tegrals of the first and second kind respectively. It can be seen from Eq. (2) that $\eta_{eff} \sim 1$, i.e. $\vartheta_{eff} \sim m/E_2$. The form-factor F can be determined from comparison with experiment. At high energies, the differential cross section for small angles attains large values.

Integration over E_2 and η can be carried out only for F = 1. We have then

$$\sigma = (e^2/24\pi^2)(R/m)\,\Phi(\eta_{max}),$$

$$\Phi(\eta_{max}) = \int_0^{\eta_{max}} \left\{4K\left(\frac{\eta}{\sqrt{1+\eta^2}}\right) + E\left(\frac{\eta}{\sqrt{1+\eta^2}}\right)\right\} \frac{\eta d\eta}{(1+\eta^2)^{3/2}}. \quad (3)$$

If we put $\eta_{max} = \infty$ (in general, η_{max} should be of the order of unity) we have $\Phi(\infty) = 9\pi^2/8$, $\sigma \sim 10^{-28}\,cm^2$. As in the scalar case,[1] the total cross section is independent of the γ-quantum energy and is proportional to R/m and not to R^2, since in the effective region for the process, that ahead of the nucleus, the ψ-function of the emitted particle has a shadow and the whole process is determined by the penumbra region.

Equation (2) has been obtained under the assumption that the nuclear radii (R_1 with respect to protons and R_2 with respect to antiprotons) are equal, $R_1 = R_2 = R$. The cross section for the process is then independent of which particle, the proton or the antiproton, is free in the final state. If $R_1 \neq R_2$, and $\Delta R \gg 1/m$, then the cross section for the process with emission of the more strongly interacting particle is, in the given approximation, exponentially small ($\sim \exp(-\alpha\Delta R)$, $\alpha \sim m$). The cross section for the process with emission of the less strongly interacting particle (the proton) can be obtained from Eq. (2) by replacing R with $2R_1$ for $R_1 > R_2$ (or with $2R_2$ for $R_2 < R_1$).

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OVERHAUSER EFFECT IN NONMETALS

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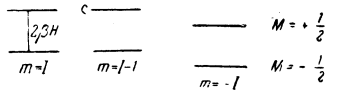
RECENTLY a number of papers[1-4] have appeared in which different modifications of the Overhauser method are proposed to obtain nuclear polarization in nonmetals. In particular, these papers discuss the polarization of the nuclei of paramagnetic atoms in salts and of the nuclei of donor and acceptor impurities in silicon and germanium. The problem is mainly to obtain a nonequilibrium nuclear polarization thanks to the fast passage effect. In the present paper we shall be concerned with obtaining a stationary nuclear polarization.

Let us consider a system consisting of a nucleus of spin I and an electron located in a magnetic field of strength H. The system will have 2(2I + 1) levels corresponding to two values of the electron spin component (M), and 2I + 1 values of the nuclear spin component (m). Assuming the external field to be sufficiently strong (Zeeman energy of the electron considerably larger than the spin-spin interaction energy of the electron with the nucleus) we get 2I + 1 transitions in the paramagnetic-resonance spectrum (selection rules: $\Delta M = \pm 1$, $\Delta m = 0$). To evaluate the population of the levels, we neglect the spin-spin interaction energy and the Zeeman energy of the nuclear spin, and we obtain 2I + 1 pairs of levels with an energy level difference in each pair equal to $2\beta H$ (see figure).



We consider the most important case, where we can neglect for the nuclear spin all interactions except the contact interaction, which is proportional to $(\mathbf{S}\cdot\mathbf{I})\delta(\mathbf{r})$. In that case we have, for the relaxation processes involving the nuclear spin, the selection rule $\Delta(M + m) = 0$.

Let complete saturation be reached (that is, let the saturation parameter be equal to unity) for all 2I + 1 paramagnetic resonance levels. We get then Overhauser's known result, i.e., the degree of polarization is equal to

$$f = B_I(2I\delta),\ \delta = \beta H/kT, \quad (1)$$

where B_I is the Brillouin function. In other words, we have the result that the effective nuclear gyromagnetic ratio is equal to the electronic gyromagnetic ratio.

In the case of nonmetals, however, we have a developed hyperfine structure of the paramagnetic resonance, and it is difficult to saturate all its components. Simple calculation shows that upon total saturation of the hyperfine structure components corresponding to a nuclear spin component equal to m, we get for the nuclear polarization

$$f = \frac{[I(I+1)-m^2](e^{2\delta}-e^{-2\delta})-m(e^{\delta}-e^{-\delta})^2}{2I[2(I+1)+(I-m)e^{2\delta}+(I+m)e^{-2\delta}]}. \quad (2)$$

In particular, we have for $\delta \ll 1$

$$f = \frac{I(I+1)-m^2}{I(2I+1)}\delta, \quad (3)$$

and for $\delta \gg 1$

$$f = (I+1+m)/2I, \quad \text{if } m \neq I,$$
$$f = 1/2(I+1), \quad \text{if } m = I. \quad (4)$$

We see thus that for small δ it is more advantageous to saturate the lines with m = 0 or m = $\pm\frac{1}{2}$ (depending on whether I is integral or half-integral) to obtain the largest f. In the case of large δ it is advantageous to saturate the line with m = I − 1. In particular, in the latter case we get $f \approx 1$ for $\delta \gg 1$, as can easily be understood (practically only the level M = $-\frac{1}{2}$, m = I will be occupied).

Experimentally the magnitude of the nuclear polarization can be measured from the intensity of the unsaturated paramagnetic resonance lines, from the intensity of the nuclear magnetic resonance lines (transitions $\Delta M = 0$, $\Delta m = \pm 1$), or, in the case of the polarization of radioactive nuclei, from the angular anisotropy of the γ-radiation.

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MEAN FREE PATH OF ELECTRONS IN HIGH-PURITY TIN

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THE production of many pure metals has been made possible by to the development of the method of multiple zone crystallization ingots.[1] Thus, multiple zone crystallization of tin ingots[2] combined with prolonged high-temperature heating of this metal in high vacuum[3] has yielded tin of very high purity.

The purification of the tin was controlled by measuring the residual resistance $\delta = R_{4.2}/R_{room}$ of samples taken from different sections of the thoroughly heated and re-crystallized ingot. (Here $R_{4.2}$ is the resistance of the sample at 4.2°K and R_{room} — its resistance at room temperature.) While working with high-purity tin, $R_{4.2}$ was found to depend on the cylindrical-sample, wire diameter, owing to the fact that this diameter became commensurate with the electron mean free path.

Figure 1 A presents δ as a function of the cylindrical-wire diameter for tin with $\delta_\infty = 1.8 \times 10^{-5}$.

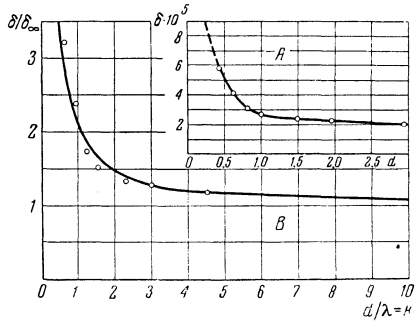

FIG. 1. A — Variation of residual resistance of tin with $\delta_\infty = 1.8 \cdot 10^{-5}$ with the diameter of the cylindrical wires. B — theoretical curve[4] of δ/δ_∞ as a function of $k = d/\lambda$ for p = 0; d — diameter of the cylindrical wires, λ — electron mean free path, o — experimental data for $\lambda = 0.65$ mm.

It is known that the investigation of the electric resistances of thin films and metal wires is the oldest method of determining the electron mean free path in these materials. This problem was theoretically investigated for cylindrical wires by Dingle.[4] His work contains a table of σ_∞/σ for arbitrary k, along with the formulas