is dominant. The transition probability should be of the same order of magnitude as in Si. Unfortunately, the absorption corresponding to this transition overlaps by ~0.01 ev the steep absorption edge of the intervalence band transition at ~0.28 ev. Nevertheless, by using an optimum impurity concentration and high spectral resolution, it may be possible to observe this transition in Ge as well as in InAs, GaAs, InP, GaP, AlP, AlAs, and AlSb where intervalence band transitions have been studied.[7]

In principle, it should be possible to observe transitions between impurity levels of bands having extrema at different values of $\vec{k}$. Such an indirect process probably involves the emission of phonons at low temperature. Thus in heavily-doped n-type Ge, transitions from the lowest $\langle 111\rangle$ impurity level to the $\langle 000\rangle$ and $\langle 100\rangle$ impurity states may be observable. The former should occur at ~0.15 ev,[8] and the latter at ~0.22 ev.[9] Similarly in GaSb, a transition from the $\langle 000\rangle$ to the $\langle 111\rangle$ impurity level should occur at ~0.08 ev.[10] However, since the transition probability is low, impurity concentrations of the order of $10^{19}/\mathrm{cm}^3$ may be required.

We have profited greatly from theoretical discussions with Professor G. F. Koster.

*This work was performed with the joint support of the U. S. Army, Navy, and Air Force.

[1]G. F. Koster has shown that the operator $\vec{\Pi}$ is given by $\vec{\Pi}=m_0\nabla_p\mathcal{H}$, where $\mathcal{H}$ is either the 4 × 4 or the 2 × 2 effective-mass Hamiltonian corresponding to $\vec{\Pi}_a$ or $\vec{\Pi}_b$. The operator $\vec{\Pi}'$ is similarly obtained from $\mathcal{H}'$, which is associated with the overlapping elements of the 6 × 6 matrix.

[2]E. O. Kane, J. Phys. Chem. Solids 1, 82 (1956).

[3]R. N. Dexter, H. J. Zeiger, and B. Lax, Phys. Rev. 104, 637 (1956).

[4]H. J. Hrostowski and R. H. Kaiser, J. Phys. Chem. Solids 4, 148 (1958); S. Zwerdling, K. J. Button, and B. Lax (to be published).

[5]A rough estimate of $\Delta\sim 0.05$ ev has been made from measurements of intervalence band transitions by L. Huldt and T. Staflin, Phys. Rev. Letters 1, 313 (1958).

[6]Based on the data of M. Cardona, W. Paul, and H. Brooks, J. Phys. Chem. Solids 8, 204 (1959).

[7]R. Braunstein, J. Phys. Chem. Solids 8, 280 (1959).

[8]S. Zwerdling, B. Lax, L. M. Roth, and K. J. Button, Phys. Rev. 114, 80 (1959).

[9]R. Braunstein, A. R. Moore, and F. Herman, Phys. Rev. 109, 695 (1958).

[10]A. Sagar, Westinghouse Research Report 6-40602-3P5, June, 1959 (unpublished).

UPPER LIMIT FOR THE ANISOTROPY OF INERTIA FROM THE MÖSSBAUER EFFECT*

G. Cocconi† and E. E. Salpeter
Cornell University, Ithaca, New York
(Received January 21, 1960)

The question of anisotropy of inertia has been discussed in some detail in a previous paper[1]; here we recall only that one of the consequences of Mach's principle could be that the value of the inertial mass M of a body depends on whether its acceleration is in the direction towards the center of our galaxy or in a direction perpendicular to it. The variation ΔM of mass with direction, if it exists, was found to satisfy $\Delta M/M<10^{-9}$.

The recent discovery of the Mössbauer effect[2] has opened the possibility of comparing frequencies of γ rays, emitted by long-lived states of nuclei, with extremely high precision. The recoil-free resonant absorption of the 14-kev nuclear γ ray of Fe^{57} has already been investigated[3,4] with sufficient resolution to observe the hyperfine structure splitting in the excited state. The Mössbauer effect has been proposed as an excellent tool for detecting the gravitational red shift[5] and for many other purposes. Here we propose its use in a search for anisotropy of inertia. Precision studies of the line shapes of the Fe^{57} transition, for instance, will serve this purpose if the atomic spins can be aligned, both in the emitter and in the absorber, and the orientation of the spins relative to the direction towards the Galactic center is varied.

Consider an Fe^{57} nucleus in a nuclear state with total angular momentum quantum number J in a ferromagnetic sample with atomic spins aligned parallel to an external magnetic field. The effect of some anisotropy of inertia is then very similar to that discussed in reference 1 for the atomic Zeeman effect, except that we are now dealing with the motion of the nucleon in the Fe^{57} responsible for the γ-ray transition (at least on a shell-model picture) instead of the motion of an electron. Let m be the magnetic quantum number referred to the magnetic field direction as axis. The interaction for each m-value with the atomic magnetic field leads to $(2J+1)$ equally spaced components of the nuclear energy level. Each component is then further shifted, if there is any anisotropy of inertia, by an amount $(\Delta M/M)\overline{T}\overline{P}_2$, where $\overline{T}$ is the average kinetic energy of the nucleon (of order 10 Mev, say) and $\overline{P}_2$ is a coefficient whose value depends on J, on $|m|$, and on the orientation of the magnetic field relative to the direction towards the Galactic center. For the nuclear ground state of Fe^{57} we have $J=1/2$ and $\overline{P}_2$ is zero. $J=3/2$ for the excited state at 14 kev and $\overline{P}_2$ is nonzero[6] for $|m|=3/2$, equal and opposite for $|m|=1/2$, and $\overline{P}_2$ changes sign as the magnetic field changes from a direction pointing towards (or away from) the Galactic center to a perpendicular direction.

The resonance absorption in the Mössbauer effect only compares the transition frequencies in the emitter and the absorber. If we neglect the magnetic moment of the Fe^{57} nuclear ground state (compared with that of the $J=3/2$ excited state), the observed pattern[3] consists of a central line plus three equally spaced satellites on each side. If the magnetic fields in the emitter and absorber are parallel to each other then the presence of anisotropy of inertia splits the first satellite into a symmetric triplet, the second satellite into a symmetric doublet, and leaves the central line and last satellite unsplit. If the two magnetic fields are perpendicular to each other, the central line is also split, into a symmetric doublet. In all cases these splittings are largest when the magnetic fields are parallel or perpendicular to the direction towards the Galactic center and vanish in between.

If the atomic magnetic fields are randomly oriented in the emitter and absorber, then the anisotropy of inertia merely contributes to the broadening of the lines. Experiments carried out so far[3,4] seem to limit this broadening to about 10^{-8} ev which already would put an upper limit of about 10^{-14} on $\Delta M/M$, the measure of the anisotropy. With small source-absorber distances the line shapes can be measured quite accurately and experiments carried out with aligned atomic magnetic fields with varying orientations relative to the Galactic center could improve the sensitivity for $\Delta M/M$ considerably.

Rather similar precision measurements will presumably be carried out by many workers in the future for quite different purposes. The present note is meant as a plea to these workers also to consider the effects mentioned above.

---

*Supported in part by the joint contract of the Office of Naval Research and the U. S. Atomic Energy Commission.

†Present address: CERN, Geneva, Switzerland.

[1]G. Cocconi and E. Salpeter, Nuovo cimento 10, 646 (1958).

[2]R. J. Mössbauer, Z. Naturforsch. 14a, 211 (1959).

[3]R. V. Pound and G. A. Rebka, Phys. Rev. Letters 3, 554 (1959).

[4]S. S. Hanna et al., Phys. Rev. Letters 4, 28 (1960).

[5]R. V. Pound and G. A. Rebka, Phys. Rev. Letters 3, 439 (1959); J. P. Schiffer and W. Marshall, Phys. Rev. Letters 3, 556 (1959).

[6]$\overline{P}_2 = 1/5$ for a single $p_{3/2}$ nucleon.

POLARIZED SPECTRA AND HYPERFINE STRUCTURE IN Fe^{57}†

S. S. Hanna, J. Heberle, C. Littlejohn, G. J. Perlow, R. S. Preston, and D. H. Vincent
Argonne National Laboratory, Lemont, Illinois

(Received January 26, 1960)

The observation in this laboratory[1] of the polarization of the resonance radiation[2-5] emitted by the 14-kev level of Fe^{57} has led to a study of polarization in the hyperfine spectrum of the resonant absorption. The apparatus and the method of producing and detecting polarization were the same as used in reference 1 except that the source and the absorber were mounted on separate Alnico magnets. The magnet carrying the absorber was attached firmly to the bed of the lathe used in our previous work.[4] The other magnet holding the source was fastened securely to the carriage of the lathe. The detector of radiation (40-mil NaI) was mounted on the axis determined by the source and absorber and it was well shielded from magnetic fields.

The motion of the carriage provided uniform velocities of the source, and the polarized spec-