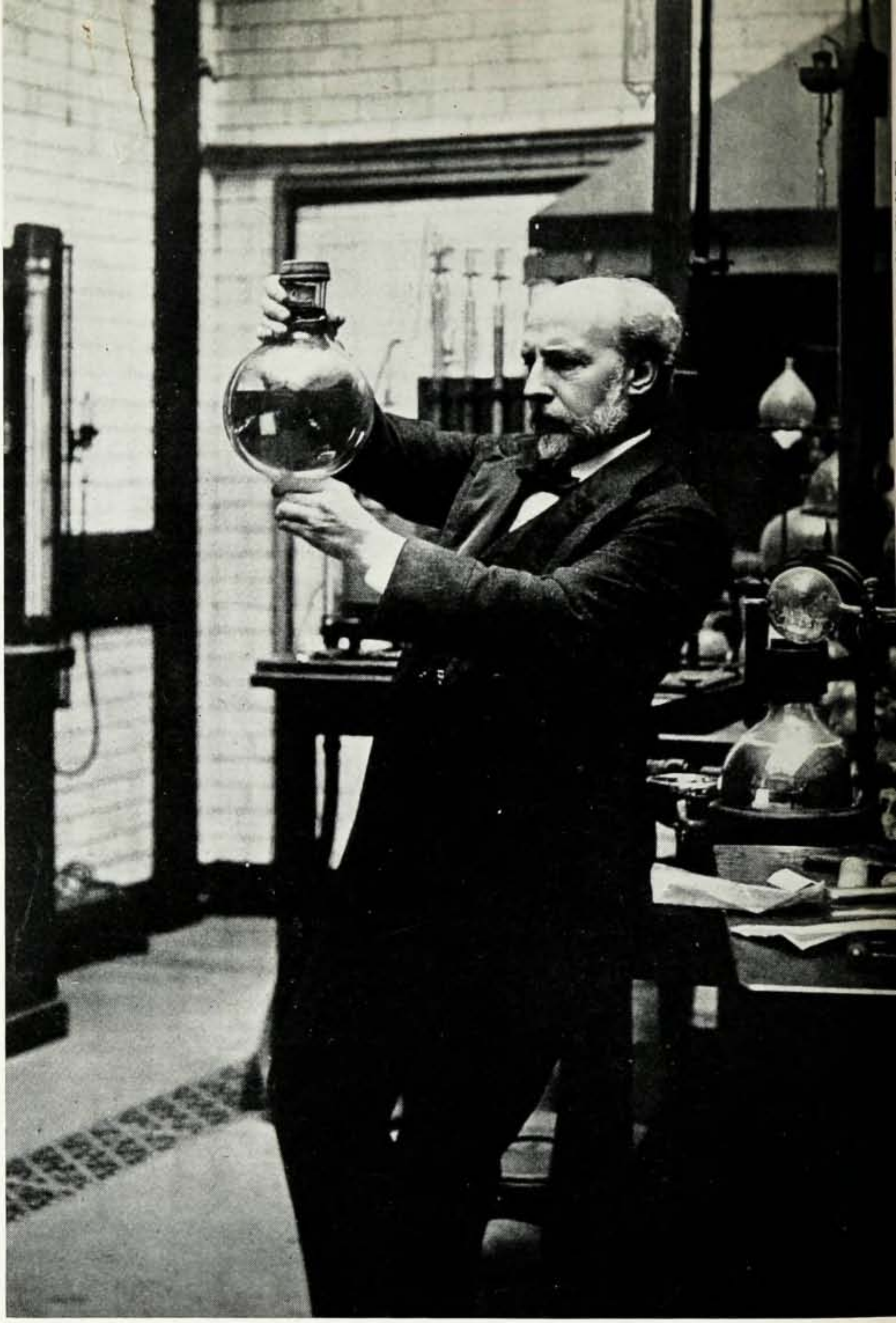
James Dewar, the inventor of Dewar vessels (Thermos flasks) and a pioneer in low temperature physics, in Britain.



LOW TEMPERATURE PHYSICS IN BRITAIN

by ***David Shoenberg***

Theories are hard put to keep up with the phenomena uncovered by the advancing experimental techniques in low temperature physics. A British physicist reviews the work going on there and in Continental laboratories.

When matter is cooled the heat agitation of the particles which make it up becomes less vigorous and this produces many characteristic effects. For instance, a great part of the electrical resistance of a metal is caused by the obstructing influence of the heat motion of the metal atoms on the electrons' motions, and so when the temperature is reduced the resistance falls. Similarly the ability of a magnetic field to line up the magnetic ions of a paramagnetic salt becomes greater as the temperature is lowered and the magnetic susceptibility rises accordingly. In the early years of this century, and particularly after the quantum theory was developed, the atomic theory of matter was applied to many such problems, and on the whole very satisfactory explanations were found for the observed temperature variation of most physical phenomena down to the lowest temperatures then available (in the region of ten to twenty degrees absolute). There were, it is true, many slight discrepancies of detail, but it looked as if these difficulties would disappear if suitable refinements were made to the theory.

Thus when, in 1908, Kamerlingh Onnes liquefied helium for the first time and so opened up a new range of low temperatures below 4.2° Kelvin or absolute (– 269.0° Centigrade, the normal boiling point of helium), it looked as if research in this new range would merely add a few points to existing graphs and would not be likely to produce anything really new in principle. It soon turned out that this was a very mistaken view, first when superconductivity, the sudden and complete disappearance of electrical resistance, was discovered, and later as various remarkable properties of liquid helium itself began to appear.

For many years Leiden had a monopoly on investigating these new effects, but in the 1920's helium was liquefied in Berlin and Toronto and plans were made for cryogenic laboratories in many other scientific centres, so that the tempo of investigation began to increase. It was only in the early 1930's that helium was first liquefied in England, though it should not be forgotten that as far back as 1898 Dewar at the Royal Institution in London had been a pioneer in liquefying hydrogen on a useful scale.

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Mendelssohn and Simon at the Clarendon Laboratory in Oxford, and Kapitza at the Royal Society Mond Laboratory in Cambridge set up the facilities for regular production of liquid helium at about the same time (1933); not long after a smaller plant was established by Jackson at Bristol and plans are afoot for liquefying helium at St. Andrews and elsewhere in Great Britain. Just before the war the possibilities of the field began to be more widely recognized and many new cryogenic laboratories have been set up or are planned in the United States. It is interesting to note that this development has been greatly eased by Collins' work at MIT in developing Kapitza's method of liquefaction into a streamlined factory-produced model.

Since the English work started on rather a modest scale its tendency has been (and still is) to explore new kinds of phenomena rather than to consolidate by detailed measurements the lines of work started elsewhere. In fact, a great attraction of low temperature physics is that it still offers so many opportunities of doing experiments where it is impossible to guess the answer beforehand. Obviously, from this point of view, the most attractive subjects are those where the theory is least complete and so it is not surprising that the properties of liquid helium and superconductivity have been particularly favoured by the English school of low temperature physics.

Just before the recent war, a whole series of quite unexpected discoveries were made about liquid helium. It had long been known that liquid helium underwent a "lambda-point" transition at 2.2° absolute (so-called because of the shape of the specific heat-temperature curve), but it had not been realized that below the lambda-point the liquid was in many respects totally unlike any ordinary liquid. Following on the discovery by Keesom in Leiden that the liquid had an abnormally high thermal conductivity, Allen and Misener in Cambridge and Kapitza in Moscow simultaneously found that the liquid could pass through very narrow channels with no measurable trace of viscosity; it was in fact both a superconductor of heat and a superfluid. Then Allen and Jones found that a pressure was developed whenever a temperature difference was established in the liquid and in suitable circumstances this pressure could project a fountain of helium a foot high. In Oxford, Daunt and Mendelssohn, following up

THE HELIUM FOUNTAIN. When light is shone on the emery powder contained at the bottom of the central tube, the temperature of the helium is raised and the resulting pressure produces the fountain of liquid helium, in this case three inches high (with suitable arrangements the fountain can be made much higher).

an observation of Rollin and Simon found that any surface connected with the liquid became rapidly covered with a mobile film hundreds of atoms thick. This film could for instance drain a vessel containing liquid helium if its level was raised above the surrounding bath, just as if the liquid was being siphoned out by a connecting tube.

All these and many other remarkable properties have given the theoreticians much food for thought. In the hands of Tisza, F. London, and Landau a theoretical scheme has been developed which correlates most of the observed effects. The liquid is thought of as made up of a "superfluid" and a "normal" part in proportions which vary smoothly with temperature and with suitable properties ascribed to them to account for the known facts. Though all are agreed that fundamentally the effects are of a quantum nature which show up in helium because of the lightness of its atoms and the feebleness of their interactions, there is still a long way to go before this quantum basis behind the theoretical scheme is understood properly. The theoretical scheme has, however, been valuable in suggesting new experiments, and has for instance recently led to the discovery by Peshkov in Moscow of a new kind of wave propagation in liquid helium, the so-called "second sound." This and other properties of liquid helium are at present being actively studied in Oxford, Cambridge, and Bristol and also in the U. S. S. R. and U. S. A.

The position in superconductivity is in many ways analogous to that just described for liquid helium. Again, a theoretical scheme exists—worked out by the brothers F. and H. London and by Casimir and Gorter—but as in helium there is no detailed understanding of the fundamental mechanism behind the scheme. It is probable that at the transition temperature of a superconductor the metallic electrons begin to condense into a kind of "quantum liquid"—similar to the superfluid part of the liquid helium. Exactly why and how this condensation takes place is still obscure, though Heisenberg in Germany and Born and Cheng in Edinburgh have made attempts to explain it in terms of interactions between the electrons among themselves and with the metallic ions. In the 1930's a good deal of experimental work in many laboratories had shown that superconductors had remarkable magnetic properties, entirely opposite to those of iron. Instead of sucking in magnetic lines of forces as does a piece of iron, a superconductor pushes them out by building up surface electric currents. The Londons' theory showed that much might be learned about the mechanism of superconductivity by measuring the very small depth in which these surface currents flow, and a good deal of work, mainly in Cambridge, has been going on both before and since the recent war in this direction. It has been shown that this penetration depth is about one hundred-thousandth of a centimeter or so and moreover that it expands rapidly as the temperature approaches the transition temperature. This can be interpreted as meaning that the proportion of "superconducting" or condensed electrons diminishes to zero as the transition temperature is approached. Another interesting development, opened up by H. London in Bristol and extensively developed by Pippard in Cambridge quite recently, has been the demonstration that, although a superconductor has no electrical resistance to a steady current, there is a measurable resistance if the current alternates with a frequency in the centimetric radar range. Work of this kind, which is also

A FLASK OF LIQUID HELIUM. This photograph was taken on April 21st, 1934, the first occasion that helium was liquefied in the Royal Society Mond Laboratory. Usually the liquid is kept in a Dewar vessel with silvered walls, and with a second similar vessel containing liquid air around it, in order to reduce the boiling rate, but in this photograph a single clear-walled Dewar vessel was used to show the liquid clearly.

being carried on at MIT and Yale, is already proving to be a valuable testing ground for tentative theories of superconductivity.

Another line of low temperature work which has been actively taken up by the British school is that of producing very low temperatures by adiabatic demagnetization of a paramagnetic salt—a method first used successfully by de Haas in Leiden and Giauque in Berkeley. Before the war, Kürti and Simon in Oxford carried out a beautiful series of experiments which demonstrated the possibilities of the method but also showed that the small interactions of the magnetic carriers in the paramagnetic salt, with each other and with the electric field of the crystal lattice, set a limit to the lowest temperature attainable by the method. Although this limit —a few thousandths of a degree absolute—sounds very low, it must not be forgotten that on a logarithmic scale it still leaves an infinity of lower temperatures to be covered. The technique of using these low temperatures for anything other than the study of the properties of the salt itself is still in its infancy, but already plans are afoot both in Oxford and Cambridge to achieve still lower temperatures with the help of nuclear magnetic moments. These moments are much weaker than those of the magnetic carriers in paramagnetic salts, but they have also much feebler interactions, so that it may be possible to achieve much lower temperatures, perhaps as low as one millionth of a degree absolute. This line of work is particularly exciting because there is no telling what new phenomena may turn up when this new range of temperatures is properly exploited.

This brief survey shows that the technical effort put into opening up the temperature range below 4.2° absolute has already paid handsome dividends and, with the considerable expansion of cryogenic facilities now going on, we may expect that the rate of progress in our understanding of outstanding problems will rapidly increase. Though these problems will no longer be so attractive once theoreticians are provided with enough material to build up adequate theories, there is a long way to go before this happens and we may hope that by then we shall have discovered new mysteries to unravel.

The large liquid hydrogen plant at the Clarendon Laboratory, Oxford, in operation. Liquid hydrogen is used as the first stage of cooling in the Oxford helium liquefiers.