# LIQUID HELIUM AND ITS PROPERTIES

A CONFERENCE on the properties of liquid helium was held at the Clarendon Laboratory, Oxford, on June 27 and 28. Welcoming the guests, Prof. F. E. Simon said that the original plan had been to have a colloquium on the subject, but the response to the invitations had shown that there was widespread interest in the problem of liquid helium which seemed to justify a meeting on a larger scale. Helium, which because of its high zero-point energy remains a liquid even at absolute zero, presents a unique possibility of studying a 'quantum liquid'. With experiments starting again after the War, this was a suitable time to bring together the experimentalist and the theoretical worker. Since the War had made it difficult for many scientific workers to keep up with current fundamental research, it had been decided to open the conference with a short survey of the existing experimental data which had been compiled by Dr. K. Mendelssohn.

The main items on the first day were lectures by Prof. M. Born and Mr. H. S. Green, of Edinburgh, on their new kinetic theory of liquids, accounts of which have recently been published in the columns of *Nature*[1,2]. Two aspects of the quantized theory are of particular interest with regard to liquid helium. The first is the fact that the states of angular momentum $l = 2, 4$, etc., give no contribution at very low temperatures, which results in a radial distribution function very different from that of a normal liquid. According to calculations by Kahn, the temperature at which the last non-vanishing state of angular momentum $l = 2$ begins to disappear coincides within 0·1° with the experimentally determined change from helium I to helium II. The other aspect is the explanation of the transport phenomena in liquid helium II as being caused by a flow of heat which is normal to the direction of the mass flow. For example, the film transport is thought to be due to evaporation on the surface of the film. In the discussion following these papers the question was left open whether there is sufficient reason to assume in all the observed transport phenomena the existence of such a causative heat flow. However, the interpretation given will certainly act as a stimulus for new experiments.

One of the most fruitful approaches to a solution of the helium problem is F. London's[3] suggestion to treat it as a condensation phenomenon of a Bose–Einstein gas. It is clear that any such model based on the properties of an ideal gas will require considerable modifications if applied to a liquid where the effect of interaction between the atoms is large. A further step in this direction has been made by Dr. H. N. V. Temperley of Cambridge, who has used the 'cage model' in which each atom has a finite chance of escaping from a cage formed by its nearest neighbours. The type of periodic field chosen is that introduced by Kronig and Penney, which is easy to handle mathematically. Making plausible assumptions on the way in which the intensity of the field depends on the volume, semi-quantitative agreement with the observed equilibrium properties of helium can be obtained. In particular, it can be shown that liquid helium II must have a negative coefficient of expansion and that the zero-point energy must be high. It is hoped that the model will also lead to an interpretation of the transport phenomena.

A fundamental difficulty inherent in the model of a Bose–Einstein gas was mentioned by Dr. H. Fröhlich of Bristol. He pointed out that if this model were rigorously applied to the case of liquid helium, the density would have to be non-uniform; it would be low on the walls and increase to a maximum in the centre of the container.

A first-hand account of recent work on the anomalous transport effects in liquid helium II which has been carried out at the Kamerlingh Onnes Laboratory at Leyden was given to the conference by Dr. J. H. Mellink. Since the discovery in 1936 that liquid helium II has an extremely high heat conductivity, exceeding even that of pure metals, it has become increasingly clear that this conduction process is a somewhat complex phenomenon which cannot be expressed in the same terms as the heat flow through an ordinary liquid. The discovery in 1938 by Allen and Jones[4] of a thermo-mechanical effect (the so-called 'fountain effect') arose directly from measurements of the heat conductivity, and this has left no doubt that in liquid helium II heat flow is accompanied by mass flow. This mass transport must not, however, be regarded as an ordinary convection process. When heat is supplied to one of two volumes of liquid helium II which are connected by a capillary link, a flow of liquid will take place towards the part that is being heated. Consequently the level in the heated volume will rise at the expense of the unheated one, and a pressure difference will be set up. This pressure difference between the warm and the cold end of the capillary is bound to force back the liquid in the direction of the heat flow, and therefore it appears that the setting up of a temperature gradient must be accompanied by a counter-current of liquid inside the capillary. It is to be expected that this two-way transport of liquid adds much to the complexity of the observed phenomena; and one of the most important questions to be settled before an explanation of the effects can be essayed is the manner in which the size of the capillary link affects the flow of mass and heat.

The work carried out in Leyden by Duyckaerts, Keesom, Mellink and Meyer[5,6,7] constitutes a systematic investigation of the heat conduction and the fountain effect in capillaries ranging from 100 μ to 0·15 μ. Except for the very largest size, for which an ordinary glass capillary tube was used, the capillary link consisted of a narrow slit between two polished glass surfaces, the width of this slit being variable. With a very narrow slit the heat conductivity of liquid helium II was found to be almost a thousand times smaller than in large capillaries, but even so it is still $10^5$ times greater than that of liquid helium I. Another interesting feature is the return, for very narrow slits, to a proportionality of heat flow to temperature difference, whereas in large capillaries the heat flow is proportional to the cube root of the temperature difference. The fountain effect, that is, the difference in pressure at the ends of the capillary, is found to be proportional to the heat current and, like the heat flow, becomes proportional to the temperature difference for narrow slits. In slits of medium diameter all the intermediate stages between the transport effects in large and very narrow capillaries can be traced. This transition is particularly apparent when the variation of the phenomena with the absolute temperature is considered. All the previous measurements of the heat conduction carried out with capillaries show that this quantity rises to a maximum at about 1·9° K. and then decreases rapidly with rising temperature to reach the normal value for liquid helium II at the λ-point (2·19° K.). Using intermediate widths of slits the Leyden workers were able to show that the maximum is displaced to higher temperatures, until in the case of the narrowest slits the heat flow rises as a monotonic function of temperature, reaching a maximum value at the λ-point. The same is true for the fountain effect, and it is significant that in wider slits there exists a proportionality of heat flow and fountain effect to the applied difference in temperature for the region of low temperatures. Near the λ-point, however, where these quantities decrease with rising temperature, the proportionality is lost.

The Leyden experiments have been extended to measurements of the development and absorption of heat by liquid helium II entering and leaving a capillary. This mechano-caloric effect, which was first observed in Oxford[8] in 1939 and afterwards investigated in some detail by Kapitza[9], is the inverse of the fountain phenomenon. Like the latter, it can be considered as part of a Carnot cycle, and, as had been shown by H. London[10], its measurement can yield information about the difference in entropy between helium flowing in the capillary and the bulk liquid. In agreement with the earlier work, the Leyden experiments show that, within the limits of accuracy, the loss in entropy suffered by the liquid in the capillary is equal to the *total* entropy of the bulk liquid. One further interesting feature of the work reported by Dr. Mellink is the observation of a critical velocity of the helium passing through the slit. Once this velocity is exceeded, overheating and subsequent relaxation phenomena make their appearance. In magnitude as well as in its dependence on temperature, this critical velocity agrees closely with that observed by Daunt and Mendelssohn[11] in helium films.

A good deal of the discussion on Dr. Mellink's paper centred around the curious fact that the critical velocity in his experiments was found to be independent of the width of the slit, an observation which does not seem to agree with earlier experiments in Cambridge and Moscow, and which also does not fit in with the theoretical interpretation given by Bijl, De Boer and Michels[12]. It is clear that more measurements are needed to clarify this and a number of other obscure points ; but there can be no doubt that the careful and detailed measurements of the Leyden workers constitute an important step forward in the understanding of these complex effects.

The rest of the experimental papers all dealt with the properties of the transfer film which covers all solid surfaces in contact with liquid helium II. Mr. K. R. Atkins, of the Royal Society Mond Laboratory at Cambridge, reported on three different methods for measuring the thickness of the film in relation to the height above the liquid level. Earlier experiments[11,13] had given this thickness as being of the order of $5 \times 10^{-6}$ cm.; but these were integrated measurements covering heights up to 20 cm. The first type of experiment makes use of the oscillations following an equalization of level between two volumes of liquid helium II which are connected by the film. Oscillations of this type have been observed before[14], when the connecting link was a capillary filled with liquid ; and they also become noticeable with films if the ratio of film width to the surface area of the free liquid is large. Making reasonable assumptions concerning the hydrodynamics of the flow, the period of the oscillation should be proportional to the thickness of the film. The second method consists in filling with liquid helium by condensation a narrow capillary to the upper end of which is attached a vessel of large surface area. Admitting successively equal amounts of helium will result in continually decreasing rises of liquid level if the thickness of the film increases rapidly with decreasing height, because at each step part of the helium is needed for thickening the film. The third method rests upon the determination of the rate of film transfer under zero pressure-head over barriers of different height. Here again assumptions have to be made about the mechanism of the flow. While the second method has as yet not yielded conclusive results, the experiments carried out so far with the first and third methods indicate that the thickness of the film is inversely proportional to the height above the liquid level, a result which does not agree with any of the existing theories[12,15].

Dr. L. C. Jackson, of Bristol, described an optical method employed by Mr. E. J. Birge and himself to measure the film thickness directly. Use is made of the change in polarization of a beam of light which is reflected on a metal plate on which a transparent film is deposited[16]. In their experiments, half the metal plate was covered with a monomolecular film of barium stearate, while the other half was covered with a layer three molecules thick. Viewing the reflected light through a quarter wave-length plate and a Nicol prism, the intensity of the two halves of the field can be made equal by a suitable setting of the latter. If now a film of liquid helium is deposited on top of the barium stearate, the Nicol must be rotated to obtain a new setting from which the thickness of the helium film can be derived. The work is still in the early stages, but the first observations suggest that the thickness measured in this way agrees with the earlier determinations.

Up to now all experiments with the transfer film rising out of the bulk liquid have been made under the vapour pressure of the latter, and it is clear that a great deal of information about the properties of the film and the transport mechanism in it might be obtained by varying the vapour pressure above the film independently. A technique for such experiments was described by Mr. J. B. Brown and Dr. K. Mendelssohn, of the Clarendon Laboratory, Oxford. Ascending from the liquid along a solid surface, the film is then allowed to enter a separate container through a great number of very fine capillaries. These capillaries readily admit helium in the form of the dense and highly mobile film, while constituting at the same time a most effective barrier against the viscous flow of the gas phase. The first experiments have shown that after the vapour pressure over the film has been temporarily reduced by pumping, it is quickly restored to what appears to be the same value as that of the free liquid. Going a step further, the film is allowed to leave the container again by a similar set of capillaries. By collecting the bulk liquid at the end of this journey, the transport along the film under reduced vapour pressure can be studied. Preliminary observations seem to indicate that under these conditions surface flow still takes place. This shows that not only will the film persist under gas pressures below the vapour pressure of the bulk liquid, but also that it must retain its characteristic properties.

The conference closed with an account and a critical survey by Prof. M. H. L. Pryce of a new (and so far unpublished) theory of super-conductivity which had been developed by Heisenberg and his collaborators.

Space does not permit of dealing with a great number of points raised in the discussion, which throughout the conference was lively and informal. Besides those mentioned above, contributions to the discussion were made by Profs. J. F. Allen, E. N. da C. Andrade, Lord Cherwell, J. D. Cockcroft, O. R. Frisch, E. A. Guggenheim, H. Jones, R. Peierls, and Drs. R. Eisenschitz, K. Fuchs, Huang Kun, H. London, A. B. Pippard and D. Shoenberg.

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# THE BOTANICAL SURVEY OF INDIA


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PROF. MUNRO FOX[1] has recently given an admirable account of the Zoological Survey of India. This department has had a glorious past when viewed in the light of scientific achievements; but as the result of various restrictions of the Central Government in India, its activities during the past fifteen or twenty years have only been a shadow of those which preceded them. Its sister department—the Botanical Survey of India—has also suffered from lack of funds and retrenchment of staff, and at present is in a far worse condition than the Zoological Survey.

The Botanical Survey of India is one of the oldest of the scientific departments of the Government of India, for it was created[2] in 1892. At that time, the science of botany was served by the independent efforts of botanists scattered throughout India. The object of the Survey, as an organisation, was to co-ordinate work on plant surveys which was being carried on in institutions under the Central and the different Provincial Governments. These were: (1) the Office of the Reporter on Economic Products with the Government of India, Calcutta; (2) the Royal Botanic Garden, Calcutta, (3) the Botanic Garden, Saharanpur, (4) Office of the Government Botanist, Madras; and (5) Office of the Government Botanist, Bombay. The Botanical Survey was started with King (the late Sir George King) as the director and leading botanist, and all other departments joined him and were subordinate to him with the exception of the Reporter on Economic Products —who maintained his independent office. There were roughly four zones of the Survey.

In the north, Duthie was the director of the Saharanpur Garden. This garden—established by the East India Company—flourished so well in those days that it was often compared with the Royal Botanic Garden at Calcutta. The great reputation of the Saharanpur Garden was due to Duthie and his predecessors Royle, Falconer, King and Jameson. All of them were responsible for building a fine herbarium and putting together a good collection of Indian plants, mainly from northern India and the north-west Himalayas.

In the west, Cooke was the government botanist, Bombay, and he collected widely in the Presidency and housed his collection in the herbarium at Poona. Unfortunately, this collection was largely destroyed by a fire in 1902 and a duplicate herbarium had to be organised at the Agricultural College, Poona. This herbarium still exists. Cooke was followed by Woodrow and Gammie. Others who enriched our knowledge of botany of this part were Stocks, Ritchie, Dalzell and Gibson[3].

In the south, Lawson was the government botanist, Madras, and he was succeeded by Barber. They organised a representative herbarium of South Indian plants at Madras. This collection was transferred to Ootacamund in 1898 and was taken back to Madras after four years. But in 1910, the bulk of this herbarium was transferred to Coimbatore, where it still exists. The botany of south India was further supplemented by some good collections by Bourne, Gamble, Fischer, Fyson and Ramaswami.

In the east, the activities of the Royal Botanic Garden, Calcutta, were increased to cover areas in the east like Assam, Burma and the Andamans. Prior to the organisation of the Botanical Survey this was not possible, and planned exploration of the country was not done. The Lushai Hills of Assam were visited by Gage in 1899, the vast deltaic regions of the Ganges called the Sundribans were explored by Prain in 1902, an expedition to Central Burma was carried out by Gage in 1903, and Burkill explored the Abor Hills in north-east Assam during 1911–12. Owing to their semi-wild conditions Burma and the Andamans presented some difficulties in those days, but King was especially interested in obtaining plants from these areas. He took up the work by sending a trained collector to live and do plant-collection work in Central Burma. He also succeeded in training two convicts in plant-collection work in the Andamans. In 1899, Prain visited the Andamans with his Indian collector Shaik Mokim and brought back to Calcutta a fine series of plants. In Burma the work was greatly supplemented by the collections made by other individuals, and mention should here be made of persons like Prazer, MacGregor, Cubitt, Robertson, Rodger and Meebold. The Forest Department of Burma early in this century organised a forest herbarium at Maymyo, and this was maintained in excellent condition mainly through the efforts of Lace and Parkinson[4]. Thus the results of all these explorations were published and are now available in the first five volumes of the *Records of the Botanical Survey of India*. Besides this, the main herbarium at Calcutta received considerable addition to its collection, and some of the duplicates of sheets were sent to Kew, Edinburgh, and other herbaria in Europe.

It will be evident from the above that, from its inception until about 1923, the Botanical Survey met, in very large measure, the needs for which it was created. The possibility of overlapping of work of this Department with the Forestry and Agriculture Departments was guarded against by the creation of