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NUCLEAR RELAXATION IN LIQUID SOLUTIONS OF HELIUM ISOTOPES

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The spin-lattice relaxation times (T_1) in pure He^3 and in He^3–He^4 solutions are measured at temperatures between 1.4 and 2.1°K and concentrations of 20–100% He^3. The relaxation times increase with increase in temperature. It is shown that the addition of He^4 to He^3 increases the relaxation time. The results agree qualitatively with the theory of Bloembergen, Purcell, and Pound.[5]

NUMEROUS studies carried out in recent years[1-5] have made it possible to develop a method of measurement of the true relaxation time (T_1) in pure liquid He^3 and to make clear the temperature dependence of T_1 in the temperature range 3.2–0.8°K. In a series of researches (see, for example,[6]) it has also been found that the impurity He^4 materially affects the relaxation process. However, the relaxation times of He^3 in solutions of helium isotopes have been measured only in order of magnitude, with very low accuracy and over a very narrow range of concentrations.[1,3,4] Inasmuch as such data can contribute additional information on the character of the interaction in He^3–He^4 solutions, we have made systematic investigations of the relaxation time over a wide range of concentrations of He^3.

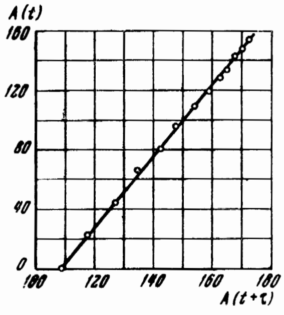

FIG. 1

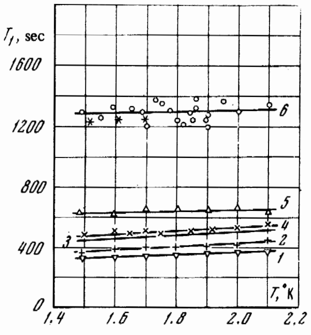

FIG. 2

FIG. 1. Dependence of the amplitude A(t) of the NMR signal at a moment of time t on A(t + τ).

FIG. 2. Dependence of the relaxation time (T_1) on the temperature for different concentrations: 1–data of Romer [2] for pure He^3; 2–data of the present work for pure He^3; 3–theoretical curve calculated from BPP; 4–x = 65% He^3; 5–x = 40% He^3; 6–x = 20% He^3, *–data with container of pyrex of diameter 8 mm.

METHOD OF MEASUREMENT

The measurements were carried out by reconstructing the signal by means of apparatus described earlier[7] at a frequency of 14 MHz. A recording of the NMR signals after saturation was made every 100 sec during a time equal to $(2.5–3)T_1$. The intensity of the high frequency field H_1 was so chosen that the saturation did not exceed 3%. To test the operation of the apparatus, a reference signal was recorded every 300 sec. Because of the large relaxation times, which, even in pure He^3, amount to about 400 sec, it is very difficult to determine the value of the equilibrium signal, and therefore a method proposed by Mangelsdorf[8] was used for the determination of T_1 from the obtained data. The essence of this method is that in the exponential restoration of the magnetization $A = A_0(1 - e^{-t/T_1})$ (where A_0 is the completely restored value), the dependence of the amplitude of the signal at any instant of time A(t) on $A(t + \tau)$, where τ is a constant quantity, is a linear one. A dependence of such a type, obtained for a solution containing 40% He^3, is shown in Fig. 1. The slope of the straight line is e^{τ/T_1}. In the use of this method, there is no necessity for the determination of the equilibrium signal. To obtain maximum accuracy in T_1, it is necessary to choose $\tau \approx T_1$. In the given case, $\tau = 600$ sec.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The scatter of the experimental data on the relaxation time of He^3 showed that T_1 depends on the geometric dimensions and the material of the containers used. A detailed discussion of this question has been given by Low and Rohrschach.[5] They considered the data of different authors and came to the conclusion that in many experiments there are two forms of relaxation: true relaxation, brought about by the dipole interaction in the liquid, proportional to the diffusion coefficient, and relaxation due to the walls of the container, which is inversely proportional to the diffusion coefficient:

$$\frac{1}{T_1}=\frac{1}{T_{1\,\mathrm{w}}}+\frac{1}{T_{1\,\mathrm{vol}}}=C_1D+\frac{C_2\rho}{D}.$$

Here C_1 and C_2 are constants and ρ is the density of the He^3. To eliminate the effect of relaxation on the walls, the measurements were carried out with spherical pyrex ampoules of diameter 8 and 15 mm (Romer was the first to point out the absence of paramagnetic impurities on the walls of pyrex glass[1,2]). The measurements were made over the temperature range 2.1–1.45°K for solutions with an He^3 content equal to 20.0, 40.0, 65 and 100%. The results of the measurement are shown in Fig. 2, where the dependence of the relaxation time on the temperature is given for solutions of different concentrations. Experiments with ampoules of diameter 8 and 15 mm for a solution with 20% He^3 content (curve 6) gave identical results (the crosses on Fig. 2 indicate data obtained with the ampoule of 8 mm diameter). In addition to the data obtained in the present work, the results of the measurements of Romer[2] for pure He^3 are also shown on the graph (curve 1), as well as the theoretical curve calculated in[9] from the formula of Bloembergen, Purcell, and Pound[10] (BPP):

$$\frac{1}{T_1} = \frac{2\pi}{5} \frac{\gamma^4 \hbar^2 N_0}{aD},$$

where a is the distance of closest approach of the He^3 atoms, γ the gyromagnetic ratio, D the diffusion coefficient, N the number of spins per unit volume, and $\hbar$ Planck's constant.

It is seen in Fig. 2 that both in pure He^3 and in the solutions, the relaxation time is weakly dependent on the temperature, slowly increasing upon increase in temperature; this is in qualitative agreement with the predictions of the BPP theory.

The relaxation times obtained in the given work for He^3 are shown to be somewhat higher than those found by Romer; however, the difference lies within the limits of the total error of the experiments (the errors in the determination of T_1 amounted to 3% for pure He^3 and 10% for the solution with concentration $x = 20\%$ He^3).

Figure 3 shows the concentration dependence of the inverse relaxation time for a temperature of 1.8°K. The data of Romer[1] are given in the graph for solutions with a content of 1.7 and 3.5% He^3 for T = 1.2°K. All the data fit well the same dependence.

As is shown in Fig. 2, the true relaxation time does not have any singularities in the vicinity of the λ transition.

In addition to the BPP theory mentioned, which gives only the order of magnitude of T_1, there are two other researches devoted to the calculation of the relaxation time in He^3–He^4 solutions. Akhiezer and Aleksin[11] undertook a consideration under the assumption that the solution was an ideal Fermi gas, and obtained the following temperature dependence at high temperatures (in comparison with the degeneracy temperature): $1/T_1 \sim T^{1/2} N_0$. Inasmuch as the effect of collisions of He^3 with the other particles or quasiparticles was not taken into account here, it is not surprising that the resultant temperature dependence does not correspond to that found experimentally.

In the work of Sing,[12] consideration was limited to the region of weak solutions and virtually reduces to the BPP formula at high temperature. Comparison with the experimental data is difficult because of the absence of measurements of the diffusion coefficient in solutions. However, it should be noted that for measurements with a container of molybdenum glass of 7 mm diameter, when the principal role is played by relaxation on the walls, an anomalous behavior of T_1 in the vicinity of the λ points of the solutions was observed for solution concentrations of 15.0, 20 and 31.8% He^3.

The data shown in Fig. 4 indicate that, as the λ point is approached from the side of He II, T_1 initially decreases, then rapidly increases, reaching a maximum at the λ point, and again decreases slightly, turning into a monotonically increasing curve. Curve 3 refers to concentrations of 44.3% He^3, the λ point of which lies below the studied temperature range. These features are evidently determined as a whole by the effect of the walls of the ampoule on the relaxation processes. Evidently a similar effect is described in[13], in which the anomaly of the relaxation on the walls was used for the recording of the λ points of the solutions. Exact clarification of the reason of these features is a rather complicated problem and requires additional investigations.

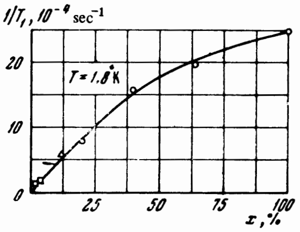

FIG. 3

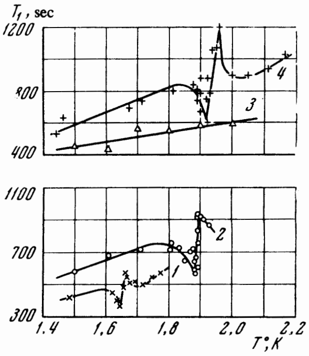

FIG. 4.

FIG. 3. Dependence of T_1 on the He^3 concentration. ○–data of the present research; △–data of the work of Romer [2], x = 12% He^3; □–data of the work of Romer and Fairbank [3] for solutions with x = 3.5% He^3 and x = 1.7% He^3 at T = 1.2°K.

FIG. 4. Dependence of T_1 on the temperature for measurements in a molybdenum container of diameter 7 mm. 1–x = 31.8% He^3; 2– x = 20% He^3; 3–x = 44.3% He^3; 4–x = 15% He^3.

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Translated by R. T. Beyer
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