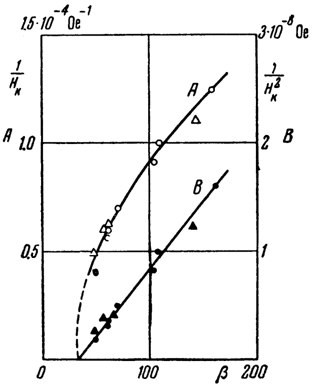

FIG. 3. Dependence of the critical field on the deformation: ●, ○) specimen Au-1; ▲, △) specimen Au-6.

the experimental accuracy the value of T_{min} is not changed by the deformation and lies for all specimens in the range 4 to 6°K. Earlier we have already reported[1] that specimens prepared from Au-4 do not show a resistance minimum. A spectral analysis performed on these samples showed that gold of the two batches (both Au-1 and Au-4) does not differ essentially in their impurity contents. On the basis of the data given in the present paper, it was assumed that specimens prepared from Au-4 after careful annealing would also, like those from Au-1, have a minimum in the r(T) curve. Experiments performed by us confirmed this assumption.

Comparing all results obtained we can conclude that the cause responsible for the appearance of a resistance minimum is the scattering of conduction electrons by impurities of some well defined elements. A decrease of the mean free path of the conduction electrons (for instance, due to the deformation) leads to a decrease of the probability for scattering of the electrons by those impurities, and as a result the anomalous properties also disappear. From this point of view, the crystal boundaries and the grain size are not responsible for the appearance of the resistance minimum.

In conclusion we consider it a pleasant duty to express our gratitude to academician P. L. Kapitza for a discussion of the results obtained.

*We should remark Schmitt[4] has noted the influence of deformation on the behavior of the resistance curves in the case where a minimum is present for copper.

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166

THE SCATTERING OF SPIN 3/2 PARTICLES BY A COULOMB FIELD

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In studying the spin of new particles it may be of interest to describe how their interaction with an electro-magnetic field depends upon their spin. This spin dependence appears clearly in such phenomena as Compton scattering, bremsstrahlung, and pair production of particles of spin 0, 1/2, 1, and 3/2 and has been considered by a number of authors.

In the present note we consider the scattering of particles of spin 3/2 by the Coulomb field of a nucleus.

The matrix element for the process looks as follows in the Born approximation:

$$\mathcal{M} = -e\int \overline{B}^i(x)\,A_k(x)\,\gamma_k B^i(x)\,d^4x,$$

where $B^i(x)$ is the spin vector describing the particles of spin 3/2, and obeys the following equation and subsidiary conditions:

$$(\gamma_k\partial/\partial x_k + M)\,B^i(x) = 0, \quad \gamma_i B^i = 0, \quad \partial B^i/\partial x_i = 0;$$

$A_k(x)$ is the 4-potential describing the nuclear field [for a static field, $A(x) = (0, 0, 0, A_4(\mathbf{x}))$]. In the p representation

$$\mathcal{M} = -2\pi e a_4(\mathbf{q})\,\overline{B}^i(p_f)\,\gamma_4 B^i(p_i)\,\delta(E_f - E_i), \quad \mathbf{q} = \mathbf{p}_f - \mathbf{p}_i.$$

Making use of the following formula in summing over the polarizations

$$\sum_m [B^i_m(p)]_\nu\,[\overline{B}^k_m(p)]_{\nu'} = (1/6E_pM)\,[(M - i\gamma p)\,(2p_ip_k/M + 3M\delta_{ik} + i\gamma_ip_k - i\gamma_kp_i - M\gamma_i\gamma_k]_{\nu\nu'}$$

(ν, ν' are spinor indices) we obtain the differential cross section

$$d\sigma = \frac{e^2}{(2\pi)^2}\frac{p^2}{v^2}\,|\,a_4(\mathbf{q})\,|^2\,d\Omega\left\{1+\frac{v^2}{3}\left(1+\frac{8}{3}\frac{p^2}{M^2}\right)\sin^2\frac{\theta}{2} + \frac{8}{9}\frac{v^2p^4}{M^4}\sin^4\frac{\theta}{2}\cos^2\frac{\theta}{2}\right\},$$

where θ is the scattering angle and $q = 2p\sin(\theta/2)$.

For a pure Coulomb field $a_4(\mathbf{q}) = -i4\pi Ze/q^2$ and the factor preceding the curly brackets yields $(Ze^2/2pv)^2\,d\Omega = d\sigma_{Ruth.}$, the Rutherford cross section.

Thus the expression in the curly brackets specifically gives the spin correction. We recall for the sake of comparison the cross section for particles of spin $1/2$ (reference 1)

$$d\sigma = d\sigma_{Ruth}[1 - v^2\sin^2\theta/2]$$

and for spin 1:[2]

$$d\sigma = d\sigma_{Ruth}[1 + (v^2p^2/6M^2)\sin^2\theta].$$

It can be seen that for spin 1 and $3/2$ the correction grows with energy, this is especially marked in the case of spin $3/2$ as it includes a factor p^4. At sufficiently high energies this may yield differences from the usual scattering picture even at relatively small angles. It should however be noted that if $q > 1/R$ where R is the nuclear radius, it is necessary to include the effect of the spread out nuclear charge.

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167

USE OF CYCLOTRON RESONANCE IN SEMICONDUCTORS FOR THE AMPLIFICATION AND GENERATION OF MICROWAVES

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As is well known,[1-3] when cyclotron resonance occurs in certain semiconductors (Ge or Si), additional lines are observed along with the main absorption lines at frequencies that are integral multiples of the fundamental cyclotron frequency. This effect is associated with the anharmonic nature of the motion of holes, which leads to the breakdown of the usual selection rules $\Delta n = \pm 1$ for the Landau levels and to the appearance of nonvanishing dipole moments for transitions with $\Delta n = \pm 2$ or 3.

This phenomenon can be utilized for the construction of regenerative amplifiers or generators at microwave frequencies, for example, by using the following method. The semiconductor sample, placed into a constant magnetic field H_0, is acted upon by the high-frequency electric "pumping" field E_p of frequency $\omega_p = n\omega_c = neH_0/m^*c$ ($n = 1, 2, 3, \ldots$, m^* is the effective mass of the hole (m_h^*) or of the electron (m_e^*)) polarized in the plane perpendicular to H_0.

If the intensity of the field E_p is sufficiently great, so that during a thermal relaxation time τ a sufficiently large number of carriers goes over into the upper energy levels, then in this system excitation (or amplification) can occur at frequencies given by $\omega_s = l\omega_p/n = l\omega_c$, $l = 1, 2, \ldots$, which can be both less than ($l < n$) and greater than ($l > n$) the "pumping" frequency. The excitation of such oscillations is facilitated by placing the semiconductor into a resonator for which ω_p and ω_s are eigenfrequencies.

According to Basov and Prokhorov,[4] in order to excite a maximum number of carriers at the frequency ω_p it is necessary to expend per unit volume of the semiconductor an amount of power given (in order of magnitude) by: $P_p \approx (10^{-7} \times 3\hbar^2\omega_p/4\pi\tau^2\,|\,d_n\,|^2 Q_p)$ w/cm^3, where $h = 2\pi\hbar$ is Planck's constant, $|\,d_n\,|$ and Q_p are the dipole moment for the transition and the figure of merit of the resonator at the frequency $\omega_p = n\omega_c$.

In the special case $\omega_s = \omega_c = \omega_p/2$ (corresponding to the resonance of the second kind in a nonlinear oscillating system) at a temperature $T \approx 2$ to 4°K we have $\tau \approx 6 \times 10^{-11}$ sec, $|\,d_2\,| \approx 10^{-15}$ cgs Esu,[2,3] from which we obtain $P_p \approx (10^{-11}\,\omega_p/Q_p)$ w/cm^3.

For the excitation (or amplification) of oscillations of frequency $\omega_s = \omega_c = \omega_p/2$ it is necessary that the density of active carriers attain the value $N_{act} \approx 3\hbar/4\pi Q_1\tau\,|\,d_1\,|^2$. In the case under discussion $|\,d_1\,| \approx 10^{-14}$ cgs Esu (reference 3) and $N_{act} \approx (3 \times 10^{10}/Q_1)$ cm^{-3}. The maximum radiated power is

$$P_s = N_{act}\hbar\omega_s/2\tau \ll P_p,$$

which in the case $N_{act} \approx 10^{10}$ cm^{-3} and $\omega_s = 2\pi \times 10^{11}$ cps will amount to approximately 5 mw/cm^3, i.e., to a significantly greater value than in the usual molecular or paramagnetic gen-