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CERTAIN PROPERTIES OF SOLUTIONS OF He^3 IN He^4

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/Figures are appended./

Many works on the separation of helium isotopes and on the properties of pure He^3 and He^3-He^4 mixtures have appeared during the last 3 years.

One reason for the great interest in these problems is the desire to study the properties of liquid He^3, a knowledge of which is essential in the theory of He II, and to consider the phase transition He I - He II in solutions of He^3 in He^4. Much interest is also attached to as complete a study as possible of other physical properties of He^3.

The great difficulties in obtaining pure He^3, or helium rich in this isotope, result from the extremely low He^3 content of ordinary helium. The concentration of He^3 in helium obtained from gas wells varies from 0.6×10^{-7} to 2.0×10^{-7} (1). The He^3 content in helium obtained from the atmosphere is approximately one order higher, i.e., 1.2×10^{-6} (2). Because of the low helium content of the atmosphere, however, it is very difficult in practice to obtain it in quantities sufficient to extract the light isotope. Therefore, helium from wells is usually used as the initial helium.

Because of the very low He^3 content of helium, ordinary concentration methods are ineffectual (3-5). For this reason, the properties of solutions of He^3 in He^4 have been little studied.

In our report, we cite briefly the results of our studies in developing an effective method for enriching the light helium isotope and in investigating the dependence of the temperature of lambda transition (transition of He I to He II) on the He^3 content and the characteristics of the phenomena of overflow of He II along a wetting film in He^3-He^4 mixtures. Description of our enriching method has been deferred awaiting a detailed report

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and we note here only that a thermomechanical effect was initially used to obtain approximately 1,000-fold enrichment, while a further 200-fold enrichment was carried out in a distillation column. This degree of enrichment does not represent the limit of the method, but was determined by the necessity of obtaining a final mixture of about 20 cubic centimeters for measuring purposes. The mixtures used for measurements contained up to 1.5 percent He^3. The concentrations were determined from a comparison (differential method) of vapor tensions over He^4 and the mixture, by using data on the vapor tension of pure He^3 (6) and assuming that Raoult's law holds for these concentrations.

Shift in Lambda Transition

The temperature of lambda transition with only several cubic centimeters of liquid helium can be determined most conveniently by observation of the temperature when the liquid begins to overflow along a wetting film. For this purpose, an instrument similar to P. G. Strelkov's instrument (7), modified for work with small quantities of the liquid, was employed to study the overflow of He II along a film. Figure 1 shows the main part of the instrument, i.e., the two legs of a thin-walled capillary tube (diameter approximately one millimeter) communicating along the helium film. The instrument was immersed in liquid helium and carefully screened from radiation.

Since the legs of the vessel are of different lengths, the helium condensed in them (through the capillary tube) stands at different lengths. When the temperature of lambda transition is reached, helium begins to overflow from the upper leg into the lower. The speed of overflow was determined for various temperatures slightly below that of lambda transition, and the position of the levels was read with a cathetometer. Since the speed of overflow close to lambda transition is a rapidly-rising linear function of temperature, the temperature of He I-He II transition can be determined from these measurements with an error not greater than 0.005 degree centigrade.

These measurements were made with liquid helium for He^3 contents of 0.34 percent and 1.5 percent. Shifts (decrease) in the temperature of lambda transition were within the limits of error of the measurements in the first case and was 0.02 degree in the second.

The result obtained does not confirm the theoretical considerations of either London and Rice (8) or Stout (9). The lambda transition, in contrast to the generally accepted point of view, was considered in the first work as a transition of the first type and it was concluded that He^3 content of more than one percent in He II was impossible; in the second work, it was found that the shift in the transition temperature was greater than the experimental value and was of the opposite sign.

While the present work was being prepared for publication, the work of Abraham, Weinstock, and Osborn (10) was published on the shift in the temperature of gamma transition, using He^3 obtained from tritium, and the new work of Stout (11), who used the results of (10). Our data on concentrations, which lend themselves to comparison, differ markedly from the results of these authors; thus, the dependence of the temperature of He I-He II transition on admixture of He^3, according to our data is $\frac{\partial\theta}{\partial C} = 1.3$ (θ the temperature of transition and C the He^3 concentration), while according to Abraham, Weinstock, and Osborn $\frac{\partial\theta}{\partial C} = 5$. According to these authors, the error in determining θ was $\pm$ 0.05 degree centigrade, which could not give the correct dependency for low concentrations (around one percent).

Overflow Along a Film

A difference in overflow, along a film of mixture and ordinary He II was revealed in determining the shift of the gamma transition in the instrument described. It is known that the speed of this overflow in He II does

not depend upon the difference of levels, and is constant at a given temperature. In experiments with He^4 in the instrument described, the picture described was actually observed. Something entirely different occurred with helium enriched with He^3. In this case, the speed of overflow decreases rapidly as the difference of the liquid levels in the legs decreases and becomes very small when this difference reaches 1-1.5 millimeters. Moreover, the dependence of the speed of overflow V (cubic centimeters per centimeter per second) on the difference of levels dn is almost linear (see Figure 2).

For experiments conducted at a temperature close to lambda transition, the overflow takes place at constant speed (slightly less than for ordinary He II at the same temperature) until the difference of levels becomes small and then decreases with further decrease in the difference of levels. Further away from the lambda temperature, the difference of levels at which the speed of overflow starts to decrease is greater, and for sufficiently low temperatures (approximately 1.5 degrees Kelvin), it will no longer be possible to replace the section with the constant speed of overflow. In the interval of difference of levels where decrease of the overflow speed is observed, this phenomena will take place in the same manner for different temperatures, but will depend strongly upon the concentration of He^3 in the liquid.

The phenomena discovered may be explained in the following way. The concentration of He^3 increases in proportion to the overflow -- namely the overflow of helium along the film from one leg to the other -- into that leg from which helium flows out, since the superfluid part of helium, i.e., He^4, flows along the film. Acting simultaneously with this mechanism is the mechanism of equalization of concentrations through the gaseous phase. At temperatures considerably lower than the lambda temperature, the overflow speed is great and rapidly causes a considerable difference in concentration. Therefore, an osmotic pressure is created which would limit the overflow if the concentrations were not equalized through the gaseous phase, and the helium would overflow only up to a certain difference of levels. This has been observed, although for a very low concentration, by Daunt, Probst, and Jonston (12) in an experiment in which equalization through the gaseous phase was eliminated.

Because of the equalization of concentrations through the gaseous phase, the overflow speed is now regulated by the speed of this equalization. The speed of equalization of concentrations through the gaseous phase will decrease just as, consequently, will the overflow speed, in proportion to the decrease of the difference of concentrations. At temperatures close to the temperature of lambda transition, the overflow speed will be low, thus causing a low difference of concentrations. In this case, overflow will take place at constant speed until the difference of levels corresponding to the osmotic pressure for low difference of concentrations is reached. Afterwards, the overflow process will again be regulated by the speed of equalization of concentrations through the gaseous phase.

In conclusion, we note that the original enrichment attained with a small instrument in which a thermomechanical effect was used for effecting further enrichment, allows us to assume that He II with concentrations of more than 30 percent He^3 exists at a temperature of 1.4 degrees Kelvin.

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/Appended figures follow:/

Figure 1

Figure 2

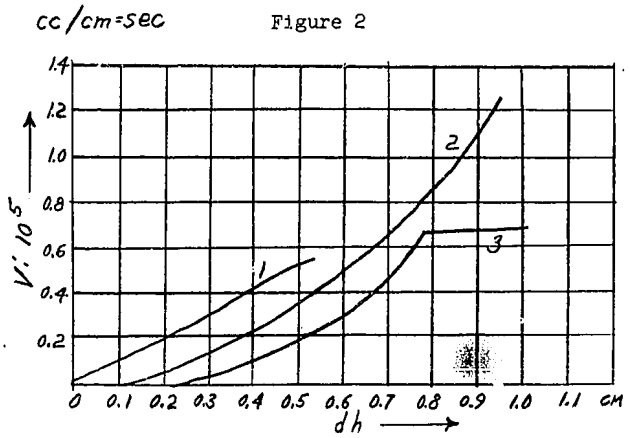

Figure 2. Dependence of the speed of transfer along the film on the difference of levels for He^3/He 1.5 x 10^{-2}. Curves 2 and 3 are shifted by 1 and 2 millimeters, respectively, along the abscissa. 1 : 1.47°K, 2 : 2.08°K, 3 : 2.10°K.

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