Instantaneous magnetostriction and its aftereffect in the region of a magnetic first-order phase transition in the compound ζ-Mn_5Ge_2

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The relationships describing the transverse magnetostriction after an instantaneous change in the magnetic field intensity H (i.e., the instantaneous value of the magnetostriction and the aftereffect) were determined in the specific case of ζ-Mn_5Ge_2 single crystals. In the case of magnetic materials in which a first-order magnetic phase transition was accompanied by a combined temperature-field hysteresis (coexistence of transitions when T and H were varied) the relationships were closely related to the thermal expansion. An anomalous fluctuating magnetostriction effect was observed and it was characterized by kinks and jumps on the linear plots vs the logarithm of the time.

INTRODUCTION

The traditional objects for investigating the magnetic aftereffect (i.e., the changes in the physical properties, representing internal thermodynamic variables, with time t) have for a long time been confined to ferromagnets.[1] The magnetic aftereffect of the magnetization appears in these materials as a result of magnetization or its reversal. It is associated with a magnetic first-order phase transition with respect to the field, which is accompanied by a magnetic hysteresis. The phase-transition field H_{pt} is zero and is independent of the sample temperature T. In the case of usual ferromagnets a change in T simply gives rise to a second-order magnetic phase transition (at the Curie point if $H = 0$).

In recent years the relaxation phenomena have been investigated also in magnetic materials with more complex magnetic structures. The aftereffect observed near first-order magnetic phase transitions not only on the scale of H but also of T is a special case. By way of example, we can mention here the time dependences of the magnetization of the compound NiS_2 near a phase transition to a state with a spontaneous magnetization,[2] the magnetoresistance of an Fe-Rh alloy near a metamagnetic phase transition,[3] the intensity and width of a magnetic neutron scattering peak of dilute antiferromagnets $RbCo_{0.85}Mg_{0.15}F_4$ and $Fe_{0.68}Zn_{0.32}F_4$ on appearance of a long-range magnetic order.[4] However, in these investigations the aftereffect has been simply noted and the relationships governing it have not been determined.

We shall report the results of an investigation of the magnetostriction aftereffect observed earlier[5] near the temperature T_{pt} of a first-order magnetic phase transition in the compound ζ-Mn_5Ge_2. The aftereffect consists of observation, after an instantaneous change in H, of an instantaneous value of the magnetostriction and subsequent changes in the linear dimensions of a sample with time.

We shall consider some characteristic features of the magnetostriction aftereffect and establish the relationship governing the instantaneous magnetostriction and the aftereffect, as a function of T, of the initial magnetic state, of H, and of the method of change of the magnetic field (switching on or off). We shall show that magnetoelastic (instantaneous magnetostriction and magnetostriction aftereffect) and thermoelastic (temperature hysteresis of the thermal expansion) properties are closely interrelated. This is due to the fact that ζ-Mn_5Ge_2 is a magnetic material in which first-order phase transitions occur as a result of variation of the field and temperature. The phase-transition field H_{pt} differs from zero and depends on T, whereas the phase-transition temperature T_{pt} depends on H and a combined temperature-field hysteresis is observed.

SAMPLES AND MEASUREMENT METHOD

Our measurements were carried out on single-crystal samples (prepared and tested as described in Ref. 5) of the high-temperature phase ζ-Mn_5Ge_2 containing 28 at.% of Ge. Complete data on the crystal structure are not yet available, but according to the results of x-ray diffraction investigations,[6] this phase has the trigonal structure with the lattice constants $a = 7.185$ Å and $c = 39.17$ Å. It has the space group $P\bar{3}c1$. A unit cell contains 128 atoms.

According to the published temperature dependences of the magnetization, lattice parameters a and c (Ref. 7), thermal expansion, and transverse magnetostriction,[5] an increase in temperature from 100 to 500 K induces four magnetic phase transitions. In particular, at $T_{pt} \approx 110$ K (in a field $H = 0$) there is a first-order transition from a postulated antiferromagnetic state to one with a spontaneous magnetization lying in the basal plane. All the measurements reported below were carried out near this transition.

The relative elongation of ζ-Mn_5Ge_2 was determined using compact resistance strain gauges by a method described in Ref. 8. The magnetostriction and its aftereffect were determined in the basal plane and along the trigonal c axis (using two different samples) in fields up to 16 kOe, directed along the c axis and in the basal plane, respectively (transverse magnetostriction). For every selected value of H, a series of measurements was carried out at different temperatures T varied monotonically from ≈ 80 to ≈ 140 K, lying outside the loops of temperature hysteresis of the thermal expansion; this was followed by cooling. At each temperature T a field H was applied instantaneously (in future we shall assume that every time the field was switched on or off the process was instantaneous), the instantaneous magnetostriction was determined, and then the relative elongation ($\Delta l / l_0$) was measured at intervals of $\Delta t = 15$ sec. When a relatively stable value of Δl was achieved (usually after an

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interval of about 10 minutes), the field was switched off and $\Delta l/l_0$ was measured again as a function of time. The switching of H on and off at a given temperature was repeated several times (cyclic variation). The next temperature was then reached by a relatively slow process ($\leqslant 2$ K/h) with the field switched off.

The relative elongation considered as a function of H, T, and t was deduced from the relationship

$$\Delta l/l_0 = [l(H, T, t) - l_0]/l_0,$$

where l_0 is the length of the sample in $H = 0$ at the reference temperature of boiling nitrogen 77 K (well below the region of temperature hysteresis of the thermal expansion). This quantity was convenient for the investigation of the relationship between the thermal expansion and magnetostriction, since the latter was governed by the difference

$$(\Delta l/l_0)(H, T, t) - (\Delta l/l_0)(0, T, t).$$

EXPERIMENTAL RESULTS

Figure 1 shows the experimental dependences $(\Delta l/l_0)(0, T, \infty)$ representing the thermal expansion measured in a field $H = 0$ while varying quasistatically the temperature T near T_{pt}. Figure 2 shows some characteristic $(\Delta l/l_0)(H, T, t)$ curves obtained by switching H on and off consecutively (keeping T and H constant). The sections A–A', C–C', B–B', and D–D' represent the instantaneous magnetostriction, whereas the sections A'–C, C'–B, B'–D, etc., comprise the magnetostriction aftereffect.

An analysis of the experimental results, including those presented in Figs. 1 and 2, enabled us to establish the following relationships.

1. The instantaneous magnetostriction observed after a change of the magnetic field depended on: a) the temperature T of a sample; b) the field H; c) the method of change (switching on or off); d) previous history, i.e., the initial magnetic state (corresponding to the rising or falling branch of a temperature hysteresis loop of the thermal expansion) and the previous switching of the field on or off. The influence of these factors on the aftereffect was indirect, because they governed the state which was assumed by the magnetic material before the aftereffect.

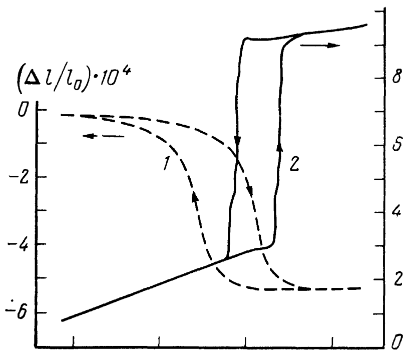

FIG. 1. Loops of the temperature hysteresis of the thermal expansion of a ζ-Mn_5Ge_2 single crystal near low-temperature magnetic phase transition, recorded: 1) along the trigonal c axis; 2) in the basal plane.

2. The magnetic aftereffect was observed at temperatures lower than the high-temperature limit of the temperature hysteresis loop of the thermal expansion, $T_h(0)$ in $H = 0$.

3. There was a definite first threshold field $H_{\text{th.1}}$ (in the case of ζ-Mn_5Ge_2 it amounted to about 9 kOe) the value of which was governed by the following conditions: a) the aftereffect corresponding to the rising branch of the temperature hysteresis loop of the thermal expansion appeared after the first switching of the field on both for $H < H_{\text{th.1}}$ and for $H > H_{\text{th.1}}$ (Fig. 2). In the range $H < H_{\text{th.1}}$ the cyclic switching of the field H on and off (after the first switching on) had practically no effect on the instantaneous magnetostriction and on the aftereffect (Fig. 2a). In the range $H = H_{\text{th.1}}$ the same cyclic switching on and off of the field resulted in stable cyclic magnetostrictive strains. However, in the case of the instantaneous magnetostriction and its aftereffect these strains were approximately the same (in absolute value) and opposite in sign for the switching of H on and off (Fig. 2b). The maximum instantaneous magneto-

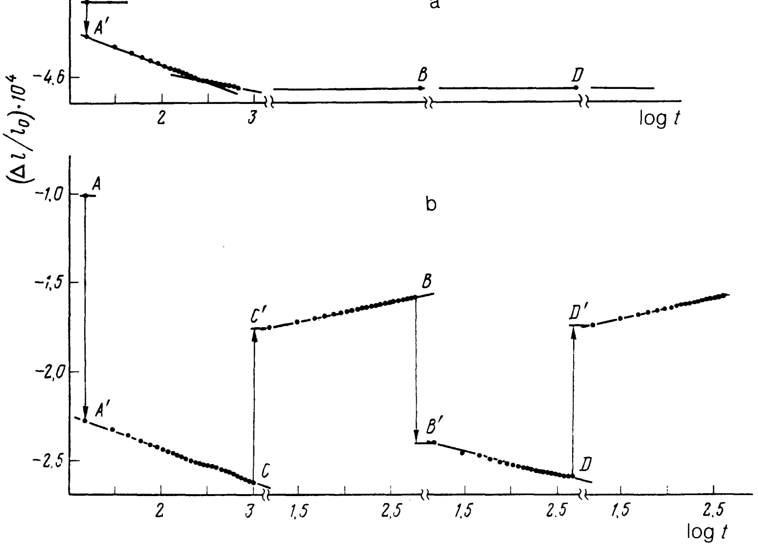

FIG. 2. Time dependences of $\Delta l/l_0$ (recorded along the c axis) in the course of cyclic switching the field on and off. The initial state corresponds to the rising branch of the temperature hysteresis of the thermal expansion: a) $H_{\text{th.1}} > H \approx 1$ kOe, $T = 109.4$ K; b) $H_{\text{th.1}} < H \approx 10$ kOe, $T = 104.4$ K.

striction was observed after the switching on of H. b) In the case of the falling branch of the temperature hysteresis loop of the thermal expansion in the range $H < H_{\text{th.1}}$ both the instantaneous magnetostriction and its aftereffect were absent when the field was switched on or off. In the range $H > H_{\text{th.1}}$, stable cyclic magnetostrictive strains existed right from the first time that H was switched on.

4. In the range of existence of the temperature hysteresis loop of the thermal expansion both the instantaneous magnetostriction and the resultant strains appearing in the course of the aftereffect were an order of magnitude greater than the magnetostriction measured outside the hysteresis loop.

5. There was also a second threshold field $H_{\text{th.2}}$. It was characterized by the fact that in sufficiently high fields H, close to $H_{\text{th.2}}$, the magnetostrictive strains could reach values of the order of the complete change on the temperature hysteresis loop of the thermal expansion (Fig. 1). At temperatures in the range $T_l(0) > T > T_h(H)$ (where T_l and T_h are, respectively, the low- and high-temperature limits of the temperature hysteresis loop of the thermal expansion in different fields) the strains observed in fields $H > H_{\text{th.2}}$ were not accompanied by the aftereffect.

6. The dependence of $\Delta l/l_0$ on t in the course of the aftereffect was usually linear obeying the log t law (Fig. 2). However, after the first switching of H there were sometimes cases of deviations from linearity, when the dependences $(\Delta l/l_0)(\log t)$ split into regions with different slopes (Fig. 2a) or exhibited discontinuities. These cases were attributed to anomalous aftereffect processes. They were observed when kinks and discontinuities appeared in the branches of the temperature hysteresis loop of the thermal expansion.

DISCUSSION OF RESULTS

We consider now the processes which can occur in magnetic materials when T_{pt} depends on H. A phase transition then occurs as a result of variation of H (when $T = \text{const}$) or T (when $H = \text{const}$) and for any one of the internal thermodynamic parameters A (magnetization, strain, etc.) we can introduce a "three-dimensional" hysteresis region in the space of H, T, and A. A section of this region by a plane $H = \text{const}$ gives the temperature hysteresis of the parameter T, whereas a section by a plane $T = \text{const}$ gives the magnetic hysteresis of A. These hysteresis regions are bounded by: 1) a rising surface along which the values of the parameter A change at $H = \text{const}$ and T rises monotonically from values less than $T_l(H)$; 2) a falling surface on which the values of A vary at $H = \text{const}$ and T decreases monotonically from values higher than $T_h(0)$.

The choice of the parameter A for the investigation of the aftereffect is generally arbitrary, because it is governed by the time dependence of the state of a magnetic material, which may be described not by one but by several thermodynamic parameters. However, in the case of ζ-Mn_5Ge_2 in view of the weak spontaneous magnetization ($I_s \approx 4$ G cm^3.g^{-1} at $T > T_{\text{pt}}$) and the relatively large change $\Delta l/l_0$ (up to 10^{-4}) it is more convenient to use the strain as the parameter A. Moreover, the errors in the determination of the strain ($\sim 10^{-7}$) are an order of magnitude smaller than in the case of the magnetization. A section of the region of hysteresis strain by a plane $H = \text{const}$ (including $H = 0$) represents a loop of the temperature hysteresis of the thermal expansion in a field H, whereas a section by a plane $T = \text{const}$ gives a magnetic hysteresis loop of the magnetostriction at a temperature T.

If we exclude the processes associated with changes in the dominant structure that can occur in low fields, we find that the strains (or changes in some other thermodynamic parameters) can be of two types. Strains of the first type $(\Delta l/l_0)_i$ appear when variation of H (or T) leaves a magnetic material in the same ith magnetically homogeneous state (single-phase strain). They are single-valued functions of H and T, which are determined for a given ith phase, and they appear instantaneously after a change in H.

If the value of T_{pt} decreases on increase in H, then a strain of the first type appears in its pure form outside the hysteresis loop, i.e., for $T > T_h(0)$ and $T < T_l(H)$. Strains of the second type appear when $T_l(H) < T < T_h(0)$. For example, in this region when $T = \text{const}$ and H is varied, we may observe a transition from a magnetic state characteristic of the ith phase to a state associated with the jth phase (in our case, this transition occurs from the low- to the high-temperature state), accompanied by magnetostrictive strains of the second type $(\Delta l/l_0)_{ij}$ representing interphase strains.

In the presence of hysteresis, when the phase transition occurs inhomogeneously starting from a nucleus, a change in H produces not only instantaneous interphase strains $(\Delta l/l_0)_{ij}(H,T,0)$ but also the magnetostriction aftereffect $(\Delta l/l_0)_{ij}(H,T,t)$. In this range of temperatures the resultant magnetostrictive strains are determined by single-phase and interphase strains, consisting of the instantaneous magnetostriction and its aftereffect.

Loops of the temperature hysteresis of the thermal expansion shown in Fig. 1 were recorded in a field $H = 0$ in the course of quasistatic ($\leqslant 5$ K/h) variation of temperature. We shall regard them as relatively stable. They manifest, in particular, stable surfaces bounding a three-dimensional hysteresis region. The experimental points fit these surface but only when the aftereffect processes are complete ($t \to \infty$). In addition to the relatively stable surfaces, there are also instantaneously unstable surfaces (observed in the limit $t \to 0$). In practice, these are the upper and lower limits of the experimentally attained values of the measurement time $t_{\max}$ and $t_{\min}$. The relatively stable and the instantaneously unstable situations are separated by unstable surfaces with time intervals $t_1, t_2, \ldots$. If an instantaneous change in the external agency induces an unstable state in the magnetic material and this state is described by a point on the surface at rest, it follows that it relaxes with time to relatively stable states (representing points on a relatively stable surface).

The processes resulting in magnetostrictive strains were analyzed and the experimental relationships were explained by plotting the temperature hysteresis loops of the thermal expansion, recorded in a given field H, on the $H = 0$ plane in the case when $H < H_{\text{th.1}}$, $H_{\text{th.1}} < H < H_{\text{th.2}}$, and $H > H_{\text{th.2}}$ (Fig. 3). The continuous curves are relatively stable and the dashed curves are the instantaneously unstable loops; the shaded loops correspond to $H = 0$.

It is clear from Fig. 3 that at temperatures T_1 and T_4 lying below $T_l(H)$ and higher than $T_h(0)$, i.e., outside the

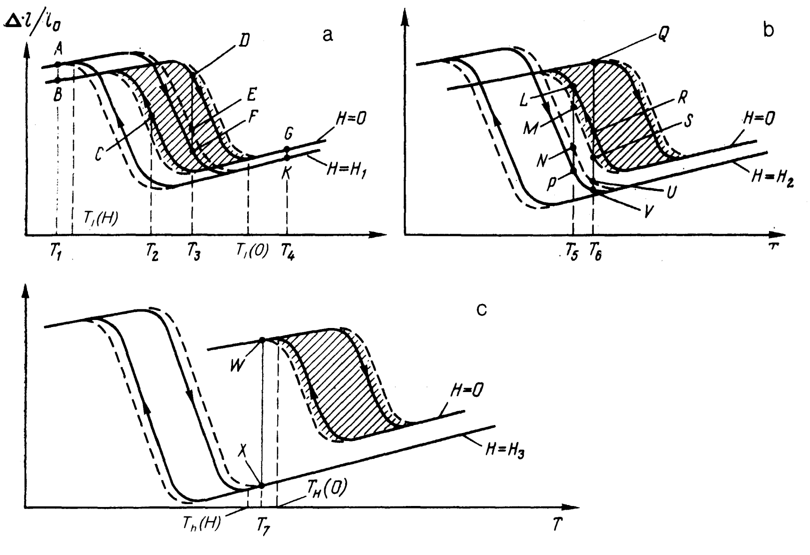

FIG. 3. Appearance of magnetostrictive strains. The continuous curves are relatively stable, the dashed curves are instantaneously unstable: a) $H < H_{\text{th.1}}$; b) $H_{\text{th.1}} < H < H_{\text{th.2}}$; c) $H > H_{\text{th.2}}$.

hysteresis region, the switching of the field on and off induces transitions between the states within one low-temperature (points A and B) or high-temperature (points G and K) phase. Switching on or off simply produces an instantaneous reversible single-phase magnetostriction, in agreement with the experimental relationships established in Sec. 2.

If $T_l(H) < T < T_h(0)$, we can see from the figures than an interphase magnetostriction accompanying the aftereffect can be observed. We shall first consider the case when $H = H_1 < H_{\text{th.1}}$ (Fig. 3a). If the initial state corresponds to the rising branch of the temperature hysteresis of the thermal expansion loop (point D), then switching on of the field H_1 gives rise to an instantaneous magnetostriction (transition from the point D to the point E on the rising branch of an instantaneously unstable temperature hysteresis loop of the thermal expansion in $H = H_1$) and then it the produces the aftereffect (transition from the point E to the point F on a relatively stable loop). The subsequent switching off of the field shows that the point F is inside a relatively stable hysteresis loop obtained for $H = 0$. In this case the state of the magnetic sample changes in such a way that the point describing this state moves along curves with a turning point and does not leave the stable hysteresis region. The absence of the aftereffect shows that the states on the curves with turning points are relatively stable and the absence of the instantaneous magnetostriction shows that motion along these curves as H is varied does not alter the concentrations of the magnetic phases. When the field is switched on again, the instantaneous magnetostriction and its aftereffect are again absent since the point F is on a relatively stable loop of the temperature hysteresis of the thermal expansion when the field is $H = H_1$. All this agrees with the experimental relationships established in Sec. 3a.

If the initial state is induced by lowering the temperature, the corresponding point C in the field $H = 0$ is located on the falling branch of a relatively stable temperature hysteresis loop of the thermal expansion, and if $H = H_1$, it lies within a relatively stable hysteresis loop. Consequently, the switching of the field on and off is not accompanied by the instantaneous magnetostriction and the aftereffect, in agreement with Sec. 3b.

The case $H_{\text{th.1}} H_2 < H_{\text{th.2}}$ is illustrated in Fig. 3b. If the initial point Q is on the rising branch of the temperature hysteresis of the thermal expansion loop, then the first switching of the field $H = H_2$ gives rise to the instantaneous magnetostriction (transition $Q \to U$) and the aftereffect (transition $U \to V$), exactly as in the case when $H = H_1 < H_{\text{th.1}}$. However, the subsequent switching of the field off and on induces cyclic transitions: $V \to S$ (instantaneous magnetostriction) and $S \to R$ (aftereffect) when the field H_2 is switched off; $R \to U$ (instanteous magnetostriction) and $U \to V$ (aftereffect) when H_2 is switched on, etc. All this is in agreement with Sec. 3a. If the initial state corresponds to the falling branch of the loop (point L), the cyclic processes begin already from the first switching on of the field: $L \to N$ (instantaneous magnetostriction) and $N \to \text{P}$ (aftereffect) when the field H_2 is switched on; $P \to M$ (instantaneous magnetostriction) and $M \to L$ (aftereffect) when the field H_2 is switched off, and so on, in agreement with Sec. 3b. A comparison of Secs. 3a and 3b shows that the first threshold field corresponds to a situation when the falling branch of a loop of the temperature hysteresis of the thermal expansion in $H = 0$ is in contact with the rising branch of the loop when $H \neq 0$. Moreover, the foregoing arguments confirm that the processes due to the first switching on of H (transitions between rising branches of the hysteresis loops) are distinct from the cyclic processes (transitions between the rising and falling branches), as mentioned in Sec. 3a.

The second threshold field mentioned in Sec. 5 is due to the fact that when the field $H_3 > H_{\text{th.2}}$ is switched on or off, transitions may take place from a magnetic state characteristic of one magnetic phase (for example, a low-temperature phase) to a state characteristic of a second (high-temperature) phase, accompanied by strains in the same phase or between phases. When this transition occurs across the whole hysteresis region (intersects this region), the magnetic aftereffect does not appear [transitions $W \to X$ and the reverse one in Fig. 3c when $T = T_7$, where $T_h(H) < T_7 < T_l(0)$]. It follows from Fig. 3c that the second threshold field corresponds to the situation when $T_l(0) = T_h(H_{\text{th.2}})$.

It is clear from the temperature dependences of the magnetostriction and the magnetization that T_{pt} of ζ-Mn_5

Ge_2 decreases nearly on increase in the field:

$$T_{pt}(H) = T_{pt}(0) - kH, \tag{1}$$

where $k = 0.55$ K/kOe (Ref. 9). We shall also assume approximately that in the investigated range of fields a change in H does not alter the shape and dimensions of the loops of the temperature hysteresis of the thermal expansion and these loops shift as a whole on increase in H toward lower temperatures in the same way as $T_{pt}(H)$. In this approximation we have

$$H_{th.1} = \Delta T_{hist}/k, \quad H_{th.2} = (T_h - T_l)/k, \tag{2}$$

where T_{hist} is the width of the loop of the temperature hysteresis of the thermal expansion $H = 0$. Substituting the experimental values $\Delta T_{hist} \approx 5$ K and $T_h - T_l \approx 7.5$ K (Fig. 1) into Eq. (2), we find that $H_{th.1} \approx 9$ kOe and $H_{th.2} \approx 14$ kOe (the values of $T_h - T_l$ and $H_{th.2}$ are given for measurements in the basal plane), in agreement with the experimentally determined values.

Knowing the characteristics of the temperature hysteresis loop of the thermal expansion for $H = 0$ (ΔT_{hist}, $T_h - T_l$, maximum change in $\Delta l/l_0$ in the loop), we can estimate the values of the instantaneous magnetostriction due to the interphase processes and to establish the possibility of the aftereffect, which is expected for specific initial states (obtained by heating or cooling from regions outside the loop), specific temperatures, and specific changes in the magnetic field.

It therefore follows from Eq. (2) that the magnetoelastic (instantaneous magnetostriction and aftereffect) and thermoelastic (temperature hysteresis of the thermal expansion) properties are related. It also follows from the fact that the initial state for magnetostrictive strains is determined by the method used to reach this state both in respect of H and T from regions outside the hysteresis loop. Moreover, the maximum values of such strains are governed by changes $\Delta l/l_0$ which occur as the hysteresis loop region is crossed along the temperature scale.

We shall now consider the aftereffect processes. The results of Ref. 5 and of the present study demonstrate that a first-order low-temperature magnetic phase transition in ζ-Mn_5Ge_2 is an inhomogeneous process involving growth of the regions of the new magnetic phase in the matrix of the old one. This is supported by, firstly, the rounded (and not rectangular) nature of the temperature hysteresis loops of the thermal expansion along the main crystallographic directions (Fig. 1). Secondly, it is supported by the existence of the magnetic aftereffect in the phase transition region, the characteristics of which assume that it is of fluctuation origin.

The relationships governing the fluctuation aftereffect in ferromagnets have been investigated quite thoroughly (see, for example, Refs. 10–12). In the case of this mechanism the walls of domains overcome existing potential barriers under the influence of thermal fluctuations. According to Néel,[10] an instantaneous change in H corresponds to a change in the magnetization I which is described quite well by a logarithmic law:

$$I = I_0 + \varkappa_{irrev} S(Q + \log t), \tag{3}$$

where I_0 is the instantaneous change in the magnetization, S is the magnetic viscosity constant dependent on the material, and $\varkappa_{irrev}$ is the irreversible differential susceptibility defined as the difference between the total and reversible differential susceptibilities.

If we write down the expression for I in the form of Eq. (3), we assume that: a) the aftereffect is governed by the magnetic state which a ferromagnet reaches after a change in H; this state is characterized by the value of $\varkappa_{irrev}$; b) the magnetization I is a smooth function of H; c) $\varkappa_{irrev}$ does not change in the course of the aftereffect (it is independent of t).

We shall assume that in this case the magnetostriction aftereffect similar to that given by Eq. (3) can be described by the relationship

$$\Delta l/l_0 = (\Delta l/l_0)_0 + (\partial(\Delta l/l_0)/\partial T)_{irrev} S'(Q' + \lg t), \tag{4}$$

which postulates—in agreement with the experimental results—that $\Delta l/l_0$ depends logarithmically on t.

However, the anomalous aftereffect (item 6 in the discussion of the experimental relationships) is not described by the above equation. In our opinion, the presence of discontinuities and kinks in the dependences $(\Delta l/l_0)(\log t)$ is related to the shape of the loops of the temperature hysteresis of the thermal expansion of the investigated samples (presence of kinks and discontinuities of the kind shown in Fig. 1, curve 2). Figure 4 shows sections of the relatively stable and unstable rising branches of the loops of the temperature hysteresis of the thermal expansion where there are discontinuities and kinks.

It follows, for example, in the case of a transition from an instantaneously unstable state H_1 to a relatively stable state A_2 the system must be at the point of the onset of a discontinuity of the curve $(\Delta l/l_0)(T)$ of some loop of intermediate stability (described by the time t_2). Consequently, the curve $(\Delta l/l_0)(\log t)$ has a discontinuity at the point $\log t_2$ (Fig. 4a). We can similarly explain kinks of the curve $(\Delta l/l_0)(\log t)$ in the presence of kinks of a temperature hysteresis loop of the thermal expansion (Fig. 4b).

We cannot therefore assume that the dependence of

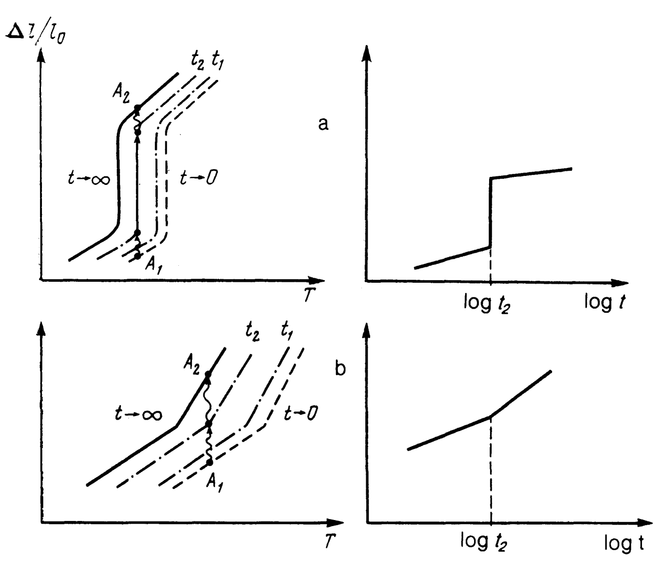

FIG 4. Schematic representation of the mechanism of the appearance of: a) discontinuities and b) kinks in the dependences $(\Delta l/l_0)(\log t)$.

$\Delta l/l_0$ on T is smooth and the value of $[\partial(\Delta l/l_0)\partial T]_{\text{irrev}}$ is constant in the course of the anomalous aftereffect. Consequently, a situation similar to cases b and c in Néel's theory does not apply to the anomalous aftereffect.

CONCLUSIONS

1. The low-temperature first-order magnetic phase transition in ζ-Mn_5Ge_2 is inhomogeneous and involves nucleation. It is accompanied by temperature and magnetic hysteresis (first-order transitions deduced by variation of T and H coexist). Magnetic materials of this type are characterized by a single hysteresis region expressed in terms of the coordinates H, T, and A (where A is in particular the strain). In this region there is a magnetostriction aftereffect of the fluctuation type involving changes in the volume of magnetic phases when $H, T = \text{const}$.

2. The existence of single hysteresis regions has the effect that the relationships describing the magnetostrictive strains and thermal expansion are mutually related. This is manifested, in particular, by the existence of two threshold fields $H_{\text{th.1}}$ and $H_{\text{th.2}}$ governing the qualitatively changes in the behavior of the magnetostriction.

3. In the case of ζ-Mn_5Ge_2 an anomalous fluctuation aftereffect is manifested by the presence of kinks and discontinuities in the linear dependences of the magnetostriction on the logarithm of time. It is associated with kinks and discontinuities of the branches of the loops of the temperature hysteresis of the thermal expansion. Therefore, the prelogarithmic factor describing the initial (before the aftereffect) state in Néel's theory cannot be regarded as a constant.

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