Spin-Lattice Relaxation Time of Conduction Electrons in Alkali Metals: Sodium (*) (**).

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Summary. — A theory of the spin-lattice relaxation time $T_1$ of conduction electrons in liquid and solid alkali metals has been calculated here. The $T_1$ is expressed in terms of the dynamical structure factor which includes a Debye phonon spectrum. The normal and umklapp processes are calculated separately. We find that the transverse phonons contribute greatly to the umklapp process. We also have measured the temperature dependence of $T_1$ in sodium metal from 100 °K to 600 °K. The experimental data are in fair agreement with our theory from 13 °K to 600 °K.

1. – Introduction.

The most comprehensive treatise on the theory of spin-lattice relaxation time $T_1$ of conduction electrons in solid metals is that given by Yafet (1). He derived a spin-flip transition matrix elements of the spin-orbit interaction, with assumptions of an isotropic Debye spectrum for the phonons and two different Debye temperatures, and was able to show that the temperature dependence of $T_1$ is analogous to that of the resistivity as given by Gruneisen’s law (2). For his derivation, the transition matrix must be calculated by treatment of umklapp processes and by introduction of three adjustable parameters.

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Recently, Helman (3) et al. found that the difficulty in determination of the adjustable parameters and the complex calculation of the umklapp process can be overcome by expressing $T_1$ in terms of the dynamical structure factor of the metal which includes the actual spectrum of lattice excitations and automatically takes into account the umklapp processes. In their calculations, only the longitudinal phonons are considered. The transverse phonons which have smaller velocities of propagation are expected, however, to have more effect on the relaxation time in the umklapp process. To integrate over all directions of the phonon wave vector $q$, they used the phonon dispersion curve given by the Born-Von Kármán model (4). But the Born-Von Kármán model, which is modified by multiplication of the frequencies by the dispersion factor given in the theory of the one-dimensional linear chain, neither represents the spectrum nor predicts the specific heat any better than the simple nondispersive models, i.e. the Debye and Einstein models.

In this study we have calculated the normal process and the umklapp process separately and have extended both the theoretical and experimental work to a temperature of 600 °K. We find that at very low temperatures, $T \ll \Theta_D$, where $\Theta_D$ is the Debye temperature of the lattice, the spin-lattice relaxation time $T_1$ should vary as $T^{-5}$. At high temperatures, the theory predicts the $T_1$ is approximately proportional to $T^{-1}$, however the umklapp processes cause the spin-lattice relaxation time $T_1$ to vary with temperature at a rate much slower than that by the normal processes. We found, from experiment, that there is a 30% discontinuity in $T_1$ at the melting point. This discontinuity is not compatible with the smooth theoretical curve that is drawn from solid structure factor. A theory including liquid structure factor can satisfactorily fit the experimental values from 371 °K to 600 °K.

2. — Theory of the spin-lattice relaxation time.

A theory of the spin-lattice relaxation time $T_1$ of conduction electrons in analogy with resistivity calculations performed by Greene and Kohn (5) was proposed by Devine and Helman (3). According to Devine and Helman, the spin-lattice relaxation time is given by

$$\frac{1}{T_1} = \frac{m_{p}^{*}}{(2\pi)^{3}} \int |I^{\pi}_{x'p'\downarrow, x\uparrow}|^{2} S(K) \, dS_{x} \, dS'_{x'},$$

where $I^{\pi}_{x'p'\downarrow, x\uparrow}$ is the matrix element of the spin-orbit Hamiltonian, which does not depend on the ionic co-ordinates, and where $S(q)$ is the dynamical struc-