Low Temperatures and their Industrial Uses

IN connexion with the Very Low Temperatures Exhibition held recently at the Science Museum in South Kensington, a series of lectures was arranged, dealing both with the production of low temperatures, and with the services which low temperature work renders to technology and to pure science.

Several of the lecturers referred to the history of the successive reduction of the various gases to the liquid state, from the time when Faraday classified as 'permanent' those gases which failed to respond to his technique, up to the liquefaction of helium by Kamerlingh Onnes in 1908. Faraday's method was to compress the gas until it liquefied. Two different processes have since been used in the attainment of still lower temperatures. Both were invented in 1877, in which year they were applied to reduce oxygen to the liquid state. One process, due to Cailletet, uses the work done during expansion to liquefy the gas, whilst the other, originated by Pictet, depends on the Joule-Kelvin effect. Cailletet's method was used by Wroblewski and Olszewski in 1885 for the liquefaction of hydrogen, and was developed commercially by Claude for the production of liquid air. It has recently been modified by Simon for hydrogen and by Kapitza for helium. The alternative method, that of the Joule-Thomson effect, was used by Linde and by Hampson for the large-scale production of liquid air, by Dewar about 1896 for liquefying hydrogen in quantity and by Onnes for the liquefaction of helium, which occurs just above 4° K.

The attainment of temperatures below 1° K., that is, the passage to temperatures below that at which helium has a reasonable vapour pressure, is a very recent achievement, although the magnetic process which has since proved successful was suggested so long ago as 1923. In dealing with this subject, Dr. F. Simon pointed out that the conception of entropy as a measure of orderliness gives a simple physical explanation of the new magnetic technique, which has enabled experimenters to reach temperatures of the order of 0·01° K., and is available down to 0·001° K. Beyond this, there will be the possibility of using the nuclear paramagnetism—the magnetism due to the spin of the nuclei of atoms—and even this will not enable us to *reach* absolute zero. This, like the mathematician's infinity, cannot be attained, but can be approached as nearly as may be desired ; in fact, as Dr. Simon pointed out, so long as there remain properties which vary with temperature, so long can we continue to use those same properties to reach lower temperatures.

In the domain of very low temperatures, where the vapour pressures of all known materials are quite negligible, the problem of insulating the cooled solid scarcely exists. There is no gas in which conduction or convection can occur, and radiation at these temperatures is extremely slight. So good, in fact, is the insulation, that the difficulty in the early experiments was to cool other bodies by contact with the paramagnetic salt which was used as 'refrigerant'. This is now overcome by making a pellet in which the substance to be cooled is in intimate contact with the cooling medium.

Turning now to the contributions which low temperature research has made, and is still making, to pure science, we must not overlook the fact that its contributions to industry are also contributions to pure science, for any material which is put cheaply on the market may be of value to the academic research worker.

In a more direct way, low temperature investigations are of value to the worker in pure science, in that they permit him to study the properties of matter under the condition where the heat motion of the atoms or molecules is reduced to a minimum, and where consequently these motions offer less of a masking effect to the actual inter-atomic forces. It is thus natural that low temperature work is more closely associated with atomic than with macroscopic physics. The phenomenon of supraconductivity is the example, *par excellence*, of the unexpected results attained in this field. It is now familiar knowledge that at sufficiently low temperatures, most metals lose their electrical resistance, but lately the subject has been pursued in more detail, and it has been found that the resistance is restored if a sufficient magnetic field is applied to the sample. The field necessary for the restoration increases as the temperature is lowered. This effect has, as a matter of fact, received no satisfactory explanation yet. Another case in which low temperature studies led to an advance in pure science was the discovery of krypton and xenon. This was described by Prof. M. W. Travers, who was present when Ramsay first fractionated liquid air and discovered them in it.

Prof. F. A. Lindemann, whose lecture dealt in the main with the theoretical aspects of low temperature research, pointed out that "low temperature" simply means "a temperature at

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which the atoms on the average contain very few quanta". It is thus in a sense accidental that the temperatures which we ordinarily think of as very low are so classified. For material in which the natural forces were of a different order, the sizes of the quanta would be different, and so the low temperature region might have been much higher or lower.

Prof. Lindemann also emphasized another important use of low temperature research. Nernst's theorem, or the third law of thermodynamics, states that entropy (that is, disorderliness, or probability of a state) decreases to zero as the temperature approaches the absolute zero of temperature. This gives us, what classical thermodynamics regarded as impossible, an absolute measure of entropy, as opposed to the measurement merely of entropy differences. Now to measure absolute entropy (from which reaction constants in chemical reactions occurring at ordinary or high temperatures can be calculated), we require measurements of the specific heats of materials right down to the point where these vanish, and hence must be able to carry out measurements at extremely low temperatures.

Since these results can be applied to such reactions as the synthetic production of ammonia and the hydrogenation of coal, they clearly impinge on the third heading under which the subject falls to be considered, namely, the practical or technological applications of low temperature research. Thus, the gases in the familiar street signs owe their commercial production to low temperature studies, and even the relatively common gas oxygen is now more frequently obtained by the fractional distillation of liquid air than by any chemical process.

The history of the commercial production of this gas, as outlined in the lecture by Mr. C. G. Bainbridge, makes a fascinating story. The barium oxide process only dates from about 1885, and, seen in the perspective of history, its duty appears to have been to build up a demand for the gas, and to stimulate the development of the associated needs, such as cylinders for its storage. It is interesting to note that the production in 1887 was about 150,000 cubic feet, and that it had risen in four years to 2 million cubic feet per annum. It is now about 8–10 million cubic feet per *week*. Its uses, too, have changed in the short period concerned. At first, it was required mainly for the lime-light, which essentially was a blowpipe, and for medical purposes. Now, the blowpipe, without the lime-light, provides one of the biggest markets, and is used in a vast variety of different industrial processes. With its aid, divers can cut steel as easily under water as it can be cut in the open air. Again, the medical or semi-medical purposes have themselves increased in number; in mine rescue work, in high altitude flying, and still more in stratosphere flights, the gas is essential, as it is in mountain climbing. (It is to be noted that all the Everest expeditions have been equipped with oxygen apparatus.) For all these purposes, the oxygen now manufactured by the liquid air process provides a cheap and easy source, and moreover, the gas so produced is actually purer than that obtained by the earlier methods. It is perhaps worthy of mention that in the factories of large users, it has now become possible to dispense with the need for transporting cylinders, which owing to their bulk and weight add appreciably to the cost of the gas. The oxygen is now distributed by pipe lines, only being evaporated at the point where it is to be utilized.

Turning from the familiar gas oxygen, we find that the fractional distillation of air yields also the so-called 'rare gases', argon, neon, helium, krypton and xenon. The last two are not in industrial use on any appreciable scale, but they have an interest here on account of the fact that they were first discovered, as Prof. Travers mentioned in his lecture, by the examination of the residues of liquid air, most of which had been allowed to evaporate. The other three rare gases were the subject of a lecture by Mr. J. T. Randall. He pointed out that helium has already been used for filling two large airships, and that it has been proposed to use the gas instead of nitrogen in the air supplied to divers. This would have the very great advantage of minimizing the danger of bubbles of gas forming in the blood when the pressure is released, since helium, unlike nitrogen, is not appreciably soluble in the blood. The most widely used gas of this group, however, is argon. Its chief use is in the gas-filled tungsten filament lamp, of which more than 1,000,000,000 are made annually. Its value here is that it lowers the tendency of the filament to evaporate, and so enables it to be run at a much higher temperature. This causes the lamp to require far less "watts per candle" than the older vacuum lamp, despite the conduction of heat through the gas to the glass envelope. The other type of lamp, the gas discharge, also relies on argon to start the discharge, although in many the vapour of mercury is the main agent for carrying the current after the discharge is started. The colours are, of course, dependent on the gas in the tube, and may be modified by the addition of luminescent solids in powder form.

All the industrial applications dealt with so far are indirect, in that the purchaser, though he may benefit from the low-temperature work, does not receive anything cold. The last example, the subject of the lecture by Dr. I. J. Faulkner, is

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direct. We have now become accustomed to the use of solid carbon dioxide for the refrigeration on the tricycles in which ice-cream is transported in the big towns. It has, however, many other industrial uses, and as many as 60,000–70,000 tons are now produced per annum in the United States. A surprising fact is that its loss by evaporation is quite moderate, being about 1–2 per cent by weight in 24 hours, on blocks of the ordinary size. It is also interesting to note that the gas itself, which surrounds the solid block, is a poor thermal conductor. This atmosphere of carbon dioxide is very useful when the solid material—'dry ice'—is used for the preservation of meat and fruit, since it prolongs the life of the latter, and tends to inhibit the growth of moulds and bacteria in the former case.

A growing, but less-known, use of 'dry ice' is in the machine shop, where it can be used for shrinking one part on to another, so that after the inner one warms up and expands, the joint is of enormous strength.

Solid carbon dioxide, like liquid oxygen, has removed the necessity for transporting heavy empty cylinders when supplies of the gas are required at a distance. By purchasing a block of 'dry ice', a customer with a suitable pressure vessel can obtain a supply of carbon dioxide gas from a cylinder which need never leave his premises. He simply inserts the block, closes the vessel and allows the carbon dioxide to evaporate. The gas so obtained is much purer than that from which the 'dry ice' was originally made, since the process has many of the features of the chemist's purification process of recrystallization.

Taken together, the seven lectures illustrate in a forceful manner the strides which have been made in the science and art of low temperature production and utilization, and also the interdependence of pure and applied science. The authorities of the Science Museum are to be congratulated on the provision of the course, which must have added very considerably to the interest of the Very Low Temperatures Exhibition itself, valuable though it would have been without them.

J. H. A.

Obituary

Sir William Hamer

By the death on July 7 of Sir William Heaton Hamer, at the age of seventy-four years, epidemiology has been deprived of one of its most zealous students.

William Hamer (he was knighted in 1923) was a scholar of Christ's College, Cambridge, and graduated twelfth wrangler in 1882. After graduating in medicine, he entered the Medical Department of the London County Council and rose to be Medical Officer in 1911, retiring in 1925.

Hamer's mathematical training showed itself in some of his earlier researches, particularly his elucidation of the periodicity of measles in London, which he attributed to rhythmic variation in the number of susceptibles in the population. His work on these lines was afterwards extended by the late H. E. Soper and, although it is now held that the phenomenon is not quite so simple as Hamer suggested, there is little doubt that changes in the proportion of susceptibles form an important element of the general problem.

Hamer was an acute critic of popular epidemiological theories, particularly those based upon bacteriological findings, and a sturdy champion of the doctrine of epidemic constitutions, to which he devoted years of study. The "English Hippocrates", Thomas Sydenham, propounded the general doctrine that all forms of acute diseases prevailing at the same time were linked together by common features in consequence of some general, possibly cosmic, influence which he was unable to define. Hamer attempted to bring this rather vague hypothesis into conformity with modern scientific results. It is generally agreed that, in pointing out the chronological relation of prevalences of obscure nervous diseases to pandemics of influenza, and in explaining the nature of such mysterious epidemics as the 'sweats' of the sixteenth century, Hamer made important contributions to knowledge. To most students, however, his later writings were difficult to follow, and he seemed to exaggerate the importance of Sydenham's views. At his best, he was a most stimulating writer, and he continued the scholarly tradition of Charles Creighton, linking modern science to the philosophical outlook of the ancient masters.

Mr. W. Newbold

The death, on June 24, of William Newbold, classical scholar, self-taught mathematician, statistician and biologist, at the age of fifty-eight years, just as he was within sight of retirement from his duties as an inspector of secondary schools under the Board of Education, and was wishing for leisure to extend his biological investigations, was a great shock to the large circle of friends to whom he had endeared himself by his ever-ready help and wise and kindly counsel.

Though Newbold never lost his delight in classical and archæological studies, his latent first-rate mathe-

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