adopting for the eigenfunctions of the 2^1S and 1^1S states the variational representations

$$\varphi_i(\vec{r}_1, \vec{r}_1) = \exp\{-(\alpha_i r_1 + \beta_i r_2)\} \sum_{l,m,n} a_{lmn} r_1^{\,l} r_2^{\,m} r_{12}^{\,n},$$

appropriately normalized and symmetrized, and using as the trial form of $\chi_i(\nu)$

$$\chi_i(\vec{r}_1, \vec{r}_2 | \nu) = \exp\{-(\gamma r_1 + \delta r_2)\} \times \sum_{l,m,n} b_{lmn}(\nu) r_1^{\,l} r_2^{\,m} r_{12}^{\,n} Y_1^{\,0}(\hat{r}_1) Y_0^{\,0}(\hat{r}_2)$$

appropriately symmetrized.

Up to 50 terms were included in φ_i, φ_f, and χ_i. The results show that the emitted photons have a continuous distribution broadly peaked at about 30 eV. The calculated lifetime against two-photon decay is 5.15×10^{-4} sec, though there remains some uncertainty in the third significant figure.

We are indebted to Mrs. J. Taylor for the use of a number of her computer programs.

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INFLUENCE OF He^4 ON EXCHANGE-LATTICE RELAXATION IN SOLID He^3

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Previous papers have reported approximate agreement[1-3] between experimental determinations of the exchange-lattice equilibrium time in solid He^3 and the theory of Griffiths.[4] We have made measurements at molar volume 19.97 ± 0.03 cc in the temperature range 0.4 to 0.6°K which show that this agreement was fortuitous and that the equilibrium time is strongly dependent on the He^4 content of the sample. Our results demonstrate an extra relaxation process with a rate proportional to He^4 concentration and a temperature variation between T^8 and T^9.

The results will be considered with reference to the "three bath model" proposed for solid He^3 by Garwin and Landesman.[5] In this region of temperature, however, the measured Zeeman-exchange relaxation times[1,2,6] are always at least an order of magnitude smaller than the observed Zeeman-lattice relaxation times, so the Zeeman and exchange systems may be considered as intimately coupled. In the bcc phase under these conditions it has been shown[1] that the signal recovery time T_1 should be given by

$$T_1 = \tau_{XL}\{1 + F^2/(3J^2)\}, \qquad (1)$$

where τ_{XL} is the exchange-lattice relaxation time, F is the Zeeman frequency, and J is the exchange frequency.

In the present experiments T_1 has been measured at various frequencies between 1.27 and 4.5 MHz for samples of He^3 containing different amounts of He^4. For each sample, values of T_1 at some fixed temperature are plotted against F^2; the results are compatible with Eq. (1), and we deduce that $J = 0.97$ MHz fits each sample.[7] This result has been used to derive τ_{XL} values from the measured values of T_1. It should be noted that all signals after saturation followed a normal exponential recovery with time.

Three processes, whose transition probabilities may be assumed to add, are expected to couple the exchange system to the lattice giving

$$(\tau_{XL})^{-1} = \eta_D + \eta_{SP} + \eta_{TP}, \qquad (2)$$

where η_D, η_{SP}, and η_{TP} are the rates for a diffusion-induced process, a single-phonon process, and a two-phonon process, respectively.

The diffusion process has been considered by Richards.[8] For the bcc phase his result gives

$$\eta_D = 14/\tau_c. \qquad (3)$$

τ_c is the jump time, related to the atomic diffusion coefficient D by

$$\tau_c = a^2/(6D), \qquad (4)$$

where a is the nearest-neighbor spacing for the lattice. For thermally activated diffusion this leads to an exponential dependence of τ_{XL} on temperature through the Arrhenius equation

$$D = D_0 \exp\{-W/T\}, \qquad (5)$$

where W is the activation energy.

The rates η_{SP} and η_{TP} have been calculated by Griffiths[4] for the particular case of a Debye solid. Applied to He^3 his results give for the bcc phase

$$\eta_{TP} = 2.6\times10^{-35}(\partial^2 J/\partial a^2)^2 T^7/\theta^{10}, \qquad (6)$$

and show that at 0.5°K the two-phonon process is much faster than the single-phonon one. Richards[8] finds that because of correlations the rate given by Eq. (6) should be reduced by 15 %.

Figure 1 shows the variation of τ_{XL} with inverse temperature for each of the mixtures used in the experiments. Two main features are apparent.

(i) At high temperatures all mixtures seem to have about the same relaxation time which varies as

$$\tau_{XL} = \tau_0 \exp\{W/T\}. \qquad (7)$$

This is consistent with relaxation by thermally activated diffusion for which Eqs. (2)-(5) give, at molar volume 20 cc,

$$\tau_{XL} = 1.47\times10^{-17}/[D_0 \exp\{-W/T\}]. \qquad (8)$$

At higher temperatures Reich has measured D directly[6] and finds

$$D = D_0 \exp\{-W/T\}.$$

From our results W is most precisely defined for the purer samples, which give a weighted mean of 13.5 ± 0.2°K in agreement with Reich's value 13.6°K. Using our values of W and τ_0 we estimate D_0 to be between 1.7×10^{-7} and 3.3×10^{-7} cm^2 sec^{-1}, in less good agreement with Reich's value of 4.3×10^{-5} cm^2 sec^{-1}.

To find out how rapidly T_1 changed with density we carried out one experiment at molar volume 20.5 cc; a similar value of W was observed but T_1 was reduced by a factor of 12 compared with that for molar volume 20 cc at the same temperature and frequency. The scatter of about 20% in the value of τ_{XL} at the highest temperatures would therefore be accounted for by an error in molar volume of about 0.03 cc; this is of the same order as the errors involved in forming the sample and corresponds to a variation of 1 atm in the filling pressure of the cell.

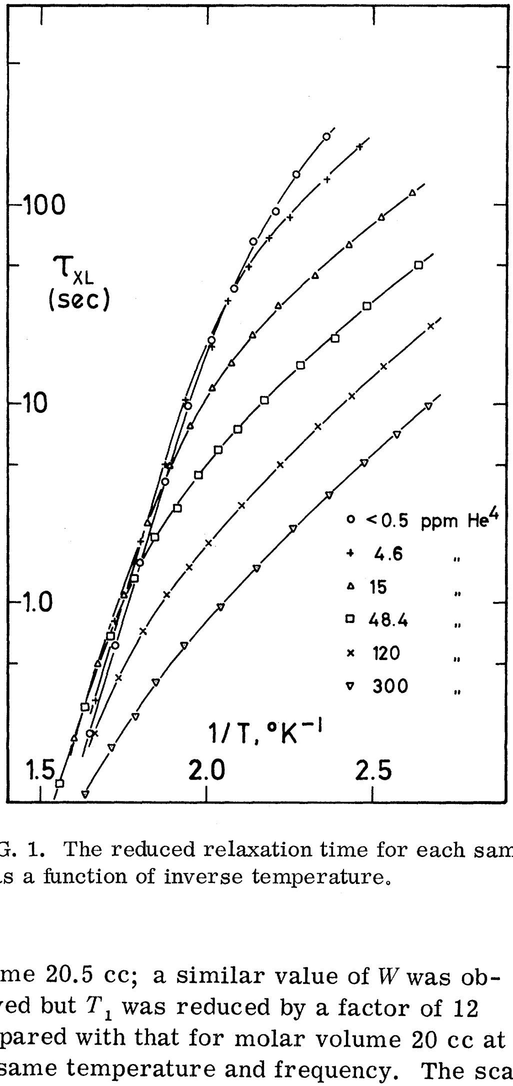

FIG. 1. The reduced relaxation time for each sample as a function of inverse temperature.

(ii) At lower temperatures the relaxation rate depends on the He^4 content of the sample and is greater than that expected from Eq. (7). We find that the experimental values of τ_{XL} for each mixture can be fitted over our whole range of temperature to an equation of the form

$$(\tau_{XL})^{-1} = (\tau_0 \exp\{W/T\})^{-1} + \eta T^n. \qquad (9)$$

The appropriate values of τ_0, W, η, and n are shown in Table I. Figure 2 is a log-log plot of τ' against temperature, where τ' is the re-

Table I. Values for the parameters of the low-temperature exchange-lattice relaxation time.

He^4 concentration x (parts in 10^6)	W (°K)	τ_0 (sec)	n	η (sec^{-1})
<0.5	13.4 ± 0.4	6.8×10^{-11}[a]	8.3 ± 2	5.10[a]
4.6 ± 0.5	13.7 ± 0.3	4.7×10^{-11}	8.0 ± 0.6	6.85
15 ± 1	13.5 ± 1	9.6×10^{-11}	8.0 ± 0.2	19.2
48 ± 2	...[b]	...[b]	8.0 ± 0.2	48
120 ± 5	...[b]	...[b]	8.5 ± 0.1	176
300 ± 15	...[b]	...[b]	8.7 ± 0.1	520

[a] No errors are quoted in τ_0 or η because these are defined to within the accuracy of the points of any pair of values taken for W and n.

[b] For these mixtures W and τ_0 were not well defined.

laxation time when the rate due to the diffusive process of Eq. (7) has been subtracted and is given by

$$(\tau')^{-1}=(\tau_{XL})^{-1}-(\tau_0\exp\{W/T\})^{-1}. \qquad (10)$$

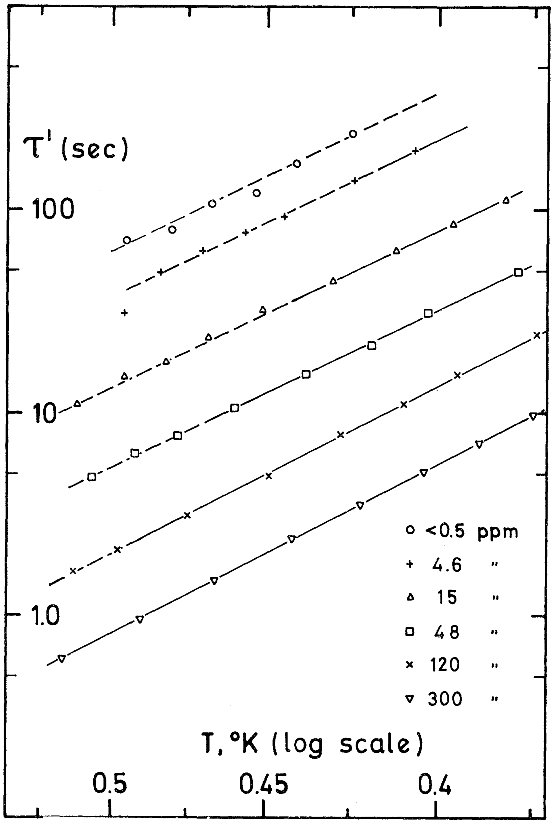

FIG. 2. The variation with temperature of the relaxation times after correcting for the effect of atomic diffusion.

A solid line of slope n has been drawn through the points for which the effect of diffusion is unimportant, and a broken line is shown where the two terms of Eq. (9) are of the same order.

To find out how the low-temperature process depends on the concentration x of He^4 in the sample, we plot in Fig. 3 the value of $(\tau')^{-1}$ observed at 0.425°K. It is apparent that for He^4 concentrations greater than about 2×10^{-5} the relaxation rate is proportional to x, but below this it flattens out at 0.004 sec^{-1}. The points lie reasonably well on the curve

$$(\tau')^{-1}=0.004+10^3x. \qquad (11)$$

Extrapolating to zero He^4 content, we estimate the relaxation rate in pure He^3 at 0.425°K and 20 cc/mole to be 0.004(±0.001) sec^{-1}. As the temperature dependence of the relaxation rate in our purest sample does not exclude T^7 it is worthwhile to compare this rate with Eq. (6). Using the J values of Ref. 1 to give a rough estimate of $(\partial^2J/\partial a^2)$, and a value of the Debye temperature θ from Sample and Swenson,[9] we

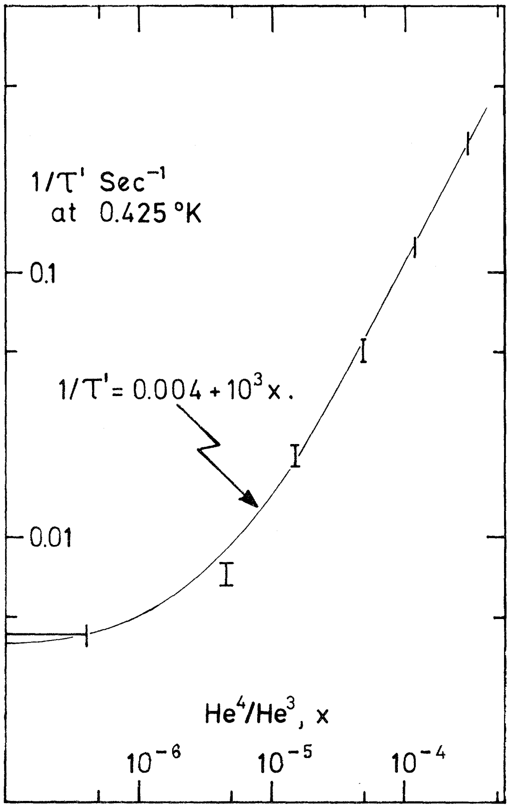

FIG. 3. The exchange-lattice relaxation time in solid He^3 at molar volume 20 cc. and 0.425°K as a function of the He^4 concentration in the sample.

obtain $(\tau')^{-1} \approx 0.01$ sec^{-1} at 0.425°K. In view of the doubtful applicability of Griffiths' calculations to He^3, this agreement is surprisingly good.

Our results show that the presence of a very small number of isolated He^4 atoms contributes to the total exchange-lattice relaxation rate by a process whose temperature dependence lies between T^8 and T^9. No theoretical calculations of relaxation times in solid He^3 containing He^4 have yet been published, but it seems a reasonable extension of Griffiths' theory to suppose that an increase in J at each He^4 site[1] would result in a locally enhanced relaxation rate. Even in the purest samples a spin diffusion coefficient derived from $\tau_{SS} \approx (J)^{-1}$ should be large enough to maintain a uniform exchange temperature.

This work will be extended to identify the temperature dependence of the intrinsic relaxation rate, and its variation with density.

We are indebted to R. B. Harrison and W. S. Truscott for the purification and analysis of the samples.

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PRODUCTION OF *d-d* REACTIONS BY BEAM-PLASMA INTERACTION IN THE STEADY STATE*

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This Letter reports an unusual deuterium plasma generated by a reflex electron beam on the axis of a simple magnetic mirror trap or modified PIG[1] configuration. The plasma is extremely turbulent, appears to be highly ionized, and emits *d-d* reaction products. It appears that the plasma's unusual nature is due to an interaction with the electron beam. Some earlier reports of electron beam-plasma interaction indicate a plasma blow-up,[2] enhanced ion and electron energies in a restricting magnetic field,[3] significant electron heating in magnetic traps,[4] a high degree of ionization when the plasma is generated along a pressure gradient,[5] and an apparent increase in the energy of some ions and electrons when the plasma is within a magnetic trap and when reduced pressure in the end regions outside the trap permits otherwise unattainable power density in the beam.[6]

We call the present device at Oak Ridge Laboratory "Burnout V," because it is the fifth in a series of modifications we have made to the conventional PIG. Each modification has enhanced this unusual effect until we can detect *d-d* reaction products originating in the plasma region. We catalog our observations of *d-d* neutrons, tritons, and protons on Burnout IV and V in Table I. The reaction rates given are estimated from the largest yields observed and the solid angle of the instrument apertures.

The 3-MeV proton data from the plasma of Burnout V are corroborated by triton and neutron measurements from both Burnout IV and V. It is only in Burnout V, however, that we are certain that the *d-d* protons originate in the plasma, within the hollow anode of the apparatus. The neutron measurements alone are inconclusive because instrument resolution is not sufficient to exclude a possible contribution from the end electrodes, which are strong *d-d* sources because of dc acceleration. The triton measurements clearly exclude the end electrodes, but do not completely exclude wall reactions within the anode. The proton