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ON THE DIFFERENCE IN PEAK HEIGHTS FROM QUADRUPOLE SPLITTING OF MÖSSBAUER SPECTRA

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IN a number of our experiments with organic tin compounds[1,2] we found a quite large difference in the peak heights from doublet splitting of Mössbauer spectra. An example is the spectrum of polycrystalline triphenylchlorstannane, $Sn(C_6H_5)_3Cl$, shown in the figure. A similar asymmetry was seen with SnO[3] and various compounds of iron.[4-6] Two proposals were made for explaining the difference in peak height from doublet splitting: 1) the doublet splitting is caused by the presence of two chemical forms of the substance, i.e., we are dealing with a superposition of two unsplit single lines with different values of the chemical (isomer) shift;[1,5,6] 2) the doublet results from quadrupole splitting—the difference in the peaks results from anisotropy of orientation of the crystals relative to the direction of motion of the γ quanta. A detailed analysis of these two assumptions and a critique of them for specific cases was given in [7].

In [2] (and in more detail, by Karyagin[8]) a third possibility for explaining the asymmetry of the doublet splitting of Mössbauer spectra was proposed, which for most cases seems to be the correct one. As is shown in these papers, the quadrupole splitting of the Mössbauer spectra from isotropic polycrystalline samples should as a rule give different peak heights, while the peaks will be equal in height only for the special case of an isotropic Mössbauer effect. Thus the asymmetry of the Mössbauer doublets does not require the presence of two chemical forms or anisotropy of the sample; it occurs even for an isotropic polycrystalline sample, as a direct consequence of the anisotropy of the Mössbauer effect for single crystals, which was treated theoretically by Kagan[9] and found in various experiments.[10,11]

In fact, for a single crystal with its axially symmetric electric field directed at an angle ϑ relative to the direction of the γ quanta, the ratio of the probabilities I for M1 absorption of a quantum by a nucleus with spin $1/2$, with transition to the $\pm 3/2$ sublevels (I_π) and $\pm 1/2$ (I_σ) of the excited nucleus can be shown[12] to be:

$$\frac{I_\pi(\vartheta)}{I_\sigma(\vartheta)} = \frac{2\sqrt{5}\,\bar{P}_0(\cos\vartheta) + \bar{P}_2(\cos\vartheta)}{2\sqrt{5}\,\bar{P}_0(\cos\vartheta) - \bar{P}_2(\cos\vartheta)} = \frac{1+\cos^2\vartheta}{5/3-\cos^2\vartheta}, \qquad (1)$$

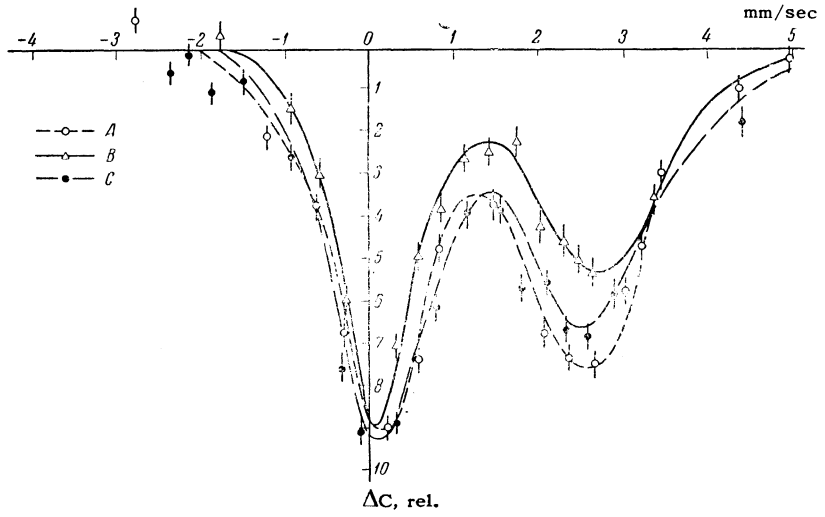
where $\bar{P}_0$ and $\bar{P}_2$ are normalized Legendre polynomials. In polycrystalline isotropic samples we get

$$\frac{i_\pi}{i_\sigma} = \frac{\int_0^\pi I_\pi(\vartheta)\sin\vartheta d\vartheta}{\int_0^\pi I_\sigma(\vartheta)\sin\vartheta d\vartheta} = 1, \qquad (2)$$

i.e., the two quadrupole peaks have equal heights. But if the Mössbauer effect is anisotropic for the single crystal and is characterized by a probability $f'(\vartheta)$, then

$$\frac{i_\pi}{i_\sigma} = \frac{\int_0^\pi I_\pi(\vartheta) f'(\vartheta)\sin\vartheta\, d\vartheta}{\int_0^\pi I_\sigma(\vartheta) f'(\vartheta)\sin\vartheta\, d\vartheta} = F[f'(\vartheta)] \neq 1, \qquad (3)$$

i.e., the two peaks differ in height, and from obser-



vation of such a difference in experiments with polycrystalline samples we can draw conclusions about the anisotropy of the Mössbauer effect for single crystals.

As a first attempt to check these arguments, we have studied the asymmetry of the peaks in the Mössbauer spectrum as a function of the degree of orientation of the triphenylchlorstannane crystal for two different settings of the sample relative to the direction of the beam of γ quanta.

Measurements of the molecular weight of $Sn(C_6H_5)_3Cl$ ($t_{melt.}$ = 107°C) cryoscopically in benzene and camphor gave values of 395 ± 21 and 357 ± 17. Thus there is no association of the molecules so that we have excluded any superposition of Mössbauer spectra of triphenylchlorstannane monomer and some of its polymeric forms.

The measurements were made at t = 78°K using the equipment at the Institute of Chemical Physics, Academy of Sciences, U.S.S.R., with a source of SnO_2. The samples were finely dispersed, well-ground powders of triphenylchlorstannane (0.07 g/cm^2) deposited on an aluminum backing. In addition to these (isotropic) samples, we also studied others that were melted onto an aluminum backing and cooled slowly, producing large-grained crystal plates with diameter more than 5 mm, which were oriented preferentially along the backing (anisotropic samples). Both types of samples were set at angles of 90 and 45° to the γ-ray beam. The experimental results are shown in the figure. For the isotropic sample, we obtained the same (asymmetric) spectrum (curve A) at both angles. The fact that the asymmetry is independent of angle eliminates the explanation in terms of a definite orientation of the sample. Changing to an anisotropic sample for a setting of 90° caused a change in the asymmetry (curve B), which eliminates the explanation of the difference in peak height as a superposition of two singlet lines from different chemical forms of the compound. Turning the anisotropic sample to 45° again gave a change in the asymmetry of the doublet splitting (curve C; all the curves are normalized to the height of the left (stronger) peak). Again this would not be the case if the doublet were due to two different chemical forms. Finally, after the anisotropic sample was reground, at both 45 and 90° curve A was observed instead of curves B and C. Thus, of the three explanations of the asymmetry in peak height for the Mössbauer effect from polycrystalline samples, only the last (the anisotropy of the Mössbauer effect for single crystals) is admissible.

In the future we plan to make a quantitative comparison of Mössbauer spectra for single crystals and isotropic polycrystalline samples.

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ON THE INTERPRETATION OF AN EXPERIMENT WITH HIGH-ENERGY NEUTRINOS

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RECENTLY there were published the results of the first experiment with high-energy neutrinos, which was made with the 32 BeV accelerator at Brookhaven.[1] The main results of this important research were: 1) the establishment of the fact that the number of muons produced by neutrinos from the decay $\pi^{\pm} \to \mu^{\pm} + \nu(\bar{\nu})$ is much larger than the number of electrons (more exactly, with the limited statistics, not one case definitely associated with the production of an electron was observed); 2) an approximate estimate of the cross sections of reactions induced by high-energy neutrinos.

That muons predominated over electrons was evidence of the existence of two kinds of neutrinos, ν_e and ν_μ. In the discussion in [1], and also in papers by Pontecorvo,[2] Markov,[3] and Schwartz [4] (which also suggested that such an experiment be done), it was assumed that in the framework of the one-neutrino hypothesis one should expect equal numbers of muons and electrons in such an experiment.

We wish here to call attention to the fact that even in the framework of the one-neutrino hypothesis the number of muons can exceed the number of electrons, and that additional experiments are needed to settle more reliably the question about muon and electron neutrinos.

The "elastic" processes of interaction with free nucleons

$$\nu + n \to p + l^- \quad (l = \mu, e), \tag{1}$$

$$\bar{\nu} + p \to n + l^+ \tag{2}$$

have been theoretically treated earlier by a number of authors.[5-8] Strong-interaction effects produce a serious uncertainty in the predictions. As has been shown by Goldberger and Treiman,[9] in the framework of the one-neutrino universal theory of weak interactions the matrix elements of processes (1) and (2) can be expressed in first approximation in the weak-interaction constant (subject to the validity of CP invariance and the $|\Delta I| = 1$ rule[10]) in terms of four form-factors: $F_{1V}(q^2)$, $F_{2V}(q^2)$, $F_A(q^2)$, and $F_P(q^2)$, which are introduced to correspond to the general expression for the matrix element [reaction (1)]

$$\bar{u}_p \left[F_{1V}\gamma_\alpha + \frac{\mu}{2M} F_{2V}\,(p-n)_\beta \sigma_{\alpha\beta} + \lambda F_A \gamma_\alpha \gamma_5 + ibF_P (p-n)_\alpha \gamma_5 \right] u_n \bar{u}_e \gamma_\alpha (1+\gamma_5)\, u_\nu, \tag{3}$$

where the quantity $q^2 = (p-n)^2 = (l-\nu)^2$ is the momentum transfer, and the other notations are the usual ones.

It is easy to see by using the Dirac equation that the contribution of the induced pseudoscalar is proportional to the mass of the lepton.

If the vector current is conserved in weak interactions F_{1V} and F_{2V} are the isovector parts of the Dirac and Pauli form-factors of the nucleon.[1)] Concerning the axial form-factor λF_A the only thing known beyond general indications from dispersion relations is its value at $q^2 = 0$. There is a well known estimate[9,11] of the pole contribution to the form-factor bF_P of the induced pseudoscalar interaction. For the most part estimates are made on the assumption that all form-factors have the same dependence on q^2. It is not hard to see that then at neutrino energies of about 1 BeV (which is close to the conditions of the Brookhaven experiment) the contribution to the cross section proportional to F_{1V}, F_{2V}, and F_A is about the same for electrons and muons in reactions (1) and (2), and the actual value of the cross section for reaction (2) is about a third of that for reaction (1). On the other hand, inclusion of the contribution of the pseudoscalar F_P leads to a great preponderance of muon production, giving electrons in about the same proportion as for the decays $\pi \to e + \nu$ and $\pi \to \mu + \nu$.