Oscillations of the Mössbauer spectrum line intensity following modulation by coherent ultrasound

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The possibility of generating coherent acoustic waves in Mössbauer absorbers is experimentally established. This generation manifests itself in intensity oscillations of the Mössbauer-spectrum components.

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Following the discovery of the Mössbauer effect of recoil-less resonant absorption (emissio of γ quanta of nuclei, an effect determined primarily by the character of the thermal motion of t nuclei,[1] experiments were performed to determine the effect of external action via ultrasound th alters the dynamics of the nuclear motion in solids.[2–5]

The theoretical premises for the understanding and analysis of such an effect were set for long ago by Shapiro,[6] and a more detailed theory was expounded subsequently in[5,7,8]

The effect of ultrasound on Mössbauer spectra leads to the onset of additional lines that a shifted relative to the central lines by energies that are multiples of the frequency Ω_{us} of t ultrasound oscillations. According to the results of[5,7,8] the intensities of the central band and t sidebands depend substantially on the character of the ultrasonic excitation. It is customary distinguish between two limiting situations[5]: a) ultrasound generation band width $\Delta\omega \ll \Gamma$(Γ is t width of the resonance level)—the so called coherent regime, b) the case $\Delta\omega \gg \Gamma$–incohere excitation.

In the latter case it is assumed that the broadening of the ultrasound band is due to relaxati processes.[5] The intensities of the unshifted line and of the satellites, depending on the intensity the ultrasound, is governed in this case by different laws. In the case (a), the intensities of t components in the spectrum are determined by

$$W_n = J_n^2(\mathbf{kA}), \qquad (a)$$

where $\mathbf{k}$ is the wave vector of the γ quantum and $\mathbf{A}$ is the amplitude of the ultrasonic wave. $n=0$, this formula yields the intensity of the central peak, and at $n=1,2,3\ldots$, the intensity of t nth satellite.

In case (b), the theory yields the relation

$$W_n = e^{-\xi} I_n(\xi), \qquad \xi = (\mathbf{kA})^2. \qquad (b)$$

There is a fundamental difference between these two relations. In the case (a) the intensiti W_n must oscillate with varying amplitudes of the ultrasound oscillations, and at certain values kA, say $kA=2$ or 4, the central peak should vanish completely. On the contrary, in the second ca there are no oscillations: the central peak decreases monotonically and the satellite intensities fir increase and then decrease to zero.

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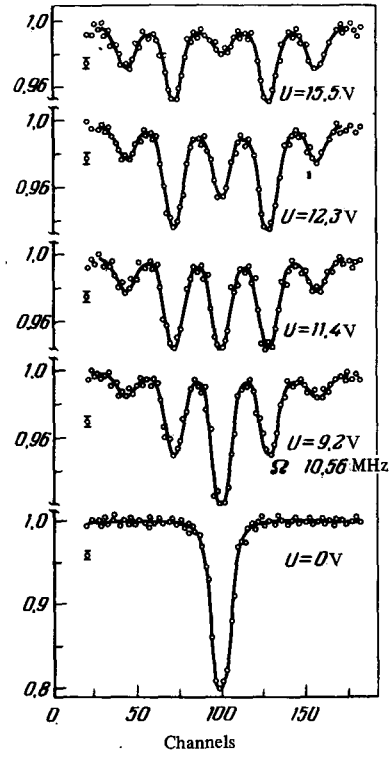

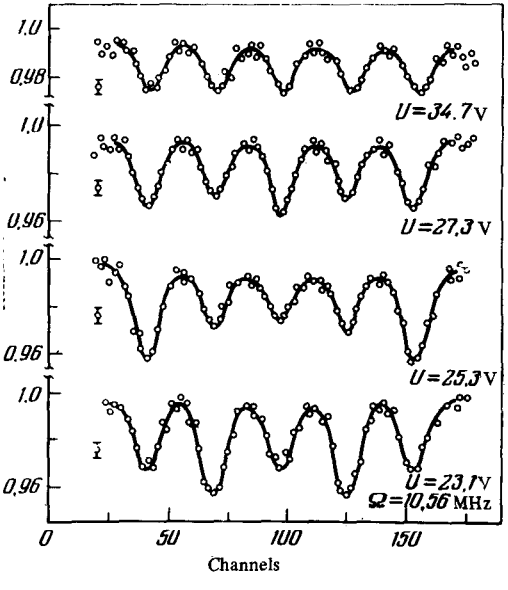

FIG. 1. Spectra of Mössbauer absorption in stainless steel vs. the ultrasound-wave amplitude.

Experiments performed by Ruby and Boleff[2] on stainless steel have shown that in their case

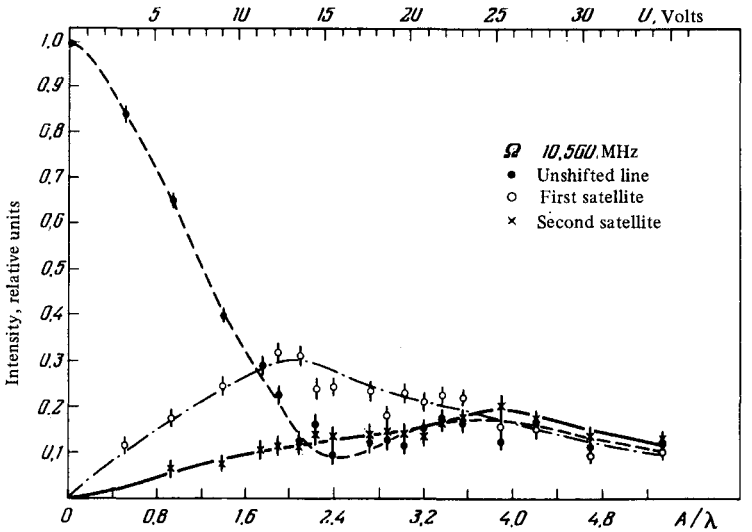

FIG. 2. Variation of the probability of the spectrum components of absorption in stainless steel as a function of the ultrasound amplitude normalized to the probability of the unshifted line.

the situation (b) is realized, i.e., W_n as a function of the intensity agreed with (2) with good accuracy. The following explanation was offered: it was stated that in stainless steel the lifetime of the ultrasonic phonons is very short, $\sim 10^{-11}$ sec, so that the ultrasound field relaxes rapidly and, by the same token, the regime (b) is automatically established.

Many experiments were subsequently performed, but the observed relations corresponded everywhere to the case of incoherent excitation. It was then assumed[2,4,5] that the realization of the first case is hindered also by the inhomogeneity in the coefficient of the transfer of ultrasounds from the generator to the sample. None the less, until recently, no experiment has been performed under conditions of coherent excitation. Interest in this question has increased recently in connection with the work of Gol'danskiĭ and Namiot,[9] who proposed to use the Mössbauer effect as a unique method for spatial resolution of ultrasmall objects. The entire idea of that work is based entirely on the realization of coherent-action ultrasound.

We report below, for the first time ever, the possibility of generating coherent sound in Mössbauer absorbers, as manifest by intensity oscillations of the spectrum components as functions of the ultrasound amplitude.

The experiments were performed on stainless steel samples ~ 20 μm thick. Longitudinal ultrasound excitation at a frequency 10.56 MHz was transmitted from an x-cut quartz transducer to the sample through a transmitting medium. The latter was glycerine and its thickness t_{gl} was chosen that $t_{gl} = n\lambda_{us}/2$, where $n = 1,2,3,\cdots$. This effected maximum transmission of the ultrasound from the quartz to the absorber. As shown by numerous experiments, the results depend substantially on the accuracy with which the condition $t_{gl} = n\lambda_{us}/2$ is satisfied in the entire sample.

Special efforts were therefore made in our experiments to ensure homogeneity of the transmission of the ultrasound intensity. To this end, the quartz, the absorber, and the upper and lower parts of the cell were carefully polished.

The characteristic Mössbauer spectra and the results of the experiment are shown in Figs. 1(a) and 1(b) and Fig. 2, respectively.

As seen from Figs. 1(a) and 1(b), up to certain ultrasound amplitudes the intensity of the ıtral component is higher than that of the first satellite, but subsequently it becomes much ver. Further increase of the ultrasound amplitude leads to a relative increase of the central peak mpared with the first satellite ($U=27.3$ V), and then to equalization ($U=34.7$ V).

It is also seen from Fig. 2 that the intensity oscillations take place between the central line and e second satellite as well as between the first and second satellites.

We have also carried out absolute measurements of the probability of the absorption lines. To is end we measured carefully the area under the entire absorption curve without the ultrasound d normalized to this quantity the areas of the components in the presence of ultrasound. The sults of this analysis are shown in Fig. 2.

The data in this figure, just as in Figs. 1(a) and 1(b), demonstrate convincingly the presence of cillations and agree well with the predictions of the theory for coherent excitation of ultrasound cillations [case (a)].

The presented data demonstrate that in this situation the relaxation of the ultrasound oscilla- ıns in stainless steel is quite weak and exerts no substantial influence. This is physically under- ındable, since in our case (just as in the earlier studies), the sample thickness was much less than e ultrasound wavelengths, and in practice the entire sample oscillates as a unit. On the other ınd, the homogeneity of the excitation and transmission of the ultrasound over the sample plays . essential role.

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