FARADAY EFFECT IN YTTRIUM GARNET AT INFRARED FREQUENCIES

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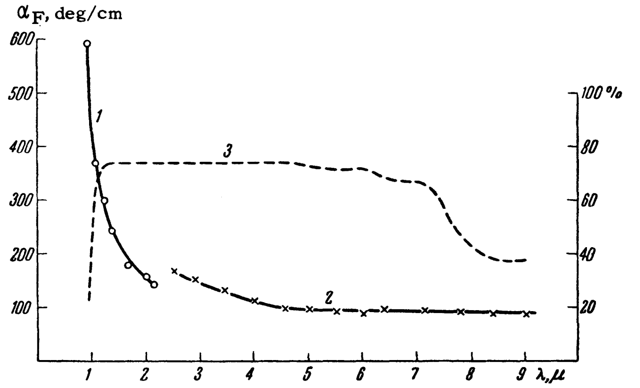
THE rotation of the plane of polarization when light passes through magnetized ferrite (Faraday effect) was measured in the visible region,[1] and also[2] in the near infrared region at a fixed wavelength $\lambda = 1\mu$. It was shown that in this region of the spectrum both the Faraday effect and the absorption of light by the ferrite are connected with the electron transitions. In this note we give the results of measurement of the Faraday effect in garnet ferrite of yttrium $Y_3Fe_5O_{12}$ with the wavelength varying from 0.94 to 9μ, that is, in the region where light absorption connected with electronic transitions ends and absorption due to lattice vibrations begins.

The experimental apparatus was a modification of that previously described for the investigation of the magneto-optical Kerr effect in the infrared region.[3] Polarized light passed through the sample and analyzer, which was oriented at 45 deg to the polarizer. The sample was a plate made of a single crystal of yttrium garnet 75 microns thick. The change in intensity of the transmitted light was measured with the specimen magnetized in a field of 3500 oe, from which one could readily calculate the specific rotation of the plane of polarization in degrees per centimeter. The figure shows the dependence of the Faraday effect on the wavelength of infrared light. Near the edge of the electronic-absorption band, at $\lambda \sim 1\mu$, the rotation of the plane of polarization drops off sharply. In the region of maximum transparency of the ferrite, and also in the region where the phonon absorption of light begins, the rotation remains approximately constant.

For non-ferromagnetic semiconductors, two causes of the rotation of the plane of polarization of infrared light have been discussed in detail:[4] 1) electronic transitions, at which the angle of rotation is proportional to λ^{-2}, 2) motion of free electrons, which leads to a rotation of the plane of polarization proportional to λ^2. The first reason can explain the sharp drop in the effect in the region of 1μ, where the angle of rotation is actually proportional to λ^{-2}. The second reason can explain neither the sign, nor the dependence on the wavelength, nor the value of the effect in the interval from 4 to 9μ, since the resistivity of the garnet is seven or eight orders of magnitude higher than the resistivity of the semiconductors in which the Faraday effect connected with free electrons is measured. It is possible that the considerable rotation of the plane of polarization of infrared light for $\lambda > 4\mu$, which is independent of the frequency, is observed only in ferromagnetic semiconductors and requires a special theoretical analysis.



Faraday effect (left-hand scale) in yttrium garnet for infrared light. 1 – glass prism, 2 – prism of rock salt, 3 – transparency of plate of yttrium garnet 75 micron thick without correction for reflection (right-hand scale).

We note that in our experiments the intensity of the transmitted light at $\lambda \sim 1\mu$ was changed by the Faraday effect by approximately 30% when the specimen magnetization was reversed. This may be of practical interest for the construction of devices of the controllable-gyrator type or light-modulator type. At other wavelengths in the investigated range, by virtue of the great transparency of the garnet, one can also obtain comparable changes in the intensity, if the thickness of the specimen is increased.

We express deep gratitude to Professor A. G. Smolenskiĭ for providing us with the single crystal of yttrium garnet.

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POLARIZATION OF RECOIL PROTONS FROM THE SCATTERING OF 300-Mev π MESONS ON HYDROGEN

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PHASE-SHIFT analysis of the differential cross sections of elastic scattering and scattering of π^- mesons with charge exchange does not give a single-valued solution. As shown by Fermi,[1] the study of the polarization of recoil protons can be of aid in the choice between the different sets of phase shifts, since they give different angular distributions of polarization.

The polarization of recoil protons in π^--p scattering has been measured thus far only in one work, on 223-Mev π^- mesons.[2] The polarization was measured at two scattering angles of the π^- mesons. Agreement was found with one set of phase shifts of the Fermi type, but the statistical accuracy did not allow the complete exclusion of one of the sets of the Yang type.

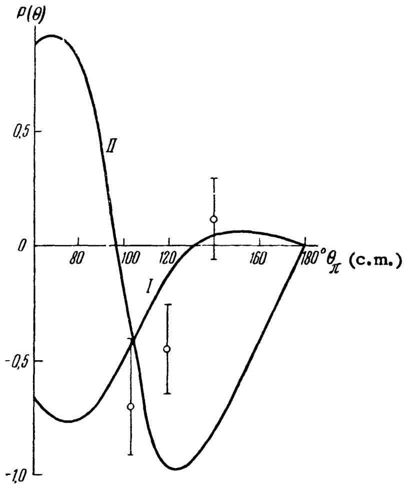
In this letter we present the preliminary results of the measurements of the polarization of recoil protons in the scattering of 300-Mev π^- mesons on hydrogen. The measurements were carried out by means of a hodoscopic system of counters, the construction of which has been described earlier.[3,4]

When the scattered π^- meson and recoil proton fall into the counters of the control system, a pulse is produced which triggers the hodoscope. In analyzing the photographs obtained, only those pictures were examined on which the process of elastic scattering of the π^- meson was recorded, and cases of scattering of the proton in the carbon target and in the walls of the gas-discharge counters were chosen. We observed 305 cases of scattering, which were separated into three groups according to the direction of flight of the recoil proton from the hydrogen target. The results obtained are shown in the table, where the data have been summed over the volume of the chamber and are shown in such a way that all cases of scattering are taken as occurring in the chamber on the right. The polarization of the recoil protons was defined as

$$P = (N_L - N_R)/P_1(N_L + N_R),$$

Proton recoil angle (deg in lab)	N_R	N_L	P
15—23	43	48	0.12 ± 0.20
24—32	85	58	-0.45 ± 0.19
33—41	45	26	$-\left(0.70^{+0.21}_{-0.32}\right)$

where N_L and N_R are the numbers of protons scattered to the left and to the right, P_1 is the analyzing power of the arrangement and was determined from the data of references 5 and 6. The direction of polarization was taken parallel to $\mathbf{k}_i \times \mathbf{k}_S$, where $\mathbf{k}_i$ is the momentum of the incident π^- meson and $\mathbf{k}_2$ is the momentum of the scattered π^- meson.



Curve I – set of phase shifts $\alpha_1 = 17.1°$, $\alpha_{11} = 11.4°$, $\alpha_{13} = -5.0°$. Curve II – set of phase shifts $\alpha_1 = 3.6°$, $\alpha_{11} = -22.3°$, $\alpha_{13} = 14.6°$.

The figure depicts the results of the present work and the polarization vs pion scattering angle curve for two sets of phase shifts obtained in reference 7. In the latter experiment it was found that the first set is the most probable. The experimental values of the polarization, as can be seen, are in satisfactory agreement with the first set of phase shifts and increase the probability that the sign of the phase shifts α_1 and α_{11} is positive.

In conclusion, we express our gratitude to A. A. Tyapkin for help in this work and R. M. Sulyaev and L. I. Lapidus for constant interest in the work.

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NON-RADIATIVE TRANSFORMATION OF THE μ MESON INTO AN ELECTRON

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1. The process of non-radiative transformation of the μ meson into an electron in the Coulomb field of the nucleus,

$$\mu^- + A_Z \rightarrow A_Z^* + e^- \qquad (1)$$

may occur with greater probability than the decay $\mu \rightarrow e + \gamma$, if the monopole form factor for the transition $\mu \rightarrow e$ is larger than the dipole form factor. Weinberg and Feinberg[1] quoted the example of the four-fermion interaction of the type $(\bar{e}\mu)(\bar{f}f)$ (where f is a charged particle) for which this situation may occur in principle. Steinberger and Wolfe[2] have made attempts to discover the process (1). According to their data the ratio of the probability of process (1) and the probability of the ordinary capture of μ mesons by the protons of the Cu^{64} nucleus is $\leq 5 \times 10^{-4}$. These experimenters searched for the reaction (1) by registering the electrons with energies of about 100 Mev.

In this note we discuss a different method for detecting the reaction (1). Let us consider a μ-mesic atom with a light even-even nucleus (for example, C^{12}, O^{16}, or Ne^{20}). In the 6 to 10 Mev region of the excitation energies these nuclei have excited states 0^+ from which decay with emission of α particles takes place.[3] Our proposed method for the detection of the process (1) consists of registering the α particles of known energy emitted by nuclei which have been excited to the 0^+ level as a consequence of reaction (1). The probability of this process can be calculated. It is equal to (in units where $\hbar = c = 1$)

$$W_{00}^{\mu e} = \frac{16}{9}\pi Z^3 \alpha^5 \mu (1 - 2\omega) \, |\mu^2 Q_0|^2 \, |f_{E0}|^2. \qquad (2)$$

Here ω is the excitation energy of the nucleus in units of the rest energy of the μ meson, μ (we assume that $\omega \ll 1$), Q_0 is the nuclear matrix element for the transition $0^+ \rightarrow 0^+$:

$$Q_0 = \langle A_Z^* 0^+ \left| r^2 - \tfrac{1}{6}(\mu r)^2 \right| A_Z 0^+ \rangle, \qquad (3)$$

and f_{E0} is the electric monopole form factor for the transition $\mu \rightarrow e$, which depends on the momentum transfer $q = p_e - p_\mu$ (p_e and p_μ are the momenta of the electron and the μ meson) in the following fashion:

$$f_{E0}(q^2) = q^2 G(q^2), \quad \lim G(q^2) < \infty \quad \text{for } q^2 \rightarrow 0. \qquad (4)$$

It is convenient to compare $W_{00}^{\mu e}$ with the probability for the ordinary capture of μ^- mesons,

$$\mu^- + A_Z \rightarrow A_{Z-1} + \nu \qquad (5)$$

(this type of reaction has now been relatively well studied in the case of C^{12}). The probability $W_{if}^{\mu\nu}$ for the process (5) has been calculated by a number of authors.[4,5] Using their result and formulas (2) and (4), we obtain

$$W_{00}^{\mu e}/W_{if}^{\mu\nu} = \frac{32}{9}\pi^3\alpha^2 \left[1 + 2(\omega' - \omega)\right] \eta \, |\mu^2 Q_0|^2 / M_{if}. \qquad (6)$$

Here ω' is the difference in energy of the nuclei $f(A_{Z-1})$ and $i(A_Z)$ (in the units μ, $\omega' \ll 1$),

$$\eta = G^2(\mu^2)/g^2, \quad M_{if} = \lambda_F^2 \, |M_F^{if}|^2 + \lambda_{GT}^2 \, |M_{GT}^{if}|^2, \qquad (7)$$

where g is the universal constant of the weak four-fermion interaction as determined from the decay time of the μ meson; M_F^{if} and M_{GT}^{if} are the Fermi and Gamow-Teller matrix elements for the allowed transition $i \rightarrow f$ including meson corrections and corrections for the finite wave length of the neutrino (see reference 4). In particular, formula (6) gives for the ratio of the probabilities of processes (1) and (5) for the C^{12} nucleus

$$W(\mu^- + C^{12} \rightarrow C^{12*} + e)/W(\mu^- + C^{12} \rightarrow B^{12} + \nu) = 1.1 \cdot 10^{-2} \eta. \qquad (8)$$

2. An effect which hinders the observation of reaction (1) (if the α particles are registered) is the Coulomb excitation of the nucleus of the μ-mesic atom by the decay electrons from the μ^- meson. This effect, however, occurs relatively seldom owing to the smallness of the phase volume. The calculation leads to the following formula for