[6] K. L. Chopra and L. C. Bobb, Acta Met. 12, 807 (1964).
[7] K. L. Chopra, Phys. Lett. 15, 21 (1965).
[8] D. Larsen and B. T. Boiko, FMM 21, 150 (1966).
[9] A. N. Fridman and S. H. Koenig, I.B.M. J. Res. Develop. 4, 158 (1960).
[10] M. S. Khaikin, JETP 47, 878 (1964), Soviet Phys. JETP 20, 587 (1965).
[11] S. Brenner, Acta Met. 4, 62 (1956).
[12] E. H. Sonheimer, Advanc. Phys. 1, 1 (1952).

## MOSSBAUER EFFECT ON $Fe^{57}$ IMPURITY NUCLEI IN $MnAu_2$

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1. The compound $MnAu_2$ has attracted the attention of many investigators. $MnAu_2$ is a helicoidal antiferromagnet with a Neel point at 90°C [1] (according to Karchevskii and Nikolaev [2], $T_N$ = 100°C). Its magnetic structure can be destroyed by a sufficiently strong external magnetic field. $MnAu_2$ affords the rare opportunity of investigating the properties of a substance both in the antiferromagnetic and in the ferromagnetic state at the same temperature.

Bearing this circumstance in mind, we have undertaken an investigation of the Mossbauer effect on $Fe^{57}$ impurity nuclei in the crystal lattice of $MnAu_2$. The purpose was, in particular, to ascertain how the transition of a substance to the ferromagnetic state affects the magnitude of the magnetic field acting on the nucleus of the impurity atom. Particular attention was paid to the behavior of the Mossbauer-effect probability in magnetic transformation.

2. The Mossbauer-effect experiments were made on a sample previously used to investigate the temperature dependence of the magnetic properties [3,4]. The $MnAu_2$ sample (in the form of a disc 18 mm in diameter and about 1 mm thick) was used as the radiation source. The atoms of the isotope $Co^{57}$ (which decays to the isomer $Fe^{57m}$) were introduced into the $MnAu_2$ lattice by diffusion at 690°C for six hours in a hydrogen atmosphere. The sample was quenched after the end of the annealing.

The absorber in the Mossbauer-effect experiments was a stainless-steel foil (70% Fe). The measurements were made with apparatus of the cam and of the electodynamic type. The Mossbauer spectra were measured in the interval from 20 to 180°C. Experiments were also made at room temperature in an external magnetic field of intensity up to 18 kOe. In these experiments, the sample was placed in a field perpendicular to the direction of emission of the registered $\gamma$ quanta, while the absorber, together with the photomultiplier, was placed in the magnetic-shielding block.

3. The results were somewhat unexpected. Figure 1 shows some of the spectra measured in the absence of an external field. As seen from the figure, no clear-cut Zeeman splitting of the spectral line is observed at room temperature ($T/T_N \simeq 0.8$). According to our estimate,

the field acting on the iron nuclei at this temperature does not exceed 15 kOe. The character of the spectrum remains likewise unchanged in a field of intensity double the threshold value

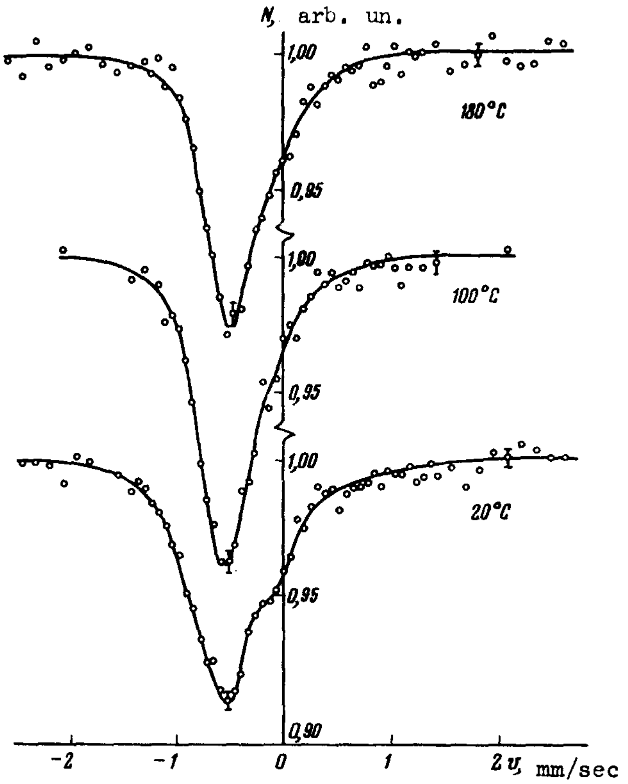


Fig. 1. Mossbauer spectra of $Fe^{57}$ nuclei in $MnAu_2$ compounds. Absorber - stainless steel 0.012 mm thick at room temperature.

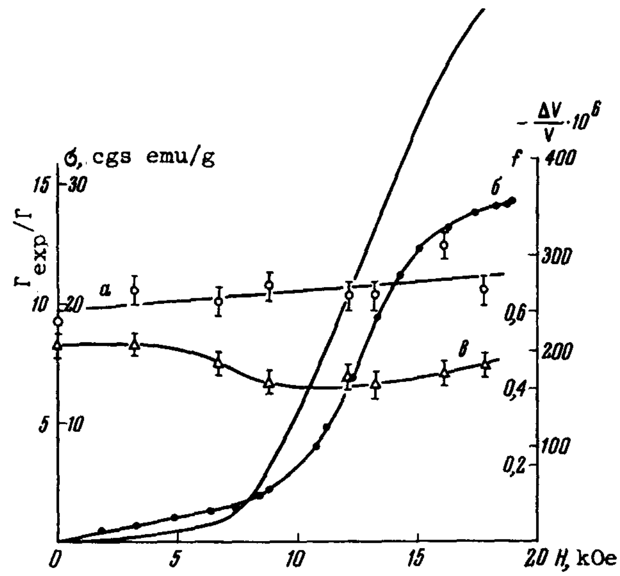


Fig. 2. a - Width of the spectrum $\Gamma_{exp}$, measured at half-height, vs. the magnetic field intensity H ($\Gamma$ = natural line width); b - sample magnetization curve; c - probability of Mossbauer effect F (determined by the "area method" [7]) vs. the field H; d - volume magnetostriction $\Delta V/V$ vs. the field H [3].

$H_{thr}$ (Figs. 2a and b). Yet for $Fe^{57}$ nuclei introduced into the crystal lattice of a ferromagnet the Mossbauer spectrum is usually represented in the form of individual components, provided the sample temperature is not too close to the temperature of the magnetic transformation.

The Fe atom in our compound is apparently in a paramagnetic state, and the observed picture corresponds to the line broadening produced in a paramagnet when the relaxation time is finite [5]. The decrease of the line width $\Gamma_{exp}$ with rising temperature at $T < T_N$ (Fig. 3a) may possibly be connected with the natural decrease in the relaxation time. Within the framework of this hypothesis, it is easy to explain the fact that a certain tendency to additional broadening is observed in an external field: the magnetic field does not lead to a direct splitting of the hyperfine structure in the presence of a strong relaxation process, but can cause line broadening.

All the obtained spectra are asymmetrical relative to their center of gravity. The character of variation of the form of the spectrum with increasing temperature (Figs. 1 and 3a) gives grounds for assuming that the asymmetry may be due to relaxation processes in conjunction with quadrupole interaction [6]. In this case the results would correspond to a weak temperature dependence of the relaxation time of the magnetic moment.

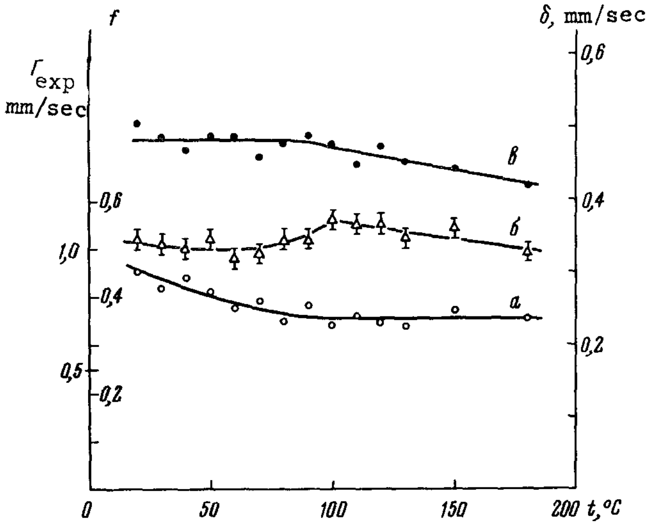


Fig. 3. a - Temperature dependence of the spectrum width $\Gamma_{exp}$; b - temperature dependence of the Mossbauer-effect probability f; c - isomer shift δ at different temperatures.

4. As to the Mossbauer effect probability, an anomaly in its temperature dependence is observed near the Neel point (Fig. 3b). This anomaly can be naturally related to the destruction of the helicoidal magnetic structure as a result of thermal motion. It is obvious that a change in the phonon spectrum of the crystal takes place during the magnetic transformation.

A fact worthy of attention is that the destruction of the helicoidal structure of $MnAu_2$ by an external field is accompanied by an anomalously large volume magnetostriction (with negative sign) [3]. Apparently, the spontaneous magnetostriction in this compound is also large, and this may influence the probability of the effect.

Such an interpretation of the behavior of f(T) near $T_N$ agrees with data on the temperature dependence of the isomeric shift δ (Fig. 3c). When $T > T_N$ the temperature coefficient $\partial\delta/\partial T$ corresponds to the so-called temperature shift. The apparent absence of a temperature shift when $T < T_N$ can be attributed to the influence of magnetostriction: it is well known that hydrostatic compression decreases the γ-transition energy of the $Fe^{57}$ nucleus [8].

The probability of the effect was altered also by application of an external magnetic field (Fig. 2c). In our opinion, this can also be due to magnetostriction deformation of the sample, although the mechanism whereby the magnetostriction affects the probability of the effect is not obvious (compare curves c and d in Fig. 2).

It is of interest to note a qualitative agreement between the dependence of the probability of the effect and of Young's modulus on the magnitude of the field [9]. This agreement is hardly accidental, since Young's modulus is an averaged characteristic of the force constants.

In light of the foregoing, it would be of interest to investigate the probability of the Mossbauer effect as a function of the field and of the temperature in substances in which the striction is large.

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[1] A. J. P. Meyer and P. Taglang, J. Phys. et Rad. 17, 457 (1956).

[2] A. I. Karchevskii and V. I. Nikolaev, FMM 11, 519 (1961).
[3] V. I. Nikolaev, A. I. Karchevskii, V. G. Tsinoev, and B. V. Vasil'ev, JETP 45, 480 (1963), Soviet Phys. JETP 18, 331 (1964).
[4] A. I. Karchevskii and V. I. Nikolaev, FMM 12, 372 (1961).
[5] A. M. Afanas'ev and Yu. Kagan, JETP 45, 1660 (1963), Soviet Phys. JETP 18, 1139 (1964).
[6] M. Blume, Phys. Rev. Lett. 14, 96 (1965).
[7] G. A. Bykov and Pham Zuy Hien, JETP 43, 909 (1962), Soviet Phys. JETP 16, 646 (1963).
[8] R. V. Pound, G. B. Benedek, and R. Drover, Phys. Rev. Lett. 7, 405 (1961).
[9] I. G. Fakidov, L. P. Volegov, and V. P. Krasovskii, FMM 20, 373 (1963).

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## DOUBLY LOGARITHMIC ASYMPTOTIC EXPRESSION IN QUANTUM ELECTRODYNAMICS

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An asymptotic expression for a scalar four-point diagram at high energy $s = (p_1 + p_2)^2$ and at finite $t = (p_1 - p_1')^2$ in the case of an interaction of the $e\varphi^3$ type with $e^4 \ln s \ll 1$ was obtained by Polkinghorne [1]. This asymptotic expression is determined by a sequence of ladder diagrams 1 and is of the form

$$\sum_{n=1}^{\infty} \frac{\alpha}{s}(\alpha \ln s\, K(t))^{n-1} \frac{1}{(n-1)!} = \frac{\alpha}{s} \exp(\alpha K(t) \ln s); \quad \alpha = \frac{e^2}{4\pi} = 1/137. \tag{1}$$

An asymptotic expression for these diagrams is best obtained by the method of Sudakov [2], by resolving the intermediate integration momentum k into a longitudinal and transverse part, $k = u\vec{p}_1 + v\vec{p}_2 + \vec{k}_\perp$. The separation of ln s takes place in the integration with respect to u and v, and K(t) is a two-dimensional integral corresponding to one loop (Fig. 1a), constructed in accordance with the usual Feynman rules, with replacement of all the intermediate momenta k by $k_\perp$ and of $d^4k$ by $d^2k_\perp$.

In the scalar case at a finite particle mass, the integrals corresponding to K(t) converge. Formula (1) is then the correct asymptotic expression, called singly-logarithmic, since for each power of α there is an equal power of ln s. If one of the particles has zero mass (photon), each loop (Fig. 1a) diverges logarithmically at small $k_\perp$.

If both particles have spin 1/2, then a logarithmic divergence occurs also for large $k_\perp$. Since the initial diagram (Fig. 1) shows now divergence in either case, the asymptotic expression (1) is no longer valid. Actually the integration with respect to $k_\perp$ in the loop is cut off at values of the order of $s^{-1}$ for small $k_\perp$ and of the order of s for large $k_\perp$. Therefore the arising logarithmic instability corresponds to the appearance of an additional