# *TEMPERATURE DEPENDENCE OF THE MOSSBAUER EFFECT ON* $Fe^{57}$ *IMPURITY NUCLEI IN A GOLD LATTICE*

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It is known that the difference in mass of impurity atoms (mass M′) and atoms of a regular lattice (mass M) has a marked effect on the character of the vibrations of the impurity nucleus in the crystal. When the ratio of the masses changes, there is not only a change in the amplitude of vibration of the impurity nucleus, but in certain cases discrete frequencies appear in the vibration spectrum. Theoretical studies by Kagan and Iosilevskiĭ[1] have shown that, on the assumption that the force constants are unchanged, the probability for the Mössbauer effect in a cubic crystal depends only on the distribution function for the vibration frequencies and on the ratio M′/M (at a given temperature). A particularly interesting case occurs when the ratio M′/M is small. As this ratio decreases, discrete frequencies appear in the spectrum. If the temperature dependence of the Mössbauer effect on the impurity nucleus is characterized by an effective Debye temperature $\Theta_{eff}$, then according to the theory, when $M'/M \ll 1$ it should be considerably larger than the Debye temperature of the regular lattice.

We have studied the probability of resonance emission of 14.4-keV $\gamma$ quanta by $Fe^{57m}$ nuclei embedded in a gold lattice ($M'/M = 0.29$), over the temperature range from 77 to 700°K.

The source of radiation was a gold foil about 0.002 mm thick, in which nuclei of $Co^{57}$ were introduced. Radioactive cobalt, deposited electrolytically on both faces of the foil, was introduced into the gold lattice by diffusion at 800°C for 2 hours in a hydrogen atmosphere. The absorbers were stainless steel foils (70% Fe) with thicknesses from 0.005 to 0.032 mm. The absorbers were kept at room temperature in all the experiments. The measurement technique has been described briefly.[2]

We found that, over the whole temperature range studied, the Mössbauer spectrum is a single line, whose width $\Gamma_{exp}$ does not change with changing temperature, and is equal to $(5.2 \pm 0.5)\Gamma$ (where $\Gamma$ is the natural width) for an 0.012 mm absorber. The absorption line was shifted relative to the emission line from a source at rest toward negative velocities by an amount $\delta$ equal to $0.78 \pm 0.05$ mm/sec at room temperature. When the sample was replaced by a similar source of stainless steel there was no noticeable change in the line shape. In both cases the line shape did not differ significantly from Lorentzian.

The magnitude of the Mössbauer effect is customarily characterized by the parameter

$$\varepsilon_{exp} = [N(v_\infty) - N(v_{res})] / N(v_\infty),$$

where $N(v_{res})$ and $N(v_\infty)$ are the counting rates of $\gamma$ quanta at exact resonance and at sufficiently high velocities v so that the resonance absorption is practically gone. If the widths of the emission and absorption lines are equal to the natural width $\Gamma$, the magnitude of the effect $\epsilon$ is related to the fraction f of "recoilless" $\gamma$ quanta and the absorber thickness $x = n\sigma_0 f'$ by the formula

$$\varepsilon = f\,[1 - e^{-x/2} J_0(ix/2)]. \tag{1}$$

Here n is the number of nuclei of the resonant isotope per cm² of the absorber, f′ is the Mössbauer probability and $\sigma_0$ is the resonance absorption cross section. If the source and absorber lines are broadened equally, a factor of $2\Gamma/\Gamma_{exp}$ should be introduced in the expression for the thickness x.

Formula (1) was used to determine the fraction f of resonance quanta. The value of the probability f′, which is needed for calculating f, was found from experiments using a stainless steel source and absorber. In analyzing the data, we took account of the resonance absorption in the source, which contains $Fe^{57}$ nuclei in their ground state. It is not difficult to show that self absorption in the source makes the experimentally observed effect $\epsilon_{exp}$ equal to

$$[\varepsilon(x + x_0) - \varepsilon(x_0)] / [1 - \varepsilon(x_0)]$$

(where $x_0$ is the effective source thickness). To find the probability f′, experimental values of $\epsilon_{exp}$ for different absorber thicknesses were compared with curves

$$[\varepsilon(x + x_0) - \varepsilon(x_0)] / [1 - \varepsilon(x_0)] = \varphi(x),$$

computed for different values of f = f′. The average depth of diffusion of the cobalt into the stainless steel was taken to be 0.003 mm. In the computations we used a value of 9.51 for the internal conversion coefficient $\alpha$.[4] At room temperature f′ was equal to $0.82 \pm 0.09$. The error given for f′ is largely due to the uncertainty in the determination of the effective thickness of the source.

By comparing the experimental values of $\epsilon_{exp}$ with the computed curves $\epsilon = \epsilon(x)$ (Fig. 1), we

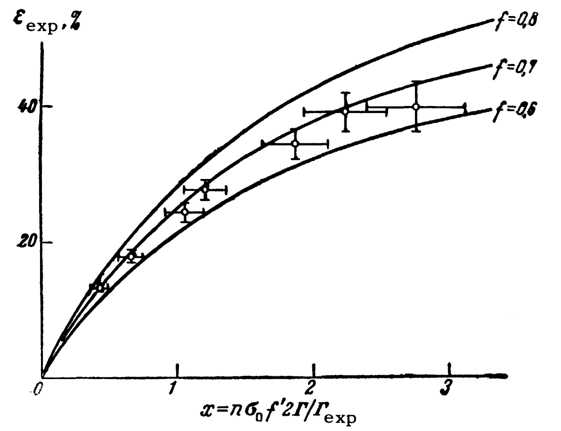


FIG. 1. Dependence of Mössbauer effect $\epsilon_{exp}$ at room temperature on absorber thickness x. The source of the radiation is $Fe^{57m}$ in a gold lattice, the absorber is stainless steel.

determined the fraction f of $\gamma$ quanta emitted without recoil by impurity $Fe^{57m}$ nuclei in a gold lattice at room temperature. A least squares fit gave $f = 0.67 \pm 0.06$.

In treating the data, corrections were made to the counting rate for the background from the 122 keV line in the $Fe^{57m}$ decay scheme. The background was determined by using copper filters from 0.005 to 0.200 mm thick.

Temperature measurements of the Mössbauer effect with a source in the form of a gold foil and with a stainless steel absorber 0.012 mm thick enabled us to determine f over the whole temperature range. Figure 2 shows the results of the temperature measurements. The dashed curve gives the temperature dependence of the Debye-Waller factor (for $\Theta = 170°$). Curve 1 shows the theoretical dependence of f as computed using the results of Kagan and Iosilevskiĭ,[1] where the frequency distribution was taken to be a Debye distribution with $\Theta = 170°$. The figure also shows a theoretical curve for $\Theta = 160°$ (curve 2). We see that the temperature variation of the Mössbauer probability is markedly different from that predicted with the Debye model. The experimental data are in good agreement with the results of theory in [1] 1) We note that on the Debye approximation we would require a Debye temperature $\Theta_{eff} \sim 300°$ ($\Theta_{eff} \approx \sqrt{M'/M}\,\Theta$) to explain the experimental data. The deviations of the data from the theoretical dependence at high temperatures may be related to anharmonicity.

The results support the assumption that the force constants are only slightly changed.

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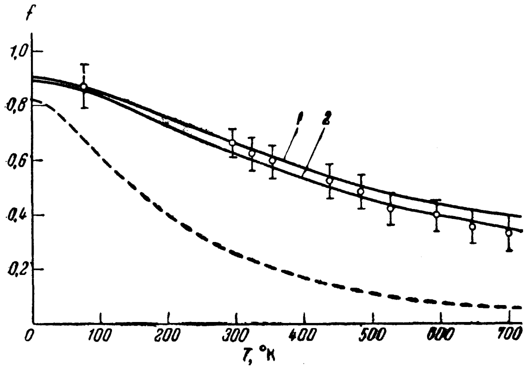


FIG. 2. Temperature dependence of probability f for resonance emission of 14.4 kev $\gamma$ quanta by impurity $Fe^{57m}$ nuclei in a gold lattice.

1)The anomalous temperature variation of the Mössbauer probability for impurity nuclei of $Fe^{57}$ in In, which was observed by Craig et al.,[5] apparently has a different origin.

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