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Self-organization in magnetics

Application of the basic principles of the theory of self-organization to processes in magnetics is shown in article. It is also shown that if ferromagnetic are under the influence of a temperature or magnetic field, they can be considered as open, non-equilibrium thermodynamic system. Such system consists of atoms, molecules, domains with the magnetic moments, and also temperature and magnetic fields which interact among themselves and environment. In article change of the linear sizes of domains upon transition through Curie's point is considered. In article change of magnetization of magnetics and magnetostriction deformation from a synergetic position is analysed.

Key words: theory of self-organization, magnetic field, non-equilibrium thermodynamic system, domain, technical saturation.

Now many examples of physical systems in which of chaotic states spontaneously there are high-ordered spatial, temporary or existential structures are known — they self-organize. Such systems can function only at the expense of a supply of an energy stream to them (and substances).

The systems capable to exchange with surrounding bodies energy, substance, and that isn't less important, information, are called open [1–3].

Macroscopic open systems consist of many objects taken for elements of structure. These elements can be microscopic (atoms or molecules in physical and chemical systems), can be small, but nevertheless macroscopic (macromolecules in polymers, organic molecules in solutions, cages in biological structures), at last, they can be and not small bodies («elementary» objects in sociology).

Thanks to complexity of open systems in them formation of various structures is possible. Thus all dissipation at formation of structures plays a constructive role. Dissipation is necessary for formation of structures in open systems.

Complexity of open systems gives ample opportunities for existence in them the collective phenomena. To emphasize a role of collective, a cooperation role at formation of dissipative structures Herman Haken entered the term synergetic that means joint action [1].

Synergetrics new interdisciplinary scientific direction; the synergetrics purpose — identification of the general ideas, the general methods and the general regularities in the most different areas of natural sciences, and also sociology and even linguistics; moreover, within synergetrics there is a cooperation of various special disciplines.

Evolution is a process of change, development in the nature and society. This concept is very general. For example, in the physical closed systems evolution in time leads to an equilibrium state. As Boltzmann on the example of the discharged gas showed for the first time, to this state corresponds, the maximum degree of randomness.

In open systems it is possible to allocate two classes of evolutionary processes [4]:

– in the first case there is a temporary evolution to equilibrium (or nonequilibrium, but stationary) to a state;
– in the second — process of evolution goes through sequence of nonequilibrium stationary conditions of open system. Change of stationary states happens thanks to slow change of so-called managing directors of parameters.

Evolution can conduct or to degradation, or represent self-organization process during which there are more difficult and more perfect structures. Thus self-organization — only one of possible ways of evolution. For the answer to a question, on what way process will develop, it is necessary to carry out the comparative analysis of relative degree of orderliness (or randomnesses) various conditions of open system. As a result of such analysis it is possible to define, whether leads the evolutionary process happening in open system to self-organization or to degradation. For obtaining reasonable answers it is necessary to know quantitative criteria of relative degree of orderliness (or randomnesses) various conditions of open system. There are difficulties of introduction of a relative measure of orderliness (or, on the contrary, randomnesses) open systems

caused by lack of accurate definitions of the basic concepts: chaos, order, degradation, self-organization. Definition of these concepts is conditional. Transition to more chaotic state should be considered as degradation. Also consideration of aberrations of a randomness is essential.

Theoretical justification of the phenomenon of self-organization of nonequilibrium open systems as process of nonequilibrium streamlining is given by I.R.Prigozhin [2] and A.P.Rudenko [3] practically at the same time independently from each other.

The following synergetic concept of self-organization is known [5]:

– objects of research are the open systems in a nonequilibrium state characterized by an intensive exchange of substance and energy between subsystems and between system with its environment. The concrete system is shipped on Wednesday which is also a substratum;

– Wednesday — set of the components her (environment) of objects which are in dynamics. Interaction of the studied objects in the environment is characterized as close action — contact interaction. The environment of objects can be realized in the physical, biological and other environment of lower level characterized as gas-similar, uniform or continuous. (As a part of system distant action — the field and mediated or information exchange is realized);

– processes of the organization and self-organization differ. The general sign for them is increase of an order owing to course of the processes opposite to establishment of thermodynamic balance of independently interacting environment elements. (The organization, unlike self-organization, can be characterized, for example, by formation of uniform stable static structures);

– emergence, interaction, also mutually assistance (for example, cooperation) and, perhaps, regeneration of dynamic objects (subsystems) more difficult in information sense, than elements (objects) of the environment from which they arise becomes result of self-organization. The system and its components are significantly dynamic educations;

– the direction of processes of self-organization is defined by internal properties of objects (subsystems) in their individual and collective manifestation, and also influences from Wednesday in which the system «is shipped»;

– the behavior of elements (subsystems) and system in general is essentially characterized by spontaneity — acts of behavior aren't strictly determined;

– processes of self-organization happen in the environment along with other processes, in particular an opposite orientation, and can in separate phases of existence of system both to prevail over the last (progress), and to concede them (regress). Thus the system in general can have a steady tendency or undergo fluctuations to evolution or degradation and disintegration.

Self-organization can have process of transformation or disintegration of the structure which resulted before process of the organization in the basis.

The given definition [5] is a necessary step on the way of development of criteria for creation of the modeling self-organizing environment.

The ferromagnetic that is under actions of temperature or magnetic fields it is possible to consider as open systems: «a ferromagnetic + a temperature field», «a ferromagnetic + a magnetic field» and «a ferromagnetic + temperature and magnetic weeding». From the thermodynamic point of view these systems meet all requirements of the synergetic concept of self-organization:

– systems «a ferromagnetic + a temperature field», «a ferromagnetic + a magnetic field» and «a ferromagnetic + temperature and magnetic weeding». represent the nonequilibrium open systems interacting with the tank — the environment which is at various temperatures;

– the system consists of the atoms, molecules and domains with the magnetic moments interacting among themselves, temperature and magnetic fields and environment. And during interaction there is an exchange of energy, and chaotic transitions between discrete power levels of atoms, molecules of domains result;

– in the environment continuously there are opposite processes: molecules, atoms and domains are excited, occupying the top excited states, and relaksirut, passing into the main unexcited state;

– as a result of interaction between the objects forming system a ferromagnetic can experience phase transition, change a form and size of the linear sizes, to a t.a there can be self-organizing processes;

– the directions of processes of self-organization are defined by mutual ratios of individual properties of objects (subsystems) in their individual and collective manifestation, and also influences from Wednesday in which the system «is shipped».

Change of magnetization of ferromagnetic under the influence of a field [4, 6].

The main feature of ferromagnetic is existence of spontaneous magnetization and that their magnetic moment is caused by spontaneous orientation of spin of electrons. These properties of ferromagnetic can be explained if to assume that there is some interaction leading to an energy prize (leading to an energy minimum) at parallel orientation of spin. Energy of such interaction counting on one particle is equal a $1 \cdot 10^{-13}$ erg = 0,1 E.

The assumption of the nature of this interaction — magnetic interactions of the nuclear magnetic moments — doesn't approach for quantitative reasons. Interatomic magnetic fields have size about 10^4–10^5 E. For creation of necessary energy (0,1 E) of interaction it is required fields about E, i.e. is 2–3 orders more. Thus, the assumption of the magnetic nature of interaction can be considered unreasonable. Magnetic interactions can matter only for ferromagnetics with very low point of Curie ($\Theta_f \sim 1$ K).

In 1927 Frenkel and Heisenberg independently and at the same time stated the assumption that in certain cases the minimum of electrostatic energy will be satisfied and at a parallel arrangement of spin of electrons.

If the ferromagnetic crystal has a form of an infinite long core with which axis the direction of easy magnetization coincides, it has to represent one continuous domain, that is all vectors of spontaneous magnetization in it have to be located in parallel each other and core axes, because:

– energy of the degaussing field is equal to zero, the coefficient of demagnetization is equal to zero;
– energy of anisotropy is also minimum as the vector of magnetization is parallel to the direction of easy magnetization;
– also exchange energy as all backs are directed in parallel each other is minimum.

Any change of an the one-domain would cause increase at least in one type of energy and consequently, would bring a ferromagnetic into a nonequilibrium state.

In usual crystals of the final sizes the one-domain magnetic structure is energetically unprofitable (figure 1, *а*). Because of existence of the degaussing field $H_0 = NI$ they possess magnetic energy $W = NI_S^2/2$. Division of a similar crystal into some domains is energetically favorable so that the next domains were magnetized anti-in parallel as thus the degaussing factor decreases N (figure 1, *б*, *в*).

Than the crystal will break into bigger number of anti-parallel domains, its magnetic energy will be that less.

Magnetic energy decreases even more if anti-in parallel the magnetized domains perpendicularly become isolated the magnetized domain (Figure 1, *е*). Thus, between domains borders with anti-parallel backs, and the more such borders, the more size of their exchange energy are created.

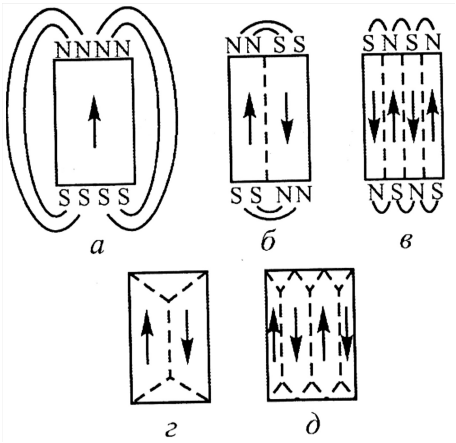


Figure 1. Simple domain structures [5, 6]

Division into domains usually energetically favorably when ferromagnetic have not really small sizes (more than 10^{-4}-10^{-5} centimeters).

The degaussed condition of a ferromagnetic at which the total magnetic moment of a body is equal to zero, turns out due to its splitting into domains in such a way that the sum of the magnetic moments is equal to zero, that is there is a self-organized process. Each of domains is magnetized before technical saturation I_s. Size I_s is defined by exchange forces and body temperature. At inclusion of a magnetic field weeding domains which direction of magnetization is closer to the direction, increase in volume due to reduction of vol-

ume of domains with less favorable arrangement of the magnetic moment, i.e. also there is a self-organized process. Then in big magnetic fields there is a turn of vectors of magnetization in domains; it is established parallel to a magnetic field; the condition of technical saturation is reached — again there is a self-organized process. At absolute zero temperature technical saturation coincides with the absolute ($I_s = I_0$) and no further increase in a field gives increase in magnetization.

At temperatures, excellent from 0 K, $I_s < I_0$ and because of influence of the thermal movement there is a quantity of the spin which aren't focused along a field.

The further increase in a field can lead to orientation of the spin which remained disorder, and growth of magnetization will proceed. This process is similar to process of magnetization of a paramagnetic at which influence of a field has to overcome influences of the thermal movement, it call Para process. Thus it is meant that Para process of technical magnetization doesn't happen changes of size of magnetization in domains, and only the direction of their magnetic moments changes.

Magnetostriction deformation [5, 6]

At magnetization the form and the sizes of a ferromagnetic changes, that is the magnetostriction is observed, there is a self-organization in the form of change of the sizes and a form.

The magnetostriction at ferromagnetics is observed only lower than temperature of Curie. Therefore, the magnetostriction has to arise because of actions of exchange and magnetic forces.

Let the one-domain ferromagnetic at Curie's a temperature have a sphere form (a circle 1 in figure 2) and its volume is so small that at fall of temperature below Curie's point only one domain is formed of it, the t is formed one area having spontaneous magnetization.

The reason causing spontaneous magnetization is exchange interaction.

Because of exchange interaction:

– there is a spin order of the electrons, atoms which are in lattice knots;

– the ferromagnetic crystal that leads to change of radius of the domain is deformed, that is there is a volume magnetostriction. To emergence of self-organised deformation of a ferromagnetic, thanks to exchange interaction it is possible to explain as follows.

During evolution the system aspires to a state with the minimum energy. In 1927 Frenkel and Heisenberg suggested that in certain cases the requirement of a minimum of exchange electrostatic energy of interaction will be met at a parallel arrangement of spin.

Exchange electrostatic energy of system

$$W_{\text{об}} = -2\sum_{ij} A_{ij}\left(\vec{\sigma}_i \vec{\sigma}_j\right); \tag{1}$$

$$W_{\text{об}} = -2\sum_{ij} A_{ij}\sigma^2 \cos\varphi_{ij} \tag{2}$$

accepts the negative, big in size, — the minimum value when exchange integral A_{ij} positive. If the exchange integral is positive, in system there can be a condition of spontaneous magnetization — ferromagnetics.

Size of exchange integral [5, 6]

$$A_{ij} = \int \varphi_i^*(q)\varphi_j^*(q)\varphi_i(q')\varphi_j(q')\left[V_{ij}\left(|q-q'|\right) + g_i(q') + g_j(q)\right]dqdq', \tag{3}$$

entering expression for exchange energy for this ferromagnetic depends on the relation, D/d, where D — distance between atoms; d — diameter d-atom covers. $V_{ij}\left(|q-q'|\right)$ — energy of interaction of electrons q end q' among themselves, $g_i(q)$ and $g_j(q')$ — energy of iteraction q and q' electrons with i-end j-ions, $\vec{\sigma}_i$ end $\vec{\sigma}_j$ — vectors of electronic spin of atoms i end j in terms of $\hbar$, $\varphi_i(q)$ end $\varphi_j(q)$ — wave function i — end j-atoms.

In order that the exchange integral was positive, performance of an inequality is necessary

$$\left|\int \varphi_i^*(q)\varphi_j^*(q)\varphi_i(q')\varphi_j(q')V_{ij}\left(|q-q'|\right)dqdq'\right| > \\ > \left|\int \varphi_i^*(q)\varphi_j^*(q)\varphi_i(q')\varphi_j(q')\left[g_i\left(q' + g_j(q)\right)\right]dqdq'\right|. \tag{4}$$

If wave functions φ_i end φ_j big near kernels, the right part (4) also big, as g_i и g_j near kernels are of great importance. Therefore, for this purpose the exchange integral was positive, wave functions near kernels have to have perhaps smaller size. Wave functions with large orbital numbers meet this condition. Atoms of

transitional metals meet these requirements. Wave functions $\varphi(q)$ quickly enough change with distance therefore size entering (4) integrals generally is defined by the size of sub integral expression in a maximum point $\varphi_\alpha^*(q)\varphi_\beta^*\varphi_\alpha(q')\varphi_\beta(q')$. In order that the exchange integral was positive, this maximum has to be rather far from kernels, that is atoms of ferromagnetic substance have to settle down far from kernels, that is atoms of ferromagnetic substance have to settle down enough far apart.

Let at a temperature of a ferromagnetic Curie's temperatures, that is in a paramagnetic state be higher, the distance between atoms will be equal D_1. If it I remained upon transition to a ferromagnetic state, exchange integral would remain invariable and it would be characterized by some point (for example, a point 1) on curve dependence of exchange integral on interatomic distance [6] (Fig. 2).

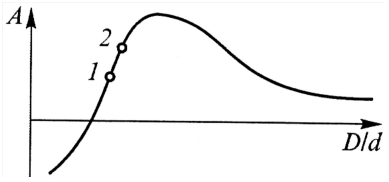


Figure 2. Dependence of exchange integral
from interatomic distance [6]

However as the system seeks for reduction of exchange energy, exchange integral, according to the equation (2) has to increase. The last leads to change of interatomic distance of D in that measure in what it doesn't increase excessively other types of energy. In the case under consideration at change of exchange integral from the value corresponding to a point 1 on the left part of curve dependence of exchange integral on interatomic distance (Fig. 2) to the value corresponding to a point 2 on the same curve, the interatomic fortune will be increased (a circle 2 in Fig. 3, *a*).

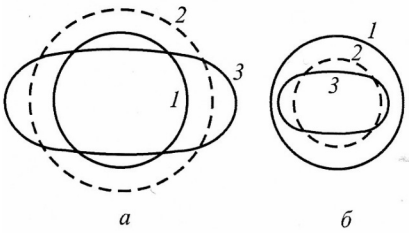


Figure 3. Scheme of a spontaneous magnetostriction: increase (and)
and reduction a sample upon transition through Curie's point [4, 6]

For a ferromagnetic which exchange integral is characterized by the point lying on the right part of curve dependence of exchange integral on interatomic distance (Fig. 2), cooling is lower than Curie's point to reduction of the sizes of a sample (Fig. 3, *b*).

Along with exchange forces of communication energy of magnetic anisotropy which causes unequal deformation of a lattice of a ferromagnetic in various directions is shown (an oval 3 in figure 3). However energy of magnetic anisotropy is about two orders less exchange, change of volume of a ferromagnetic upon transition by Curie's point generally is defined by exchange energy, and influence of energy of magnetic anisotropy is reduced to change of a shape of a body.

The considered deformation of domains is carried out in the absence of an external magnetic field. Thus, upon transition through Curie's point there is a magnetization of domains, and together with it a spontaneous magnetostriction.

We will consider change of the linear sizes of such domain [4, 6].

Any radius vector of a ferromagnetic ball (Curie's points are higher) we will designate through $\vec{\beta}$ (Fig. 4).

As a result of cooling of a ferromagnetic Curie's points and his transformations into the magnetic domain the end of radius vector are lower $\vec{\beta}$ it will be displaced on a vector $\vec{u}$. Vector $\vec{u}$ end $\vec{\beta}$ are connected by equality

$$u_i = \alpha_{ik}\beta_k,$$

who α_{ik} — tensor of the second rank which is function of the direction of magnetization of the domain:

$$a = f(I_s) \text{ or } a = f(\alpha_1, \alpha_2, \alpha_3). \quad (5)$$

Thus, if before emergence of a striktion any point of a sphere was defined by a vector $\vec{\beta}$, that after deformation it will be defined by a vector $\vec{\beta}' = \vec{\beta} + \vec{u}$. As ferromagnetic crystal anizotropen, vector $\vec{\beta}'$ generally doesn't coincide in the direction with a vector $\vec{\beta}$. Absolute lengthening

$$\Delta\beta = |\beta'| - |\beta|.$$

Size of relative lengthening

$$\lambda = \frac{\Delta\beta}{\beta}$$

is called as a spontaneous magnetostriction of a ferromagnetic crystal in this direction. If $\vec{\beta}$ — single vector, size of a spontaneous magnetostriction λ_t it is possible to write down as

$$\lambda_t = |\beta'| - |\beta| = \sqrt{(\beta_1 + u_1)^2 + (\beta_2 + u_2)^2 + (\beta_3 + u_3)^2} - \sqrt{\beta_1^2 + \beta_2^2 + \beta_3^2}, \quad (6)$$

who $\beta_1, \beta_2, \beta_3$ — components $\vec{\beta}$; u_1, u_2, u_3 — components $\vec{u}$. It is important that $\beta_1, \beta_2, \beta_3$ are values of the directing cosines.

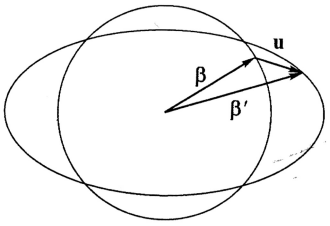


Figure 4. Vector scheme of the spontaneous magnetostriction [5, 6]

(6) it is possible to spread out the equation in a row Taylor. If to neglect the highest degrees u_i end β_i we will receive

$$\lambda_i = u_1\beta_1 + u_2\beta_2 + u_3\beta_3.$$

Components u it is possible to write down as

$$\begin{aligned} u_1 &= a_{11}\beta_1 + a_{12}\beta_2 + a_{13}\beta_3, \\ u_2 &= a_{21}\beta_1 + a_{22}\beta_2 + a_{23}\beta_3, \\ u_3 &= a_{31}\beta_1 + a_{32}\beta_2 + a_{33}\beta_3. \end{aligned} \quad (7)$$

Considering a crystal of cubic symmetry, considering the parity of effect resulting in equality $\alpha_{ij} = \alpha_{ji}$, and to substitute in the equation (6) values u_1, u_2, u_3 from (10.11) turn out

$$\lambda_t = a_{11}\beta_1^2 + a_{22}\beta_2^2 + a_{33}\beta_3^2 + 2a_{12}\beta_1\beta_2 + 2a_{23}\beta_2\beta_3 + 2a_{31}\beta_3\beta_1. \quad (8)$$

Coefficient α_{ii} end α_{ij} it is possible to write down as follows:

$$a_{ii} = a_0 + a_1\alpha_i^2, \; a_{ij} = a_2\alpha_i\alpha_j,$$

who a_1, a_2, a_3 — some constants. Then expression (8) will assume an air:

$$\lambda_1 = a_0 + a_1(\alpha_1^2\beta_1^2 + \alpha_2^2\beta_2^2 + \alpha_3^2\beta_3^2) + 2a_2(\alpha_1\alpha_2\beta_1\beta_2 + \alpha_2\alpha_3\beta_2\beta_3 + \alpha_3\alpha_1\beta_3\beta_1). \quad (9)$$

Expression (9) describes the size of a spontaneous magnetostriction in any direction of the domain when cooling it from temperature above Curie's point up to one temperature lower it. Components $\alpha_1, \alpha_2, \alpha_3$ — specify the direction of spontaneous magnetization, and components $\beta_1, \beta_2, \beta_3$ — the chosen direction in the domain. We will consider a spontaneous magnetostriction of a multidomain crystal [5, 6]. Let the crystal will be in the form of the sphere consisting of many domains with three directions of easy magnetization along axes [100], [010], [001].

When cooling after transition through a point of Curies various domains are spontaneously magnetized along various directions of easy magnetization, and the crystal changes the sizes, but doesn't change a form. It can be shown on the example of an iron crystal.

In a crystal of iron six groups of the domains (six magnetic phases) characterized by the following directing cosines are formed:

phase 1 и 2: $\alpha_1 = \pm 1, \alpha_2 = 0, \alpha_3 = 0$;

phase 3 и 4: $\alpha_1 = 0, \alpha_2 = \pm 1, \alpha_3 = 0$;

phase 5 и 6: $\alpha_1 = 0, \alpha_2 = 0, \alpha_3 = \pm 1$.

All directions equally probable and equivalent. The equation (9) assumes an air:

phase 1 end 2: $\lambda_1 = a_0 + a_1\beta_1^2$;

phase 3 end 4: $\lambda_2 = a_0 + a_1\beta_2^2$;

phase 5 end 6: $\lambda_3 = a_0 + a_1\beta_3^2$.

For the first phase for which the vector of spontaneous magnetization coincides with the direction [100], magnetostriction size for any direction can be calculated, having written down values of the directing cosine β corner between the interesting direction and axis [100]. Similarly business for other phases is. The average size of a spontaneous magnetostriction for all crystal with many domains can be calculated as average from a magnetostriction of all phases in this direction:

$$\bar{\lambda} = \frac{\lambda_1 + \lambda_2 + \lambda_3}{3} = a_0 + \frac{a_1}{3}\left(\beta_1^2 + \beta_2^2 + \beta_3^3\right),$$

as $\beta_1, \beta_2, \beta_3$ — the directing cosines chosen relatively [100], [010], [001] directions, $\beta_1^2 + \beta_2^2 + \beta_3^2 = 1$. Then

$$\bar{\lambda} = a_0 + \frac{1}{3}a_1. \qquad (10)$$

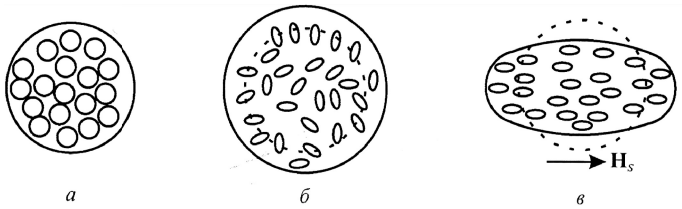
From (10) it is visible, the directing cosines didn't enter final expression of average size of a spontaneous magnetostriction, i.e. in a multidomain crystal the average size of a magnetostriction doesn't depend on the directions. The crystal keeps a sphere form with the changed diameter. In the same way when cooling a multidomain ferromagnetic crystal of any form from temperature Curie's points up to one temperature lower are higher than it the crystal form remains, but the sample sizes change. Thus magnetization of a crystal in the absence of the external magnetizing field is equal to zero.

The spontaneous magnetostriction is observed not only when cooling a ferromagnetic through Curie's current, it is observed and at change of the magnetizing field at a constant temperature.

The size of the magnetostriction arising at change of the magnetizing field at a constant temperature significantly depends on the direction of magnetization of rather crystallographic axes.

We will consider a case of magnetization of a ferromagnetic before saturation.

Cooling of a ferromagnetic from temperature is higher than Curie's point, let be realized according to the following scheme. In Figure 5, and the ferromagnetic having a form of a sphere and being at a temperature is represented Curie's temperatures are higher ($T > \Theta$). In it areas which after cooling lower than temperature of Curie will turn into domains are allocated. Magnetization of each area it is equal to zero ($I_S = 0$), and consequently, it is equal to zero and the general magnetic moment M ferromagnetic ($M = 0$).



а) $T > \Theta$, $I = 0$, $M = 0$; *б*) $T < \Theta$, $H = 0$, $M = 0$; *в*) $T < \Theta$, $H = H_S$, $I = I_S$, $M = M_S$;

Figure 5. The scheme of transition of a ferromagnetic through Curie's point [5, 6]

In Figure 5, the ferromagnetic is shown at a temperature below temperature of Curie ($T < \Theta$); the magnetizing field is absent ($H = 0$). At $T < \Theta$ under the influence of exchange interaction in the allocated areas of a back of atoms are built in parallel to each other and spontaneously there is a spontaneous magnetization,

magnetic domains are formed. Though thus spontaneous magnetization of each domain not equally to zero ($I_S \neq 0$), the general magnetic moment is equal to zero ($M = 0$), as the directions of magnetization of separate domains in volume of all crystal of a ravnoveroyatna along all directions of easy magnetization. According to a ratio (10) upon transition from a state *a* in a state the sample would keep a sphere form with the changed diameter.

In figure 5, *в* the ferromagnetic which is at the same temperature as in a case is shown *б* (T < Θ). However now the external magnetic field is attached to it $H = H_S$, magnetizing a sample before saturation. From (9) follows that now all sample will change the form. Really, the equation (9) sets relative change of the sizes of a ferromagnetic with uniform magnetization on all volume. It describes change of the sizes both one domain without external field, and a multidomain crystal upon transition through Curie's point in an external field, namagnivayushchy to saturation. Thus, according to the provided scheme the equation (9) describes transition of a crystal from a state *a* in a state *б* in Figure 5.

Magnetostriction size at magnetic saturation it is possible, subtracting from (9) equation (10):

$$\lambda_S = \lambda_t - \overline{\lambda} \text{ or } \lambda_S = a_1\left(\alpha_1^2\beta_1^2 + \alpha_2^2\beta_2^2 + \alpha_3^2\beta_3^2 - \frac{1}{3}\right) + 2a_2\left(\alpha_1\alpha_2\beta_1\beta_2 + \alpha_2\alpha_3\beta_2\beta_3 + \alpha_3\alpha_1\beta_3\beta_1\right). \quad (11)$$

In the equation (11) in which the direction of magnetization is set by the directing cosines $\alpha_1, \alpha_2, \alpha_3$, magnetostriction size λ_S in some direction is defined by the directing cosines $\beta_1, \beta_2, \beta_3$.

In case of a magnetostriction along the directions [100] and [111] constants a_1 end a_2 it will be expressed in more convenient look. Change of the sizes of a ferromagnetic in the direction of the enclosed field is called a longitudinal magnetostriction. We will consider the size of a longitudinal magnetostriction for the directions [100] and [111]. In this case the directing cosines of magnetization and a magnetostriction are equal among themselves: $\alpha_i = \beta_i$.

According to the equation (11) magnetostriction λ_{100} for the direction [100] it is equal

$$\lambda_{100} = \frac{2}{3}a_1,$$

As $\alpha_1 = \beta_1 = 1$, $\alpha_2 = \alpha_3 = \beta_2 = \beta_3 = 0$.

For the direction [111]

$$\lambda_{111} = \frac{2}{3}a_2,$$

as $\alpha_1 = \alpha_2 = \alpha_3 = \beta_1 = \beta_2 = \beta_3 = 1/\sqrt{3}$.

Thus, $a_1 = (3/2)\lambda_{100}$ и $a_2 = (3/2)\lambda_{111}$. Expression (11) can be copied as follows:

$$\lambda = \frac{3}{2}\lambda_{100}\left(\alpha_1^2\beta_1^2 + \alpha_2^2\beta_2^2 + \alpha_3^2\beta_3^2 - \frac{1}{3}\right) + 3\lambda_{111}\left(\alpha_1\alpha_2\beta_1\beta_2 + \alpha_2\alpha_3\beta_2\beta_3 + \alpha_3\alpha_1\beta_3\beta_1\right). \quad (12)$$

For longitudinal effect in any direction, considering that

$$\alpha_i = \beta_i \text{ end } \alpha_1^2 + \alpha_2^2 + \alpha_3^2 = 1$$

have

$$\lambda = \lambda_{100} + 3\left(\lambda_{111} - \lambda_{100}\right)\left(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2\right). \quad (13)$$

As the magnetostriction doesn't go beyond elastic deformations, assuming that the module the Ship's boy *E* isotropic, energy of magnetoelastic deformation of unit of volume can be written down in a look

$$W_{\text{м.упр.}} = E\lambda^2/2,$$

or, considering the equation (13), in a look

$$\mathrm{W}_{\text{м.упр.}} = \frac{E}{2}\left[\lambda_{100} + 3\left(\lambda_{111} - \lambda_{100}\right)\left(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2\right)\right].$$

Having added energy of crystallographic magnetic energy to expression

$$W_{\text{k}} = K_0 + K_1\left(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2 + \alpha_3^2\alpha_1^2\right) + K_2\alpha_1^2\alpha_2^2\alpha_3^2$$

we will receive expression for the general energy of magnetic anisotropy

$$W_{\text{a}} = K_0 + K_1\left(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2 + \alpha_3^2\alpha_1^2\right) + K_2\alpha_1^2\alpha_2^2\alpha_3^2 + K_3\left(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2\right)^2. \quad (14)$$

Conclusions

If domains which are magnetized anti-in parallel, spontaneously become isolated perpendicular to the magnetized domain, decrease in magnetic energy of all system is observed.

In magnetics which are placed in an external magnetic field, self-organization processes gain development:

- spontaneously volume at domains which direction of magnetizations closely to the direction weeding due to similar reduction of volume of domains with less favorable arrangement of the magnetic moments increases;
- in big magnetic fields there is a spontaneous turn of vectors of magnetization in domains before achievement of a condition of technical saturation of a ferromagnetic;
- after achievement spontaneous orientation of the spin moments of the electrons which remained disorder because of the thermal movement along a magnetic field happens a ferromagnetic of a condition of technical saturation at further increase in an external magnetic field.

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Магнетиктердегі өз бетімен жүретін ұйымдастыру құбылыстары

Мақалада магнетиктерде жүретін физикалық үдерістерді талдау үшін синергетиканың өзін-өзі ұйымдастыру ұстанымы пайдаланылған. Ферромагнетик температура және магнит өрістерінен тұратын жүйені ашық, орныксыз термодинамикалық жүйе деп қарастырған. Жүйе өзара және ортамен әсерлесетін атомдардан, молекулалардан, магнит домендарынан, температура және магнит өрістерінен тұрады. Кюри температурасы маңында болғанда домендердің сызықтық өлшемдері өзгереді. Магнетиктердің магниттелгіштігінің өзгеруі және магнит өрісі әсерінен магнетиктердің деформациялану құбылысы синергетика ілімі тұрғысынан талданған.

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Самоорганизация в магнетиках

В статье применены основные принципы теории самоорганизации к процессам в магнетиках. Показано, что ферромагнетики, находящиеся под действием температурного или магнитного полей, можно рассматривать как открытую, неравновесную термодинамическую систему. Система состоит из атомов, молекул и доменов с магнитными моментами, температурных и магнитных полей, взаимодействующих между собой и окружающей средой. Рассмотрено изменение линейных размеров доменов при переходе через точку Кюри. Проанализированы изменение намагниченности магнетиков магнитострикционная деформация с точки зрения синергетики.

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