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# Relationship between galvanomagnetic phenomena and bulk elasticity in magnet-containing structures of semiconductors, dielectrics and metals

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In 60-70ies of the last century, an opinion was formed that the principal electro-magnetic phenomena in metals, semiconductors and dielectrics had been well studied and understood on the base of model theoretical representations. Later on, the studies were devoted mainly to detailing. However, the revealed experimentally colossal magnetoresistance (CM) and properties of high-temperature superconductivity (HTSC) brought the attention of scientists to the

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question of important corrections to the image of galvanomagnetic phenomena. No attention was given to the investigation of critical phenomena in magnet-containing systems from viewpoint of formation of structural phase transitions [1] and the laws of bulk elasticity in metals, semiconductors and dielectrics. And we have to analyze dissimilar experimental results (changes in symmetry, volume, structure instability, displacement of the lattice sites, jumps in properties, etc.) within the framework of structural phase transition when the dynamic rearrangement is due inner anisotropic elastic stresses. The principal aim of this study is the ascertaining of the relation between the bulk elasticity and magnetism through the physics of galvanomagnetic phenomena.

The correlation of changes of electrical conductivity and magnetism in transitional and rare-earth elements was studied in details first by Dutch scientists Jonkerom and van Santem [2]. In the course of extended studies, magnetic semiconductors were of high interest. This area of investigations touched upon single crystals and polycrystals of multi-component structures where the physical influence of magnetic field resulted in the absence of magnetic compensation. We accept the state of magnetic non-compensation as a property of the structure formed by sites bound by valent and free electrons. By definition, the sites are associated with atoms and molecules with non-compensated magnetic spins (small magnets). Magnetic factor reaches its maximum at $T=0^0K$ and vanishes at high structure-forming temperatures.

The studied phenomena have become ever more important after the colossal magnetoresistance was discovered in some structures in the region of phase transition (PT) [3,4] when the jump of electrical conductivity by several orders of the magnitude was noted. During the last 10-15 years, a lot of publication appeared in this field, but the problem has not been fundamentally solved yet on the base of existing models. We should note that these studies were directed at the estimation of the interrelation between structural changes caused by different substitutions and influences of T, P and H parameters and affecting magnetic and transport properties. From the other hand, these models did not take into account the mechanisms of bulk elasticity. That is the regularity that is revealed in linear and non-linear dependences of magnetostriction properties in monocrystal $LaMnO_3$ [5] at varied T and H (see Fig.1). The causing role is also played by elastically deforming stresses and elastic anisotropy at formation of the jump of the properties and hysteresis at the structural phase transition of the second type [6] where the temperature of the phase transition decreases with the rise of the magnetic field whereas magnetostriction dependences have the characteristic jump of properties near the phase transition observed on monocrystal $LaMnO_3$ [5] with selected direction in a wide range of magnetic fields at fixed temperatures. This result allowed us to establish the role of sign alteration of the effect of elastic stresses with H and T change for the evolution of striction properties. The shift of the

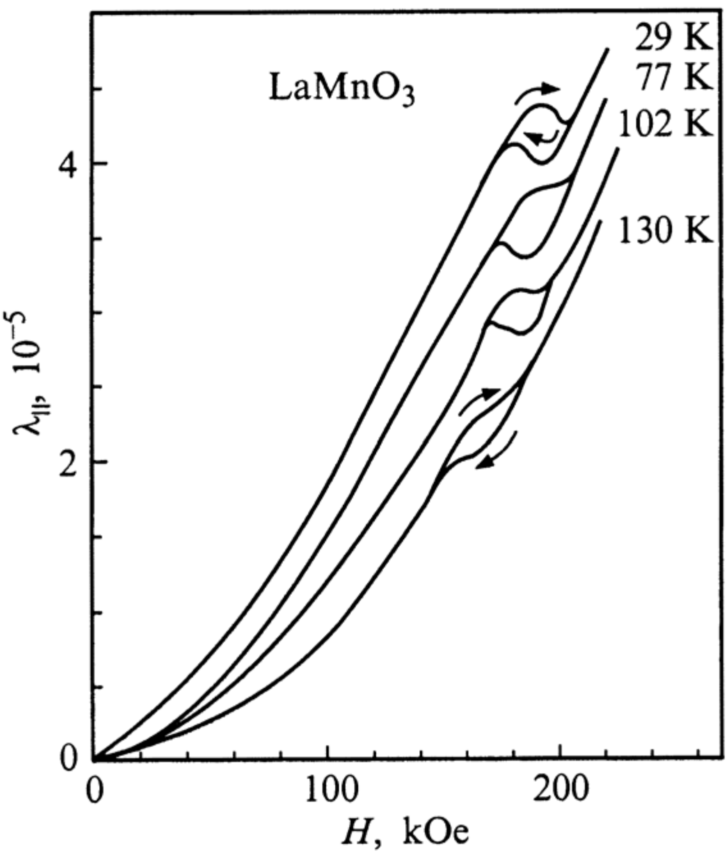


**Figure 1.1.** Field dependences of longitudinal magnetostriction of $LaMnO_3$.

priorities in the form of linear regularity of magnetic stresses at the initial parts of the selected dependences takes place due to the contribution of thermal elastic deforming stresses.

In the variety of papers and methods, we can note studies where high hydrostatic pressures were taken as a parameter. Under the uniform compression, the following physical process is modeled in the structure: the interatomic distances are changed under action of external mechanical stresses. But the pressure effect makes sense in these studies if pressure values correspond to coefficient of bulk compressibility which is low in the studied samples (about $10^{-5}$-$10^{-7}$), by definition. As a result, it is very difficult to study physical processes at low temperatures under pressure of about 3GPa. At the same time, the results show that the application of such pressures help in the understanding of relationship between the energy of elasticity and magnetic, electronic and structural changes in the course of investigations of galvanomagnetic phenomena.

Numerous reviews and papers on investigations of combined compositions based on manganese perovskites drew our attention to interlacing small changes of parameters in compounds of one type and it became possible to distinguish the properties of metals, dielectrics, ionic and covalent crystals and changeable character of phase transition. In this variety of investigations, there was an important regularity in changes of PT accompanied by considerable jump of the properties. This fact was a subject of thorough studies, individual model researches and search for analogies. It also determined the direction of model theoretical presentations. The problem of jump of properties remains the principal one. Thus, in papers by Landau [6], there is a detailed study of jumps of superconductivity properties in the neighborhood of phase transitions for the magnetic field strengths over than zero (Fig. 2). The model theoretical presentations based on quantum mechanics and the numerous applied methods have demonstrated this problem to be the casual basis of a property, magnetic-field orientation, sample shape and affecting the state of the phenomena. In the course of the experiment, they are accompanied by both the jump in properties and the important ascertained fact of the process, volume change and changes in symmetry of the structure. It should be noted that the multiple model presentations using the theories of exchange and anisotropy, the molecular field theory do not used the concept of elastic stresses to explain the physical processes [11]. Model presentations do not take into account the regularities of elasticity displayed by thermodynamic parameter affecting the structure, first of all. The causing role of mechanisms of elastic anisotropically deforming stresses has not been established at formation of the structural phase transitions.

Together with marking out the regularities of linearity in magnetostriction, magnetization, magnetoelasticity and magnetoresistivity, the role of elastic properties is noted, too. A direct method of such investigations needs the analogy to be drawn, i.e. combined influence of field H and pressure P. It is difficult in magnet-containing systems because of the high coefficient of compressibility in solids. It varies between $10^{-2}$-$10^{-8}$. This fact is the casual basis for both the magnetism and structural phase transition.

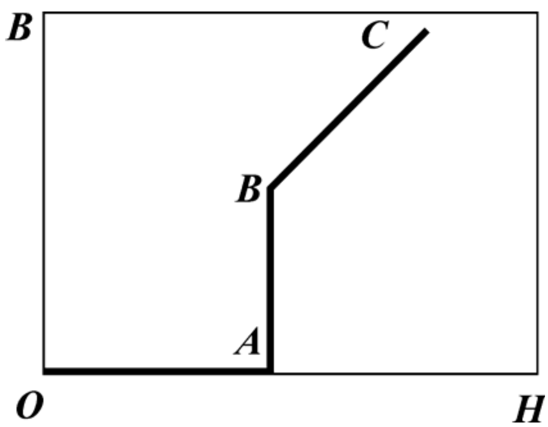


**Figure 1.2.** Dependence of induction from tension of the magnetic field in the first-order superconductor [8].

Considering the existing contradictions in the understanding of the nature of striction in superconductors and magnets, we see that the statement of the problem of structural phase transition eliminates uncertainty in the mechanisms of formation of jump of properties in the whole range of solids. By such analysis, we can explain discontinuity of properties of magnetization, heat capacity, resistivity, high frequency properties and show the regularities of elasticity for Hall and Lifshits effects. We can also explain peculiarities of the physical process of Meissner effect with specific changes of symmetry and volume affecting the intensity of magnetic factor (magnetic non-compensation) of the superconducting phase during semiconductor – metal transition with common regularities of magnetostriction. The results of studies of classical magneto-dielectrics are the most demonstrable with respect to the processes of establishment of relation of resonance properties and magnetization near structural phase transitions. The outskirts of a phase transition are characterized by the reaction of frequency spectrum with approaching the point of the structural phase transition under varied external thermodynamic parameter as T, P or H.

Intensive experimental studies of $CuCl_2{\cdot}2H_2O$ have shown first-order phase transition to be the structural one with the characteristic jump of properties near $0^0$K and the succeeding regularity of growth of T at rising H.

As far back as in the first experimental work by Paulus [7], a regularity was revealed with respect to the jump of magnetization properties at temperature between 1.5-40 K (Fig.3) and that of linearity before and after the jump of PT properties. Multiple experimental results obtained with using high-frequency methods, hydrostatic pressure, by change of the sample shape, elastic and magnetoelastic properties enabled the authors to present regularities of the structural phase transition and to split the system to superconducting and metallic phases [8]. As a consequence, it can be stated, that numerous studies of the sublattice “flip-flop” is purposeful study of regularities of the structural phase transition with changes of properties in the region of PT under the influence of magnetic field through mechanisms of magnetic elastically deforming stresses.

Persistent interest in peculiarities of galvano-magnetic phenomena in metals in high magnetic fields at low temperatures has attracted the attention of researchers. Plentiful results can be found in first papers by Kapitsa [9] who has distinguished the linear law of resistance increase in some metals andnoted how changes in field direction with respect to orientation of the structure influence the properties. Those were the works where the author suggested the idea explaining the linear growth of the resistance under H effect. The influence of the magnetic field results in structural failure affecting the conductivity in the systems of impurities or lattice defects. The field H impacts

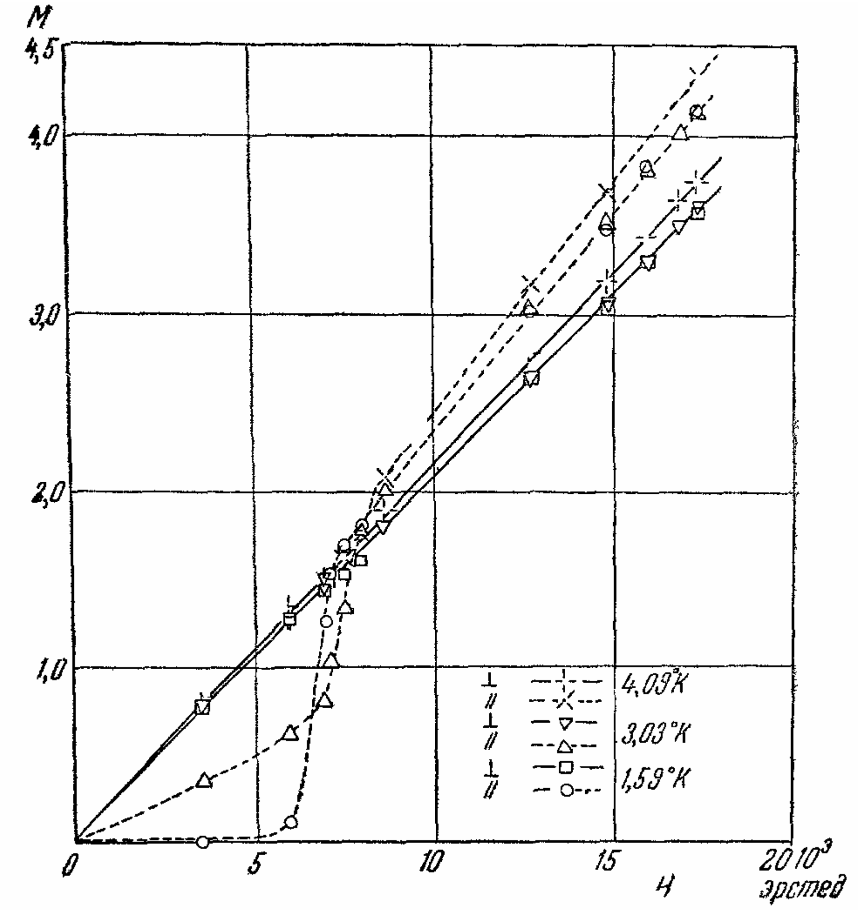


**Figure 1.3.** Magnetization along the a and b-axes as a function of field [6].

the motion of electrons and is a disrupting factor of the structure of location of atoms, sites and the lattice in whole that determines the electron mobility, in turn.

In succeeding papers of Lazarev [10], it was found that practically in the whole of investigated metals, the quadratic growth of the resistance with the magnetic field was followed by the linear dependence in high magnetic fields. The dynamics of current carriers because of the magnetic field strength and depending on orientation appears as the anisotropy of properties.

These regularities are grounded by theoretic diversity and universal topology of Fermi surface which are the basis of model presentations for the case of galvanomagnetic phenomena in pure metals. Unfortunately, there are no theoretical developments where the role of the energy of elastic deformation and regularities of the anisotropy of elasticity were taken into account for analysis of structural changes, phase transitions, magnetism and conductivity.

New approaches to investigation of dynamics of critical phenomena generalized the structural phase transitions to be universal on a microscopic level, which takes into consideration the defining contribution of the elastic deformation and anisotropy of elasticity to the jump of the properties. Consideration of these specific mechanisms, more exactly of the energies, is not simple because of the lack of consecutively developed basis where the accounted laws of bulk elasticity would not contradict to the existing phenomenological theories.

In this analysis and generalizations, the attention is drawn to the fact that in methodology of the classical mechanisms, the common dynamic regularities coincide with those of simple processes. This is understood as mechanical determinism. But in the quantum mechanics, there is a dynamic which does not coincide with that of single processes by virtue of specific understanding of a “state” and nor grounds the mechanical determinism. As a consequence, the dynamic interpretation of quantum mechanical presentations with a definite degree of restrictions could not explain a real physical process satisfying the principles of the classical mechanical determinism. Is it not a neglection in the understanding of real physical processes and in the grounding of their model theoretical presentations?