this estimate, the acceleration produced by the static earth $\sim M/\rho\tau^2\gamma^2$. Now $\tau \sim 10^{10}$ light years and ρ probably lies between 10^{-31} gm/cc (a lower limit for the density due to galaxies) and 10^{-27} gm/cc (an upper limit for the mean density within a typical cluster of galaxies). Hence $10^{-8} < \kappa < 10^{-4}$, so that indeed $\kappa M/c^2\gamma \ll 1$. With this estimate of κ, the acceleration produced by the earth lies between 10^2 cm/sec^2 and 10^6 cm/sec^2. It is therefore natural to identify this acceleration with the acceleration due to gravity of 981 cm/sec^2, and thus to assert the principle of equivalence. In this case $\kappa \sim G$, and we arrive at the well-known relation

$$G\rho\tau^2 \backsim 1 ,$$

leading to a mean density $\rho \sim 10^{-28}$ gm/sec^3.

Of course the principle of equivalence is further confirmed by the three crucial tests. The advance of perihelion is of particular interest since it involves a nonlinear contribution from $\kappa\theta^{ij}$ of order κ^2. The bending of light is linear in κ and is therefore less interesting, although it does confirm that the gravitational potential is a tensor. Finally the gravitational red shift is of interest because it might be used to test the minimal coupling principle. For in the laboratory test using the Mössbauer effect,[24] the γ rays move along a path short compared with the length scale of the earth's gravitational field. Hence any nonminimal coupling that might exist between the electromagnetic field and the curvature tensor is unlikely to be important. On the other hand, in the astronomical tests, the light path is long compared with the length scale of the gravitational fields involved so that the effect of a nonminimal coupling would be more likely to be measurable. While we do not anticipate that such an effect will be observed, it appears to be worthwhile to continue the astronomical attempts, which also of course may have direct astrophysical interest.

[24] R. V. Pound and G. A. Rebka, Phys. Rev. Letters **3**, 439 (1959).

CONTRIBUTED PAPERS FOR SESSION VIII

Relativity Experiments Using a Rotor

D. C. Champeney, G. R. Isaak, and A. M. Khan, *University of Birmingham, England*

Experiments to test relativistic effects with a Mössbauer source and absorber mounted on a spinning rotor are described. With the source mounted at the center and an absorber at the tip, a relative change in frequency of $\Delta\nu/\nu = +K(u_a^2/2c^2)$ is found with $K = 1.03 \pm 0.03$, where $\Delta\nu$ is the apparent excess of source frequency caused by rotation, u_a is the absorber velocity, and c is the velocity of light. The use of the apparatus as a sensitive variant of the Michelson Morley experiment is described, an ether drift of velocity $\bar{v}$ past the apparatus giving rise to a linear shift of $\Delta\nu/\nu = +\bar{v}\cdot(\bar{u}_a - \bar{u}_s)/c^2$, where $\bar{u}_s$ and $\bar{u}_a$ are the source and absorber velocities in the laboratory reference frame. Using the fact that with source and absorber at opposite tips no quadratic Doppler effect is expected leaving only the linear term, experiments are described which indicate that the diurnal amplitude of $\bar{v}$ in the east-west direction at Birmingham (England) was less than some 5 m/sec in the second half of August 1963.

Internal Conversion Coefficient of 14.4-keV Fe^{57} Transition*

A. H. Muir, Jr., *North American Aviation Science Center*
E. Kankeleit, and F. Boehm, *California Institute of Technology*

Using conventional nuclear spectroscopic techniques the total internal conversion coefficient of the 14.4-keV transition in Fe^{57} has been measured in an attempt to clarify the discrepancy between a recent value $\alpha_T = 9.94 \pm 0.60$ reported by Thomas *et al.*[1] and the generally accepted previous value of Lemmer *et al.*,[2] $\alpha_T = 15 \pm 1$. In the present determination both argon–methane proportional counters and a NaI(Tl) scintillation crystal spectrometer were used to measure the intensity of the K x rays in the Co^{57} decay relative to the 14-keV γ-ray intensity. From this result, $I_K/I_\gamma = 5.58 \pm 0.3$, we obtain the following K-shell and total conversion coefficients for the 14-keV transition: $\alpha_K = 8.44 \pm 0.5$, $\alpha_T = 9.51 \pm 0.5$. This α_T, which is in agreement with the result of Thomas *et al.*, is compared to other measurements and to theory. The α's estimated from Mössbauer experiments are all less than 10. There is some evidence[3] that α (Mössbauer) is significantly smaller than α (nuclear). This possibility is not understood.

* Part of the support for this work was provided by the U. S. Atomic Energy Commission.

[1] H. C. Thomas, C. F. Griffin, W. E. Phillips, and E. C. Davis, Bull. Am. Phys. Soc. 7, 120 (1962); Nucl. Phys. **44**, 268 (1963).
[2] H. R. Lemmer, O. J. A. Segaert, and M. A. Grace, Proc. Phys. Soc. (London) **A68**, 701 (1955).
[3] S. S. Hanna, R. S. Preston, and W. S. Denno, Rev. Mod. Phys. **36**, 469 (1964) [preceeding abstract].

Mössbauer Cross Section in Metallic Iron*

S. S. Hanna, R. S. Preston, and W. S. Denno, *Argonne National Laboratory*

A method has been evolved for measuring the Mössbauer cross section $f\sigma_0$. The total area in the absorption dip (or dips) is measured for a thin absorber and for a very thick one, the thickness ratio being as high as 40. As is well known in resonant absorption processes, the area ratio for a given thickness ratio determines the resonant cross section. In order to minimize the effect of nonresonant background, the absorbers are prepared so as to have very nearly the same electronic absorption. This can often be achieved by using samples of different isotopic content. The entire problem, from fitting the data to a set of overlapping

Lorentzian lines to determining the cross section, has been programmed for an IBM-704 computer.

In applying the method to metallic iron, the source was Co^{57}–Cu and the detector was a proportional counter. The total absorption area in the 6-line pattern was determined for various foils with $f\sigma_0$ ranging from 4 to 150. The analysis gives a value of $f\sigma_0 \approx 2.6 \times 10^{-18}$ cm^2. With $f \leq 1$, $\sigma_0 \geq 2.6 \times 10^{-18}$ cm^2. This places an upper limit of about 8 on the internal-conversion coefficient α; but recent direct measurements[1,2] of α give values between 9 and 10. The reason for the discrepancy is not understood. The most serious difficulty in the method described above arises if there is line broadening in the absorber. However, a correction for any such broadening would only lead to a still smaller value of α.

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* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] H. C. Thomas, C. F. Griffin, W. E. Phillips, and E. C. Davis, Jr. Nucl. Phys. **44**, 268 (1963).

[2] A. H. Muir, Jr., E. Kankeleit, and F. Boehm, Phys. Letters **5**, 161 (1963).

The Distribution of Nuclear Magnetism in the Ground and 14.4-keV States of Fe^{57}†

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Measurements of the hyperfine structure anomaly (Bitter–Bohr–Weisskopf effect) is a well-known technique[1] in atomic spectroscopy for comparing the distribution of nuclear magnetization between ground and long-lived isomeric states. Similar measurements can be made with Mössbauer scattering comparing the ratio of g_0/g_1 as determined by an internal hyperfine interaction and by an external magnetic field. (g_0 and g_1 are the ground and excited state gyromagnetic ratios, respectively.) The relevant equation is $(g_0/g_1)_{\mathrm{hyp}} \simeq (1 + \epsilon_0 - \epsilon_1)(g_0/g_1)_{\mathrm{ext}}$, where ϵ_0 and ϵ_1 measures the deviations of the ground and excited state magnetization from that of point dipoles. Measurements of $(g_0/g_1)_{\mathrm{hyp}}$ in metallic iron by Preston *et al.*[2] gives -1.750 ± 0.002. We have determined $(g_0/g_1)_{\mathrm{ext}}$ to be -1.740 ± 0.010 by measuring the hyperfine splitting in a titanium-1% Fe alloy at room temperature in an external field of 110 kOe. The error in this first run is mainly due to uncertainties in the linearity of the velocity spectrum. Thus $\epsilon_0 - \epsilon_1 \simeq +0.5 \pm 0.5$. The Bohr–Weisskopf estimate, assuming $g_l \simeq 0.4$, is $\epsilon_0 - \epsilon_1 \simeq +0.6$. The point dipole value for μ_1 may be $\sim$0.5% larger than the Mössbauer value[2] of $\mu_1 = -0.155$.

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* Supported by the U. S. Atomic Energy Commission and the Air Force Office of Scientific Research

[1] See, for example, H. H. Stroke, R. T. Blin-Stoyle, and V. Jaccarino, Phys. Rev. **123**, 1326 (1961).

[2] R. S. Preston, S. S. Hanna, and J. Heberle, Phys. Rev. **128**, 2207 (1963).

Mössbauer Effect in CoO†

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The Mössbauer Effect in a dilute concentration of radioactive Co^{57} in CoO is being investigated. Preliminary results with a stainless steel absorber give a single, narrow, unsplit absorption peak shifted from zero velocity by 1.0 mm/sec above the Néel temperature of 291°K. Below the Néel temperature, at 276°K, the single peak is replaced by the characteristic 6-line hyperfine pattern of Fe in a magnetic field of approximately 1.0×10^5 Oe. The data are consistent with doubly ionized Fe; evidence for higher valence states is not observed.

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The Mössbauer Effect of Sn^{119} in Vanadium, Gold, Platinum, and Thallium

V. A. Bryukhanov, N. N. Delyagin, and Yu. Kagan, *Academy of Sciences, USSR* (presented by A. A. Maradudin)

The recoilless resonance absorption of 23.8-keV γ rays by Sn^{119} nuclei in vanadium, gold, platinum, and thallium has been measured over a wide temperature range. These measurements have been performed on solid solutions of tin in vanadium (1.6, 3.45, 7.22 at. % Sn), gold (1.7, 3.2 at. % Sn), platinum (1.5 at. % Sn), and thallium (3.6, 9.2 at. % Sn). The experimental data are compared with the predictions of the theory of Kagan and Iosilevskii.[1] Good agreement is found in the whole temperature range. No discrepancies have been found between samples of different concentration within experimental error.

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[1] Yu. Kagan and Ya. A. Iosilevskii, Zh. Eksperim. i Teor. Fiz. **42**, 259 (1962); **44**, (1963) [English transl.: Soviet Phys.—JETP **15**, 182 (1962); **17**, 195 (1963)].

Nuclear Orientation Using the Mössbauer Effect

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In the successive transitions of the beta and gamma decays, the excited and ground states of the daughter nucleus are effectively polarized, when the satellites of the Mössbauer effect are separately observed. In this case we can design various experiments to detect parity nonconservation and time-reversal invariance in beta decay with a great precision.[1] In particular, the relative intensity of the beta ray in coincidence with a Mössbauer satellite $m_2 \to m_3$ is given in a decay scheme,

$$j \xrightarrow{\beta} j_1 \xrightarrow{\gamma_1} j_2 \xrightarrow{\gamma_2} j_3,$$

where the γ_1 ray is unobserved. The dependences on θ and θ' which are emission angles of the beta ray and the γ ray with respect to the spin orientation of j_2 ($\mathbf{j}_2 \cdot \mathbf{p} = \cos\theta$ and $\mathbf{j}_2 \cdot \mathbf{k} = \cos\theta'$) are completely separated. In the case of beta decay of M_n^{57}, the coincidence rate of beta ray with the Mössbauer satellite, $m_2 = \pm j_2 \to m_3 = \pm j_3$ is given by

$$W(\theta) = 1 \mp \frac{P}{W} \frac{\mathrm{Re}\,(C_A^* C_A')[6/5 + (26/35)\delta^2]}{(|C_A|^2 + |C_A'|^2)(1 + \delta^2)} \cos\theta$$

with $\delta^2 = (E2/M1)^2 \ll 1$. A parity experiment on M_n^{57} is now being done by Dr. H. Appel of Karlsruhe, Germany.[2]

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[1] M. Morita, Phys. Rev. **122**, 1525 (1961).

[2] H. Appel, private communication.

A Parity Experiment on Mn^{57} Using the Mössbauer Effect

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A parity experiment in weak interactions will be performed using recoilless emitted gamma rays of 14.4 keV from Fe^{57}. The individual Zeeman components have to be observed in coincidence with a preceding beta particle and the asymmetry of the $\Delta m = \pm 1$ gamma-ray transition rates has to be determined. We intend to investigate the decay of Mn^{57} which has a half-life of 1.7 min. The spin sequence is

$$7/2^{+} \xrightarrow{\beta^{-}} 5/2^{+} \xrightarrow{\gamma_1} 3/2^{+} \xrightarrow{\gamma_2} 1/2^{+}$$

γ_1 will be unobserved. The numerical calculation of the asymmetry coefficient has been carried out by M. Morita and R. Morita.[1] Mn^{57} will be produced by the reaction $Fe^{57}(d,2p)Mn^{57}$ in the Karlsruhe isochronous cyclotron. After irradiation the probe will immediately be taken to the experimental area by a pneumatic target circulating system. Radiation damage or recoil effects may alter the fraction of recoilless emitted gamma rays or even prevent us from observing resonance lines. But the latter is very unlikely. Hopefully, we think preliminary results will be available for the conference.

[1] Paper submitted to this conference.

On the Possibility to Observe the Mössbauer Effect in Rhodium-103

J. P. Sage, *DRME, Paris, France*

We have estimated the theoretical possibility of observing recoilless emission of gamma radiation in Rh^{103}. The first excited state of Rh^{103} is a 40-keV level; its lifetime of 54 min shows that an experimental procedure similiar to that used with the observation of the resonance in Ag^{109} must be used.[1] The computed fraction of recoilless rays emitted should vary from 0.52 at 4°K to 0.3 at 300°K using the Debye temperature of rhodium metal. This fraction is much larger than in the case of the silver experiment. Since the resonant excitation efficiency is proportional to $f^2\Gamma/\Gamma'$, where Γ and Γ' are the natural linewidth and real linewidths, the increase of the f value (recoilless fraction) in Rh^{103} gives a higher expectation for the experimental observation of the Mössbauer effect in this element.

[1] G. E. Bizina, A. G. Beda, N. A. Burgov, and A. V. Davydov, Rev. Mod. Phys. **36**, 358 (1964) [this issue].

Magnetic Moment Measurements from Combining Mössbauer Scattering with Angular Correlation Techniques*

Paul H. Barrett,† *Laboratory for Nuclear Science, MIT*, and *University of Claifornia, Santa Barbara*
Lee Grodzins, *Laboratory for Nuclear Science, MIT*

By measuring the precession of the angular distribution of the resonantly scattered gamma rays in a magnetic field, the magnetic moment of the excited state of many Mössbauer levels may be determined. A technique for making these measurements has been developed and measurements on the 2+ state of Os^{186} (137 keV) and W^{186} (122 keV) will be discussed.

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† On leave from the University of California, Santa Barbara.

Velocity Modulator Using Analyzer as Waveform Generator

E. Kankeleit, *California Institute of Technology*

A multichannel analyzer is used in the time mode. A quartz-controlled signal generator scans through the channels repetitiously. The routing bistable of the two halves of the memory generate a square wave. The wave is fed to operational amplifiers to produce a triangular wave. This then is taken as a reference signal for a feedback system which includes a wide band amplifier and an electromechanical drive.