at sea level is recognized as the line of Antarctic Convergence. To the south of the broad easterly current a series of whirls are probably formed. These circular movements, of which the greatest is found in the Weddell Sea, are stationary and dependent upon the topographic features of the bottom of the sea, and of the coast line of the antarctic continent. In the regions of these whirls the places have to be sought where the Antarctic Bottom water is formed. To the north of the easterly current one finds the sub-Tropical Convergence representing the boundary between the warm and saline water from the Atlantic or Indian Oceans and the sub-antarctic water. Along this boundary surface, whirls are probably also developed, but these are not stationary but represent travelling disturbances which uphold processes of mixing. Through this mixing, the character of the

eastward-flowing water slowly changes. The water in 65° S. and approximately 28° W., which Merz and Wüst have considered as being of Atlantic origin, belongs according to our view to the great whirl of the Weddell Sea, which, however, represents a closed system to the south of the current from the Pacific, and therefore the warm and saline intermediate water of the Weddell Sea is for the most part of Pacific and not of Atlantic origin. The so-called Indian Ocean intermediate warm and saline water found in the southern part of the Weddell Sea is no doubt typical water of the circumpolar system.

I have had the advantage of discussing these results with Dr. H. U. Sverdrup, to whom I wish to express my grateful thanks.

¹ Defant, *Z. Gesell. Erdkunde*, Berlin, 1923.

² Wüst, *ibid.*, p. 506, *et seq.*

Helium Liquefaction Plant at the Clarendon Laboratory, Oxford

By Prof. F. A. LINDEMANN, F.R.S., and T. C. KEELEY

THE main properties of liquid helium have been familiar to men of science for a great many years. The only object therefore in liquefying it is in order to cool other substances the characteristics of which it is desired to study in the neighbourhood of the absolute zero. It has long been known that the heat capacity of solids becomes extremely small at low temperatures. Thus the latent heat of evaporation of 20 mgm. of liquid helium is sufficient to cool 60 gm. of copper from the temperature to be attained with liquid hydrogen boiling under a reduced pressure to the boiling point of helium.

It is easy to design apparatus so that the substances the properties of which at low temperatures are under investigation, are cooled to the temperature of the surrounding liquid or solid helium and maintained at this temperature with a minimum of waste. It seemed preferable, therefore, to instal a small inexpensive apparatus requiring comparatively little liquid hydrogen, which can therefore be operated frequently or duplicated at comparatively small cost, rather than to indulge in a plant designed to produce liquid helium in large quantities. In any event, the financial resources available would have imposed this choice, even had the alternative procedure been considered desirable.

The apparatus which has been installed at Oxford is of a type developed by Prof. Simon and Dr. Mendelssohn in Berlin and Breslau. Two concentric cylinders capable of withstanding a pressure of some 150 atmospheres surround the space in which the substance under investigation is placed. Helium under a pressure of about 100 atmospheres is introduced into the space between the cylinders. The upper part of the annular space between the cylinders is separated from the lower, in which the helium is compressed, by a metal sheet, thus forming a small metal container

which is joined by a spiral of thin copper tubing to a source of pure hydrogen. The whole is held in position on a German silver tube in the centre of a larger metal vessel containing hydrogen or helium gas at low pressure which can be evacuated by means of a mercury vapour pump. This outer vessel together with the copper spirals through which the hydrogen and helium are introduced is immersed in a Dewar flask containing liquid hydrogen.

When temperature equilibrium has been attained, hydrogen is introduced into the top vessel under a pressure of two or three atmospheres. Passing through the copper spirals, this liquefies owing to the excess pressure and runs down into the metal container over the double-walled helium cylinder. A tap to the mercury vapour pump is now turned on and a high vacuum produced in the metal box, so that the helium container with its superposed pot of liquid hydrogen is thermally insulated save for the necessary connecting tubes.

The yield of liquid helium is improved if the compressed helium is further cooled by boiling the hydrogen in the inner container under reduced pressure. If the helium is now allowed to expand, about half of it liquefies and the central space with the experimental substances it contains is cooled to the temperature of the surrounding helium. By evacuating the space above the liquid, that is, causing it to boil under reduced pressure, one can, of course, reduce the temperature to within one or two degrees of the absolute zero.

In the apparatus used at Oxford the helium lasts for about an hour and a half. If the experiment is not finished in this time, one can repeat the process in a few minutes at very small cost in liquid hydrogen. The helium expands into a rubber bag and is recompressed into a cylinder so that very little gas is lost. The temperature during the experiment can be observed on a large-

scale manometer connected through a fine tube to a small vessel containing helium in the liquefaction space. The apparatus cost approximately £30. Since there is no need to recompress the helium rapidly, a small cheap compressor is sufficient.

The liquid hydrogen required is produced in a plant of the standard pattern designed in the Physico-Chemical Institute in Berlin which has been in use at Oxford for some years now without giving any trouble. Impurities in the hydrogen are condensed by a preliminary expansion and continuously removed by a slow stream of hydrogen. With a compressor capable of dealing with ten cubic metres of free gas an hour and an expenditure of approximately 1.4 litres of liquid nitrogen per litre of liquid hydrogen, this plant produces some $2\frac{1}{2}$ litres of liquid hydrogen per hour. Liquefier and compressor together cost approximately £350.

The liquid hydrogen is stored in pyrex Dewar flasks silvered and exhausted in the laboratory. As their efficiency equalled that claimed for the

more complicated double vessels developed by Prof. Kapitza, they have been retained.

If low temperature work expands and a large number of experiments are in hand simultaneously, it may be necessary to consider the use of the continuous Linde process of liquefaction. In view of the cost of the gas and the precautions necessary for its recovery, its distribution involves considerable inconvenience, which for the time being are scarcely worth facing. The mere liquefaction, of course, offers no difficulties and there is little doubt that the Berlin type of apparatus, which is already in use in many laboratories, will prove as serviceable and efficient as the hydrogen liquefier, should it ever be necessary to change over to this system.

Finally, a word of thanks is due to Dr. Mendelssohn, who kindly brought the liquefier over from Breslau and placed all his knowledge and experience unreservedly at the disposal of the department. But for this, it would scarcely have been possible to obtain, without hitch or trouble, liquid helium within one week of the arrival of the apparatus in Oxford.

Metrology by Light Waves at the National Physical Laboratory*

IN 1923 the International Committee of Weights and Measures accepted the eventual use of a wave-length of light as the ultimate standard of length. Already in the previous year the Board of Trade had recognised the need of replacing the existing Imperial standard yard by a standard more in accord with modern requirements. For these reasons it was decided that the National Physical Laboratory should establish means of realising a wave-length standard of length and with it determine the length of the Imperial standard yard in terms of that wave-length.

The paper cited below, by Messrs. J. E. Sears, Jr., and H. Barrell, gives an account of the apparatus and methods which complete the first stage of this programme.

The new apparatus is of the type used by Benoît, Fabry and Perot, but is distinguished from the two previously existing instruments of this type in very many features of design. The more important new characteristics of the apparatus result from two radical departures from what was aimed at in the earlier instruments.

In the first place, Benoît, Fabry and Perot compared their optically determined metre etalon with a line standard by the usual methods of microscope observations, with the aid of fine lines scribed on the polished edges of the terminal glass plates of the metre etalon; the prototype metre being a line standard, such procedure was unavoidable at some stage of the work. In contradistinction to this, the apparatus at the National Physical Laboratory derives the length of an end standard directly from the length of the metre

etalon by optical interference, the ends of the etalon being polished parallel to a high optical precision by the Pitter Gauge and Precision Tool Co. of Woolwich by a technique worked out at the Laboratory in 1920. This procedure avoids one of the most difficult steps in the earlier work—the correlation of the positions of the reflecting surfaces of the metre etalon with those of the graduation lines.

Secondly, the new apparatus is so designed that measurements may be made either in air under controlled conditions, or in vacuum, and it thus makes possible new determinations of the refractive index of the air under various atmospheric conditions, which in any event will be needed before a wave-length definition of unit of length can be finally adopted for measurements of the highest precision. Measurements of this kind involve the observation of such variable factors as temperature, barometric pressure, humidity and possibly even carbon dioxide content of the air, and there are disagreements among the published values of the effects of these factors on the refractive index of the air.

It may be also noted here that the separation of the plates in the etalon which is used for the initial measurement has been increased from the 1/16 m. used in the two earlier instruments to 1/12 m., thereby leading to a greater relative accuracy in the basic measurement.

Although the above-mentioned new features of design are in principle the most important, those interested in the design of instruments will perhaps derive most pleasure in considering other details. The apparatus is characterised by a full envisagement of what functions were to be carried out and an adequate provision of means for their convenient

* "A New Apparatus for Determining the Relationship Between Wave-Lengths of Light and the Fundamental Standards of Length", by J. E. Sears and H. Barrell, *Phil. Trans. Roy. Soc., A*, vol. 231, pp. 75-145. Sept. 16, 1932.