

THE MÖSSBAUER EFFECT

A CONFERENCE REPORT

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DESPITE the fact that the University of Illinois campus is "centrally isolated"¹ more than 80 physicists (including the discoverer, Rudolf Mössbauer) from 23 university, government, and industrial laboratories in eight foreign countries and the United States converged on Allerton House, the University of Illinois conference retreat, on June 5. They came to report their most recent, unpublished experiments and to present and discuss their ideas for future research in the exciting field of recoilless gamma-ray absorption.² The meeting was held as an On-Site Advisory Meeting to the Air Force Office of Scientific Research; it was arranged in less than six weeks by Hans Frauenfelder of the University of Illinois with the support and cooperation of Max Swerdlow (Solid State Directorate, AFOSR). All discussions were informal and it was assumed that everyone at the meeting knew

everything published on the Mössbauer effect. At each of three half-day sessions several related problems were presented.

Monday morning, June 6, K. Singwi (Argonne) opened the discussions on theory, chaired by H. J. Lipkin (Rehovoth). Singwi gave a summary paper on the theory of the Mössbauer effect generalized for an arbitrary system of interacting particles by expressing the relevant transition probability in terms of a space-time self-correlation function. He suggested how Mössbauer-type experiments could be used to give information regarding the diffusion of atoms in solids and liquids.

F. Boehm (Caltech) was chairman of the session on isotopes. Participants helped D. Nagle (Los Alamos) complete a list of isotopes in which the Mössbauer effect has been observed. These are Ir^{191} , W^{182} , Fe^{57} , Sn^{119} , Ir^{193} , Er^{166} , Zn^{67} , Eu^{153} , Tm^{169} , Dy^{161} , Hf^{177} , Re^{187} . Nagle then reported in some detail on the Los Alamos Zn^{67} experiment. The observation of an effect in Zn^{67} is experimentally quite difficult and requires temperatures below 2°K and very low levels of vibration in the entire set-up. It is, however, of high interest since Zn^{67} yields the narrowest lines observed so far in Mössbauer effect.

A half-hour coffee break afforded time for continuing the informal discussions generated by the first two sessions. The last morning session, chaired by S. De Benedetti (Carnegie Tech), was given over to a discussion of experimental problems. Because many of the Mössbauer experiments involve the Doppler effect, some of the difficulties are of a different nature from

¹ A term used by Debye to describe Ithaca, N. Y., and equally applicable to Urbana, Illinois.

² Normally, in the process of emission or absorption a nuclear gamma ray loses an amount of energy large compared to the natural line width. This loss is due to Doppler effect and the energy goes into recoil motion of the emitting or absorbing nucleus. Mössbauer [Z. f. Physik **151**, 124 (1958)] found that under favorable circumstances, namely for an atom tightly bound in a solid at low temperature, emission and absorption can occur without such an energy loss. The recoil energy is taken up by the crystal as a whole, without emission of phonons. This effect, first found in Iridium¹⁹¹, makes it possible to observe resonance absorption of nuclear gamma rays without high speed rotors or elevated temperatures. It opened the way to direct measurements of the widths of narrow transition lines, as well as to the observation of small energy shifts due to nuclear, atomic, and macroscopic causes.

The interested reader is referred to the following review papers: S. De Benedetti, "The Mössbauer Effect", *Scientific American* **202**, 72 (1960); W. Kock, "The Mössbauer Radiation", *Science* **131**, 1588 (1960); and H. Lustig, "Mössbauer Effect", to be published in the *American Journal of Physics*, Jan. 1961.



R. Mössbauer addresses physicists assembled at Conference on the Mössbauer Effect.

those usually encountered by nuclear physicists. P. Craig (Los Alamos) presented a list of these technical and physical problems: linear vibration motion at liquid helium temperature, specimen preparation and heat treatment, etc. The second speaker, R. S. Preston (Argonne), discussed in detail methods of achieving relative velocities between source and absorber, such as reciprocating uniform motion or sinusoidal movements. Techniques are based on wheels, lead screws, lathes, cams, hydraulic devices, etc., for the former, and electromechanical transducers for the latter. J. G. Dash (Los Alamos) reported on an experiment of the Los Alamos group to measure the effect of very low temperatures on the hyperfine structure of Fe^{57} . The results indicate that the 122-kev transition in Fe^{57} is electric quadrupole and that the decay of Co^{57} is allowed. From the direction of the asymmetry they find that the internal magnetic field in Co is negative with respect to the domain direction.

Monday afternoon was reserved for individual discussions and walks in the Allerton gardens, embellished with splendid statuary. Most of the participants took advantage of the rare June weather to continue their scientific exchanges while leisurely strolling the many footpaths of one of the most beautiful estates in the Middle West.

After refreshments and dinner, everyone repaired to the library again for the evening session on relativity which began at 7:30 p.m. C. W. Sherwin (Illinois) was chairman. This topic is one of the "hottest" and perhaps the most dramatic of the many applications of the Mössbauer effect. R. V. Pound (Harvard) described several recent aspects of the gravitational red shift ex-

periment. The latest cumulative results give for the ratio of the observed to the calculated gravitational shift 0.99 ± 0.047 without a monitor channel, and 0.97 ± 0.054 with the monitor channel. Relativity experiments which can be done with the Mössbauer effect are the transverse Doppler effect (Harwell), the temperature Doppler effect, and possible consequences of Mach's principle.

Sherwin then discussed the temperature dependence of the Mössbauer effect as an experimental test of the "clock paradox". He regards source and absorber as miniature space ships. The average speed of the atoms is about that of a jet airplane and the acceleration of the order of $10^{15} g$. The nuclear "clocks" are communicating continuously by means of a periodic light signal of the frequency f_0 with the source at room temperature and the absorber at very low temperature. It is found experimentally that the absorber must move toward the source with a velocity of about 0.01 cm/sec in order to shift the received signals back to the normal frequency f_0 , where maximum absorption occurs. Thus, the inertial clock measures the traveling clock to be running slow. By contrast, for a source at very low temperature, the maximum absorption occurs only when the absorber is moving away from the source. In this case, the traveling clock (absorber) measures the inertial clock (source) to be running fast, in comparison to its own time standard. Thus both sets of measurements yield the same result: the traveling clock invariably runs more slowly than the clock in the inertial frame.

The evening session on nuclear applications was introduced by J. D. Jackson (Illinois). H. A. Weiden-



Mössbauer Conference participants. Left to right, top row: M. Swerdlow (Solid State Directorate, AFOSR), H. Frauenfelder (University of Illinois), C. S. Wu (Columbia University). Bottom row: R. Mössbauer (Caltech), R. V. Pound (Harvard), and A. Abragam (CEN, Saclay).

müller (Caltech) described the applicability of the Mössbauer effect for getting nuclear data on lifetimes, spins, magnetic moments, multipole moments, and transition rates in beta decay. Weidenmüller drew attention to the fact that the Mössbauer technique is of no advantage except for very short lifetimes. In the discussion A. Abragam (Saclay) pointed out that Mössbauer experiments can also be conducted with long-lived isotopes (e.g., Ag^{109}) despite their narrow line widths, by rigidly attaching the source to the absorber for a time comparable to the lifetime and then measuring the induced radioactivity of the absorber after separating it from the source.

R. Barloutaud (Saclay) reported on Sn^{119} experiments for determining magnetic and quadrupole moments, and Lipkin presented a calculation by L. Tassie (Rehovoth) which predicts an interference of the Mössbauer and photoelectric effects. L. Grodzins (MIT) reported on an experiment done with Fe^{57} by looking for asymmetries in gamma intensities toward and away from the magnetic field direction. He and his co-workers considered a nuclear state completely polarized in the $+\frac{3}{2}m$ state, which subsequently decays by $m-1$ emission to the $+\frac{1}{2}m$ state. If parity were not conserved, then one would obtain an asymmetry in the gamma intensities toward and away from the magnetic field. For the completely polarized transition from $-\frac{3}{2}m$ to the $-\frac{1}{2}m$ state, the opposite intensity pattern would have to be observed. Grodzins and co-workers found no asymmetry within statistical error, which confirms the conservation of parity in strong interactions.

C. S. Wu (Columbia) chaired the Monday evening

session on chemical shifts. I. Solomon (Saclay) reported on an investigation of the splitting of the line due to quadrupole interaction and chemical shift in pyrite and marcasite. Results are shown in Table 1.

Table 1

Material	Quadrupole Interaction	Chemical shift
Fe	0	0
Stainless steel	0	1.2 Mc/sec
FeS_2 (marcasite)	5.5 Mc/sec	3.8 Mc/sec
FeS_2 (pyrite)	7.0 Mc/sec	3.7 Mc/sec
Fe_2O_3	2.8 Mc/sec	4.6 Mc/sec
$\text{Fe}^{++}[\text{Fe}_2(\text{SO}_4)_3]$	0	6.2 Mc/sec

Although the discussion about line width came up several times during the day, the session devoted to this subject, chaired by M. Hamermesh (Argonne), lasted until midnight (and informal discussions lasted even longer), with very few participants leaving before the end of the session. M. A. Clark (Chalk River) discussed how to reach the natural line width of the 14-keV transition in Fe^{57} . G. J. Perlow (Argonne) reported on the Co^{57} preparations at Argonne. R. E. Holland (Argonne) described a coincidence experiment on 123-keV vs 14-keV transitions of Fe^{57} done by the Argonne group to investigate the time dependence of the Fe^{57} line shape. The relevant theory has been furnished by M. Hamermesh. E. L. Garwin (Illinois) reported on a similar experiment of the Frauenfelder group. S. Harris (Illinois) has performed a quantum mechanical calculation which agrees with the classical calculation of Hamermesh.

To the solid-state physicists, a very exciting application of the Mössbauer effect is to the study of internal fields in crystals. P. Anderson (Bell Laboratories) began his duties as chairman of that session at 8:15 a.m. on Tuesday, June 7, by remarking that the Mössbauer effect is simplest in the material which magnetically is the most complicated, i.e., iron. He said that this technique is probably the best for the study of the transitions in ferrites. S. S. Hanna (Argonne) gave some results concerning the effect of temperatures on the hyperfine splitting in iron. A. M. Portis (Berkeley) discussed the connection between Mössbauer effect and nuclear magnetic resonance (nmr). Up to room temperature, nmr-type experiments give more information than Mössbauer experiments. However, at higher temperatures the Mössbauer effect seems to promise some advantage. For nmr-people the Mössbauer effect can furnish a first indication of where the search for resonances should be made.

W. Marshall (Harwell) pointed out that the following five contributions to the internal field exist: *s*-electron contribution at the origin, spin-orbit interactions, dipolar effect in salts, contribution due to the conduction electrons in metals and the contribution due to the mixture of *d*- and *4s*-electrons. He remarked that the calculation of these terms yields an internal field in cobalt which agrees in magnitude with the one found experimentally by the Argonne group, but has the opposite sign! Hence some parts of the theory must be violently wrong.

In the session on resonance experiments and ultrasonics, directed by Abragam, Perlow reported on the attempts of his group to use the Mössbauer effect in detecting the separation between the two excited levels of Fe^{57} , which is 25.8 Mc/sec. Preliminary results reported by Perlow show that the transmission increases by 10 percent at 26 Mc/sec when the rf is swept between 20 and 30 Mc/sec. S. L. Ruby (Westinghouse) described an experiment on acoustically modulated γ rays from Fe^{57} in which the effect of acoustically generated low-energy phonons on the gamma spectrum has been studied.

The session on Rayleigh scattering, with Portis as chairman, was introduced by Barloutaud discussing the possible use of the recoilless Rayleigh scattering in nuclear resonance scattering. A. J. Bearden (Cornell) reported that experiments were underway to use the Mössbauer effect in an attempt to map the excitation spectrum of liquid helium.

The closing remarks, summarizing the two-day conference, were appropriately given by the 31-year-old Rudolf Mössbauer (now at Caltech). He pointed out, after discussing some of his own research both at Munich and at the California Institute of Technology, that these experiments do not require expensive equipment, enormous machines or excessive amounts of space. Hence smaller research groups at universities can participate along with the larger national laboratories. Mössbauer indicated promising areas where this technique could be utilized, emphasizing the possibili-



C. W. Sherwin and E. L. Garwin (University of Illinois), J. Corbett (GE Research Laboratory), W. M. Visscher (Los Alamos), M. Hamermesh and G. J. Perlow (Argonne National Laboratory).

ties in solid-state research in determining internal fields, vibrational spectra in metals, rare earths, and compounds. According to him, the "experiments with recoil-free absorption are especially attractive because they interlace various branches of physics, for instance, nuclear and solid-state physics".

He expressed the thanks of all the participants to the Illinois hosts and particularly to Hans Frauenfelder and to Mrs. Margaret Runkel, who worked so tirelessly to arrange not only the meeting but the accommodations and transportation of the attending scientists and to expedite them in such a short time.

The meeting adjourned for the final luncheon after Max Swerdlow (Solid State Directorate, AFOSR) expressed the gratification of the Air Force for the success of the meeting and the hope that research in this exciting area would continue and that other meetings would be held to provide important interchange of ideas.

By its very nature, this conference was unique; it was the first to be called on the subject, attended by the discoverer, held in ideal weather conditions in an idyllic isolated setting. The Solid State Directorate of the Air Force Office of Scientific Research is to be commended for its part in encouraging a meeting at so early a stage in the development of a new and rapidly expanding field.

[A limited number of copies of the proceedings of the Conference on Mössbauer Effect (AF Tech. Note 60-698) which includes a bibliography of published and unpublished scientific papers is available from Prof. H. Frauenfelder, Physics Department, University of Illinois, Urbana, Ill.]