COULOMB-RECOIL-IMPLANATION MÖSSBAUER EXPERIMENTS WITH ^{73}Ge†

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It has been shown that nuclear states suitable for Mössbauer studies can be populated by Coulomb excitation.[1-3] We have developed a new method, combining the Coulomb-recoil-implantation technique,[4] recently used in conjunction with perturbed-angular-correlation measurements,[5] with the Mössbauer effect. This method extends the range of application of Coulomb-excitation Mössbauer experiments, providing a wider selection of host materials for a given target nucleus. In many cases information about solid state and nuclear properties goes beyond that obtainable by Coulomb-recoil-implantation perturbed-angular-correlation measurements. In this experiment, we have implanted Coulomb-excited ^{73}Ge into metallic chromium, and observed the Mössbauer effect with the 67.0-keV de-excitation radiation.

Targets with 0.3 and 0.4 mg/cm^2 of ^{73}Ge, evaporated onto chromium-plated copper discs, were bombarded with a 3- to 5-μA beam of unanalyzed oxygen ions (predominantly O^{4+} and O^{5+}) from the Oak Ridge National Laboratory tandem accelerator. The terminal voltage was 5 MV. The temperature of the absorber was maintained at 78°K using the equipment described previously.[1] The target was from 5 to 10°K higher in temperature, depending on the beam current. The Mössbauer effect with a given absorber was measured as a function of the beam current (i.e., target temperature), and all measurements were extrapolated to 78°K.

Since the detection of the backscattered ions with a solid-state ring counter (cf. Refs. 4 and 5) is impractical with the large beam currents used, the implantation ratio η = (No. excited implanted nuclei)/(No. excited nuclei) has to be determined. It is calculable by numerical integration from a knowledge of the Coulomb-excitation differential cross section[6] and range-energy relations for heavy ions.[7] With the simplifying assumptions that (1) the scattering is isotropic in the center-of-mass system and (2) the target thickness d is small compared with the maximum range R_0 of the excited nuclei in the target material, the following expression for η is obtained:

$$\eta = \tfrac{1}{2}(1+\sin\gamma) - \frac{d}{3R_0}\left(\frac{3R_p\sin\gamma - d}{2R_p\sin\gamma - d}\right),$$

where γ is the angle between the beam and the target plane, and R_p is the projectile range in the target material. For our target ($d = 0.3$ mg/cm^2, $\gamma = 45°$) this formula gives $\eta = 0.78$, a a value which is only 10% larger than the result of a calculation with the differential cross section given in Ref. 6.

Three Mössbauer spectra are displayed in Fig. 1. The spectrum in Fig. 1(a) was obtained

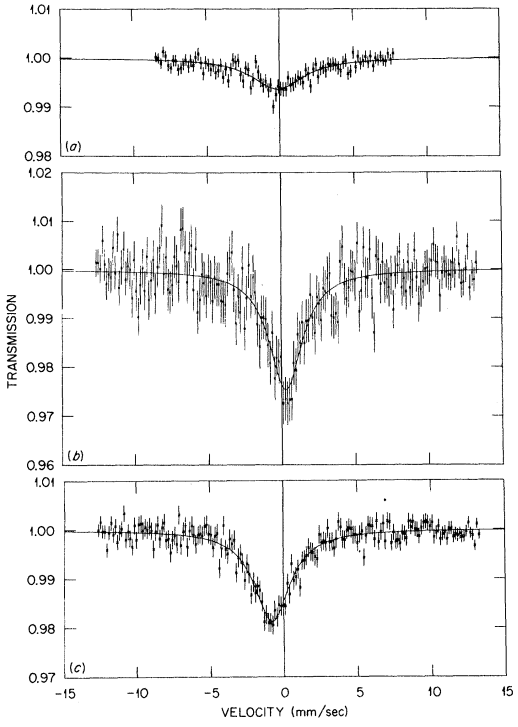

FIG. 1. Mössbauer spectra with 67-keV γ rays following Coulomb excitation of ^{73}Ge, at liquid-nitrogen temperature. All spectra include a correction for background gammas in the window of the single-channel analyzer. (a) Target: 2.5-mg/cm^2 ^{73}Ge on Al; absorber: 200-mg/cm^2 natural Ge. (b) Target: 0.3-mg/cm^2 ^{73}Ge on Cr; absorber: 140-mg/cm^2 natural Ge. (c) Target: 0.4-mg/cm^2 Ge on Cr; absorber: GeO_2 (140 mg/cm^2 Ge).

with a 2.5-mg/cm^2 ^{73}Ge target and a 200-mg/cm^2 natural-germanium absorber (cf. Ref. 3). With this target thickness η is less than 0.1. The maximum absorption is 0.6%. The spectrum shown in Fig. 1(b) was taken with a 140-mg/cm^2 natural-germanium absorber and is one of a series of spectra which differed only in the absorber thickness. All of these measurements were performed with a 0.3-mg/cm^2 target. The absorbers were powdered natural germanium in araldite. The spectra were fitted with a single line of Lorentzian shape since there was no evidence of hyperfine structure. The results of this series of measurements are summarized in Fig. 2.

In the absence of hyperfine interactions one may obtain values for the recoilless fraction of target and absorber from the thickness dependence of the linewidth (Fig. 2, *a*) and of the maximum absorption (Fig. 2, *b*).[8] The following parameters have been used for the evaluation of the recoilless fractions: the nuclear spins $\frac{9}{2}$ for the ground state and $\frac{11}{2}$ for the 67.0 keV state, the internal conversion coefficient $\alpha = 0.23$,[9] the natural abundance of ^{73}Ge, 7.8%, and the implantation ratio $\eta = 0.71$. We obtain for the recoilless fraction of ^{73}Ge in germanium (absorber), $f_a(78^\circ\mathrm{K}) = (6.0 \pm 0.6)\%$, and of ^{73}Ge in chromium (target), $f_S(78^\circ\mathrm{K}) = (5.8 \pm 0.4)\%$.

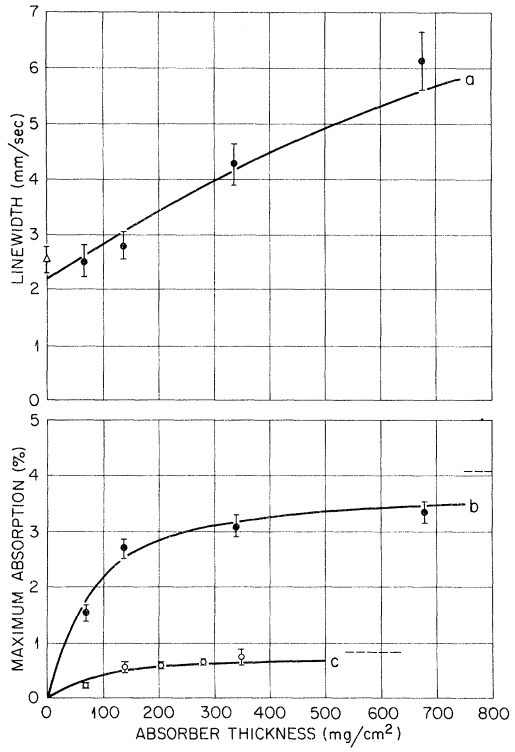

FIG. 2. Dependence on absorber thickness (natural Ge) of *a* linewidth, *b* maximum absorption with a target of 0.3-mg/cm^2 Ge on Cr, and *c* maximum absorption with a target of 2.5 mg/cm^2 Ge on Al. The solid curves were calculated with the relations of Ref. 8 and the parameter values given in the text. Broken lines in *b* and *c* indicate the saturation absorption for infinite absorber thickness.

Salter[10] has shown that within the framework of the quasiharmonic approximation of lattice dynamics, certain scattering properties of crystals may be predicted from thermodynamic data. He gives for the characteristic temperature of germanium which may be used to calculate f the value $\Theta_M = 298^\circ\mathrm{K}$. The value derived from our measured f is $\Theta_M = (292 \pm 10)^\circ\mathrm{K}$.

An extrapolation of the linewidth (Fig. 2, *a*) to zero absorber thickness gives $2\Gamma = 2.2 \pm 0.2$ mm/sec. This should be compared with $2\Gamma_e = 2.5 \pm 0.2$ mm/sec calculated from the electronically measured lifetime of the excited state,[9] $\tau = (2.33 \pm 0.2) \times 10^{-9}$ sec. The agreement between these values supports the assumption of no hyperfine interaction made in the computation of the recoilless fraction.

The maximum absorption versus absorber thickness for the 2.5-mg/cm^2 germanium target is shown in Fig. 2, *c*. The recoilless fraction of the target obtained from these data is $f_S(78^\circ\mathrm{K}) = (0.84 \pm 0.08)\%$, a value which is very small compared with the result for a germanium absorber. An x-ray investigation of the targets before and after irradiation showed a complete conversion from the crystalline to an amorphous state. The small recoilless fraction must certainly be a consequence of this drastic change in the germanium structure.

The data shown in Fig. 1(c) were taken with a GeO_2 (hexagonal) absorber. Here we are interested in the isomer shift of ^{73}Ge in GeO_2 with respect to that in pure germanium. Combining the isomer shifts of the two spectra in Figs. 1(b) and 1(c), we obtain (e.g., Wegener[11])

$$\delta = C(|\psi_{GeO_2}(0)|^2 - |\psi_{Ge}(0)|^2)\Delta R/R$$

$$= -1.0 \pm 0.1 \text{ mm/sec},$$

where $C = 1.8 \times 10^{-24}$ cm^4/sec for a spherical nucleus of constant charge density, including relativistic corrections. We assume the electronic configurations $4s^1 4p^3$ for germanium, and for the Ge^{4+} ions in GeO_2, $4s^0 4p^0$. It is then possible to calculate from the tables of Watson and Freeman[12] that the difference of the elec-

tron densities at the ^{73}Ge nuclei is $(|\psi_{GeO_2}(0)|^2 - |\psi_{Ge}(0)|^2) = -5.6\times10^{25}$ cm^{-3}. With these assumptions the change in nuclear radius is $\Delta R/R = +1\times10^{-3}$. A small isomer shift between Ge absorbers and germanium in chromium targets, $\delta = +0.17 \pm 0.07$ mm/sec, indicates a reduction in s-electron density for germanium in chromium.

We cannot exclude the possibility of radiation damage in the chromium from our present results. However, no changes in the Mössbauer spectra were observed during an irradiation time of approximately one week. It may be assumed that any radiation damage occurring in the target takes place in a time short compared with a few hours.

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LASER-PRODUCED DIELECTRIC BREAKDOWN IN LIQUIDS WITH RESULTING ABSORPTION OF A SECONDARY LIGHT BEAM

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We have observed phenomena in various liquids which we attribute to laser-produced dielectric breakdown. They are (a) a long-lived attenuation of a secondary light beam, (b) a small amount of forward scattering of the secondary light beam, (c) a distortion of the trailing edge of the laser pulse, and (d) a luminescence, coincident with the laser pulse, and having a low-intensity long-lived tail. The breakdown we believe is localized at particle sites in the liquids and results in pockets of dense plasma. In a liquid with particles of well-defined size, we observe a threshold in laser power below which no luminescence is seen and the other effects are also apparently absent. A threshold in field strength for luminescence is strongly suggestive of dielectric breakdown. These effects are produced at relatively low laser powers of the order of a few megawatts per square centimeter depending somewhat on the liquid and the number and size of nucleating sites. No extensive macroscopic cavitation occurs.[1]

A xenon flash tube together with a monochromator was used as a secondary source. The flash-tube output of approximately 2-μsec duration was made to coincide with the output pulse of a Pockels-cell, Q-switched ruby laser, OTI Model 130. The attenuation of the secondary beam was monitored with an RCA 1P28 photomultiplier. The laser and flash tube beams could be made to intersect in the sample cell at various angles and over path lengths from 0.5 to 10 cm. Changes in intensity of 0.3% in the secondary beam could be measured reliably.

The most striking phenomenon is the attenuation of a secondary light beam (see Fig. 1). The attenuation rises sharply coincidentally with the laser pulse and decays slowly with a time constant of a few hundred nanoseconds