Temperature Dependence of the Overhauser Effect in Metallic Lithium

N. A. BEKESHKO AND E. I. KONDORSKII
Moscow State University

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OVERHAUSER has shown[1,2] that in metals the saturation of resonance associated with conduction electrons must result in a high degree of nuclear polarization.

Brovetto and Cini[3] have considered the case of high temperature and weak constant magnetic fields and have obtained the following formula for the quantity P which characterizes the degree of nuclear polarization:

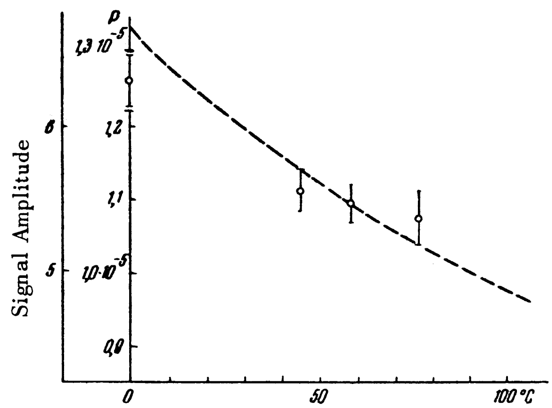
$$P = (1 + I)(\gamma_n + s\,|\gamma_e|)\,\hbar H_0 / 3kT. \qquad (1)$$

Here γ_e and γ_n are the gyromagnetic ratios of the electrons and nuclei of the metal, I is the nuclear spin, H_0 is the magnetic field strength, T is the absolute temperature and s is the saturation parameter of electron resonance.

Brovetto and Ferroni[4] found that the equilibrium value of the nuclear polarization is independent of the relaxation time and depends only on the magnetic field strength, temperature and degree of saturation of electron resonance. Bloch[5] and Korringa[6] showed that nuclear polarization must also be observed in nonmetals.

The nuclear polarization predicted by Overhauser and others was first observed by Carver and Slichter[7] in experiments with metallic lithium and later by Beljers, Van der Kint and Wieringen[8] in experiments with the free radical of diphenylpicrylhydrozyl. We present here the results of an investigation of nuclear polarization in metallic lithium at various temperatures from 77.2 to 373° K.

This experiment was performed in a constant magnetic field of 30.1 oersteds generated by Helmholtz coils. The sample consisting of 6 cm^3 of metallic lithium dispersed in oil was placed in a glass test tube within the two coils. The first coil was connected to an oscillator with an output of about 70 watts. The frequency of this oscillator was set equal to 83.6 Mc, the Larmor precession frequency of electrons in the magnetic field. The second coil was included in a double T bridge supplied by an oscillator of frequency 49.89 kc, which was the Larmor precession frequency for nuclei in the same field. The specimen was prepared by cooling during continous stirring of the lithium powder in oil heated above the melting point of lithium (in an argon atmosphere) followed by cavitation crushing in a sound field. The lithium particles were smaller than the depth of the skin layer at 83.6 Mc.



The increase of nuclear polarization was observed through the strengthening of the nuclear magnetic resonance signal. The 49.89 kc signal was transformed into a 465 kc signal which was detected, amplified and observed on an oscilloscope screen. The signal was modulated with 200 cycles. The constant magnetic field, the hf magnetic field and the 49.89 kc magnetic field were mutually perpendicular. The coils and samples were placed in a special housing and the hf oscillator was in a brass container. When the hf was not switched on the nuclear magnetic resonance signal could not be observed because it was weaker than the amplifier noise. In all of the measurements, the same amplifier gain and degree of bridge balance were maintained.

The results are shown in the Figure. For comparison of experiment and theory, the figure includes the curve which represents the temperature dependence of nuclear polarization of lithium in a field of 30.1 oersted as calculated from Eq. (1) with $s = 0.9$ (broken curve). The separate circles represent the experimental values. The ordinates of the circles represent the nuclear magnetic resonance signal amplitude in arbitrary units of a corresponding scale; the strength of the nuclear resonance signal is known to be proportional to the degree of nuclear polarization. We note also that Ref. 7 contains a quantitative comparison between the theoretical and the experimentally observed degree of polarization at room temperature.

The figure shows that with increasing temperature, the signal strength is reduced. The experimental signal strength ratio at 0 and 57° is 1.15, and the corresponding ratio of the values of P calculated from Eq. (1) is 1.21.

Our data are a basis for concluding that the resonance line width increases as the temperature drops.

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The Character of Nucleonic Forces

A. Z. DOLGINOV
Leningrad Physico-Technical Institute, Academy of Sciences, USSR

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ANALYSIS of experimental data on proton-proton scattering apparently allows us to draw the conclusion that the principal role is played by $^1S_0$ and $^3P_0$ states in the energy region up to 400 Mev[1-3]. There is no basis for thinking that the concept of a potential is generally inapplicable in this region of energy; however, numerous attempts to explain the observed character of the scattering and polarization for *pp* and *np* collisions, using central, tensor and (lS)-forces[4], have been unsuccessful. In order to describe the large contribution of $^3P_0$ and the small contribution of $^3P_1$ and $^3P_2$ states, we introduce the interaction operator in the form

$$\hat{U} = {}^1\!/_4 (1 - \sigma_1\sigma_2) V_1 + {}^1\!/_3 V_2 [(\mathbf{l}\mathbf{S})^2 - \beta], \qquad (1)$$

where $\frac{1}{2}\sigma$ and $\mathbf{l}$ are the spin and orbital momentum operators of the nucleon, $\mathbf{S} = (\sigma_1 + \sigma_2)/2$; V_1, V_2 and β are functions of the invariants r, $\partial/\partial r$, S^2 and l^2, while β is such a function that $\beta\psi_{^3P} = \psi_{^3P_0}$; $\psi_{^3P}$ is the wave function of the system in ^3P states. It is not difficult so to choose β that the second term in (1) plays a role only in the triplet states, for example, $\beta = l^2S^2/4$. It is obvious that

$$\hat{U}\psi_{^3P_0} = V_2\psi_{^3P_0}, \quad \hat{U}\psi_{^3P_1} = \hat{U}\psi_{^3P_2} = 0,$$

i.e., $\hat{U}$ does not act on the $^3P_1$ and $^3P_2$ states.

We shall not consider here a possible explicit form for V_1 and V_2, since the existing phase analysis is not unique and does not give reliable information on the phases. Nevertheless, data on the character of the interaction in ^3P states make reasonable the separation of the forces in the form (1) and the consideration of the remaining part of the potential (which leads to scattering into the states $^3P_1$ and $^3P_2$) as a small correction. It is possible to choose the values of V_1 and V_2 to account for $\delta_{^1S_0}$ and $\delta_{^3P_0}$, and to guarantee the smallness of all the remaining phases[5,6].

A more accurate description of $^1D_2$, ^3F and the other states, and also an account of the small contribution of $^3P_1$ and $^3P_2$ can be achieved by the introduction into $\hat{U}$ of additional terms [tensor forces, (lS) forces] of corresponding magnitude. We note that a small phase shift $\delta_{^3P_1}$ and $\delta_{^3P_2}$, which does not appreciably disturb the isotropy of the angular distribution, can have a strong effect on the character of the polarization of the nucleons.

Data on *np* scattering at $T=0$ could be explained on the basis of the assumption of a central static potential[1]. If a detailed analysis shows that forces of the form $V_2[(\mathbf{l}\mathbf{S})^2 - \beta]$ do not give an appreciable contribution at $T=0$, then V_2 can be multiplied by $(1 + \tau_1\tau_2)$, where τ is the isobaric spin operator of the nucleons.

A number of authors[7,8] have pointed out that in the nuclear shell model, along with $(\mathbf{l}\sigma)$ forces, one must introduce other, velocity-dependent forces. For example, Nilsson[8] has observed that the expression for the average potential of a nucleus ought to contain terms proportional to l^2. We note that $l^2 \equiv (\mathbf{l}\sigma)^2$, *i.e.*, it has the same character as the operator $(\mathbf{l}\mathbf{S})^2$ in Eq. (1). It is well known that velocity-potentials are equivalent to nonlocal potentials (the potential operator is an integral operator). It is possible that the appearance of terms of the