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SEARCH FOR THE ANISOTROPY OF INERTIA USING THE MÖSSBAUER EFFECT IN Fe^{57}†

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The width of the central resonance absorption line in the Mössbauer effect in Fe^{57} has been found by several observers to be considerably greater than the natural linewidth.[1-4] In all these cases the emitting and the absorbing nuclei were randomly oriented, and the possibility arises that this widening is due to an external perturbation which affects the nuclear levels.

An intriguing mechanism for line broadening has been pointed out by Cocconi and Salpeter.[5,6] The locally asymmetric distribution of matter in the universe, in accordance with Mach's principle, may cause a local anisotropy $\Delta M = \frac{2}{3}(M' - M'')$ in inertia. Here M' is the inertial mass for matter accelerated towards the center of the Galaxy and M'' the inertial mass for acceleration perpendicular to this direction. Such an anisotropy ΔM would give rise to a shift in atomic[5] and nuclear[6] energy levels. In the case of Fe^{57}, the shift would occur only for the excited state with spin 3/2. Cocconi and Salpeter compute the level shift ΔE to be $(\Delta M/M)\overline{T}\overline{P}_2$, where $\overline{T}$ is the average kinetic energy of the nucleon responsible for the transition, and $\overline{P}_2$ has the value 1/5 for the most favorable relative orientation between the nuclear angular momentum and the line to the galactic center. Assuming $\overline{T} = 10$ Mev and a line broadening of 10^{-8} ev, Cocconi and Salpeter conclude that $\Delta M/M$ has an upper limit of about 1 part in 10^{14}.

Since the excess broadening of the center resonance line is large, it is easy to determine whether it arises from effects due to the Galaxy. In our first test, we placed both the Fe^{57} source and the Fe absorber in parallel magnetic fields of about 1000 gauss. In this condition, the atomic magnetic fields at the emitting and absorbing nuclei are parallel and the postulated galactic shifts should be the same for each of the corresponding magnetic sublevels in source and absorber. Thus any line broadening due to anisotropic inertia should disappear. The experiment showed, however, that over a twenty-four hour period there was no significant change in the linewidth between the two conditions: (1) no magnetic field, random domain alignments, and (2) source and absorber in parallel magnetic fields. The accuracy of this test is limited by the fact that, although the domains are aligned, the local magnetic fields at the nuclei in the source and absorber are different, producing an additional broadening effect. The results showed clearly that the majority of the excess broadening was not due to the Galaxy.

To perform a more sensitive test for a possible galactic effect, a magnetic field of about 600 gauss at the moving horizontal absorber[3] was aligned in the north-south direction. The source was placed in a magnetic field of similar magnitude, but lying in a vertical, north-south plane, and oriented at +45° with respect to the horizontal (see Fig. 1). Each sidereal day, the galactic center rotates once around a line parallel to the earth's axis, changing its direction with respect to the magnetic fields of source and absorber. Cocconi and Salpeter assume that the level shift reaches an extreme value when the magnetic field H is perpendicular to the line toward the galactic center, and again when it is parallel to that direction. At an intermediate angle the level shift vanishes.

In the experimental arrangement, shown schematically in Fig. 1, there is an interval of about 10 hours, centered at 17:30 sidereal time, when the line toward the galactic center makes nearly equal angles with the two magnetic field directions. Under these conditions, no relative shift is expected in the upper state energy levels between the source and the absorber. In contrast, there is about a 3-hour interval, centered at 06:30 sidereal time, when the galactic line is nearly 90° with respect to the absorber, but nearly 45° with respect to the source. During this latter period, the source should be essentially unaffected by the Galaxy, but the energy levels of the upper state in the absorber should experience their maximum shift. With the Galaxy at the nadir, the shape of the center line should change, since it splits into two lines nearly symmetrically displaced in frequency, but whose intensities have a ratio of about 2:1.

We have made a number of runs through a complete sidereal cycle using the arrangement of Fig. 1 looking for periodic variation in (a) the amplitude of the center of the line, and (b) the amplitude of four Doppler-shifted points on the side of the line. We also examined the shape of the entire center line at various sidereal times to see if there were any obvious deviations from symmetry.

In addition, we made observations with the angle ϕ of Fig. 1 at -45°. For this arrangement, the line to the Galaxy makes equal angles with the two magnetic fields twice a day (at about 13:00 and 22:00, sidereal time), when no relative shift between the excited levels of the source and the absorber is expected, but a near-maximum relative shift is expected when the Galaxy is near the nadir (05:00) and also when it is due south (17:30).

The experiments were performed during the period March 2 through March 12, 1960, at lat. 40°N, long. 88°W.

Using the arrangement of Fig. 1 for $\phi = 45°$ and for $\phi = -45°$ the amplitude of the center point of the absorption line was constant as a function of sidereal time to within the expected statistical fluctuations of ±0.3% with the confidence level of 40% by the χ^2 test. Similarly, the amplitude at the half-intensity point was constant to within ±0.3% with a confidence level of 25%.

As an additional check, we looked for fluctuations in the amplitude of the center point of the line for the case where the magnetic fields were parallel, both horizontal and pointing north, $\phi = 0$. For these conditions no variation is expected and no significant time variation was found.

With the experimental linewidth of 1.2×10^{-8} ev, a splitting of the center line of magnitude $\Delta E = 1\times10^{-9}$ ev would have resulted in a clearly observable sidereal variation. Thus, since $E = 14.4$ kev, $\Delta E/E$ is less than 1×10^{-13}.

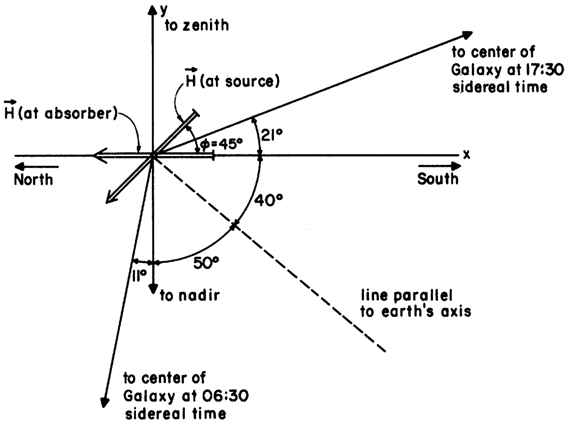

FIG. 1. The geometrical relationships between the magnetic fields on the source and the absorber with respect to the direction to the center of the Galaxy. Tests were also made with $\phi = -45°$.

In order to calculate $\Delta M/M$ from $\Delta E/E$ certain assumptions must be made. Following Cocconi and Salpeter, and taking $\overline{T} = 10$ Mev and $\overline{P}_2 = 1/5$, we get the limit $\Delta M/M < 5\times10^{-16}$. Both assumptions are, however, open to debate, especially since the magnetic moment of the ground state[7] and of the excited state[8] of Fe^{57} are considerably smaller than one would expect from the shell model.

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HIGH-FREQUENCY STUDIES ON SUPERCONDUCTING TIN*

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Microwave studies of normal metals both with and without a static magnetic field have provided information on the shape of the Fermi surface[1] and on the effective masses of the electrons.[2] In this note, the surface impedance measurements at 1 kMc/sec on superconducting tin[3] both with and without a magnetic field are analyzed to study changes in the band structure which accompany the transition from the normal to superconducting metal. It is found that for superconductors the zero-field experiments are relatively insensitive to the band structure as compared with experiments on the field variation of the surface impedance. Secondly, it is suggested that different carriers are important in the two problems, with the "heavy" electrons dominating the zero-field measurements, and the "light" electrons more important in the field-dependent studies.

The recent extension[4] of the Serber two-fluid model calculation of the superconducting surface impedance Z to include the term proportional to H_0^2 in $Z(H_0)$ allows an analysis to be made of the data for $H_0 > 0$, H_0 being the static magnetic field at the surface. The temperature dependence of the normal and superconducting electron concentrations in the superconducting state is taken to be that predicted by the Gorter-Casimir two-fluid model, i.e., $N_n = N_0 t^4$ and $N_s = N_0(1 - t^4)$, in which N_0, N_n, and N_s are the total, normal, and superconducting electron concentrations, respectively, and $t = T/T_c$ is the reduced temperature.

For both $H_0 = 0$ and $0 < H_0 < H_c$, H_c being the critical field at the temperature T, the Serber two-fluid treatment predicts the magnitude and temperature dependence of Z in terms of the parameters $(m^* v_F)$ and λ_0, which characterize a given specimen. The quantities m^* and v_F are the effective mass and Fermi velocity of the normal electrons in the superconducting state and λ_0 is the penetration depth λ of the dc magnetic field evaluated at $T = 0$°K. These quantities determine a dimensionless parameter α_0 given by

$$\alpha_0 = \frac{\lambda_0}{\delta_n} = \lambda_0 \left(\frac{3\pi^2 \omega N_0 e^2}{m^* v_F c^2} \right)^{1/3}, \tag{1}$$

in which δ_n is the superconducting skin depth for the rf fields in the extreme anomalous limit appropriate to the total electron concentration N_0. The quantities N_0 and λ_0 are known from other measurements. The temperature dependence of α_0 is attributed to the variation of $(m^* v_F)$ with T. The value of $\alpha_0 = 0.16$ is appropriate for Sn, if $m^* = m_0$ (free electron mass), $v_F = 6.6 \times 10^7$ cm/sec (normal state value)[5] and $\lambda_0 = 5.0 \times 10^{-5}$ cm.[6]

The determination of α_0 for a single-crystal tin sample[3] was made for both $H_0 = 0$ and $H_0 > 0$. For comparison, the field variation of Z was also measured and analyzed for the same sample in the normal state.[7] Figure 1 shows a reduced temperature plot of the zero-field surface re-

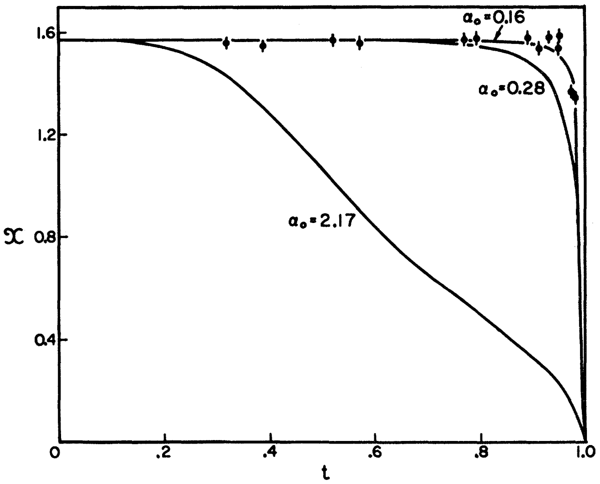

FIG. 1. Plot showing zero-field surface reactance vs reduced temperature. The solid curves give the dimensionless quantity $\mathfrak{X} = [c^2 X(0)/16\pi\nu\lambda]$ as calculated from the two-fluid model for three values of α_0 (see text). The experimental points are for a single-crystal tin sample at 1 kMc/sec.