A paper published earlier [1] examined the reasons why the growth rate of martensite crystals in iron alloys was not a function of temperature, whereas the nucleation rate in the general case should be described by a curve with a maximum. Up to the present time, however, there have been no experimental data on the temperature dependence of the nucleation rate during the martensitic transformation in iron alloys. In Reference [2] a method was suggested for calculating the activation energy, provided the volume of martensite crystals was not a function of the degree of transformation. It was later shown, however, that the theoretical equation adopted for the isothermal transformation did not correspond to the initial experimental data [3], since as the martensitic transformation developed, the size of the crystals decreased by a large factor [4].

We investigated the effect of temperature and the degree of transformation on the rate of nucleation and on the size of the martensite crystals in iron alloys under conditions of a purely isothermal transformation ruling out the possibility of athermal martensite forming. On the basis of the relationships studied we determined the thermodynamic characteristics of the process — the activation energy and work of formation of the martensite crystal nuclei. The data obtained confirmed the dislocation nature of the martensitic transformation.

In order to determine the nucleation rate for any phase transition, we must first calculate the number of particles which have formed in the given area over a certain time, and then ascertain the number of particles which
Fig. 1. Structure of martensite obtained under isothermal conditions at -68°C (alloy with 23.02% Ni and 3.35% Mn). x 300.

have formed per unit volume per unit time, that is to say, we must go on to consider the nucleation rate. The conventional method involves a clear-cut separation of the individual crystal formations. For the case of martensitic transformations in iron alloys, this is possible in those containing carbon when all or a considerable amount of the martensite is formed during change in temperature. In the case of a purely isothermal transformation, calculations of the number of crystals in the plane of the section proves impossible in practice because of the indistinguishable nature of the formations, their mingling and superimposition. Figure 1 shows a typical structure for isothermal martensite in the iron-nickel-manganese alloy. It follows from examination of this structure that the thickness of the martensite crystals can be determined with quantitative accuracy. Moreover, the method of random section in the body [5] can be used to determine the surface of the martensite crystals per unit volume $S = \frac{2a \cdot b \cdot d}{N}$. The relative volume $V$ of the ferromagnetic component — the martensite — can also be determined by the magnetometric method.

If the martensite crystal is shaped like a flat parallelepiped with sides $a$, $b$, and $d$ for a volume of $1 \text{ mm}^3$, it can be expressed by the following equation

$$V = \frac{a \cdot b \cdot d}{N} = \frac{2a \cdot b \cdot d}{N}$$

where $N$ is the number of crystals formed over the given interval of time. Substituting $b$ into Equation (2), we get

$$N = \frac{S}{a \cdot b \cdot d} = \frac{S \cdot a \cdot 2 \cdot d}{4a \cdot b \cdot d}$$

The thickness of the martensite crystals was taken as the mean of 400 measurements of $a' [6]$:

$$a = \frac{a'}{2}$$

According to Reference [5], for a degree of reliability of 0.7, 400 intersections give a maximum possible relative error in $a$ of about 3%.

The martensite crystal surface $S$ was determined for 400 intersections, i.e., with the same degree of reliability. The absolute error in determining the volume of the martensite phase was 1.2 - 1.4% [3].

The length of the martensite crystals $b$ was determined by substituting $a$, $N$, $V$ or $S$ into Equations (1) or (2).

The isothermal martensitic transformation was studied with the use of an iron alloy containing 23.02% Ni and 3.35% Mn similar to the alloys used in [7] and [8]. During cooling in air from 1200°C the martensite point occurs at 10°C. Further cooling in liquid nitrogen leads to the formation of 72% martensite. In order to bring about a purely isothermal transformation over a wide temperature range, specimens sealed in two quartz ampoules were cooled inside the furnace from 1200°C to room temperature in the course of 3 hours. Stabilization of the austenite caused the transition temperature to drop, and also reduced the degree of final transformation (down to about 25% martensite).

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Kinetic characteristics of martensitic transformations. Figure 2 shows a diagram for isothermal martensite transformation. The temperature range over which the process actively occurs is -50 and -155°C. Accordingly, the study was carried out at -55, -68, -94, -114, -129 and -155°C. The results of determining $N$ for the degree of transformation 5, 10, 15, and 25% are shown in Table 1.

![Fig. 2. Diagram showing isothermal martensite transformation in iron-nickel-manganese steel.](attachment:image.png)

On the basis of the data in Table 1, page 482, and Figure 2, above, we calculated the nucleation rate of the martensite crystals.

The temperature dependence of the nucleation rate during the martensite transformation coincides qualitatively with similar relationships studied earlier for processes of the crystallization type, Figure 3, page 482. The dependence of $a$ on the degree of transformation under

$^3$The relationship derived by the authors is valid for the given alloy, since it was only in this case that the investigators were able to obtain an isothermal martensitic transformation in the pure form. The relationship derived cannot be extended to cover other iron alloys, particularly steels, in which virtually no isothermal martensitic transformation is observed (Editors' note).