THE MÖSSBAUER EFFECT ON Sn^{119} NUCLEI IN GOLD, PLATINUM, AND THALLIUM MATRICES

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The probability for recoilless resonant absorption of 23.8-keV γ rays by Sn^{119} in matrices of gold, platinum and thallium has been measured over a wide range of temperatures. Measurements were made on solid solutions of tin in gold (1.7 and 3.2 at% tin), in platinum (1.5 at% tin), and in thallium (3.6 and 9.2 at% tin). The experimental data are compared with the results of the theory developed in recent work by Kagan and Iosilevskiĭ.[2,3] Good agreement is obtained between the experimental and theoretical values for the probability of the effect over a whole range of temperatures. Within the limits of error no difference was observed in the effect for alloys with different concentrations.

1. INTRODUCTION

IN a preceding paper[1] we investigated the Mössbauer effect on Sn^{119} nuclei embedded in a matrix of vanadium. The existence of a phonon spectrum for vanadium, which was determined independently from experiments on scattering of cold neutrons, made it possible for the first time to give an absolute comparison of the experimental results with the theory of the Mössbauer effect on impurity nuclei which was worked out earlier by Kagan and Iosilevskiĭ.[2,3] This comparison showed a good agreement between theory and experiment over a wide temperature range. The case of tin introduced into a vanadium matrix corresponds to embedding a heavy atom of mass m', which is responsible for the Mössbauer effect, in a light lattice. We know that in such cases, if the force constants are unchanged, there are no discrete frequencies in the vibration spectrum. Only the spectral density of the square displacement of the impurity atom changes (relative to the case of an ideal lattice), and with increasing ratio m'/m becomes more and more localized in the region of low frequencies.

But when m'/m is less than one, in addition to the quasicontinuous vibration spectrum there may be discrete frequencies; then part of the spectral density of the square displacement is associated with high-lying localized levels, and this essentially changes the character of the temperature dependence of the effect and its value for T = 0 (for more detail, cf. [2,3]). When the ratio m'/m is considerably below one, if there is no change in the force constants the probability of the effect should, roughly speaking, be given not by the characteristic frequency of the ideal matrix, but by a quantity $(m/m')^{1/2}$ times larger.

The theory developed earlier[2,3] enables us to get expressions for the probability of the effect of recoilless absorption f' over the whole temperature range for the case where there are discrete frequencies present in addition to the quasicontinuous spectrum. The results of the theory are rigorous, provided that there is no significant change in the force constants. For the case of a monatomic cubic matrix, the corresponding expressions are functionals of the frequency distribution function of the phonon spectrum $\Psi(\omega)$ of the matrix, of the mass ratio m'/m, and of the temperature:[2,3]

$$f' = \Phi\{\Psi(\omega), m'/m, T\}$$

(in [3] results are also given for an anisotropic crystal, where to calculate f' one needs a more detailed knowledge of the phonon spectrum). The experiment with the vanadium matrix already showed that when the impurity atom is introduced there is no significant change in the force constants. Assuming that this result is a fairly general property of solid solutions of low concentration, one can also tackle the problem of an absolute comparison of theory and experiment for the case of a light Mössbauer atom, when there are discrete frequencies in the vibration spectrum. This problem is treated in the present paper.

2. DESCRIPTION OF THE EXPERIMENT

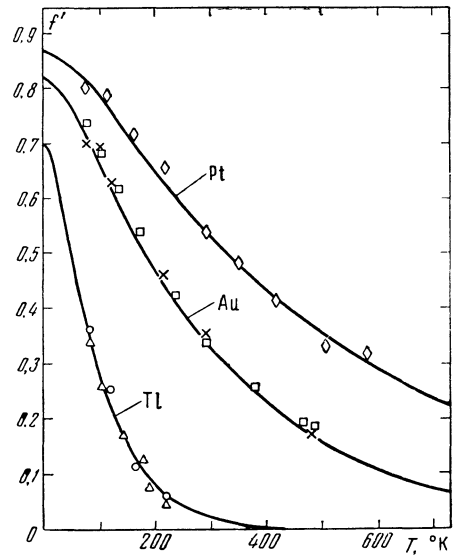
We have studied the Mössbauer effect for Sn^{119} nuclei embedded in heavy matrices of gold, plati-

num and thallium. These hosts are convenient for study, since tin forms solid solutions with them over a wide range of concentrations. The use of absorbers containing heavy elements causes considerable difficulties in carrying out the experiment because of the strong nonresonant absorption of the 23.8 keV quanta. In principle this difficulty could be avoided by using the corresponding solid solutions as sources. But in the present case this could not be done: the low specific activity of Sn^{119m} sources and the low concentration of tin in the solid solutions prevents the preparation of sources of sufficient intensity. In addition fundamental difficulties arose in determining the absolute value of the probability of the effect; these were related to the need for determining the fraction of 23.8-keV γ quanta in the total flux of radiation recorded by the detector.

For this reason we employed our usual measuring technique, using the solid solutions as absorbers. The solid solutions were prepared by alloying gold, platinum and thallium with tin enriched to 66.3% in Sn^{119}. We used solid solutions with a tin concentration of 1.7 and 3.2 at% for the case of gold, 1.5 at% for the case of platinum, and 3.6 and 9.2 at% for the case of thallium. The measurements were made with sources in the form of tin dioxide or magnesium stannide (in the latter case, as we showed in [4], the emission line had the natural width). The characteristics of the source, the methods of measurement and handling the data, and the experimental equipment were described earlier (cf. [1,4]).

For all the solid solutions studied the resonance absorption spectrum consisted of a single symmetric line. The values of the shift of the absorption line for an absorber temperature of 77°K (relative to the absorption line of SnO_2 at room temperature) were +1.99 ± 0.03 mm/sec for the tin-gold alloy, +1.42 ± 0.04 mm/sec for the tin-platinum alloy, and +2.85 ± 0.03 mm/sec for the tin-thallium alloy. For the tin-gold and tin-platinum alloys the absorption line width Γ_a was 0.34 ± 0.04 mm/sec, which agrees within the limits of error with the natural width; for the tin-thallium alloy Γ_a was equal to 0.40 ± 0.04 mm/sec. Within the accuracy of the experiments the values of the shifts and widths Γ_a were independent of the concentration of tin in the alloys. No effect of temperature on the width Γ_a was seen.

Resonance absorption spectra for the tin-gold alloys were measured over the temperature range from 77 to 485°K, and for the tin-platinum alloy from 77 to 580°K. The low characteristic temperature of thallium limited the temperature range in the case of the tin-thallium alloy to the range 77—220°K. The computation of the probability f′ for recoilless absorption was made by a method similar to that used earlier.[1,4] Over the temperatures given above, the values of f′ changed from 0.74 ± 0.10 to 0.19 ± 0.03 for the tin-gold alloy (3.2 at% tin), from 0.80 ± 0.11 to 0.32 ± 0.05 for the tin-platinum, and from 0.36 ± 0.05 to 0.06 ± 0.01 for the tin-thallium alloy (3.6 at% tin). We may mention that the error cited includes the error in the measurement of Γ_a, so that the relative change of f′ with temperature is determined with a much lower error. The results are shown in the figure. One interesting point is that within the accuracy of the measurements there is no difference in the effect for alloys with different concentrations.



Temperature dependence of recoilless resonance absorption of 23.8-keV γ quanta by Sn^{119} nuclei in matrices of gold, platinum and thallium: × and ⊡—gold matrix (1.7 and 3.2 at% tin), ◇—platinum matrix (1.5 at% tin), ○ and △—thallium matrix (3.6 and 9.2 at% tin). The solid curves are the theoretical values.

3. COMPARISON WITH THEORY. DISCUSSION OF RESULTS

There are unfortunately no direct measurements of the phonon spectrum for matrices of gold, platinum and thallium. Therefore (unlike the case of vanadium) we had to use an approximation for the function $\Psi(\omega)$. We used the Debye approximation for $\Psi(\omega)$, with $\theta = 230°$ for platinum, $\theta = 90°$ for thallium and $\theta = 170°$ for gold.

The probability f′ is summed over the phonon spectrum of the matrix. Thus its sensitivity to features of the phonon spectrum is to a large extent smoothed out, so that even when using an approxi-

mate expression for $\Psi(\omega)$ one can hope to keep all the essential features of the temperature dependence of the effect. The solid curves in the figure show the computed values of f′ as a function of temperature, obtained from the formulas given in [2,3]. In all three cases there is agreement between the measured and computed values within the accuracy of the measurements. The agreement holds both for the absolute values of f′ and for their relative changes with temperature. The experimental values show some systematic excess above the theoretical values, but this does not exceed the limits of error.

A common feature of all three cases is the slow decrease of the effect with increasing temperature. The characteristic temperature describing the temperature dependence of f′ is equal to $\Theta(m/m')^{1/2}$, where Θ is the characteristic temperature for the matrix. As mentioned above, this result is related to the presence of discrete vibrations of the impurity atom.

The experimental data agree with the theoretical results, which were gotten assuming that the force constants are unchanged. Thus the arguments presented earlier [1] concerning the slow change in the force constants for the case of solid solutions of low concentration receive new support. The earlier results [1] and those of the present work show a good agreement between the experimental and theoretical values of f′ over a wide temperature range both for the case of $m'/m > 1$ and $m'/m < 1$.

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