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BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

PETROLEUM INVESTIGATIONS

AND

PRODUCTION OF HELIUM

ADVANCE CHAPTER FROM BULLETIN 178
WAR WORK OF THE BUREAU OF MINES

BY

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CONTENTS.

of fuel oil, kerosene, long-time burning oil, signal oil, and "mineral seal oil," and is considering specifications for lubricants, particularly those used by the Railroad Administration.

The investigations relating to specifications for petroleum products were conducted by Messrs. Naramore, Perdew, Hill, and Beal.

INVESTIGATIONS OF AIRPLANE-MOTOR FUELS.

About August 2, 1917, the bureau arranged to cooperate with the Aviation Section of the Signal Corps in studying fuels for airplane engines. Information collected through visits to a number of aviation fields, by conferences with organizations testing airplane motors, and by correspondence indicated that no reliable data were available regarding the proper fuel for aviation motors. This work was done by E. W. Dean, petroleum chemist.

TESTS WITH DIFFERENT FUELS AND ENGINES.

The bureau arranged with the engineers at Langley field to make some actual flying tests to ascertain the advantages of certain grades of gasoline. Flying tests with Curtis training planes, indicated that plain "motor" gasoline gave as good results as a "high test" Pennsylvania product. The Italian fliers at Langley reported, however, that their engines tended to overheat when "motor" gasoline was used. The tests were made by C. Netzen, chemical engineer, and E. W. Dean.

After it was seen that the problem was what increase in efficiency would be possible through improved design if the fuel were better, an arrangement was made with the officials of the McCook aviation field and with the reseach organization of the Dayton-Wright Airplane Co. to cooperate in thorough tests of different engines and gasolines. This work included tests with a small air-cooled high-compression engine, tests with a single-cylinder high-compression Liberty engine, the preparation of special fuels (including cyclohexane), flying tests at the Dayton-Wright and Wilbur Wright fields with De Haviland airplanes equipped with Liberty motors, and tests in the altitude chamber of the Bureau of Standards.

Many interesting and important facts were learned. The general conclusion was that a mixture of 70 per cent cyclohexane and 30 per cent benzol (so-called "hecter") seemed the most desirable for use in fighting airplanes. This fuel permitted the use of engines having compression ratios as high as 7.5 to 1, which applied to the Liberty motor would develop perhaps 10 per cent more power.

The cessation of hostilities prevented the development of commercial cyclohexane plants. Flying tests at the Wilbur Wright field, completed after the signing of the armistice, showed that the use of a high-compression motor with cyclohexane as fuel gave a standard De Haviland No. 4 airplane a full thousand feet extra of "ceiling" (maximum flying altitude).

The investigation of aviation gasoline was conducted chiefly by Clarence Netzen and J. P. Smootz, assistant petroleum technologists.

COOPERATIVE TESTS WITH BUREAU OF STANDARDS.

It was realized soon after this country entered the war that ordinary motor gasoline was not suitable for use in airplanes, particularly at high altitudes. The Bureau of Standards constructed an altitude chamber for testing airplane engines under conditions similar to those encountered at various altitudes from sea level to 30,000 feet. Different types of fuels were tested to determine which were most satisfactory at high altitudes. The Bureau of Mines coöperated by collecting samples of various grades of gasoline, special fuel mixtures, and close-cut gasoline. In April and May, 1918, arrangements were made with the Atlantic Refining Co. and the Union Oil Co. of California to make special close-cut gasoline with a boiling range of 10° C. if possible. A special fuel was made from absolute alcohol and gasoline, the absolute alcohol and a blend of gasoline and benzol being prepared in the Washington laboratory of the Bureau of Mines. All the fuels, about 100 samples, tested by the Bureau of Standards in airplane engines were submitted to distillation tests in that laboratory. W. E. Perdew collected the samples; C. P. Bowie and M. J. Gavin, assistant refinery engineers, assisted in obtaining gasoline cuts from the Union Oil Co. of California.

ADVICE ON GASOLINE PROBLEMS.

Considerable time was spent in advising the oil division of the Fuel Administration on problems particularly relating to tests and manufacture of gasoline. At the request of Mr. Requa, director of the oil division, a report was prepared on the potential production of airplane gasoline in the United States. This report, made by H. H. Hill with the assistance of E. W. Dean and J. P. Smootz, showed that the maximum estimated requirement could be met if the use of gasoline for motor cars was restricted.

SUPPLEMENTARY INVESTIGATIONS IN CONNECTION WITH AIRPLANE FUELS.

In some airplane engine tests at the McCook field aluminum pistons were seriously corroded. Investigation showed that the corrosion was not caused by impurities in the fuel and could be controlled by lubrication. The corrosion tests were made by Messrs. Netzen and Smootz.

Two samples of German airplane gasoline, analyzed at the Pittsburgh laboratory of the bureau by H. H. Hill, proved to be petroleum gasoline, carefully refined.

Samples of gasoline from Borneo and from Sumatra were found to be suited for aviation fuel. The analyses were made by Mr. Hill and by N. A. C. Smith, assistant petroleum chemist.

INSPECTION OF OVERSEAS SHIPMENTS OF GASOLINE.

In the latter part of July, 1918, a report was received in this country that some gasoline shipped in May, 1918, had given trouble in airplane engines in France, and that the loss of a number of planes had been attributed to its use. In a letter dated August 1, 1918, Col. U. G. Lyons, of the Fuel and Forage Division of the War Department, requested the Bureau of Mines to furnish inspectors for testing all shipments of gasoline.

Details were arranged at a conference between Col. Lyons and H. H. Hill in New York, August 26, 1918. C. R. Bopp was assigned to the task and spent practically his entire time from August 25 to December 1, 1918, inspecting shipments of gasoline for service overseas, from the Atlantic Refining Co., Philadelphia; Gulf Refining Co., Philadelphia; and the Standard Oil Co. of New Jersey; and the Tidewater Oil Co., Bayonne, N. J. Mr. Bopp inspected shipments representing 8,000,000 gallons of motor gasoline, 2,600,000 gallons of export aviation gasoline, and 725,000 gallons of fighting gasoline. W. G. Hiatt inspected at Gulf ports 55,000 barrels of motor gasoline for the American Expeditionary Forces.

EFFICIENCY IN RECOVERY OF GASOLINE FROM NATURAL GAS.

The attention of oil men was called to the feasibility of treating natural gas of any gasoline content, however small, at any pressure by the absorption process. As tests of the residual gases from compression plants showed incomplete recovery of gasoline vapors, the bureau pointed out that the gasoline in the residual gas can be saved at small cost by an auxiliary absorption unit.

Through the bureau's efforts companies recovering gasoline from natural gas by compression have come to realize the waste of gasoline in the gases discharged from water-cooled coils, and have put in compression or absorption units to save this gasoline. The average loss in the gas being discharged from the plants examined was about 0.3 gallon per 1,000 cubic feet. In one plant the adoption of recommendations by bureau engineers effected a saving equivalent to $120 a day.

The investigations of absorption and compression plants were conducted by W. P. Dykema, assistant petroleum engineer, aided by R. O. Neal, assistant chemical engineer.

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COLLECTION AND DISSEMINATION OF DATA ON THE REFINERY INDUSTRY.

In the fall of 1917 maps showing the oil fields of the United States, storage centers, refinery capacity, and consumption statistics were prepared for the Fuel Administration by H. F. Mason, petroleum economist.

During the summer of 1917 a census of the refineries of the United States was made in order to determine the status of the refining industry, and to furnish the War and Navy Departments with reliable information as to the consumption of crude oil and the output of gasoline, kerosene, and other products. Practically every refinery was visited. The figures thus obtained were grouped according to districts in a report compiled at the Washington office. Messrs. Bowie, Tough, Beal, Wadsworth, Netzen, Hill, Jacobs, and Wiggins were engaged in this work.

After the United States Fuel Administration was established, the petroleum division of the Bureau of Mines, by request, continued to compile monthly statistics of the refining industry. The work was in charge of Mr. Mason.

On account of the value of petroleum coke in the electrode business and in the production of caustic soda and chlorine, a census of the manufacturers and the production of that commodity was made by Mr. Mason in December, 1917.

On account of the possible shortage of ammonia during the summer of 1918, estimates were prepared by Mr. Mason, in May, 1918, for the Fuel Administration, as to the amount of ammonia the oil refineries would need for the year. Mr. Mason made a similar investigation of the sulphuric acid used in the oil-refining industry for the first seven months of 1918. Also, he prepared other special reports for the Fuel Administration.

In September, 1917, a report on the supply of fuel oil available for naval purposes was prepared for the Shipping Board by J. H. Wiggins. A report was prepared in cooperation with members of the United States Geological Survey for the Council of National Defense, giving a resumé of the condition of the petroleum industry during April and May, 1917, especially as regards the supply of and the demand for crude petroleum.

A map and report showing the gasoline storage facilities in the United States was prepared for the Signal Corps in August, 1918, by Mr. Wiggins. He also prepared a report for the War Department in February, 1918, giving comparative data on costs, labor, etc., for transporting gasoline by pipe line and tank car in France.

In March, 1918, a map showing the oil fields of the world and their production was prepared for the United States Fuel Administration by A. W. Ambrose.

In January, 1918, C. H. Beal and A. W. Ambrose, in cooperation with members of the Geological Survey, prepared for the Shipping Board a report dealing with the need for Mexican oil in this country.

ESTIMATING FUTURE PRODUCTION OF OIL AND GAS, AND APPLICATION TO WAR REVENUE TAXATION.

Three months were spent in cooperative work with the Bureau of Internal Revenue on methods for estimating depletion charges in determining excess profits and income taxes for oil and gas properties. Because of the difficulties involved, no satisfactory method had been worked out and no final settlement of taxes on oil and gas properties had been made for three years. The method adopted by the Bureau of Internal Revenue was based on the methods devised by C. H. Beal and J. O. Lewis, petroleum engineers of the Bureau of Mines. Mr. Lewis had charge of the compilation of curves and data for the Mid-Continent oil fields, and Mr. Beal for the fields of California. A. R. Elliott assisted in compiling curves for the report. The principles adopted should benefit the petroleum industry and enable the Treasury Department to compute depletion allowances by an easy and equitable method.

During 1918, reports were prepared from time to time for the Capital Issues Committee on the issuance of stock by oil companies. For many of the properties a detailed field investigation and a thorough search of all available literature were required. Messrs. Dykema, Beal, and Ambrose conducted this work.

ESTIMATE OF COST OF GAS FOR NAVAL ORDNANCE PLANT.

The Navy Department requested the United States Geological Survey to prepare a report on the amount of gas available for the armor-plate plant to be constructed at Charleston, W. Va., and asked the Bureau of Mines to estimate the cost of producing the gas and of piping. The request to the Bureau of Mines was made about November 10, 1917, by Rear Admiral Ralph Earle, chief of the Bureau of Ordnance of the Navy.

A detailed estimate was made of the cost of drilling, of laying pipe, and of installing a compression plant for gas from the properties described by the Geological Survey, the cost of the gas being based on the survey's estimate of the volume. The report was made December 18, 1918, by Messrs. Wiggins and Dykema.

In September and October, 1918, at the request of the Secretary of the Navy, through Rear Admiral Earle, a report was made by R. V. Mills, petroleum technologist, and A. R. Elliott, assistant engineer, on the gas property from which it was proposed to furnish gas to the naval ordnance plant near Charleston.

VALUATION OF OIL PROPERTIES IN THE NAVAL PETROLEUM RESERVES.

In a letter dated January 18, 1918, Hon. Scott Ferris, chairman of the House Public Lands Committee, requested Secretary Lane to supply certain information on the petroleum industry. One of the most important and difficult questions asked was the value of the oil properties in the naval reserves. The information was compiled during February, 1918. The appraisal of the lands was made by Messrs. Beal and Ambrose.

EFFICIENCY IN DEVELOPMENT OF CALIFORNIA OIL FIELDS.

At the request of the Fuel Administration an investigation was made to determine the possibility of maintaining and of increasing the production of oil in California by drilling promiscuously, as in the past, and by drilling at selected locations, without encroaching upon the naval petroleum reserves. At that time the outlook was that the production of oil in California would have to increase to meet the war demand, and the only practicable way of doing this was to drill in selected localities where the maximum amount of oil could be obtained with the least labor and cost.

The work was done during April and May, 1918, by Messrs. Beal and Ambrose, with the assistance of R. E. Collom, chief deputy State oil and gas inspector of the California State Mining Bureau.

CENSUS OF OIL-WELL CASING.

The War Trade Board requested the Bureau of Mines to furnish information as to whether exports of oil-well casing should be restricted. A census of the amount of casing in reserve in the different oil fields of the country was begun about December 20, 1918, and lasted until February 1, 1919. Oil-pipe companies gave information as to past and probable future demand, past and estimated future production, and amount on hand of all kinds of casing. A careful study of the foreign oil fields was included as it was necessary to provide pipe for those fields that were supplying petroleum to the allied nations. Mr. Ambrose was in charge of this work.

ECONOMY IN USE OF OIL FUELS.

Various problems in connection with oil-fuel economies were investigated for the western division of the Fuel Administration. A number of fuel-saving devices were examined, such as burners, carburetor attachments, gages for small oil tanks in buildings, and gas radiators. Twenty-five boiler plants about San Francisco Bay and 226 power plants in California using fuel oil were inspected and recommendations made that effected a saving of 5 to 25 per cent at each plant. Demonstrations were given at San Francisco of the use of powdered coal as a substitute for oil fuel. This work was done by C. P. Bowie of the bureau, who acted as technical adviser of the western division, and by J. M. Wadsworth, petroleum engineer of the bureau, who served as State administrative engineer for the California Fuel Administration.

The Bureau of Mines, in cooperation with the National Automobile Chamber of Commerce and the Council of National Defense distributed copies of a poster showing how gasoline is wasted and giving instructions for preventing waste.

TESTS OF FUEL OIL MIXED WITH POWDERED COAL.

From May 1 to June 1, 1918, cooperative tests of colloidal fuel oil were conducted for the Submarine Defense Association of America. The fuel was composed of Navy fuel oil so mixed with powdered coal as to retain the coal in suspension. The tests were made on the U. S. S. *Gem* by Messrs. Wadsworth and Perdew.

PROSPECTING FOR OIL IN THE BRITISH ISLES.

In cooperation with the British Government, through its agents, Pearson & Son, the Bureau of Mines selected drillers and drilling material for prospecting for oil in the British Isles. The cooperative work was conducted chiefly by C. H. Beal, A. W. Ambrose, V. L. Conaghan, and M. A. La Velle, Messrs. Conaghan and La Velle, expert drillers of the Bureau of Mines, leaving the service of the bureau to take charge of the drilling work.

UTILIZATION OF OIL-SHALES.

In July, 1917, W. E. Perdew, in a trip through the oil-shale fields of Colorado and Utah, collected information on the companies organized, the proposed methods of retorting, and details of some special types of retorts. Samples of shale from various districts in this country were tested for their oil content. Mr. Perdew also compiled a résumé of the oil-shale industry. The work on oil shale was continued by M. J. Gavin and W. D. Bonner. Under supervision of D. T. Day, consulting chemist of the bureau, a retorting plant is in process of construction at Elko, Nev. The funds for erecting the plant have been provided by the Southern Pacific Co.

PROTECTION OF OIL AND GAS IN MID-CONTINENT FIELDS.

Work to prevent waste of oil and gas became of vital importance in war time. Much effort was spent on introducing methods for protecting oil and gas sands by mudding and cementing, and in assisting operators in difficult drilling jobs. Particularly valuable results were obtained in the Cushing field, Oklahoma, where the production of oil was increased several thousands of barrels daily by excluding water from the wells with cement on the recommendations of A. A. Hammer and B. H. Scott. In the Butler County field, Kansas, where water threatened to cause much damage, the bureau's engineers rendered timely assistance. Also, an educational campaign was conducted to arouse producers and call their attention to methods for preventing oil and gas sands from being flooded. The use of cement to shut off bottom water materially increased the production of many oil wells in Kansas and Oklahoma. This work was conducted by A. A. Hammer, B. H. Scott, H. R. Reuch, J. O. Lewis, F. B. Tough, and Thomas Curtin.

A similar investigation of the water problems in the Illinois fields was conducted in cooperation with the State geological survey during six months, April to September, 1918. In a well repaired according to the recommendations of the bureau engineers, the flow of water decreased to less than one-third and the settled production of oil more than doubled. As a common valuation of settled production in Illinois is $2,000 a barrel of daily output, the value of this property was increased by about $20,000.

The work was done by F. B. Tough, assisted by Frank Madden, of the Bureau of Mines, and by M. L. Nebel, assisted by S. W. Williston, of the State geological survey.

EXAMINATION OF THE SALT CREEK FIELD, WYOMING.

In September, 1918, the Secretary of the Interior requested the Bureau of Mines to examine the Salt Creek oil field of Wyoming. F. B. Tough and B. H. Scott, of the bureau, spent a month in that field and prepared a preliminary report, which showed that present methods of drilling and producing are wasteful. They suggested means of checking the waste and recommended that steps be taken to safeguard the equity that the Government has in the field.

MISCELLANEOUS LABORATORY TESTS AND ANALYSES.

Fuel oil used by the War Department at the Watertown Arsenal, Watervliet Arsenal, Fort Sill, and Panama is purchased on specifications. Samples of the consignments received are analyzed at the bureau's petroleum laboratory at Pittsburgh. During 1917 and 1918, samples representing purchases of more than $1,000,000 were analyzed.

At the request of the Ordnance Department of the Army, the Bureau of Mines inspected the wash oil used at certain toluene recovery plants. About 15 samples were examined, the work being done principally by N. L. Shoop, D. C. Dunn, and N. A. C. Smith.

While in London, Mr. Naramore was requested to obtain information concerning the available supply of American fuel oil that would meet British Admiralty specifications, which are more exacting than those of the American Navy. Tests conducted at the Pittsburgh petroleum laboratory showed that practically all distillates and some residuum fuel oils would meet the British viscosity requirement. The laboratory investigation was undertaken by J. P. Smootz and N. A. C. Smith.

Some experiments were conducted by H. H. Hill at the Pittsburgh petroleum laboratory for the American University station to ascertain the best oil for saturating Army blankets to be used as screens to exclude poison gases from dugouts.

During the summer of 1917, 25 samples of emulsified lubricating oil from the Washington Navy Yard were analyzed and tested for viscosity and water content by J. P. Smootz, N. L. Shoop, and N. A. C. Smith.

Various preparations alleged to increase the efficiency of gasoline were tested and found to be worthless. This work was done chiefly by Clarence Netzen, H. H. Hill, and C. R. Bopp.

Various products that were claimed to be satisfactory substitutes for motor gasoline were analyzed and engine tests of some of them were made. The analyses were made by E. W. Dean, H. H. Hill, and C. R. Bopp.

Among devices tested by the bureau which had been offered the Government for the duration of the war were the Swan process for reclaiming waste crank-case oils, the Armstrong-Godward vaporizer, and a so-called motor perfector, the last two being designed to increase the efficiency of gasoline.

Mr. Perdew investigated the Swan process for the bureau and made a favorable report. The bureau recommended the adoption of the process to the Council of National Defense, and later to the French Scientific Commission during its visit to Washington. The process was put into use by the French Government.

The Armstrong-Godward device was designed to vaporize the gasoline-air mixture delivered by a metering carbureter. After mechanical developments had been in progress about a year the device was pronounced ready for final tests at the Bureau of Standards. These tests had not been completed in November, 1918. The investigation was conducted by C. Naramore, E. W. Dean, W. E. Perdew, and E. F. Hewitt, consulting engineer.

Tests made by W. A. Jacobs in August, 1917, at Waukesha, Wis., of the "motor perfector," a device for adding moisture to the gasoline-air mixture in a carbureter, indicated that it was no better than others already on the market.

CRACKING OF OILS.

Experiments in cracking oil from the Humble field, Texas, showed that the distillates were suitable for the manufacture of gasoline by cracking processes. The experiments were made in May and June, 1918, by W. A. Jacobs and D. C. Dunn.

In May, 1918, through an arrangement with the Gasoline Corporation, which controls the Greenstreet cracking process, six engineers of the petroleum division witnessed a series of test runs with the process at a plant in East St. Louis, Ill.

RIFLE CORROSION PROBLEMS.

At the suggestion of Gen. Ainsworth, United States Army, retired, the petroleum division of the bureau studied the causes of corrosion in Army rifles after being cleaned. A number of preparations designed to prevent corrosion with a single cleaning were collected and analyzed. Results of firing tests, made in cooperation with the Pittsburgh division of the Ordnance Office, have been negative, as no signs of corrosion have appeared. The rifles were stored in a dry room after cleaning, and failure to develop aftercorrosion may have been due to this cause. The investigation is being continued. The tests were made by H. H. Hill, W. A. Jacobs, and N. A. C. Smith.

TESTS OF THE DUNN TRENCH HEATER.

Tests for the War Department of the Dunn oil heater showed that the heater had some advantages over the regulation Army stove for heating tents. C. R. Bopp supervised the tests, which were made at the War College Barracks, Washington, D. C., June 26 and 27, 1918.

PRODUCTION OF HELIUM FOR USE IN AIRSHIPS.

One of the great scientific and technical triumphs resulting from the application of exact knowledge and inventive genius to problems of military importance has been the large-scale production of helium, making this hitherto exceedingly rare gas available for use in balloons and dirigibles. The following account of the bureau's work in connection with helium was prepared by Dr. Andrew Stewart.

DISCOVERY OF HELIUM.

During the solar eclipse of August 18, 1868, P. J. C. Janssen noted in the solar chromosphere a bright yellow line near to but not identical with the D_1 and D_2 lines of sodium. Frankland and Lockyer called the line D_3 and, as it was referable to no known terrestrial substance, ascribed it to a hypothetical element which they called *helium*, from the Greek word *helios*, the sun.

In 1889, Dr. W. F. Hillebrand, of the United States Geological Survey, reported in the American Journal of Science that in analytical work on uraninite, which he began in 1888, he had obtained up to 2½ per cent by weight of a peculiar gas by treating the mineral with non-oxidizing inorganic acids. This gas had the characteristics of nitrogen, yet was different from any nitrogen known, and was thought by Hillebrand, on purely negative grounds, to be some allotropic form of that element. Lack of proper equipment, however, precluded any further researches on the subject. As a matter of fact, a certain percentage of the gas so found by Hillebrand was nitrogen.

The attention of Sir William Ramsay, the distinguished British chemist, was later drawn to Hillebrand's work, and he repeated the latter's experiments. He separated from cleveite, a variety of uraninite, a gas identical with that of Hillebrand, in the spectrum of which was found, with Sir William Crookes' aid, the D_3 line of Janssen, proving that in the gas there was present a new element, to which the name "helium," borrowed from Frankland and Lockyer, was given. On sparking this gas with oxygen to eliminate nitrogen, removing the excess oxygen with phosphorus, introducing the residual gas into an exhausted spectrum tube and passing an electric current through it, a bright yellow glow was obtained. Examined with a spectroscope, this glow gave rise to a series of lines in the red, green, and blue, but most prominent was the bright yellow line of

Janssen. In 1895 the characteristic line of this gas was discovered in the spectrum of the atmosphere by Kayser, and the element was isolated from the air by Ramsay and Travers in the same year.

OCCURRENCE AND PROPERTIES.

Helium is widely distributed in nature, but generally in minute quantities. The amount of it in the earth's atmosphere is exceedingly small, being present in the proportion of only 1 volume to 250,000 volumes of air. It has been found, as mentioned above, imprisoned within radioactive mineral substances, in the gases evolved from some thermal springs, in those emanating from volcanoes, and also in the natural gas of several gas fields in the United States (notably in Kansas, Oklahoma, Ohio, and also Texas). In some of the natural gas of this country helium is present in amounts as high as 2½ per cent. Of late, emissions of helium in comparatively large quantity have been reported from the boric acid soffione of Larderello, Tuscany, Italy. It issues from the earth at Stassfurt, Germany, and at Karlsbad. The natural gas in certain parts of Europe also contains helium, but in much smaller quantity than in our own.

Helium is one of a series of very rare, inert gases—other members being neon, argon, krypton and xenon—all of which are present in very small quantities in the atmosphere. Thus far every attempt to make these gases enter into chemical combination has failed. Helium is, next to hydrogen, the lightest of known substances. The gas, although twice as heavy as hydrogen, has in balloons a buoyancy or ascensional power of 92.6 per cent, as compared with the latter. The reason for this is that the buoyancy of a gas is measured not directly by its weight, but by the difference between its weight and that of the air displaced. Both hydrogen and helium are so light as compared with air that the difference in their lifting power is relatively insignificant. For example, 1,000 cubic feet of pure hydrogen will lift a weight of 75.14 pounds whereas the same amount of pure helium will lift 69.58 pounds, and a mixture, containing 85 per cent helium and 15 per cent hydrogen, which is the gas contemplated for all-around aircraft use, will have 93.4 per cent of the lifting power of hydrogen and will lift 70.18 pounds.

In its physical behavior, helium is the nearest approximation to the ideal perfect gas. It is monatomic and liquefies at even lower temperatures than hydrogen. By its evaporation in vacuum, Onnes, of Leyden, produced it in liquid form, first cooling it in solid hydrogen and then expanding it through a small nozzle. Liquefied helium is a colorless, mobile liquid, having a density of 0.122; hence it is the lightest liquid known. It boils at 4.5° absolute, and has a critical temperature of about 5° absolute, with a critical pressure of 2.75 atmospheres. By the rapid evaporation of liquid helium, a temperature below 2.5° absolute has been reached, but solid helium has not been produced. The low dielectric strength of helium permits electric discharges to pass through it with much greater ease than through most gases, and its conductivity for heat is very high.

Helium has been proved to be the end product of the emanations of radioactive substances, but the origin of its presence in natural gas has not been established. The helium content of some natural gas is relatively so large and the radiation from radioactive material is so small that derivation from such material would seem entirely out of the question. In the whole world not more than three ounces of radium have yet been isolated; but it must be remembered that radioactive material is very widely distributed in nature and that helium generation has been going on through countless ages of past time. A great many factors enter into consideration in this question, however, and it is difficult to set up an unassailable hypothesis regarding it.

Helium is of prime importance in aeronautics because of its great buoyancy, because of its rate of diffusion and consequent wastage through fabrics being only half that of hydrogen, and, above all, because of its chemical inertness. The effectiveness of hydrogen-filled dirigibles in war, owing to the high inflammability of hydrogen, was reduced to the vanishing point when means of combating them with incendiary propectiles were developed. Even under peace conditions, the great hydrogen-filled envelope of the dirigible constitutes a serious hazard because of possible ignition from atmospheric electricity, or from flames originating in the power plant of the craft. Helium, however, being absolutely inert, can not be ignited or exploded, and even mixtures containing certain amounts of hydrogen with helium can, as has been indicated above, be used with perfect safety in lighter-than-air craft.

INITIATION OF THE RESEARCH WORK.

Up to April, 1918, helium had been obtained only in extremely small amounts, as a curiosity in scientific laboratories, so that the total quantity separated in the whole world probably did not exceed 100 cubic feet, the cost of production being about $1,700 to $2,000 a cubic foot. Hence, although the possibility of helium as a lifting gas had been realized, its practical use seemed out of the question.

In the development of a process by which helium is now being produced in large quantities, the Bureau of Mines was the pioneer and has taken the leading part. In March, 1916, the Director of the

Bureau of Mines called the attention of Dr. F. G. Cottrell, chief metallurgist of the bureau, to a new process for air separation that embodied some novel and striking features, the bureau being interested then in the cheap production of oxygen for use in blast furnaces. This process had been evolved by Fred E. Norton, a graduate of the Massachusetts Institute of Technology and an engineer of wide experience and international reputation; Mr. Norton had pooled his patents with E. A. W. Jefferies and the consolidation became known as the Jefferies-Norton processes.

On February 28, 1915, Sir William Ramsay wrote to Dr. R. B. Moore, of the Bureau of Mines, who had worked with him in investigating the rare gases of the atmosphere. Sir William said, among other things: "I have investigated blowers—that is, coal-damp rush of gas—for helium for our Government. There does not appear to be anything in the English blowers, but I am getting samples from Canada and the States. The idea is to use helium for airships."

As the United States was not yet in the war and strict neutrality was being maintained by this country, these remarks were passed over by Dr. Moore, but he remembered that in 1907 Dr. H. P. Cady, of the University of Kansas, had found more than 1 per cent of helium in some natural gas from Kansas, and he realized what it would mean if such helium could be made available for balloons and dirigibles. Dr. Cady and D. F. McFarland were the first investigators to discover helium in natural gas; in 1907 they published a paper on the subject in the Journal of the American Chemical Society.[a]

In April, 1917, Dr. Moore attended a meeting of the American Chemical Society in Kansas City, Mo., where a paper on rare gases was read by Dr. C. W. Seibel, of the University of Kansas, who had worked under Dr. Cady. In the discussion that followed Dr. Moore pointed out the possibility of helium for war-balloon use if its separation from natural gas could be accomplished at a reasonable cost. He asked Dr. C. L. Parsons, chief chemist of the Bureau of Mines, who was present at the meeting, to take up the matter with bureau officials on his return to Washington, and this Dr. Parsons did.

In April, 1917, the Director of the Bureau of Mines placed G. A. Burrell (later Col. Burrell) in charge of the bureau's war-gas work. The Bureau of Mines had initiated this work, chiefly on gas masks, smoke screens, and toxic gases, in cooperation with the Army and the Navy. Mr. Burrell, who had been in charge of gas investigations for the Bureau of Mines from 1908 until 1916, had analyzed natural gas from different fields and knew of its helium content. He had thought of helium as a possible filler for balloons and dirigibles and

[a] Cady, H. P., and McFarland, D. F., the occurrence of helium in natural gas and the composition of natural gas: Jour. Am. Chem. Soc., vol. 29, 1907, pp. 1523 et seq.

had mentioned the matter to F. A. Lidbury, of the Oldbury Chemical Co., and from him learned of Sir William Ramsay's interest in the subject and of the presence of helium-bearing gas in Canada. Prof. Satterly and Prof. Patterson, of the University of Toronto, began experiments looking to the separation of helium from Canadian natural gas January 1, 1916. They used a Claude-system unit, at Hamilton, Ontario, but had much trouble in eliminating the heavier hydrocarbons of the natural gas.

Mr. Burrell was aware of the possibilities of the gases of the Petrolia field, in Texas, in regard to helium yield, and had samples sent to Dr. Cady for analysis. These samples contained about 1 per cent of the element. Thereupon, Mr. Burrell took up the question of utilizing this gas for helium recovery, with Dr. Cottrell and Dr. Moore, and the matter was discussed at length.

On May 12, 1917, Mr. Burrell wrote to Maj. C. DeF. Chandler (now Col. Chandler, of the Air Service), asking for an expression of opinion as to whether helium possessed sufficient advantages for use in balloons to warrant undertaking its production; and Messrs. Burrell and Moore, at the latter's suggestion, conferred with Maj. Chandler to ascertain whether the Army would consider furnishing the necessary funds for the project. G. O. Carter, of the Bureau of Steam Engineering of the Navy Department, learned from Maj. Chandler of this matter and became interested in it on behalf of the Navy Department.

At this time several conferences were held to discuss helium production from every angle, and opinions and views, all favoring it, were obtained from Dr. Cady, T. B. Ford, then in charge of the low-temperature laboratory of the Bureau of Standards, and O. P. Hood, chief mechanical engineer of the Bureau of Mines.

Dr. Cottrell advised Mr. Burrell to get in touch with Mr. Norton, for the possible employment of his process to separate helium from natural gas; accordingly, Mr. Norton was asked to come to Washington, where he arrived on June 4, 1917. Asked for a minimum estimate on the cost of a small experimental plant for the purpose, Mr. Norton estimated that a plant with a capacity of about 5,000 cubic feet of helium a day, to try out his process, might be constructed for about $28,000. With this data in hand, the Director of the Bureau of Mines did his utmost to push the investigation. On July 19, 1917, he addressed a letter to the Chief Signal Officer of the War Department, requesting an allotment of $28,000 to try out the Norton process, and on July 20, 1917, Secretary Lane wrote to the Secretary of War on the same subject.

Dr. Moore had suggested to Dr. Cottrell that the Linde Air Products Co. and the Air Reduction Co., established firms in the business of gas liquefaction and separation, be brought into the helium undertaking, and in this suggestion Dr. Cottrell had heartily concurred. So these firms and one other (the Lacy process) were asked to cooperate with the Government, and developments finally culminated in a recommendation on July 26, 1917, by the joint Army and Navy Airship Board, of an allotment of $100,000, in equal shares from Navy and Army appropriations, to make helium available as a substitute for hydrogen for balloons and dirigibles. It was further recommended that arrangements be made with the Bureau of Mines to carry out the undertaking. On July 31, 1917, the Aircraft Production Board recommended that this be done.

About this time Capt. R. B. Owens, of the Signal Corps, went to England on a special mission. He had become very enthusiastic as regards helium, especially the possibilities of the Norton process, and took with him a letter from Mr. Burrell, which he presented to the British Admiralty. This led to the dispatch to this country of Commander C. D. C. Bridge and Lieut. Commander S. R. Locock, as a commission on behalf of the Admiralty to canvass the helium situation in this country and to investigate the Norton process. Through Vice Admiral Richard H. Peirse the Admiralty had written to Dr. R. A. Millikan (later Lieut. Col. Millikan), of the National Research Council, on July 25, 1917, that, on the strength of researches instituted by the Board of Inventions and Research, it had decided to fit up an experimental plant to investigate whether the use of helium for airships was practicable. The Admiralty was anxious to obtain from the United States 100,000,000 cubic feet of the gas at once and to contract for a further supply of 1,000,000 cubic feet a week, being particularly interested in the Norton process on account of the possibility of its greatly reducing the cost of producing helium, which the Admiralty feared would be prohibitive by the older, established processes. It was estimated that the best that could be expected from these older processes would be about $80 a thousand cubic feet.

DEVELOPMENT OF PLANTS FOR HELIUM PRODUCTION.

After the $100,000, mentioned previously, was allotted for helium work, the director of the Bureau of Mines placed Mr. Burrell in charge of the investigation. Mr. Norton started the design of a plant along the lines of his process, he and Mr. P. McD. Biddison, chief engineer of the Ohio Fuel & Supply Co., being appointed consulting engineers of the bureau. With others they made a field survey to determine the best site for operations. Dr. Cady was appointed consulting chemist on the staff of the Bureau of Mines; he and his assistants at the University of Kansas, particularly Dr. C. W. Seibel, did a large amount of analytical and research experimental work on helium, the results of which influenced the designs of the various helium plants that were constructed later. Dr. Cady also made valuable researches into the limits of inflammability of helium and hydrogen mixtures, and carried out a number of experiments on the permeability of balloon fabrics by helium.

The work in connection with the helium undertaking began at this time to assume such proportions and to broaden so much that Mr. Burrell felt that he would be unable to carry it on properly, his time being fully occupied with other pressing duties. Therefore, Prof. W. H. Walker, of the Massachusetts Institute of Technology, was asked to assume charge. This he did for a few weeks, and possibly it was at his suggestion that, for purposes of secrecy as a war measure, the name "argon" was substituted for helium and the three experimental plants finally constructed became known as "argon" plants. After Prof. Walker gave up this charge to become chief of the Chemical Service Section of the War Department, with the rank of lieutenant colonel, the helium work was carried on mainly by Dr. F. G. Cottrell in Washington and Mr. Norton and Mr. Biddison in the field, all under Dr. Manning's personal supervision, with Mr. Carter acting for the Navy and the Army, and the Linde Air Products Co. and the Air Reduction Co. cooperating so far as their processes were concerned. Contracts were closed with these two companies in November, 1917, and a contract was made with the Lone Star Gas Co., controlling the Petrolia field, for a supply of gas. Construction of a Linde plant and a Claude (Air Reduction Co.) plant was begun at Fort Worth, Tex., almost immediately after the contracts were executed. These plants, known respectively as "Argon Plants 1 and 2," were completed in March and in May, 1918. On May 11, 1918, Profs. Satterly and Patterson visited Fort Worth to inspect the plants and expressed themselves as highly pleased with what they saw. On February 2, 1918, Dr. Manning assigned F. C. Czarnecki to Fort Worth as superintendent of the Linde and Claude plants; also, about the same time Mr. J. R. George, jr., was assigned to assist Dr. Cottrell in Washington in conducting the helium work, with special reference to the Norton process. On January 1, 1919, Dr. Andrew Stewart succeeded Mr. George. In the spring of 1919 Dr. L. H. Duschak was for some time associated with the helium project.

In June, 1918, the director of the Bureau of Mines placed Dr. R. B. Moore in general charge of all three helium plants, as his personal representative. After visiting New York for consultation with the presidents of the Linde and the Air Reduction Cos. and to arrange for even closer cooperation of those corporations with the Government, Dr. Moore went to Worcester, where he conferred with Mr. Norton, and then went directly to Fort Worth. He has been actively connected with the helium work up to date, June, 1919.

The coming to this country of the British commission, in the fall of 1917, stimulated the interest of the Army and the Navy in helium. At a conference called by the director of the Bureau of Mines in his office, those present, besides Dr. Manning, were Commander Bridge, Lieut. Commander Locock, of the British commission; Prof. John Satterly, of the University of Toronto; Lieut. Commander Arthur H. Marks, Bureau of Construction and Repair, United States Navy; Capt. P. Pleiss, of the Signal Corps, United States Army; G. O. Carter, Bureau of Steam Engineering, United States Navy; Dr. W. H. Walker, Dr. C. L. Parsons, G. A. Burrell, P. McD. Biddison, F. E. Norton, Dr. Marston T. Bogert, National Research Council; W. W. Birge, president of the Air Reduction Co.; and Dr. B. S. Lacy. The helium project was discussed exhaustively and, as a result, recommendation was made that an appropriation of $500,000 be made available from Army and Navy funds, in equal shares, for four separate experimental plants, under the systems of Linde, Claude, Norton, and Lacy, respectively; that is to say, all systems recognized as practicable were to be given a trial. Later, the Lacy system was dropped. The recommendation was transmitted to the proper authorities of the Army and the Navy.

The $500,000 allotment was appropriated pursuant to a resolution of the Aircraft Production Board of October 17, 1917, but, on the recommendation of the Navy Department, the Norton process was excluded from the benefits of any share thereof. This unexpected action was embarassing both to the Bureau of Mines and to the British commission, but the Navy Department adhered to it and induced the War Department to take the same stand. Not until, at the Navy Department's insistence, the Norton process had been submitted to the searching examination of the National Research Council and that body had, by the unanimous action of a special committee, reported favorably on it January 14, 1918, was a further sum of $100,000 made available for the Norton process, on January 18, 1918. The special committee of the National Research Council was composed of Dr. Harvey N. Davis, of Harvard University; Dr. Edgar Buckingham and Dr. C. W. Waidner, of the Bureau of Standards; Dr. W. S. Landis, of the Air Nitrates Corporation; and S. L. G. Knox, consulting mechanical engineer, and later scientific attaché of the United States Embassy at Rome.

The Norton process is the latest practicable development in liquefying and separating gases. The Linde process (Plant No. 1) depends upon the so-called Joule-Thomson effect, obtained by the sudden expansion of a highly compressed gas through a small orifice, or nozzle, and the consequent cooling of the gas, the process being elaborated into a self-intensive or cumulative cycle of heat interchange by causing the cooled gas, on escaping, to circulate around the tube leading the initial gas into the apparatus.

George Claude, of Paris, conceived the idea of a liquefaction cycle with an expansion engine interpolated. Although the Joule-Thomson effect is used in the Claude cycle (Plant No. 2), its value is reduced to a minimum because the compression of the gas in this system is lowered. The maximum cooling effect is produced by the expansion engine because the compressed gas, on expanding in the engine cylinder, is made to do work and thus its temperature is lowered.

In the Norton process (Plant No. 3) three expansion engines are used, liquid is throttled, and the heat interchanger and fractionating still are of new design. In the Linde system an enormous expenditure of power is demanded to compress the gas in order to obtain the maximum effect of throttling, and this energy is then wasted. The Claude system requires much less compression power, but in this system the energy stored in the compressed gas is also dissipated. In the Norton system the requirement for gas compression is reduced to a minimum by the interpolation of the multiple-expansion engines, and what is needed is conserved and reapplied through the energy developed by these engines. Thus the maximum cooling effect is obtained at a minimum cost.

Construction of the Bureau of Mines (Norton process) plant, later known as Argon Plant No. 3, on the enlarged basis of a maximum production of 30,000 cubic feet of helium a day, was begun on April 3, 1918, and was completed October 1, 1918. The cost was $148,398.29, the estimate for the plant enlarged to the proportions given having been $150,000. During the early construction work at this plant Mr. Biddison's services were of especial value; succeeding him, April 20, 1918, George A. Orrok was appointed consulting engineer of the Bureau of Mines and has since been identified in this capacity with Plant 3.

The first site picked for the helium plants was at Fort Worth, Tex., selected by Messrs. Norton and Biddison, but later the Otto, Kans., region was deemed more advisable, as the natural gas there is exceptionally rich in helium; the supply, however, proved inadequate. The Bureau of Mines plant (Norton process) was then located at Petrolia, Tex., adjacent, for obvious reasons, to the properties of the Lone Star Co., but the plants of the Linde Co. and the Air Reduction Co., because of their requiring more water and more power, were built at Fort Worth, about 100 miles to the southeast, and were supplied with Petrolia gas through the Lone Star Co.'s pipe line.

The approximate cost of Plant No. 1 (Linde) was $245,000; that of Plant No. 2 (Air Reduction) was $135,000. The capacity of the first plant for producing 90 per cent helium from 0.4 per cent to 1 per cent helium-bearing natural gas, was 5,000 cubic feet a day, and that of the second was 3,000 cubic feet a day.

Plant No. 1 was the first to start, March 6, 1918. Its production of helium began April 8, 1918, when 27 per cent gas was obtained. Progressively better results were achieved until a purity of about 70 per cent on straight runs was reached. By reprocessing, the purity of this gas was raised to 92½ per cent. Plant No. 2 began to operate May 1, 1918, and on May 13 finally produced gas of 62 per cent to 70 per cent purity, which was reprocessed by Plant No. 1 to 92½ per cent. In all, about 200,000 cubic feet of 92½ per cent helium has been produced by Plants 1 and 2. This gas has been stored in steel cylinders at a pressure of 2,000 pounds to the square inch, each cylinder containing about 200 cubic feet expanded to atmospheric pressure. Of these cylinders 750 were ordered sent to France for aeronautic purposes and were on the dock at New Orleans awaiting shipment when the armistice was signed. They were returned to Fort Worth.

In order to coordinate properly all the different agencies concerned in the helium project, and to take steps for controlling effectively the exploration and conservation of helium, a committee consisting of one representative from each of the three governmental departments chiefly concerned was appointed by resolution of the Aircraft Board on August 23, 1918. G. O. Carter, chairman, represented the Navy; Dr. Harvey N. Davis, the Army; and George A. Orrok, the Department of the Interior. Up to and including October 23, 1918, there had been recommended and allotted from Army and Navy appropriations, in equal share, funds aggregating $1,090,000 for Plants 1, 2, and 3 and expenses incident to their maintenance and operation. The expenditure of this $1,090,000 has not only added vastly to human knowledge, but has supplied a commodity worth, at prewar prices, approximately from $250,000,000 to $400,000,000; and has prepared a war weapon for the United States of incalculable potency.

Construction of all three helium plants was carried out by the Constructing Quartermaster Corps of the Army, cooperating with the Bureau of Mines, and the finances of the helium undertaking have been handled by the finance division of the Bureau of Aircraft Production and the accounting section of the Bureau of Mines.

In August, 1918, the War and Navy Departments, realizing the paramount importance of insuring a supply of helium for military purposes, determined to build a large plant that would produce 30,000 cubic feet of the gas a day. This plant, to be constructed along the lines of the Linde process, is to be situated at Fort Worth, Tex., and arrangements have been made for a lease of the Petrolia gas pool and for a Government pipe line to convey gas from Petrolia to Fort Worth.

On December 8, 1918, the Aircraft Board submitted a report to the Secretary of War and the Secretary of the Navy, in which the change in the military situation because of the signing of the armistice was noted, the helium situation was reviewed, and recommendations for the future were made. Four different programs for further work on helium were submitted, that designated as "Plan C" being preferred. This was as follows:

Operation of Plant No. 3, for three months	$36,000
Construction of production Plant No. 1	1,700,000
Operation of production Plant No. 1 for 8 months, producing 7,200,000 cubic feet helium	750,000
Pipe-line construction	1,800,000
Petrolia field lease	1,500,000
Total expenditures	5,786,000
Salvage	500,000
Net cost	5,286,000
Helium production, cubic feet	7,200,000

On December 17, 1918, the Director of the Bureau of Mines, in a letter to the Secretary of the Navy and the Secretary of War, submitted a report by the engineers of the bureau. This report outlined a plan similar to "Plan C," but provided for further operation of all three experimental plants, also for a new Claude unit, and included a fund for conservation purposes. The bureau's engineers were convinced that the cost of producing helium had not been reduced to a minimum and that undoubtedly in the long run money would be saved by perfecting producing methods through further experimental work. In any event, it was felt that something should be done toward conserving the Nation's helium supply.

On December 27, 1918, the Secretary of the Navy wrote to the Director of the Bureau of Mines disapproving further experimental work by the Government, other than the small amount countenanced for Plant No. 3, under "Plan C," and advising him of the adoption of "Plan C." On January 9, 1919, Maj. Gen. Jervey, of the General Staff of the Army, wrote advising that the War Department concurred in the action of the Secretary of the Navy and that the accomplishment of "Plan C" would be entrusted to the Navy Department.

Pursuant to this plan, the director of the Bureau of Mines ordered Plants 1 and 2 shut down on January 23, 1919, but asked that Plant 2 be permitted to continue work, at its own expense, for a limited time in order to try out an improvement in its apparatus. On this basis, the Navy and War Departments consented to the further operation of Plant No. 2, the Navy agreeing to furnish gas of a higher helium content from its new pipe line (contemplated under "Plan C") when this would be completed, about May, 1919.

The Bureau of Yards and Docks of the Navy Department took physical possession of Plant No. 2 and of the Government property of Plant No. 1, and assumed all expenses incurred by the Government incident to these plants as of April 1, 1919. Plant 1 has been dismantled and the Linde Air Products Co. is to repurchase such of its apparatus and equipment as it agreed to do under its contract with the Bureau of Mines. All helium produced at these plants has been placed in the custody of the Navy Department at its special request.

Although only $36,000 was provided for further operation of Plant No. 3, under "Plan C," a visit of inspection to this plant by Commanders H. N. Jenson and H. T. Dyer, Lieut. Commander Smith and G. O. Carter, on behalf of the Navy Department, about March 15, 1919, so convinced the Navy officials of the exceptional merits of the Norton process and the possibilities of the plant in respect to producing high-purity helium at a minimum cost that they became strongly in favor of affording it every opportunity to prove itself.

After overcoming many obstacles that could not be foreseen, Plant No. 3, on April 2, 1919, began to produce helium, and by 5.30 a. m. April 3, a purity of 19.8 per cent was reached. Helium production continued until that afternoon, when it became necessary to shut down for some minor repairs. On April 17, 21 per cent helium was made, and it is confidently expected that helium of the highest purity will soon be produced by this plant on a large scale.

On April 15, 1919, the Director of the Bureau of Mines called a conference in his office to discuss matters incident to the further operation of Plant 3 and kindred matters. There were present, besides the Director, Commander Jenson, representing the Navy; Col. C. DeF. Chandler, Col. A. L. Fuller, and Dr. H. N. Davis, representing the Army; and George A. Orrok, Fred E. Norton, L. H. Duschak, W. A. Ambrose, and Andrew Stewart, representatives of the Bureau of Mines. Fred E. Norton, who had come from Texas for the purpose, gave a detailed report on the operation of Plant No. 3 and described the need for alterations in and additions to its apparatus to insure the greatest possible efficiency. It was the sense of the meeting that liberal allotments of funds should be made for the continued experimental operation of the plant, with regard to its ultimately being run as a production unit. As a result of this conference, the Director of the Bureau of Mines recommended an allotment of $100,000 to make the alterations and acquire the equipment referred to. This fund has been made available, one-half by the Army and one-half by the Navy.

COOPERATING AGENCIES.

During the course of the work of the Bureau of Mines on processes of helium extraction, G. S. Rogers, of the United States Geological Survey, undertook a reconnoissance of the natural-gas fields in the United States with regard to their possible helium supply, so far as that might be judged by the analysis of samples of gas from existing wells and the study of geological conditions. In this work Dr. Cady and Dr. C. W. Seibel rendered valuable assistance in analytical investigations.

On April 3, 1918, the petroleum division of the Bureau of Mines began work on the possible discovery of natural gas yielding helium, and from April 3, 1918, to January 1, 1919 conducted intermittently administrative work relating to the conservation of such natural gas. Examinations as to the possibility of obtaining helium in Montana, North Dakota, Washington, California, and southern Canada were made by C. H. Beal, J. O. Lewis, and A. W. Ambrose.

Following a conference between Dr. Cottrell and members of the staff of the Bureau of Standards, the Director of the Bureau of Mines, on December 14, 1917, requested the Bureau of Standards to undertake the determination of certain physical properties of methane, especially with regard to its latent and specific heats and specific volumes over a wide range of pressures and temperatures. The purpose of this inquiry was to facilitate the experimental operation of the helium plants, in which liquid methane plays an important part.