Board of Inventions of the Admiralty that, on account of its lightness and non-inflammability, helium might prove of great service for balloons and airships. Prof. J. C. McLennan was asked to initiate experiments to see whether helium could be separated in quantity from the natural gases escaping from the earth in certain districts of Canada which were known to contain about 1 per cent of helium by volume. Arrangements were made on a semi-commercial scale to purify the helium by liquefying the methane and other gases present. The impure helium was concentrated in the non-liquefying portion. In this way, many thousands of cubic feet of helium were prepared and transported in cylinders at high pressure. About the same time, the Bureau of Mines of the U.S.A. began similar experiments on a large scale, using the natural gases of Texas, which are rich in helium. Large quantities of helium were separated by liquefaction methods, and the cost of the helium was found to be sufficiently low to use it in airships in the place of hydrogen. Apart from the cost of transport, the expense of separation of helium decreases with the concentration of the helium in the natural gases. The commercial prospects of the use of helium in airships and other purposes have led to a search for rich concentrations of helium.

While most natural gases contain less than 1 per cent of helium, much richer mixtures have been recently found by boring. One source in Grand County, Utah, has a helium content of 7 per cent. Another was found in Colorado yielding as high as 8 per cent. The gas appears at a depth of about 950 feet in what is known as the Wingate sand. The Helium Company has erected a plant at Thatcher, Colorado, for purification of the helium obtained from this source. Analysis shows that the gas contains 15 per cent carbon dioxide, 8 per cent helium, 1·75 per cent methane, and the rest nitrogen. The plant installed has a capacity of about 600,000 cubic feet of the gas per day, corresponding to a possible annual production of 12 million cubic feet of helium. With such a rich helium mixture, the cost of separation should be much less than in the plants treating the natural gases of much lower helium content.

It is possible that similar rich concentrations may be found on the eastern slopes of the Rocky Mountains in Canada. A small gas field was found a few years ago not far from Toronto which had a content of 0·8 per cent helium. The rights of those wells have been secured for the University of Toronto in order to have an ample supply of helium for cryogenic experiments in the laboratories.

At the time of its discovery, helium was considered to be a rare gas and a litre of helium was a precious possession. The helium originally employed by Kamerlingh Onnes for the liquefaction of helium was painfully obtained by heating radioactive minerals. This is in striking contrast to the position to-day, when the annual production of helium is measured by millions of cubic feet, and where sufficient quantity will be available at a comparatively low cost for filling several large airships now in course of construction.

A. M. Liapounov, 1857–1918.

By A. J. PRESSLAND.

FROM time to time, French versions of the writings of A. M. Liapounov have become available to the scientific public; but the obituary notice in the *Proceedings* of the Academy of Sciences in Leningrad (1919, p. 367, by Stekloff), and other papers, are in Russian. Quite recently the Academy has published two brochures, one a biography and the other a general survey of Liapounov's work on Chebichev's problem, and the following is a digest of this material.

A. M. Liapounov, the eldest son of M. V. Liapounov and a grandson of V. A. Liapounov, registrar of the University of Kazan, was born on May 25, 1857. Six of his immediate kinsmen attained to academic eminence. His father, an astronomer of repute, died in 1868, leaving a young family. So the boy was brought up for a time by a married aunt, in whose house he increased his acquaintance with people of intellectual distinction. In 1870 he entered the third class of the gymnasium of Nishni-Novgorod, where he was taught Latin, Greek, and elementary science. He read widely, Buckle, Draper, Humboldt, Réclus, and Karl Ritter being his favourite authors, and he developed a love for exact science. The national idealism that was then popular did not appeal to him, but he was attracted by the study of economics and the theory of the struggle for existence.

In 1876 Liapounov passed out of the gymnasium with the highest distinction and matriculated at St. Petersburg, where at first he attended the lectures of Mendeléeff, which he soon forsook for those of Chebichev. To the latter is due the inspiration of Liapounov's researches. Chebichev laid stress on *Anschauung* and *Realien*, holding that research work was valuable only when it lent itself to application, and theory useful only when it emerged from a consideration of particular cases.

Chebichev directed Liapounov to the problem of determining the free surface of a liquid gravitational mass that was rotating about an axis. He had already proposed the problem to prominent students such as Zolotarev and Sophia Kovalevskaya, but no one of them seems to have made noteworthy progress. The problem has a long history. Newton noted that an ellipsoid of revolution can be a surface of equilibrium, but Maclaurin was the first to give it serious consideration; on this account an ellipsoid of revolution which is a form of equilibrium is called an ellipsoid of Maclaurin. D'Alembert showed that for every angular velocity less than a given limit there were two Maclaurin ellipsoids, each compressed in the direction of the axis of rotation. Laplace showed that, as the moment of angular momentum increased, the smallest axis of the ellipsoid decreased until the angular velocity reached its maximum, after which the angular velocity decreased to zero and the ellipsoid flattened out, becoming ultimately a thin disc of infinitely large radius. Hence for each value of the angular velocity there will be two Maclaurin ellipsoids, and Lagrange was of the opinion that these were the only two possible ellipsoids of equilibrium. But Jacobi proved that the ellipsoid with three unequal axes was also a possible form.

Jacobi's solution was examined by Meyer and Liouville. The latter showed that in certain cases a long thin ellipsoidal spindle might be obtained, the largest axis of which increased without limit and the other two approached zero in magnitude and unity in ratio. So it can be proved that, within certain limits of the value of the angular velocity, there may be three ellipsoids of equilibrium—two of Maclaurin and one of Jacobi; within other limits, two only each of Maclaurin, and the latter may coincide giving one only, of Maclaurin.

Chebichev told Liapounov that easy but novel problems which could be solved by well-known methods were of no value in testing the powers of a young research student. Such a student required something that presented obvious difficulties. So the problem was enunciated thus: "It is known that for certain values of the angular velocity the ellipsoidal form no longer serves as a surface of equilibrium for rotating homogeneous liquids. Does it change into some new form of equilibrium which, for small increments of angular velocity, differs but little from an ellipsoid?"

Domestic misfortune interrupted Liapounov's university career; but he won a university prize, and after graduation chose as the subject of his M.A. dissertation "Some Particular Aspects of Chebichev's Problem", which he defended before a board of which Bobilev and Korken were members. In 1885 he was recognised as a *privat-dozent* and was preparing to lecture on the theory of potential when he received a call to the chair of mathematics at Kharkov. His new duties, which were increased by work at the local technical institute, were so strenuous that he had to defer the presentation of his dissertation for the doctorate, for five years. The subject was "Some General Aspects of Chebichev's Problem". These two dissertations were translated into French and published by Davaux in 1904, 1908.[1]

In 1901 Liapounov was elected a member of the Academy of Sciences at St. Petersburg and thus secured the leisure and the freedom from financial cares that enabled him to resume his work on the problem. He soon discovered that to the first approximation there were no new forms and that a second approximation was hard to obtain. In his M.A. dissertation he had discussed the stability of the ellipsoids of Maclaurin and Jacobi and had found that when Maclaurin's became unstable they changed into those of Jacobi, and that the latter when they became unstable appeared to change into a new figure having algebraic surfaces of the third degree (Poincaré's pear-shaped figure).

Within a year of the publication of the M.A. thesis Poincaré mentioned in *Comptes rendus* that he had been in correspondence with Lord Kelvin on the subject. Lord Kelvin had arrived at results but had given no proofs. Poincaré reached the same results as Liapounov but by less stringent methods, and Poincaré assumed that the figures sought really existed. In answer to Liapounov's inquiry, Poincaré replied that he had not proceeded beyond the first approximation and that the methods of successive approximations did not provide a proof of the existence of the figures, since the difficulty of finding a second approximation was insurmountable. His assertion, that the figures sought existed, seemed to Liapounov to be based on intuition, and when Poincaré's memoir appeared in *Acta Mathematica*, Liapounov was dissatisfied with it.

When Liapounov, twenty years later, resumed consideration of the problem, he soon found where the difficulty of the second approximation lay. Poincaré and Liapounov, when seeking the new figure that differed but little from the given ellipsoid, had compared it with the given ellipsoid. Liapounov now overcame the difficulty by introducing an ellipsoid confocal with the given one and passing through that point of the surface sought at which the potential of the attracting liquid is under consideration. By this means Liapounov easily obtained approximations to any given order and was able to prove the series convergent. Thus Liapounov was able to give a rigorous proof of the existence of those forms of equilibrium already known and to show that there were no intermediate forms.

There are other special solutions of the general problem. Poincaré and Sophia Kovalevskaya have treated an annular form such that the section of it made by a plane through the axis of rotation is approximately an ellipse. There are also cylindrical forms of equilibrium which provide material for mathematical problems. Liapounov directed attention to the case of two liquid masses separated from one another and each rotating round an axis, which passes through the common centre of gravity and is perpendicular to the line joining the centres of gravity of the two separate masses, and found that when they were sufficiently far apart their surfaces of equilibrium differed but little from ellipsoids; and he proved that for homogeneous liquid the pear-shaped figure is unstable.

This result is at variance with the results obtained by Poincaré and Darwin, each of whom found difficulty in obtaining a second approximation. Poincaré found one by a special process which yielded no further approximations. Darwin adopted the result, which supported his theory of cosmogony. Liapounov, however, declared that Poincaré's methods were not rigorous, since they were based on approximate formulæ, whereas his own were obtained by exact formulæ.

The stumbling-block had been an expansion of the potential due to Lagrange and Laplace. No proof had been given that this expansion was admissible. Liapounov replaced it by a new expansion having a smaller parameter, established the admissibility of the new expansion, applied the methods of successive approximations, showed how to find these approximations to any required order, proved that his approximations were convergent, and generalised his investigations.

Liapounov's papers on Chebichev's problem are contained in four volumes published between 1906 and 1914, written in French and extending to 768 folio pages. It is understood that Liapounov left a large amount of manuscript which will be published when circumstances permit. This remark applies also to the papers of Leonard Euler. In 1902, the Academy of Sciences proposed to mark the bicentenary of the birth of Euler (1907) by the issue of a complete edition of his works. A committee consisting of A. A. Markov, B. B. Galitzin, and A. M. Liapounov was appointed to deal with the matter. It is possible that the latter has left papers dealing with the subject.

It is painful to describe the last days of Liapounov. Russia was involved in political and social turmoil, and it was at one time feared that Liapounov might suffer like Lavoisier. This fear happily was unfounded. His wife was attacked by tuberculosis and he was threatened with cataract. They went to Odessa in search of health, and there his wife died. A few days later, on Nov. 3, 1918, he died in Leningrad as the result of a voluntary act.

[1] Ann. T(oulouse), 2 ser. t. 6; 1904. Ann. T., 2 ser. t. 9; 1908.

Two Historic Electric Power Stations.

AT an ordinary general meeting of the Newcomen Society held in London on April 15, and at the seventh annual meeting of the American members held in New York on April 16, two papers were presented dealing with two historic electric power houses. One of the papers was by Mr. G. A. Orrok and dealt with the Pearl Street station in New York, the first central station in the world; the other was by Col. R. E. B. Crompton and gave a history of the first installation of house-to-house electric supply in England, the power house of which was described as "the parent generating station of Great Britain". It was the invention of the incandescent light, the perfecting of the dynamo, and the invention of the multiple arc system, with its corollary in the feeder system and three-wire system, which brought the central station into being as a means of furnishing a means of transmitting light, heat, and power in any amount and to such distances as might be required. In the early 'eighties, many private installations of electric lighting plant were laid down, and generating plant was supplied to individual buildings and ships, but the two stations referred to at the meeting of the Newcomen Society were the first stations in the United States and England respectively to supply electric current to customers in the same way that gas and water had been supplied.

The Pearl Street station was due to the genius of Edison, from whose note-books of 1878 and 1879 can be gathered some of his earliest ideas on electric power generation and distribution. The Edison Electric Light Co., the parent company of all the Edison companies, was incorporated early in 1880, and the Edison Electric Illuminating Co. of New York, the local company, held its first meeting on Dec. 20, 1880.

To the latter belongs the credit of erecting the Pearl Street station, which began operations on Sept. 4, 1882, and by the end of 1883 had 455 customers and more than 11,000 lamps installed. The original plant consisted of four Babcock and Wilcox boilers of 200 h.p. each, supplying steam at 120 lb. pressure to Porter-Allen high-speed engines of 125 h.p. each, directly coupled to the famous 'Jumbo' dynamos. As the station was half a mile from the river, it was a non-condensing station and the coal consumption at first was about 10 lb. per kw. hour. A serious fire on Jan. 7, 1890, interfered with its operation for a time, and five years later this pioneer station was closed down and the property disposed of.

Many interesting particulars of the electrical equipment of the station were given by Mr. Orrok. From the dynamo brushes the current was led by round copper bars to spring-controlled switches, the design of which was taken from the short-circuiting switch under the telegraph key. The station bus bars were fixed to wooden insulators bolted to the walls. There were neither voltmeters nor ammeters, as such things had not been invented.

Crude as many of the devices were, they met the situation and enabled central station companies to do business. Referring especially to Edison's chemical meter, in which each unit of current invariably removed a definite amount of zinc from one metal plate to another, Dr. Orrok said: "Was there ever a more beautiful combination of parts—each dependent on a simple physical or chemical law—than was presented in this ingenious commercial device for translating first the lamp-hour, then the ampere-hour, and finally the kilowatt-hour values into dollars and cents? . . . It is no exaggeration to say that no single device in the whole system did more to lay the solid foundation for the commercial and financial success of the Edison stations from the first than the chemical meter."

The first central station in Great Britain, dealt with in Col. R. E. B. Crompton's paper, was situated in Kensington and was erected by the Kensington Court Company, afterwards the Kensington and Knightsbridge Company, started by Col. Crompton to supply electricity to the houses they erected on a site which had been cleared by the company promoter, Baron Grant, but which had passed into the hands of the Land Securities Company.

In the generating station were installed two