THE ATTAINMENT OF LOW TEMPERATURES

II BELOW 1° ABSOLUTE.

In my last broadcast I mentioned that temperatures in the neighbourhood of 1°K can be readily obtained by allowing liquid helium to evaporate rapidly at low pressures. Using very powerful pumps to evaporate the liquid, one may, by this method, reach about .8° or .7°K; but not much lower, since at lower temperatures the vapour pressure of even helium becomes extremely small, and the evaporation of the liquid practically ceases.

The attainment of still lower temperatures is made possible by a ~~novel~~ method suggested some years ago by Giauque in America and by Debye in Germany. The idea underlying this method is very simple. ~~It is well known that~~ Many of the salts of the iron and the rare-earth groups of metals are magnetic, and their magnetism is due to the ionized metal atoms in these salts behaving like elementary magnets. In the presence of a magnetic field these magnets will naturally tend to ~~align~~ aline themselves along the field. Their regular ~~alignment~~ alinement, however, will be much hampered by the thermal agitations in the salt. The lower the temperature, the feebler will be these disturbances, and hence the more intense the magnetization. If the elementary magnets are completely free, it can be shown that the intensity of magnetization ~~should~~ ought to vary inversely as the absolute temperature. Conversely, if the magnetization of a given salt is found experimentally to follow the inverse temperature law, one may conclude that the elementary magnets in it are practically free. Judged by this criterion, the elementary magnets in manganous, ferric, and a few other salts remain almost completely free right down to the lowest temperatures obtainable with liquid helium. This indeed is ~~to be expected~~ as it should be, since the elementary magnets in these salts are the spinning electrons, and the electronic spins are little affected by their environments in these salts.

In the absence of a magnetic field these elementary magnets will be oriented at random, and by applying the field they can be made to take up definite orientations in ~~the field~~ it. ~~We thus have at our disposal~~ There is thus a new method of producing order or disorder, ~~as may be desired~~, namely by magnetizing or demagnetizing ~~the~~ a substance, and this method is available ~~to us~~ even at the lowest temperatures obtainable with liquid helium. ~~In~~

Just as the possibility of producing ~~my last broadcast I showed how the possibility of producing~~ order ~~and~~ or disorder ~~can be produced there~~ by the compression ~~and the~~ or expansion ~~respectively~~ of a gas, ~~can be utilised to~~ ~~in order to obtain~~ can be utilized to produce ~~produce~~ cold, so too ~~In the same manner we can utilise~~ the magnetic method of producing order and disorder, can be used ~~to enable us~~ to reach temperatures very much below the temperature of rapidly evaporating helium.

The salt is magnetized, and ~~is~~ cooled down to the lowest temperature that can be conveniently obtained with liquid helium. It is then insulated from thermal contact with the surroundings, and the magnetic field is suddenly removed. The elementary magnets will then get into disarray, and in the process will take up the heat required for the purpose from the substance as a whole. Since the specific heat of the substance is very small at these low temperatures; the removal of heat from it ~~the substance by demagnetizing it~~ will produce a considerable lowering in its temperature.

Using a suitable salt, and a high magnetic field, Prof. de Hass in Leyden reached a temperature as low as .005°K ~~has been reached~~ by this method. ~~by Prof. de Hass in Leyden.~~

For ~~I wish now to say a few words about~~ the measurement of these low temperatures, the use of a gas thermometer is out of the question, since the vapour pressure of even helium at these temperatures is extremely low. For example, at .05°K the pressure should be of the order of 10^{-62} ~~62~~ of a millimeter of mercury, which is an incredibly low pressure. ~~Indeed~~ It would indeed be absurd to talk of a vapour pressure under these conditions.

Hence we have to adopt some other method for the measurement of these low temperatures. ~~I mentioned just now that~~ In some of the salts which are found to be suitable for the demagnetization experiments, the magnetization ~~e~~ is inversely proportional to the absolute temperature; and ~~that~~ this is so even at temperatures in the neighbourhood of 1°K. If we assume that this inverse proportionality will hold accurately at all temperatures, including temperatures close to ~~the~~ absolute zero, the observed intensity of magnetization -- which is easily measured -- of some suitable substance, can itself serve as a measure of the temperature. The assumption of inverse proportionality between the intensity of magnetization and the temperature, on which this

~~above-temperature-scale-is-based--cannot~~

~~above~~ temperature scale is based, cannot of course be correct at very low temperatures, since the assumption of complete freedom for the elementary magnets will break down at these temperatures. At any temperature there will in practice exist a small restriction, which, however, will be negligible in comparison with the thermal agitation. But when we go down much below .1°K, the thermal agitation practically disappears, and the restriction to the freedom of orientation of the magnets ~~will~~ becomes relatively conspicuous.

Thus the magnetic scale of temperatures postulated above, though very convenient to use and to reproduce, will be ~~purely~~ an arbitrary scale. But it is easy to calibrate ~~the scale~~ it in terms of the thermodynamic scale of absolute temperatures. Two sets of measurements are necessary for this purpose. One ~~way~~ is found by ~~to~~ repeating the demagnetization experiment with different initial magnetizations, and ~~to~~ finding on the magnetic scale the different ~~lo-w~~ low temperatures that will be reached. This set will give us measures of the disorder present in the salt at these different temperatures. The second is obtained by ~~set of measurements consists in~~ finding the specific heat of the substance at these low temperatures. For this purpose Prof. Simon at Oxford uses an ingenious method: he supplies known amounts of energy in the form of ~~soft~~ gamma-rays from a specially chosen radio-active substance, ~~which are so soft as to be completely absorbed by the salt,~~ and ~~he~~ measures the temperatures, on the magnetic scale, both before and after such an irradiation. These two sets of measurements can be shown, with the help of a well-known thermodynamic relation given long ago by Kelvin, to be sufficient to enable us to calibrate the magnetic scale in terms of the absolute scale.

I may mention immediately that the two temperature scales do not differ appreciably above .1°K.; ~~and~~ at lower temperatures the data at present available are not sufficient to enable us to make such a comparison. ~~I shall have more to say on this point presently.~~

~~It will be desirable~~ It is good at this stage to answer the question:

"What determines the lowest temperature obtained in the demagnetization experiment?" ~~Of course~~ The initial temperature and the strength of the magnetic field used ~~in the experiment~~ ~~would~~ will obviously have much influence. But the ultimate limit to the low temperature attained with a given substance will ~~obviously~~ depend on the unavoidable restrictions to the freedom of orientation~~s~~ of the elementary magnets, which, though feeble, will become conspicuous at very low temperatures. The greater the freedom of these magnets, the lower will be the final temperature attained. This result would imply that if we can find a substance which contains elementary magnets that are even more free than the spinning electrons, we can use such a substance for producing still lower temperatures. ~~We have~~ There is such a substance in some of the diamagnetic compounds whose atomic nuclei have spin magnetic moments. These nuclear magnetic moments will be some 2000 times smaller than the electronic moments; but at those low temperatures even the nuclear moments can lead to appreciable magnetization.

The proposed experiment with the new substance can be done in two stages. We can use the ordinary demagnetization method to produce temperatures of the order of .01°K or less; then, starting with this temperature, we can, with the help of the new substance, produce much lower temperatures.

There is, however, a catch in the argument ~~underlying the above proposal for~~ about the two-stage experiment, which may well prove fatal to ~~the~~ its success. ~~of the experiment.~~ The greater the freedom of the elementary magnets, the ~~larger~~ longer will be the time taken either ~~for~~ to magnetizing the substance or ~~for~~ demagnetize it; and for a given substance, the lower the temperature, the ~~larger~~ longer will be this time. For convenience we may call this time "the time of relaxation." On a rough calculation one finds that even for the electronic magnets, which may be presumed to be less free than the nuclear magnets, the time of relaxation, which at .05°K is of the order of a few seconds, becomes ~~some thousands of~~ several years at .01°K. ~~is of the order of a few seconds.~~ There does not, therefore, seem to be much chance for the success of the proposed two-stage experiment.

Indeed, ~~the above~~ these values for the relaxation time of the electronic magnets suggest that even in the ordinary demagnetization experiments with electron magnets, the body temperature of the demagnetized substance -- which is called the lattice temperature -- may not be as low as the measured temperature on the magnetic scale would suggest. In the demagnetization experiment the lattice might have been left over at a temperature of $.05^{\circ}$K or so, and the measured temperature may refer only to the electronic spin moments, which might have ceased to be on ~~chan~~ exchange terms with the lattice. This would imply the coexistence of two different temperatures for the body, one for the spinning electrons in it, and the other for the lattice. I am here treading on rather uncertain ground.