We wish to extend our thanks to Ronald Amrine, John Bicek, and Richard Davies for their excellent help in adapting our experiment to the Van de Graaff accelerator.

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

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MÖSSBAUER EFFECT OF THE 29.4-keV NEUTRON CAPTURE GAMMA RAY OF K^{40}†

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Capture of a thermal neutron by K^{39} leads to the formation of an excited level in K^{40} with energy of about 7.8 MeV. After the emission of one or more energetic gamma rays, approximately 30% of the neutron captures result in the population of an excited level at 29.4 keV. We have observed Mössbauer resonance absorption of the 29.4-keV gamma ray resulting from the decay of this latter state. Emission of the energetic photons preceding the formation of the 29.4-keV level leaves the K^{40} nucleus with a distribution of recoil energies up to a maximum of about 800 eV. Energies of this order can be expected to displace the atom from its normal lattice site. However, our measurements indicate that radiation damage from this effect does not substantially diminish the recoilless fraction, f, in insulators (KCl and KF) or in metals (K). It appears, therefore, that thermal neutron capture can be used to excite a variety of new nuclei which have not been accessible for Mössbauer study through radioactive decay.

In this experiment a $\frac{1}{2}$-in.-diameter thermal neutron beam of about 3×10^6 neutrons/sec was extracted from the Omega West reactor. The targets, consisting of natural potassium in the forms K, KCl, and KF, were all about 0.3 cm thick. The resonance was observed at two temperatures, 4 and 78°K, and using two absorber thicknesses, 4.3 and 10.6 mg/cm^2, of K^{40}. Each absorber was $\frac{3}{4}$ in. in diameter and consisted of KCl enriched to 30.3% in K^{40}. The effective neutron cross section of K^{39} for production of the 29.4-keV isomer is about 0.6 b. With the arrangement described,. typical counting rates were about 2500 counts/min. Target and absorber were mounted in a cryostat fitted with thin Al windows for passage of the neutron beam and the 29.4-keV gamma ray.

Motion of the absorber was obtained with a velocity sweep system in which the sinusoidal

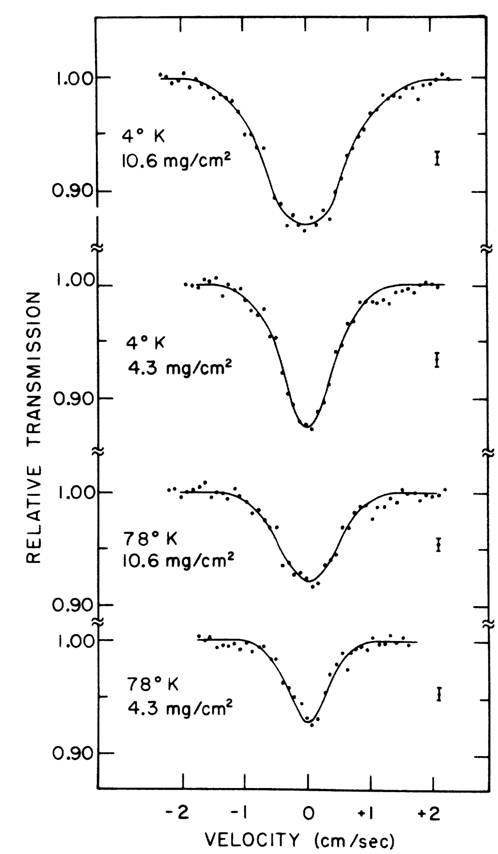

FIG. 1. Relative transmission of 29.4-keV gamma rays from a KF source through a $K^{40}Cl$ absorber as a function of velocity, temperature, and absorber thickness.

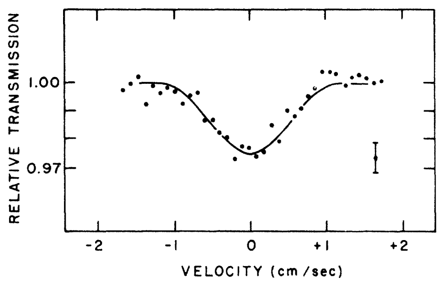

FIG. 2. Relative transmission of 29.4-keV gamma rays from a metallic-potassium source through a $K^{40}Cl$ absorber (4.3 mg/cm^2) at 4°K.

motion of a twin loudspeaker arrangement mounted outside the cryostat was transferred to the absorber by a thin-walled Inconel tube. The normalized spectra obtained for KF and for metallic potassium are shown in Figs. 1 and 2. The observed absorption amplitudes and areas must be corrected for background caused by high-energy radiation and by the 27.2-keV Te x ray, which is produced in the 2-mm NaI detector by capture of scattered neutrons. This latter process represents a 5 to 10% contamination in the observed 29.4-keV peak.

Table I lists the corrected values of the parameters derived from the various spectra, together with values of the background correction factor. To obtain the recoilless fractions we have extended Lang's[1] calculation of absorption areas to larger values of absorber thickness. The f values so obtained are listed in Table II, together with a comparison of the Debye temperatures inferred from these values and those derived from specific-heat data. The apparent temperature dependence of Θ_f is consistent with a moderate decrease in observed recoilless fraction resulting from source production. Calculation of f values for the KCl absorber requires the internal conversion coefficient of the 29.4-keV transition. In the absence of an experimental measurement of this quantity, we have used $\alpha = 0.35$ derived from Rose for a pure $M1$ transition. If one assumes only a small admixture of $E2$ in this transition, then the value of f for the KCl absorber would be substantially increased. The observed linewidth for the cubic KF, when corrected for absorber thickness, yields a half-life for the 29.4-keV level of 4.3 ± 0.9 nsec. This is in agreement with the directly measured value[2] of 3.9 ± 0.35 nsec. From this fact and from the measured f values, we conclude that the recoilless emission process is not greatly impaired by the method of formation of the source.

In a parallel effort, Ruby and Holland[3] have

Table II. The recoilless fraction, f; Debye temperature, Θ_f, derived from f; and the Debye temperature, Θ_D, derived from specific-heat data.

	Temp. (°K)	f	Θ_f (°K)	Θ_D (°K)
KF	4	0.23 ± 0.03	145	~320
source	78	0.14 ± 0.02	190	~320
KCl	4	0.18 ± 0.04	120	225
source	78	0.11 ± 0.02	175	218
K	4	0.036 ± 0.01	60	98
source	78			99
KCl	4	0.28[a]	...	225
	78	0.12[a]	...	218

[a]The theoretical $M1$ internal conversion coefficient has been used to compute these values of f. Due to this uncertainty, errors are not assigned.

Table I. The temperature, absorber thickness, absorption amplitude, linewidth, absorption area, isomer shift, and background correction factor, (signal + noise)/signal, for KF, K, and KCl targets.

Target compound	Temp. (°K)	Absorber thickness (mg/cm^2 K^{40})	Background corrected amplitude (%)	Linewidth (cm/sec)	Corrected area (cm/sec)	Isomer shift (mm/sec)	$\frac{S+N}{S}$
KF	78	10.6	13	1.08 ± 0.22	0.149	+0.02 ± 0.2	1.60
	78	4.3	13	0.66 ± 0.14	0.104	−0.14 ± 0.2	1.76
	4	10.6	21	1.44 ± 0.28	0.346	−0.16 ± 0.2	1.60
	4	4.3	22	0.92 ± 0.18	0.238	+0.02 ± 0.2	1.76
K	78	4.3	<1	...	...	...	1.5
	4	4.3	3.6	1.02 ± 0.20	0.0376	−0.2 ± 0.4	1.5
KCl	78	4.3	7.7	0.94 ± 0.20	0.0796	+0.4 ± 0.4	2.76
	4	4.3	16	1.08 ± 0.22	0.195	−0.14 ± 0.2	2.76

studied the Mössbauer effect in K^{40} using the reaction $K^{39}(d,p)$ to populate the 29.4-keV level. Their measurements, made at 78°K, indicated no observable resonance with KBr and KOH targets. With metallic potassium they observed a resonance amplitude of about 1%, although in the latter measurement there is some uncertainty concerning the chemical form of the source. These authors have speculated that radiation-damage effects caused by the method of production are responsible for their failure to observe resonant absorption in insulators.

The isomer shifts for K, KCl, and KF (see Table I) are essentially zero. Assuming electronic configurations of $3s^23p^64s$ and $3s^23p^6$ for the metallic source and the KCl absorber, respectively, an upper limit can be established for the change in nuclear radius, $\Delta R/R = (R_{29.4} - R_{\text{gnd}})/R_{\text{gnd}}$, between the ground and first excited states of K^{40}. The error limit of ±0.4 mm/sec obtained for metallic potassium yields a value of $|\Delta R/R| < 0.004$. K^{40} consists of a $d_{3/2}$-proton hole and an $f_{7/2}$ neutron outside the doubly closed-shell Ca^{40} nucleus. According to Goldstein and Talmi[4] the odd nucleons couple together to form the 4^- ground state, a 3^- first excited state (29.4 keV), and two higher states with spins 2^- and 5^-. On the basis of this model one would expect no change in nuclear radius as these particles are recoupled. Our results for $\Delta R/R$ are consistent with this picture.

The authors wish to express appreciation to the members of groups CMF-9 and P-2 for making available much of the apparatus with which this experiment was performed. They are also grateful to S. L. Ruby and R. E. Holland for communicating their results prior to publication.

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MICROWAVE-PHONON-ASSISTED TUNNELING IN SUPERCONDUCTING DIODES

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In this Letter we present data on tunneling between superconductors induced by transverse microwave phonons. The coherent sound waves give rise to an extra tunneling current, ΔI_S, which depends strongly on the voltage bias across the tunnel diode. The bias dependence for transverse phonons is remarkably different from that reported earlier[1] for longitudinal phonons. Similarly, the dependence of ΔI_S on the acoustic power is different for the two polarizations. To the best of our knowledge this is the first time that such a dependence on the phonon polarization was observed. Our results disagree with those published recently by Lax and Vernon.[2]

The measurements were performed on Al-Pb tunnel diodes deposited on one of the ends of optically polished single-crystal rods. The rods were 1 in. long with end faces parallel to better than 6 sec of an arc. Sound waves were excited in the rods using standard pulse-echo techniques. Power from a microwave transmitter, in the form of 1-μsec pulses, was fed into a re-entrant cavity[3] resonating at a frequency $\nu = 9.3\times10^9$ cps. The ends of the rods opposite the tunnel diode, $\frac{1}{8}$ in. in diameter, were inserted into the cavity. In the early measurements sound waves were generated by surface excitation[3] using X- and AC-cut quartz rods. To eliminate possible effects due to the piezoelectric field associated with the sound wave, measurements were also performed on tunnel diodes deposited on [100] germanium, and Z-cut quartz rods. In these cases the sound waves were generated by overtone resonant transducers bonded to the rods. The results obtained with the two techniques were in agreement.

The effect of the microwave excitation on the tunneling current was detected by a low-noise pulse amplifier. Coincident with the transmitter pulse a large pulse was observed in the