroughly and take two or three readings at different parts of the scale. From these, the relative density could be determined at once. It was not necessary by this method to adjust the pressure until the indicating point was at a fixed position. A reading correct to two decimal places could be obtained with this instrument in about five minutes. The temperature of the air used for calibrating the balance should, of course, be known, and then, if the other determinations were made at a different temperature, a correction could be applied.