

Chapter 8

The role of bulk elasticity in the mechanisms of the realization of the structural PT

Introduction

At present, the number of papers dealing with the study of magnet-containing multi-component manganite systems increases due to high experimental potentialities. Some uncertainty presents in the form of anomalies, peculiarities, numerous effects with contradictory interpretation of mechanisms of the colossal magnetoresistance (CMR) realization. While studying magnetic–phase states, an attempt was made to relate the formation of the CMR state to the changes of the bulk magnetostriction in single crystals of different manganites, as noted in reviews [171, 172] and papers [173-175]. But it is not clear what phases and mechanisms are responsible for the changes. A number of anomalies, effects, features have been revealed for manganites modified by different chemical additives of varied percentage, e.g. giant negative magnetostriction, identity of modification of electronic properties influenced by both the temperature and the magnetic field H . Unfortunately, the role of phase transition (PT) has not been understood and grounded completely in the course of analysis and substantiation of the majority of anomalies and effects in properties where the main attention was paid to the determination of strong bonds between unfilled electron shells and to their reaction to the influence of thermodynamic parameters with magnetic properties taken into account. Moreover, an interpretation of the Curie temperature was indistinct to some extent. The interest to the correspondence between hydrates and manganates with respect to similarities and divergences of lattice and magnetic effects was shown in review [172]. The conception of two co-existing phases was used as the approach to the analysis of colossal magnetostriction phenomenon. The elastic energy was separated from the Hamiltonian and omitted, being replaced by the term of phonon degrees of freedom.

The results of investigations of peculiarities are demonstrative for magnetic and electric properties [175]. Here the colossal magnetoresistance in $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0.45$) was explained by high negative bulk magnetostriction, and changes in parameter (x) are considered as a correlation of magnetoresistance, magnetostriction, magnetization resulting in anomalies and singularities. Paper [176] is of a special interest, where peculiarities of semiconducting regions with varying conduction current in $\text{Eu}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ were analyzed and an original explanation of a giant maximum on the

isotherms within the low-temperature range was suggested. Besides, the differences were shown between magnetization at varied temperature of the sample with the field and without it, which are typical for the studied system from the viewpoint of the authors.

The role of the oxygen-isotopic substitution in the $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ system was studied in [177], where peculiarities of the metal – dielectric transition and regularities of changes of the low-temperature phase of a unclear nature were substantiated.

In [9, 6, 181, 182], new approaches and explanation have been used to study T-P-H influence on properties and PT in single-crystal samples of low-temperature magnetodielectric $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, magnetic semiconductor LaMnO_3 and its analogues.

An impact of bulk elasticity mechanisms on the structure has been shown to be identical. In the mentioned papers, the specified variety of critical lines and points underlined the causal basis of the mechanisms of elastic stresses and their role in processes of a sign inversion, change of parameter priorities, and a sign inversion of thermodynamic parameter effect on the properties in different phase states. The direct correlation was supposed to exist between changes of the structure, magnetic and electronic properties; the dominating role of mechanisms of bulk elastic stresses was grounded. Numerical values of P-T-H impact were suggested, a correspondence was established between the linear change of properties and critical lines for $\text{La}_{0.56}\text{Ca}_{0.24}\text{Mn}_{12}\text{O}_3$ (1kbar- 6.1 K – 2.3 kOe), $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (3 kbar – 1 K – 4kOe), LaMnO_3 (5.2 K – 2.5 kOe). The role of thermoelasticity, magnetoelasticity, baroelasticity was shown separately.

It should be noted that just results [6] generated new approaches to the grounding of the specified critical points. In [181], it was shown that the binding energies of electrons located from the center to a periphery of an atom or a molecule differed by two and more orders of magnitude as followed from the analysis of P-T-H impact and general conclusions. This tendency of the binding energy was less noticeable for peripheral electrons participating in the formation of a lattice structure of a multi-component system. It relatively agreed the energy of elastic stresses, a decisive factor of any thermodynamic influence. The results allowed us to conclude that any construction of model theoretical presentations remained incomplete without an account of the causal role of volume changes of the structure forming the PT and properties under the T-P-H influence.

In order to emphasize the role of bulk elasticity laws of for properties and PT, we should draw attention first to the following example given as early as 1931. P.A. Kapitsa [178] and noted a high interest in the results of studies of resistance changes in different metals under high magnetic fields. In some cases, the resistance value was shifted by 20-30%. In the field, the resistance changed linearly. It was found in another study of magnetostriction in high

fields for bismuth that the parameter (tension) changed along a trigonal axis while the compression was normal to it.

Unfortunately, methods of investigations under the hydrostatic pressure were far from being perfect at that time. Our result shows only a combined T-P-H effect through mechanisms of ED stresses. It provides an objective consideration of physical processes; otherwise, new approaches cannot be elaborated. Far in the past, the lack of experiment could not give an impulse to the development of model-theoretical representations to substantiate real physical processes.

The object of the present paper is an analysis, drawing analogies and generalization of regularities of an evolution of structural phase transitions and properties in multi-component structures of magnet-containing systems of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, $\text{Eu}_{0.55}\text{Sr}_{0.45}\text{MnO}_3$, $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$. It is also aimed at the presentation of unambiguous T-P-H impact through mechanisms of EAD stresses and settling the question of the presence of anomalies and regularities in view of the laws of the bulk elasticity. We will also specify the peculiarity of a structural phase transition at $T=0$ K and an opportunity to treat this critical point as a triple one.

As the considered problem is ambiguous, I should like to cite academician P.L. Kapitsa: "Science develops as follows - the ascertained facts remain unshakable, while theory is constantly changing, developing and is under revision. The most powerful spur to the development of a theory is from a new experimental fact which contradicts a settled view...". So, the main motive power in the development of physics is the search for and the revealing of contradictions.

8.1. The regularities of the elastic properties in the processes of formation of direct and inverse hysteresis effects

Numerous studies of copper chloride dehydrate $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ [6, 64, 181] were taken as a basis for drawing analogies and correspondences in mechanisms and regularities of changes of structural phase transitions and properties of the mentioned multi-component magnet-containing systems. The interrelation of elastic mechanisms was established for the joint thermodynamic influence of P-T-H on multi-component magnet-containing structures.

Let us pay attention to [64, 65] where X-ray diffraction studies were done under hydrostatic pressure. Basing on experimental results, the authors have directly evaluated numerical parameters of bulk elasticity and estimated both the changes of elastic properties along the considered directions and the anisotropy of compressibility in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ orthorhombic single crystal at room temperature. Considerable changes in position of the resonance

absorption lines were revealed by resonance methods due to an important factor of the shape and relationship of parameters in the sample [187]. The role of elasticity anisotropies in the bulk was stated to be the decisive one for the formation of the position of PT and for changes of magnetic and electronic properties, as believed. This was the reason of considerable differences in the results for bulk samples as compared to films of the same composition.

In [6], the method of analogies and comparison was used to set up a correspondence between changes in magnetostrictive properties in LaMnO_3 and magnetization in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$. The causal role of thermoelasticity and magnetoelasticity in mechanisms of the effect on regular linear changes of properties has been specified (Fig. 8.1a, 8.2a). Note that there was a very important regularity of the identical effect of T and H on both the magnetostriction dependence (Fig. 8.1a) prior to phase transition and on magnetization properties (Fig. 8.2a) after the phase transition. It can be assumed that the considered areas have identical mechanisms of the effect and belong to the conducting (metallic) phase in the region where changes of the properties under H and T impact are antipodal. One more very important result has been established for magnetization properties at the initial part of the dependence (Fig. 8.2a). The stable tendency of evolution of the properties under unambiguous T and H influence was separated and the sign reversion of the position of the critical line of the field – temperature dependence with critical point $P(T_p, H_p)$ was found. An essential jump of the properties was observed at this line, and the position of the structural phase transition area was determined by T_{st} equal to 0 K, according to the approximation method. These regularities were believed illustrating that changes revealed in this region affiliated it to the superconducting phase. Such statement implies new approaches to the substantiation of regularities for phase diagrams [6, 181], low-frequency properties at 0°K and at specified temperatures in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$. These important results emerged from new methods of an analysis where elastic linearity appeared to be defining for changes of properties. The corresponding plots do not contradict the logics of reversible physical processes under study in principle, making it possible to distinguish the structural phase transition in LaMnO_3 T_x (H_x , $T=0$ K) and in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ T_x ($H_x=5.5$ kOe, $T=0$ K).

Since it is a problem to obtain experimental results just at 0 K, it is very important to find general signs of evolution of properties accompanying PT that are formed under T-P-H impact (so-called secondary indications). The presence of these signs in another systems and samples will help in defining the generalizing role of the mechanisms of EAD stresses in structural transformations. So we could distinguish these regularities with full confidence in a large number of papers where the authors considered them as effects, anomalies and peculiarities.

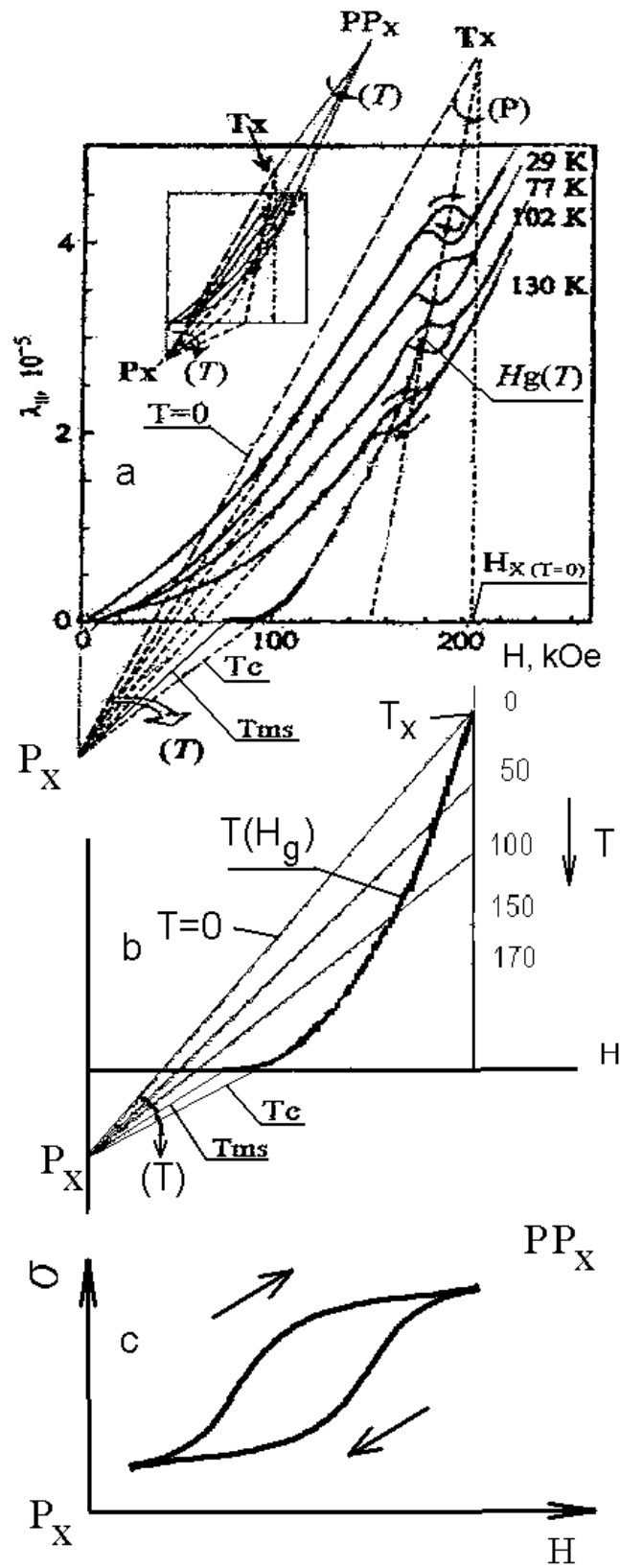


Figure 8.1. a) Field dependences of the longitudinal magnetostriction for LaMnO_3 ; b) Field-temperature dependence $T_p(H_g)$ of PT. c) Dependence of magnetization change in hysteresis effect.

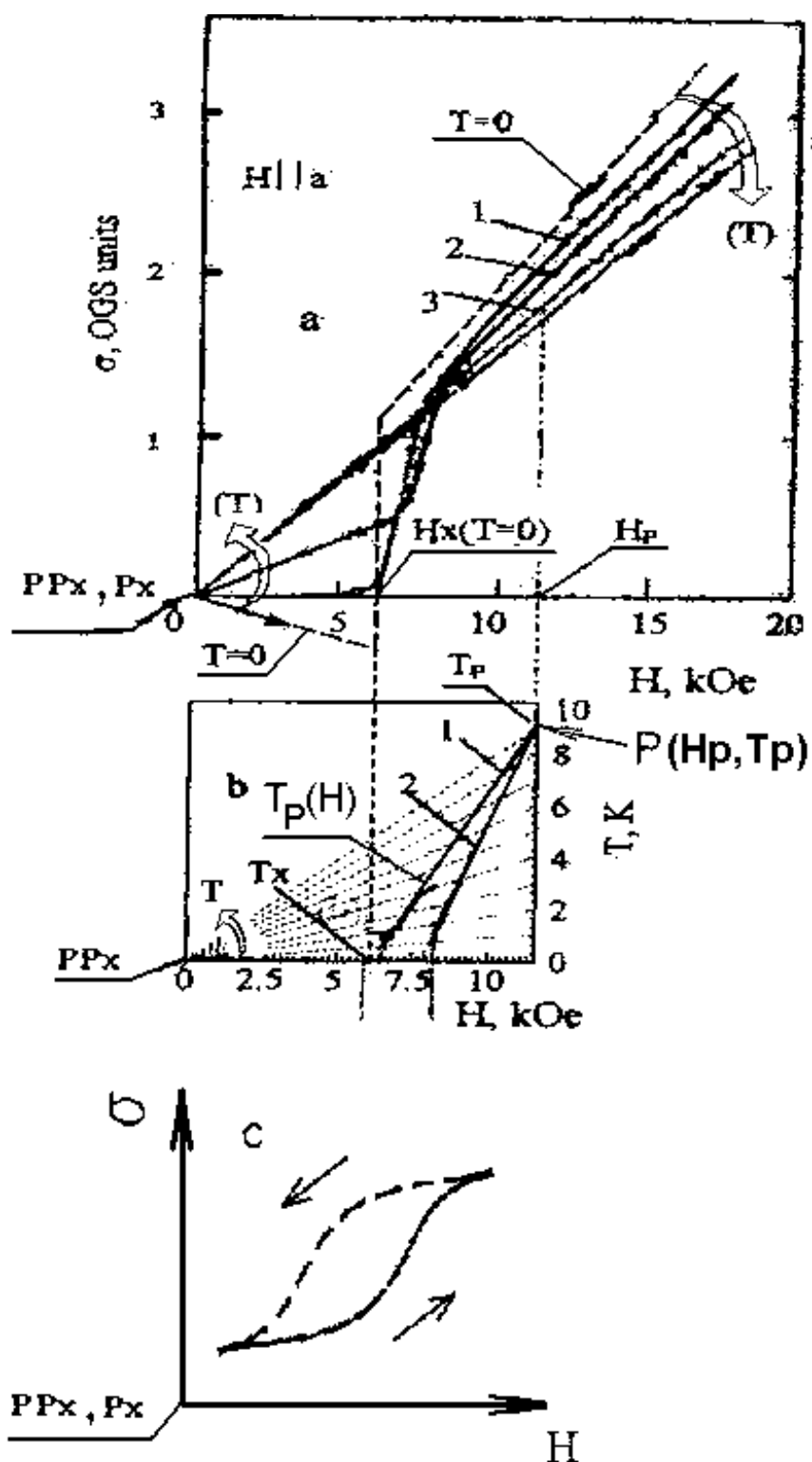


Figure 8.2. a) Field dependences of longitudinal magnetostriction for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$; b) Field-temperature dependence of changes in the phase transition $T_p(H)$, $T_p(H, P)$ for $P = 11.2$ kbar in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$; c) Dependence of magnetization change in the effect of inverse hysteresis in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$.

It should be added that the analysis of the mentioned dependences illustrates the relation between the features of magnet-containing structure and the positions of critical points P_x , PP_x on Fig. 8.1a, 8.2a. Both the content of magnetic material and structural changes connected with the composition and technology of sample preparation displace the position of critical points P_x , PP_x and T_x (Fig.1a,b) and metal – semiconductor interfaces, as a consequence of critical lines in the form of PT field-temperature dependences $T(H_g)$. That is why the point of PP_x and P_x coincidence (Fig. 8.2a,c) as well as the sign reversal of position of the critical line of PT field – temperature dependence $T_p(H)$ shows that the critical line separates both the conducting (metallic) phase and, I suppose, the superconducting phase in this case. The result qualifies the effect of thermo-elastically deforming compression as regularity of antiphase temperature impact and points to a peculiarity of the structure and the anisotropy of EAD stresses. It also emphasizes their causal role in formation of essential changes such as a jump in the region of PT at 0°K. With regularities revealed for a model structure, new multicomponent systems are to be found where similar mechanisms of the effects repeat conditions for the formation of structural PT and changes of properties.

One of the examples of considering the revealed regularities of T and H impact through mechanisms of EAD stresses and the definition of the role of specified critical lines $T_p(H)$ and points P_x , PP_x is the analysis of various experimental results relating immediately to the modification of properties of direct and inverse hysteresis effect.

Prior to the consideration of the effect of the conventional hysteresis (Fig. 8.1a, c) on magnetostriction dependences in the area of the phase transition in LaMnO_3 , we pay attention to the significance of the role of thermo-magnetically EAD stresses in mechanisms of the impact of thermodynamic parameters (T,H) determined and grounded in [6]. It was shown that P and H influence through “cooling – heating” effects and sign inversion, i.e. changes of priority of thermo – and magnetically EAD stresses in structural phase transitions, magnetic and resistive properties. A conformity of regular changes in magnetization has been determined in phase states (diagrams) of low- temperature magneto-dielectric $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ [181].

These results and regularities as well as position of critical lines and points relating to LaMnO_3 properties rise a question of their role in hysteretic evolution near the structural phase transition.

Thus for LaMnO_3 magnetostriction behavior, the role of “cooling” effect from the magnetic field is related to regularities of P_x critical point at the initial section. It should be noted that the temperature change is in antiphase with the dynamics of evolution of magnetization properties influenced by H. The next regularity is the behavior of the dependence after PT in a new phase state

where the properties are changed in compliance with regularities of changes with respect to PP_x critical point (Fig. 8.1c).

At this section of the dependence, the properties are influenced by “heating” effect under the reverse run, i.e. upon magnetic field (H) release. In this case, the jump of properties follows directly from changes in the sample, but already with respect to the position of PP_x critical point where the properties return to the initial phase with the temperature rise (Fig. 8.1a, c).

This physical process is a conventional hysteresis in the region of structural phase transition. It is formed by regularities of mechanisms of elastic stresses and obeys the primary role of the critical points and lines.

The next example of the change of $CuCl_2 \cdot 2H_2O$ magnetization properties allows to find a regularity (Fig. 8.2a, c) corresponding to the effect of reverse hysteresis and to explain it from viewpoint of PP_x and P_x critical points and changes in $T_p(H)$ field-temperature dependence of the structural phase transition taken into account. The result shows that in our case, the dependence of the form of critical line separating $T_p(H)$ phases is controlled by the position of PP_x critical point (Fig. 8.2b); the changes of magnetization at the initial section belonging to the superconducting phase are regularities of magnetic field “cooling” effect, they are fixed in antiphase to T change with respect to the position of PP_x critical point (Fig. 8.2c).

There is one more phase change on the dependence of Fig. 8.2a, b with H increases: a jump in magnetization, but already in the metallic phase and with respect to a P_x critical point (Fig. 8.2c). As a consequence, there follows magnetic field H release at the expense of the elastic expansion. And the “heating” effect develops on magnetization dependence with respect to P_x accompanied with a phase change, but now in view of PP_x critical point. That is why the properties are unambiguously influenced by both T and H. This is a wide-spread result supported by the revealed regularities.

Such a conclusion is an example of a new definition of the effect of direct and inverse hysteresis studied for a long time. It detects the principle sources of changes of properties in the region of a structural phase transition, which are related to the position of PP_x and P_x critical points. The analysis gives a convincing proof of the role of mechanisms with investigated differences, it can be also a demonstrating example of the presence of secondary signs that confirm the causal role of EAD stresses in regularities of direct and inverse hysteresis.

8.2. The structural first-order phase transition in $Sm_{1-x}Sr_xMnO_3$ and $Eu_{0.55}Sr_{0.45}MnO_3$ systems

The analysis of magnetization dependences and critical PP_x and P_x points (Fig. 8.2a) before and after structural phase transitions shows that the influence of temperature change on properties prior to and after the PT is of a sign-

alternating character. It means that the magnetization increases with T and H increase first (any changes are to be considered with respect to a PP_x critical point). The temperature affects the magnetization value as well. As noted, these changes of properties are associated with the superconducting phase. The dynamics of T and H influence after the phase transition is in antiphase at the next section of the dependences where changes of properties are examined starting from P_x critical point. The magnetization increases with the field and decreases with the temperature rise. It follows that the changes of properties belong to superconducting (metallic) phase for both LaMnO_3 magnetostriction properties and $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ magnetization on the mentioned sections. As a consequence, the critical line of $T_p(H)$ (Fig. 8.2b) was the interface between phase states with sign-alternating influence of the temperature. This result can also be considered as a secondary factor.

By drawing analogies in regular changes of magnetization properties for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (Fig. 8.2a) and magnetization for LaMnO_3 (Fig. 8.1a) and marking the alternation of sign in position of $T(H_g)$ (Fig. 8.1c) and $T_p(H)$ (Fig. 8.2b) critical lines, we can conclude that:

- a) in the first case, the field – temperature dependence $T(H_g)$ separates metallic and semiconducting phases;
- b) in the second case, the structural phase transition realized at $T_{st}=0$ K and the field-temperature dependence $T_p(H)$ is none other than the interface (and what is important) between superconducting phase and conducting (metallic) one;
- c) the critical line of $T_p(H)$ (Fig. 8.2b) which generalizes structural phase transition changes after the jump of properties and after the effect of thermoelastic – deforming compression (Fig. 8.2a,b) under the magnetic-field cooling effect, terminates at the fixed temperature $T_p=9.2$ K. The location of $P(T_p, H_p)$ critical point fixing the boundary position of a structural phase transition may be specified as the point of the intersection of approximated $T_p(H)$ and $T_p(H, P)$ critical lines.

The estimated role of secondary indications observed in changes of properties in the course of reversible physical processes in varied magnetic fields and temperatures as well as the determined position of critical points and their sequence PP_x and P_x in property change enables one to state convincingly that the primary influence of thermodynamic parameters T, H, P is a regularity of the mechanisms of EAD stresses.

Analyzing the regularities and determining secondary indications, we can treat the results of a number of papers [5, 175-177, 180] in order to trace anomalies and peculiarities. It should be noted that the experimental results refer to investigation of multi-component magnet-containing mono – and polycrystalline samples for the taken manganite compositions.

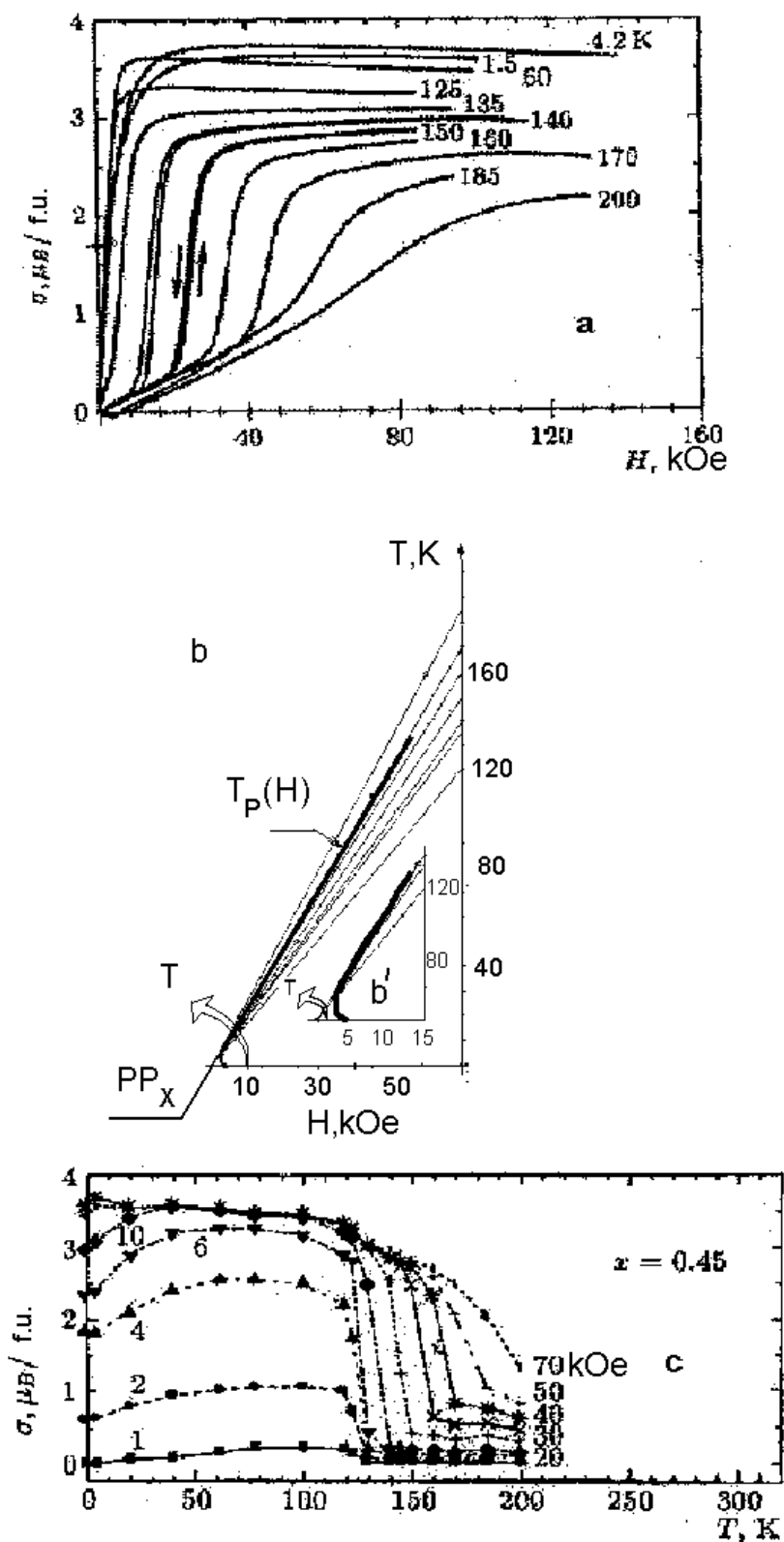


Figure 8.3. a) Magnetization isotherms for different temperatures in $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ compounds for $x = 0.45$; b) Field-temperature dependence of changes in $T_P(H)$ - the phase transition in $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$; c) Temperature dependence of magnetization in variable magnetic fields.

For the analysis, the most demonstrative are experimental results for manganites of combined $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ composition [175] with their peculiar magnetic, elastic and magnetoelastic properties. The authors consider dependences of changes of properties for samples with $x=0.45$. Magnetization isotherms (Fig. 8.3a) have a singularity in the form of a jump of properties at the initial section of the dependence for fixed temperatures. With H increase, a relative linearity at the region of saturation tends to maintain the magnetization, while the process of temperature growth changes the properties towards decreasing. The authors state that the maxima of conductivity on $\rho(T)$ dependences change by several orders of magnitude at low temperatures for all the investigated compositions, and magnetoresistance of samarium manganites of the taken composition (as stressed by the authors) reaches colossal values in relatively low magnetic fields. For instance, the magnetoresistance makes 44% for composition with $x=0.45$ and $H=0.84$ kOe. The attention is attracted to a stable regularity of changes at isotherms (Fig. 8.3c) with a jump of properties at the initial section of the dependence for all H fixed. The conformities retain in the whole temperature range up to 125°K. With changing T , the magnetization decreases in the region of the jump, i.e. with T increase in high magnetic fields, the magnetization diminishes linearly.

This result has made it possible to characterize and to substantiate the presence of general secondary indications in changes of properties of that structure:

- a) the inverse hysteresis observed in the region of phase transition allows us to treat the changes as a structural phase transition with the typical field – temperature dependence $T_p(H)$ with changes occurring at PP_x critical point (Fig. 8.3b);
- b) stable changes of magnetization isotherms after the jump of properties corresponding to PT, where the magnetic field enhances the properties whereas the temperature growth results in a significant decrease of the properties. It should be noted that this region of the phase state corresponds to the metallic conductivity;
- c) regularities of the magnetization increase under T, H influence observed on Fig. 8.3c show that at the initial section prior to the structural phase transition, the changes of properties under T and H effect occur in one phase (in view of position of PP_x critical point). After the PT, the magnetization changes in antiphase to relative changes of T and H (Fig. 8.3b,c). This result repeats changes in the magnetization for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (Fig. 8.2a,b).

Such regularities broaden the region of applicability of the specified critical lines and points and confirm the presence of mechanisms of EAD stresses in the formation and changes of first-order structural phase transition and properties, as a consequence.

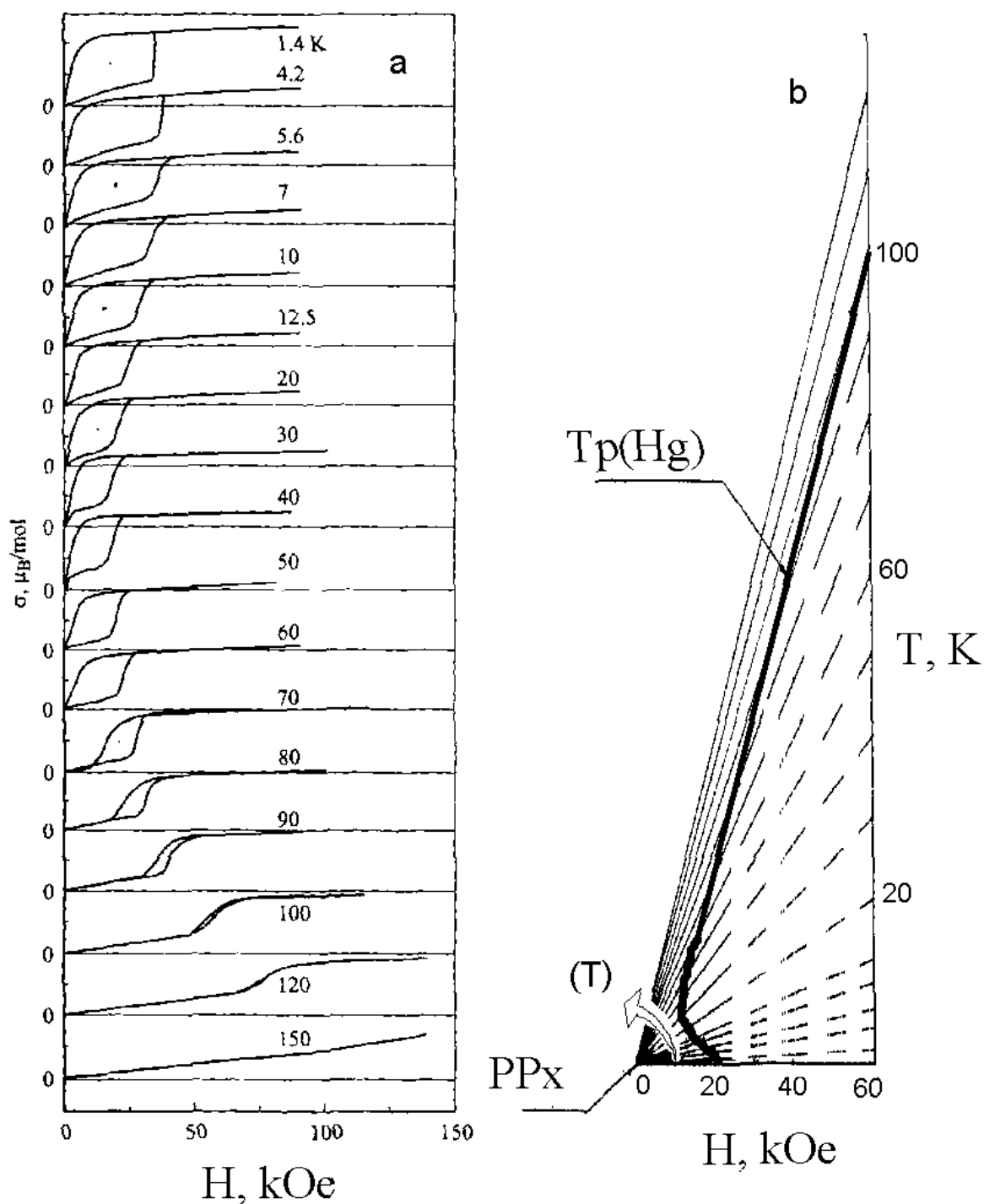


Figure 8.4. a) Magnetization isotherm for different temperatures in $\text{Eu}_{0.55}\text{Sr}_{0.45}\text{MnO}_3$; b) Field-temperature dependence of changes in phase transition $T_p(H_g)$ in $\text{Eu}_{0.55}\text{Sr}_{0.45}\text{MnO}_3$.

For further substantiation of regularities of elastic stresses in the formation and changes of structural phase transition and properties, we analyze magnetic, elastic, magnetoelastic, resistive and magnetoresistive properties of polycrystalline $\text{Eu}_{0.55}\text{Sr}_{0.45}\text{MnO}_3$ [176]. The paper presents a large bulk of experimental results. The authors show that the studied ceramics is a

polycrystalline single-phase perovskite of orthorhombic structure and, what is very important, they pay attention to the identity of the results to the properties of ceramic samples of other compositions: $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ ($x=0.4, 0.45$), EuMnO_3 . Let us examine the changes of magnetization (Fig. 8.4a) where hysteresis changes in magnetization jump within the temperature range of 1.4°K-150°K are explicitly seen on isotherms. Here we note the run of inverse (anomalous) hysteresis (Fig. 8.5b) analogous to the behavior of magnetization for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (Fig. 8.2c). The authors suppose that the structure remains dielectric in a wide range of low temperatures according to the resistivity properties (Fig. 8.5a). This important notice enables us to assume that the structural phase transition at 0°K can be triple-point regularity and magnetic field H displays a jump in magnetoresistivity through mechanisms of magneto-EAD stresses due to superconducting phase realization.

It should be noted that the resistivity should be much beyond the limits of changes in resistance with T decreasing, as follows from the logics of the experiment (Fig. 8.5a). Most probably, the sensitivity of measurements was not high enough to register the peak of ρ change at a level of 10^{10} - 10^{12} at temperatures tending to 0°K. And it is shown in fact that the temperature dependence of thermoelastic expansion is practically linear with the low-temperature measurement errors being taken into account (Fig. 8.5a).

The above result makes it possible to note one more regularity shown on T and H dependences of magnetization (Fig. 8.5d). Here we see a jump-like increase of the magnetization at the initial section of isotherms with H fixed as well as magnetization decrease with T rising at the final part of the dependence. These changes are similar to those on the isotherms of Fig. 8.2a. They are the regularities of unambiguous change of the magnetization as a function of T and H at the initial section of the corresponding superconducting phase with $T_P(H)$ critical line separating phase states and corresponding to PP_x critical point (Fig. 8.2b). The subsequent evolution results from the antiphase impacts of T and H in the conducting (metallic) phase, i.e. there is a sign-alternating temperature effect after the phase transition. In $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, the behavior of properties is similar (Fig. 8.2a). The changes observed on magnetization isotherms (Fig. 8.5c) make it possible to consider this result as a secondary indication for this composition.

The analytical results emphasize peculiarities of formation of structural phase transition and make it possible to construct and to single out $T_P(H_g)$ field – temperature dependence basing on changes of parameters of inverse hysteresis, Fig. 8.4b. It is a regularity attached to the position of PP_x critical point. The critical line of $T_P(H_g)$ separates two phase states (superconducting and conducting (metallic) phases). It also displays the regularities of structural phase transition at $T_{st}=0^\circ\text{K}$ and it is a dependence of the dynamics of changes influenced by the position of the averaged magnetic field H_g determined in this paper.

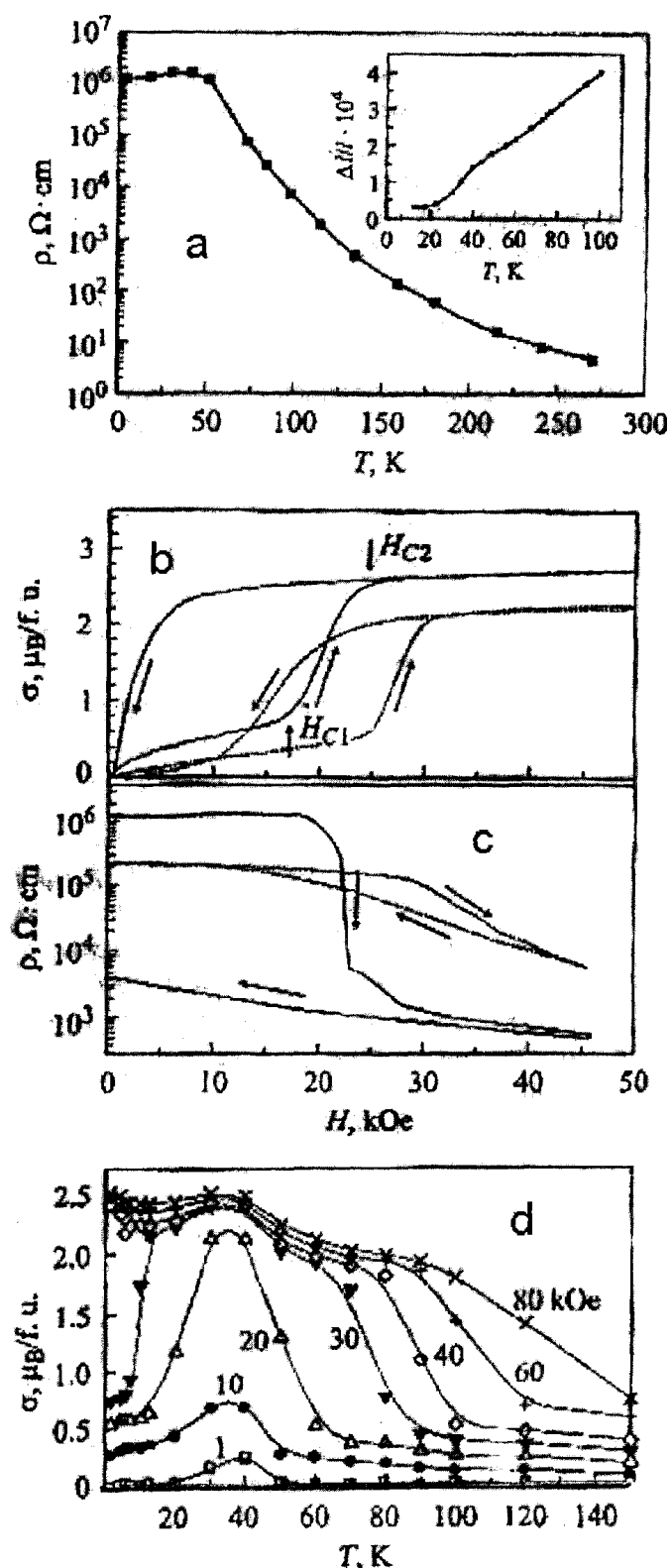


Figure 8.5. a) Temperature dependence of resistivity. Temperature dependence of thermal expansion in $\text{Eu}_{0.55}\text{Sr}_{0.45}\text{MnO}_3$. b) Magnetization isotherm $p(H)$ in changes of inverse hysteresis for $T = 20$ K, 60 K; c) Isotherms of changes in electrical resistance (H) for $T = 20$ K, 60 K; d) Temperature dependence of magnetization $p(T)$ in different magnetic fields.

It follows that the role of field and temperature influence through mechanisms of EAD stresses is a causal basis of volume change and the formation of structural phase transition and properties, as a consequence. Moreover, the position and sign alternation of critical lines and points determine the regularities of the impact in the form of changes of properties in both phases separated by the structural phase transition. Such an explanation implies that the role of elastically deforming stresses is the basic one as the binding energy directly corresponds to and interacts with elastically and anisotropically deforming mechanisms of volume change in this case. They are also the primary cause of PT changes and properties at the expense of mechanisms of thermoelastic and magnetoelastic effects of T and H.

An extensive experimental result [175] of studies of phase states and peculiarities of electrical properties in manganites of $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ system was also treated in [177] in the course of investigations of a similar sample. The authors believe that the peculiar isotopic oxygen substitution helps in the identification of the metal - dielectric phase states. They pay attention to a composition with x between 0.4 and 0.5 where a jump of electrical resistance and sudden changes of the coefficient of volumetric expansion and magnetostriction were found out. High sensitivity of all physical characteristics to negligible composition changes, the lack of information for the explanation of properties of the above manganates have made us to propose the analysis of our own in view of the role of T-H-P influence through EAD-stress mechanisms. We take the data for $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$, $x=0.500$. For the sample with $x=0.500$ and isotropic substitution, there is a phase transition separating metallic and dielectric phases within the low-temperature range. And a relatively weak influence of external magnetic field on magnetostrictive dependence (Fig. 8.6a) via mechanisms of magnetoelastic compression brings the system to a new phase state and, what is important, the corresponding maxima of the electrical resistance have much decreased and shifted to the region of higher temperatures under the influence of H. The temperature hysteresis decreases as well. As the result of resistivity change is incomplete, we show changes of ρ for $T=0^\circ\text{K}$ (the dot-and-dash line) to be of the order of 10^{11} - 10^{12} by approximation (Fig. 8.6a). This behavior of the dependence makes us to ascertain a regularity, that changes in thermoresistivity under magnetic-field effect (H=1T, 2T, 4T) fix the position of temperature maximum at T_{pp} point. The specified effect corresponds to $T_{pp}=0$ K on the dependences (Fig. 8.6a). So, we can state that the structural first-order phase transition is realized at 0 K in this sample.

It is also noted that the maximum MR is shifted in magnitude attaining colossal values for the mentioned samples. So, we can construct the field – temperature dependence of changes in PT showing the behavior of $T_p(H)$, Fig. 8.6c. It is the critical line separating superconducting and conducting phases

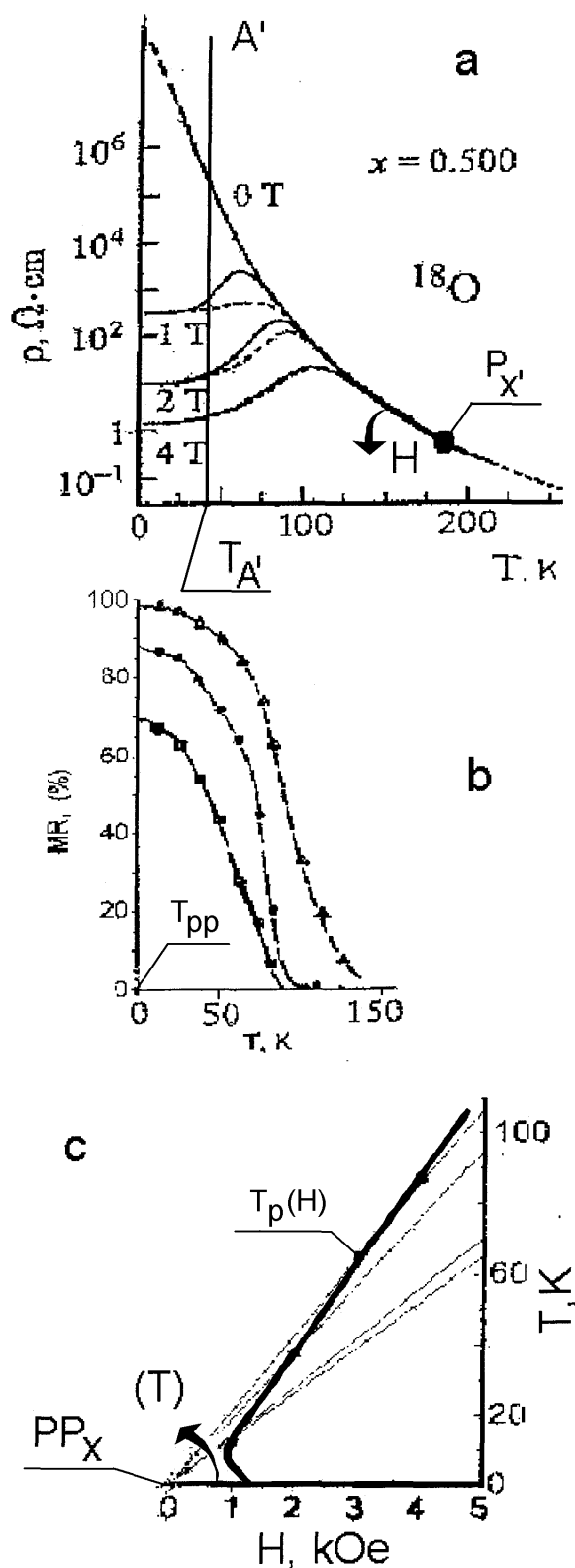


Figure 8.6. a) Temperature dependence of electrical resistance for $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ samples ($x = 0.500$) with ^{18}O and magnetic field of 1 T, 2 T, 4 T; b) Dependence of magnetoresistive effects MR (%); c) Field-temperature dependence of changes in phase transition $T_p(H_g)$.

with the position directly related to PP_x critical point responding to a real physical process. The authors stress that both the peculiarities of crystalline structure and the obtained results are similar to properties of single-crystalline samples of $Sm_{0.55}Sr_{0.45}MnO_3$ composition [179] having the rhombic space symmetry as well. The authors note that there are no structural phase transitions in the temperature range of 1.4-300°K but this statement is not entirely correct. It follows from our conceptions and secondary indications of $T_{PP-const}=0^\circ K$ rule that the pointed critical temperature fixes the structural phase transition and $T=0^\circ K=T_{PP}$ responds to the position and properties of a triple point. The real character of the structural phase transition is $T_p(H)$ field-temperature dependence and changes of magnetic and electronic properties are consequences of peculiarities in different phase states revealed by the analysis.

With important factors of secondary indication taken into account, the given results make it possible, first, to show the role of T-H impact through mechanisms of EAD stresses and, second, to confirm convincingly the importance of the discussed critical lines and points and the role of bulk elasticity.

8.3. The causal role of regularities of the elasticity in the formation of the colossal magneto-resistivity

The consecutive analysis of the effect of elastic stresses on the formation of structural phase transition and magnetic properties of the mentioned magnet-containing media raised a question, how the properties of conductivity behave at any changes of structure influenced by elastic stresses.

The demonstrative are results of [181] considering mechanisms involved in formation of the dynamics of resistive properties in magnetic semiconductors. The authors studied the behavior of resistivity in a bulk ceramic sample $La_{0.56}Ca_{0.24}Mn_{1.2}O_3$ as a function of three thermodynamic parameters T-P-H (Fig. 8.7a). The revealed regularities, with respect to the linearity in a wide T-P-H range, show the role of mechanisms of elastically deforming stresses in the region of metallic phase and, what is very important, make it possible to ascertain the correlations (6.3°K-1 kbar-2.3 kOe). It follows that the hydrostatic pressure of ~18 kbar creates conditions at the expense of volume decrease, through mechanisms of backpressure, thus resulting in changes of conductivity properties, which are in turn analogous to the temperature decrease by ~120 K. Similar effect is observed in the case of magnetoelastic compression of 8 kOe corresponding to changes in resistivity analogous to temperature decrease by ~21°K. As formulated, there is an important regularity in such processes, i.e. conductivity redistribution because of the relaxation of inner stresses during volume reduction. As the thermoelastic expansion is associated with considerable inner stresses, the

influence of elastic and magnetoelastic compression induced by the backpressure diminishes the inner stress. The process clarifies that any volume change due to thermoelastic, baroelastic, magnetoelastic compression relates directly to the inner-stress reduction in the system, while a volume decrease is directly related to the enhancement of the energy of atom-electron coupling, by definition.

On the dependence (Fig. 8.7a) the denoted important factor of a nearly double jump in the region of PT where the phase states are separated implies that changes have occurred already in the semiconducting phase. Such changes of properties are based on the presence of structural phase transition in a reversible physical process. In this case, the regularity is the equality of temperature maxima of thermobaroresistive, thermomagnetoiresistive and thermobaromagnetoiresistive effects $T_{PP}=T_{mc}$ that corresponds to the temperature of the structural phase transition. It can be consequently stated that the regularity $T_{PP}=\text{const}$ is the law of conformity conservation for elasticity and magnetoelasticity anisotropies, which was first proved in [6] (Fig. 8.7b).

Next, the shown critical lines of $T_{ms}(P)$ and $T_{ms}(H)$ are regularities of phase state separation and dynamics of their changes under the influence of hydrostatic pressure and magnetoelastic compression (Fig. 8.7a). It is obvious that the field-temperature and thermobaric dependences reflect mechanisms of elastic stresses and the important role of thermo- and magnetoelasticity anisotropy participating in the processes. It is stressed that the dynamics of both the jump and resistivity reduces in two coexisting phases under P and H effect.

Now we consider typical changes of properties of semiconducting phase. Here we single out P_x point of intersection of the dependences by means of approximation. The critical state defines the relation between T-P-H induced change of properties and the real physical process of elastic-compression mechanisms. It means that any changes in volume towards reduction, e.g. a decrease of temperature parameter, affect the regularities of changes of properties in a way similar to hydrostatic pressure P effect and magnetic field H effect through magnetoelastic compression. These mechanisms directly relate to changes in volume and correspond one to another. As a consequence, it can be stated that position of P_x' critical point functions as a relatively conforming equality of interacting binding energy and energy of elastic stresses in the system.

It follows that a decrease in volume at the expense of the revealed mechanisms of T-P-H influence modifies the binding energy of the atomic-electron system, and the structural phase transition separates a large symmetry volume in one phase from a smaller symmetry volume in another new phase. The extent of changes depends on values of thermo-elastic stresses.

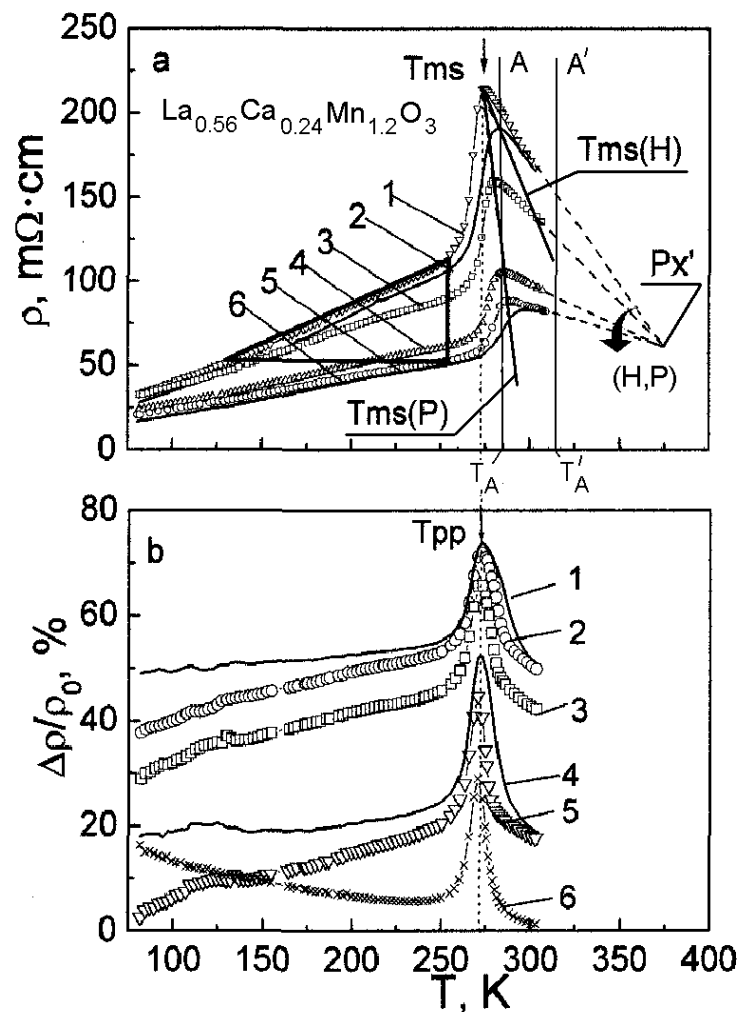


Figure 8.7. a) Temperature dependence of resistivity of $\text{La}_{0.56}\text{Ca}_{0.24}\text{Mn}_{1.2}\text{O}_3$ ceramic sample: 1 - $P = 0$ kbar; 2 - $P = 0$, $H = 8$ kOe; 3 - $P = 6$ kbar; 4 - $P = 12$ kbar; 5 - $P = 18$ kbar; 6 - $P = 18$ kbar, $H = 8$ kOe; b) Temperature dependence of baroresistive, baromagneto-resistive, magneto-resistive effects: 1 - $H = 8$ kOe, $P = 18$ kbar; 2 - $P = 0$, $H = 8$ kOe; 3 - $P = 12$ kbar; 4 - $P = 6$ kbar; 5 - $P = 6$ kbar $H = 8$ kOe; 6 - $H = 8$ kOe.

Methods applied for revealing regularities in the formation and changes of structural phase transitions, for determining the metal-semiconductor, dielectric-superconductor-conductor phase states, as well as triple point positions enable us to show the role of magnetoelastic mechanisms in the colossal magnetoresistance effect by means of the results of changes of resistivity:

- a) to begin with, we pay attention to the behavior of dynamics of dependences of resistivity change under T-P-H effect (Fig. 8.7a). With changing T and P, we have a region on $T_{mc}(P)$ dependence marked by T_A temperature. Following the change of pressure with respect to P_x' critical point, it is stated that with P increase, including the “cooling” effect, we

observe resistivity change for fixed T_A and this corresponds to the semiconductor-metal phase transition. The process is fixed by a sudden (not so high jump) change of properties in $T_{ms}(P)$ critical line. Similar regularity of changes in resistivity properties is found at T_A and in the “cooling” effect of magnetoelastic compression by magnetic field H . A sudden (jump-like) resistivity change will be observed during semiconductor-metal transition through the critical line of $T_{mc}(H)$, Fig. 8.7;

b) following result is the most demonstrative and the analogy can be drawn by regularities of changes of properties according to investigations of electrical resistance for $Sm_{1-x}Sr_xMnO_3$ (Fig. 8.6a). With T_A' fixed, the “cooling” effect results first in dielectric-superconducting transition and there occur more essential changes in this range with further H increasing, i.e. resistivity reduction under the influence of mechanisms of magnetoelastic stresses. The process of the change of properties becomes apparent by a noticeable resistivity jump in the region of phase separation where $T_p(H)$ critical line has an intersection.

That are these regularities that explain the behavior of resistivity isotherms $P(H)$ in a wide range of magnetic fields. This is illustrated on Fig. 8.5a by dependences for fixed $T_1=20^\circ K$, $T_2=60^\circ K$ in $Eu_{0.55}Sr_{0.45}MnO_3$. At the initial section for $T_1=20^\circ K$, the change of properties with H increase corresponds to regularity of the “cooling” effect, when it is obvious that resistivity ρ is invariably high, so it is the dielectric phase. We note that there is a jump of resistivity in the field of 20 kOe (Fig. 8.5c) that conforms the field-temperature dependence of the structural phase transition toward the superconducting phase with a considerable reduction of resistivity at the field raising. During the inverse process of H decrease (Fig. 8.5c), the “heating” effect presents in resistivity properties as a transition from superconducting to conducting (metallic) phase followed by changes in the region of dielectric phase with $H \rightarrow 0$. Thus, it can be noted that the mechanisms of magneto-elastic stresses relate directly to conductance and they are the primary cause of the colossal magnetoresistivity effect currently studied.

An analysis of changes of properties represented on Figs. 8.7a and 8.6a attracts out attention to dynamics of resistivity change in semiconducting phase and to the position of critical point P_x' (Fig. 8.7a) and dielectric phase on isotherms of electrical resistance (Fig. 8.6a). This result clearly shows the scheme of changes of properties in the course of volume reduction as a result of T decrease and P increase. Similar result is observed in the case of H effect. In other words, the influence of these parameters on structural changes occurs involving the elasticity. This influence is unambiguous and conformal. The correspondence allows us to take P_x' critical point into consideration and to represent P and H effects by mechanisms of baroelastic and magnetoelastic

compression backpressure. It should be noted that anisotropy of thermo- and magnetoelasticity plays the principal role in the formation of structural phase transition, and the anisotropy of elastic stresses creates conditions for volume decrease in a reversible physical process. It is also an important factor for concentration of stresses preventing the mobility of conduction electrons in both semiconducting and dielectric phase till the boundaries where the structural phase transition develops accompanied by jumps of heat capacity and properties.

A consecutive determination of the role of elastic stresses (compression) reveals regularities for the discontinuity of structure in the range of PT in a reversible physical process [182 – 184]. There is also a jump of properties (heat capacity) and temperature increase giving negligible changes of properties due to high stresses developed in the system, as shown by our analysis. This is also indicated by the observed accordance of temperature-to-pressure correlations and by a comparatively low binding energy. At low temperatures, such changes occur in the form of a large jump of properties due to low energies of elastic stresses but with enhanced binding energy.

8.4. Secondary signs of the structural phase transitions and their role in the establishing of the regularities of ED stresses

The performed analysis makes it possible to generalize and systematize the results of ascertaining of secondary indications in regularities of magnetic, elastic and magnetoelastic properties in $\text{Sm}_{1-x}\text{Sr}_x\text{MnO}_3$ compounds [175], they are:

- a) inverse hysteresis is fixed, the jump in properties and the tendency of magnetization decrease with temperature growth are observed (Fig. 8.3a);
- b) unambiguous growth of magnetization properties under T and H effect (the initial section of the dependence) is present as well as sign-alternating change of properties under the influence of H and T after the jump in properties. Temperature parameter affects the properties of different phase states in antiphase (Fig. 8.3c);
- c) the regularity of changes in the field-temperature dependence $T_p(H)$ is revealed by averaging the position of jump of properties with the typical role of the initial point relating to PP_x under the temperature change in angular coordinates (Fig. 8.3b,c);

Similar results with the revealed regularities corresponding to secondary indications have been observed in studies of peculiarities of magnetic, elastic, magnetoelastic properties in $\text{Eu}_{0.55}\text{Sr}_{0.45}\text{MnO}_3$ compounds [176]. Here we note dependences obtained at $T=1.4^\circ\text{K}$, that are close to those for $T=0^\circ\text{K}$:

- a) the parameter was changing linearly within the whole interval of measurements because of thermoelastic compression (Fig. 8.5a). The method of approximations makes us to show the maximum of resistivity at the level of 10^{11} - 10^{12} in dielectric phase (Fig. 8.5a);
- b) considerable and obvious changes of the inverse hysteresis were present on the magnetization isotherms including $T=1.4^\circ\text{K}$, as well as the typical reduction of properties with T increasing (Fig. 8.5c);
- c) unambiguous growth of magnetization with T and H increase was observed at the initial section of the dependence followed by the antiphase effect of T and H at the final stage (Fig. 8.5d);
- d) the analysis of the dynamics of changes on magnetization isotherms (Fig. 8.4a) makes it possible to mark and represent the regularity of the field-temperature dependence as $T_P(H_g)$, i.e. as the critical line of the structural phase transition with $T_{st}=0^\circ\text{K}$, separating superconducting and conducting (metallic) phases with the typical position of PP_x critical point and respective change of the temperature.

It should be added that the observed character of evolution of properties and the determined critical temperature $T_{st}=0$ K meets the requirements set forth for the formation of superconducting and conducting phase. It is also a regularity satisfying the conditions of the triple point.

Hence, it can be concluded that one more critical point P with H_P and T_P coordinates can be taken into account for the samples under investigation. This point was shown first in [6] and determined by approximation and intersection of changes in the field-temperature $T_P(H)$ and field-baro-temperature dependences $T_P(H,P)$ presented on Fig. 8.2b. To determine such a point in studied structures, a cycle of investigations of properties and PT influenced by thermodynamic parameters T - H and by one important parameter (the hydrostatic pressure P) should be performed.

By extending potentialities of the analysis on revealing secondary indications, the same regularities can be found in so-called anomalies of magnetic and magnetoelastic properties in $\text{Nd}_{1-x}\text{Ca}_x\text{MnO}_3$ single crystals in strong magnetic fields [180]. The represented dependences of magnetization for composition with $x=0.45$ demonstrate inverse hysteresis of change of properties and make it possible to show definitely that changes of the field-temperature dependence of PT are in correspondence with respect to PP_x critical point. It should be noted that magnetization decreases with temperature rise, and $T_P(H_g)$ field-temperature dependence is a consequence of temperature of the structural PT detected at 0°K . The results to be analyzed might be more reliable provided investigations accounting for selected directions. The same conclusion follows from the analysis of properties and anomalies of changes of phase transitions in $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ single crystals [6].

While analyzing the technology of structure formation, we should note that this process is followed by weakening of energies of atom-electron bonds at high energies of thermo-elastic stresses when a combination of chemical elements is exposed to high temperature. The further volume change at the rate of T-P-H influence is connected with the redistribution of these energies.

Therewith, physical influence of parameters (e.g. T decrease, P raise, H increase by the mechanisms of elastic stress (compression)) is the basis of formation of structural phase transitions and the realization of a jump of properties at the boundary of phase states. Hence we can state that the role of energies of elastic stresses prevails at high temperatures. The analysis carried out shows that the reduction of the temperature in the course of volume compression redistributes the energy of elastic stresses toward reduction.

Special attention should be paid to the extreme variant determining the energy state of the system at the temperature varied with taking into account the minimal volume at 0°K. The volume is minimal, the binding energy is maximal due to electrostatic Coulomb interactions at comparatively small elastic stresses which are neglected in used theoretical models of quantum mechanics. That was the fact created the necessary prerequisites for introduction of conception of an equilibrium state in Bohr-Levin postulate as well as magnon definition in the theory of spin magnetism [11, 183].

Taking into account the proven mechanisms of realization of physical processes using real experimental results (significant hysteresis of magnetization at $T=1.53^{\circ}\text{K}$ in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ (Fig. 8.2a) and at $T=1.4^{\circ}\text{K}$ in $\text{Eu}_{0.55}\text{Sm}_{0.45}\text{MnO}_3$ (Fig. 8.4a)), we can doubt theoretical models based on ideal postulates and containing significant restrictions [183]. The existence of considerable binding energies verified by quantum-mechanical definitions side-by-side with elastic stresses forming a structural phase transition (a triple point) exactly at 0°K is the driving force of a real physical process. The evidence of the existence of a structural phase transition at 0°K is the availability of a number of secondary indications enlisted in a number of papers in the form of jumps of heat capacity, magnetization, HF-properties, striction etc. that emphasizes the real importance of the mechanisms of elastic stresses.

As a consequence, the formulated regularities contradict to the statement about the absence or insignificant value of elastic stresses. They are hardly small enough, to deny or neglect the elastic energy forming the phase transition exactly at 0°K.

While generalizing and emphasizing the role of elastic stresses, we should suppose their importance in both dielectric and semiconducting phases. The reduction of the volume down to the boundary of the phase transition forms a phase state as a concentrator of elastic stresses preventing electron motion.

Here the superconducting and conducting phases are manifestations of PT at 0°K with the reversible jump in properties (a rupture) of the structure.

The revealed regularities of elastic stresses treated as the main cause of volume change under T-P-H effect through mechanisms of bulk elasticity as well as the relation of these mechanisms to changes in electric conduction let us to assume that not all the electrons participate in conduction. Some of them are located at the filled shells that are most bound to nodal points (ions) and at the same time least relate to the processes of electric conduction. The mobility originates from the fact that the binding energy of electrons located from atom or molecular center to periphery is two and more orders of magnitude lower in the case of multi-component systems. Since the binding energy of peripheral electrons participating in the formation of lattice structure can be in a relative correspondence with the energy of elastic stresses, and then namely the electrons can play a principal role in structure changes and be a defining factor of T-P-H thermodynamic influence.

As known, every single-crystalline or polycrystalline structure is formed by repetition of groups of ions, molecule, atoms in the bonds, thus forming sites, and the experiment shows that in lattice sites the atomic and molecular magnetism develops as magnetic non-compensation. Such non-compensation is the maximum at $T=0^\circ\text{K}$ (Fig. 8.1a- magnetostriction dependence; Fig. 8.2a – magnetization dependence) and it goes to zero at high temperatures directly connected with processes of volume change. Showing the role of the laws of cubic elasticity we stress that if changes in volume are not accounted for completely, any methods of theoretical modelling remain an approximate solution with the empirical selection of coefficients to define changes in the exchange. The approximations taking these volume changes into account need much correlation.

The presented methods of analysis, the established regularities of elastic stresses in physical processes of formation of phase transitions and properties in multi-component magnet-containing structures are separated among fair quantity of results and facts. The main goal of the present paper is the demonstration of universality of the chosen methods of analysis. This aim demanded the intuitive formulation of principles of correct account for macro- and mezosopic properties.

The establishment of causing role of elastic stress energies and natural fact of their separation at formation of critical lines and points [6] attracted our attention to [171, 177, 180, 185]. There a wide spectrum of studies of multi-component magnet-containing structures is presented in the form of varied parameter dependences of phase diagrams of $\text{Re}_{1/12}\text{Al}_{1/2}\text{MnO}_3$ [171, 185] compounds, $\text{Pr}_{1-x}\text{Ca}_x\text{MnO}_3$ monocrystals and $\text{Pr}_{1-x}\text{Sr}_{1/2}\text{MnO}_3$ [177] and $\text{Nd}_{1-x}\text{Ca}_x\text{MnO}_3$ [180], too. Presented in [6] for LaMnO_3 and $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ properties, the selected methods of analysis allow us to establish analogous

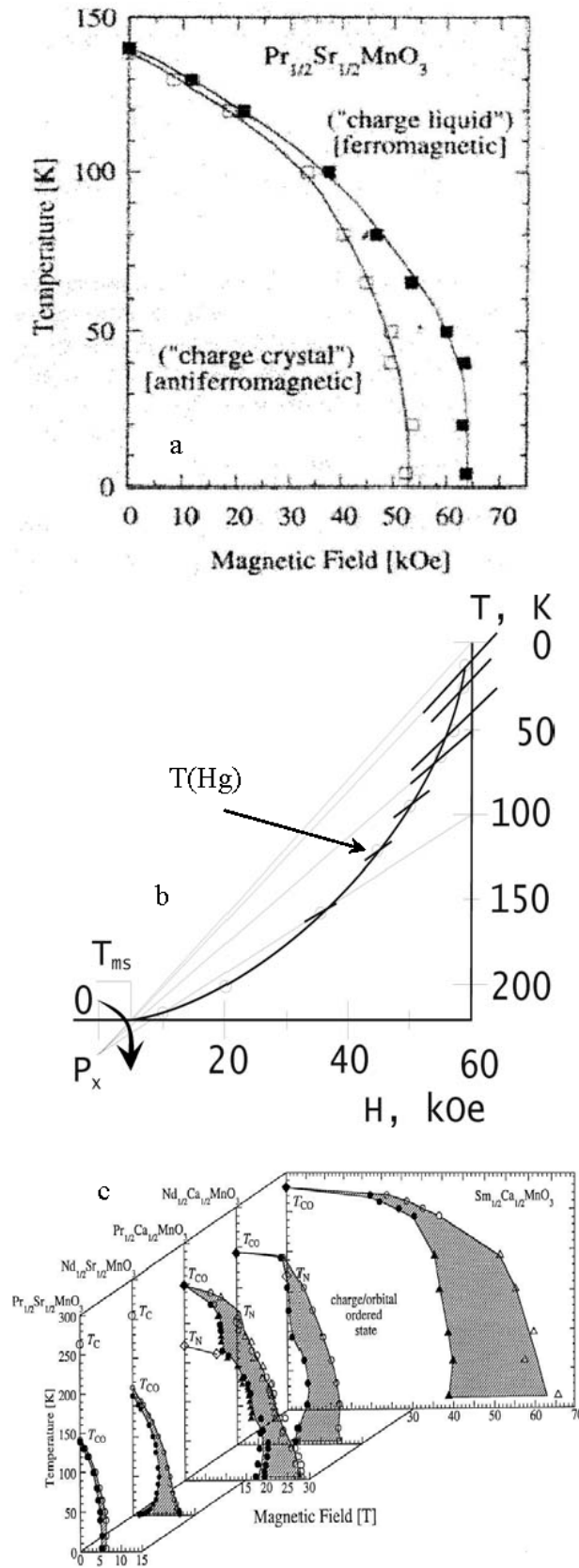


Figure 8.8. a) phase diagram [177] of $\text{Pr}_{1/2}\text{Sr}_{1/2}\text{MnO}_3$; b) Temperature-field dependence of phase transition with critical point P_x ; c) The charge-ordered phase of various compounds $\text{Re}_{1/2}\text{Ae}_{1/2}\text{MnO}_3$ plotted on the magnetic field-temperature plane.

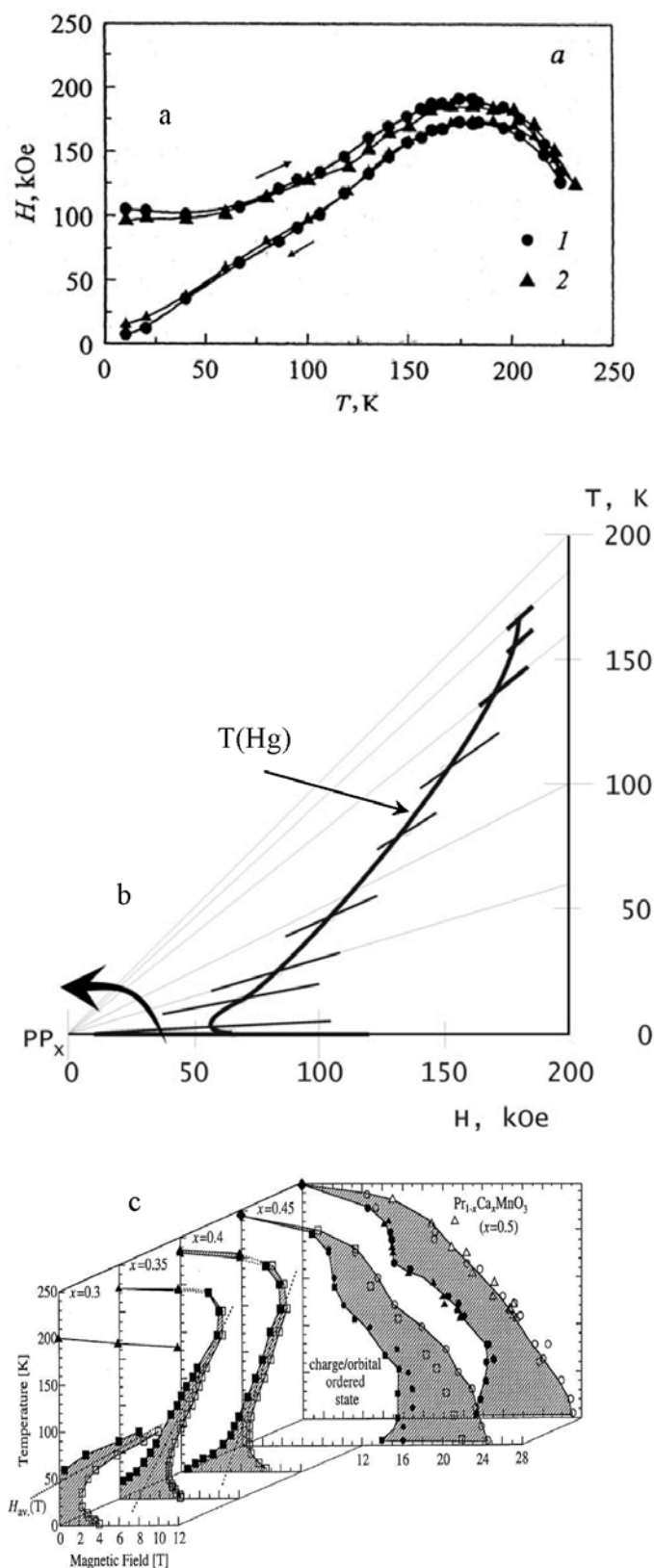


Figure 8.9. a) phase diagram [180] of $\text{Nd}_{1-x}\text{Ca}_x\text{MnO}_3$ ($x=0.45$); b) Temperature-field dependence of phase transition with critical point PP_x ; c) The charge-ordered state of $\text{Pr}_{1-x}\text{Ca}_x\text{MnO}_3$ at several hole concentration plotted on the magnetic field-temperature plane.

regularities also in these papers. We should note that the singled-out $T(H_g)$ dependence (figs. 8.8b, 8.9b) is the average result of the handling of changes of magnetization and magnetostriction. The identity of these properties shows their complete dependence on the mechanisms of magnetoelasticity.

The exhibition of $Pv_{1/2}Sv_{1/2}MnO_3$ phase diagram [177] (fig. 8.8a) as $T(H_g)$ dependence with separated Px critical point and $T_x(H_x T=0)$ shows common regularities with $LaMnO_3$ (fig. 8.1a,b). Only the positions of the singled-out critical points are changed. Similar dependences can be established for the whole manifold of phase diagrams of the varied compositions of $Re_{1/2}Al_{1/2}MnO_3$ (fig. 8.8c). The character of the singled-out dependences is analogous (fig. 8.8b), except the position of the critical lines and points.

The succeeding result is presented in the form of a phase diagram of magnetization and magnetostriction of $Nd_{1-x}Ca_xMnO_3$ monocrystal [180], fig. 8.9a. The cited results have the form of temperature-field dependence $T(H_9)$ (fig. 8.9b) separating superconducting phase and metal analogous to phase transition in $CuCl_2 \cdot 2H_2O$, fig. 8.2b.

The established position of the critical points PPx allowed us to separate the same regularities in phase diagrams of monocrystal $Pr_{1-x}Ca_xMnO_3$ too, where small concentrations of the composition $x=0.3; 0.35; 0.4$ can be treated as a phase transition (fig. 8.9c) analogous to the corresponding structural phase transition in $CuCl_2 \cdot 2H_2O$. The succeeding changes of the composition $x=0.45; 0.5$ result in sign alteration of the position of the critical line (fig. 8.8b) [6] corresponding to the phase transition analogous to monocrystal $LaMnO_3$ behavior (fig. 8.1b, 8.8b) with the singled critical point Px .

We should note that the magnetization of the superconducting phase changes under the influence of T and H in single-phase state.

The derived regularities are justified by the methods of the carried analysis where the causing role belongs to the energy of elastic stresses. If the volume elasticity is not taken into account in model presentations, it means the abandonment of the analysis of the role of elastic energy in formation and evolution of structural phase transitions and properties.

8.5. Conclusions

Contemporary problems related to conducting magnet-containing media entail study of numerous experimental results obtained for systems of various compositions. Being based on the laws of bulk elasticity, new methods are to be used to analyze reversible physical processes induced by thermodynamic parameters.

The investigated objects are finite-size samples prepared by the conventional technology. By the method of high-temperature annealing, the chemical compounds are formed with repeated sites and bonds in the structure. The atomic-electronic binding energy is optimally minimal in that process of

high-temperature heat removal, while stresses are maximal. These are the structure-forming principles of energy distribution. Subsequent cooling directly relates to heat removal and the mechanisms of thermo-elastic compression involved. An obvious evidence is the linearity of the lattice parameter within the temperature range of 300-1000° K [170] in $\text{La}_{0.875}\text{Sr}_{0.125}\text{MnO}_3$ and down to 0°K as shown by our analysis. This is a clear acknowledgement of the role of bulk elasticity in physical processes under the temperature, magnetic field or hydrostatic pressure influence. Such a consideration shows that any heat transfer is also a causal basis of the involvement of mechanisms which modify (expansion-compression) internal elastic stresses. As a consequence, there follows the sign-alternating influence on structure change, i.e. heat application (heating) means the increase of elastic stresses, heat removal (cooling) results in the decrease of elastic stresses. From this standpoint, similar processes are observed when baroelasticity and magnetoelasticity mechanisms are involved as shown by the results of our analysis [185].

The relation between thermodynamic effect through heat-transfer processes and mechanisms of elastically deforming stresses in structure changes has not been exposed finally, that is why their causal role in the formation of properties and PT has not been studied completely by model theoretical representations. This is because there is no complete understanding of relations between heat capacity (heat transfer) and elastic stresses and because of uncertainty in substantiation of the role of these mechanisms and significance of the estimating values of energies in a variety of physical processes studied.

Being a complex inhomogeneous process with peculiar linear regularities, elastic-anisotropic deforming stress can be taken into account with respect to power distribution by means of coefficients, but not always grounded. Moreover, the heat transfer, the heat conduction and elastic stresses are bound in the structure of energies of mobile electrons, and linear changes observed in properties and PT determine the causal role of elasticity, more exactly of bulk elasticity in the processes of T-P-H effect.

When treating the heat transfer as a factor forming elastically deforming stresses in the structure and also redistributing the energy of interactions, we can conclude that in the laws of interactions and conformities one should take into account:

- a) the energy of quantum-mechanical forces determined by the short-range atomic-electronic bonds;
- b) the energy of heat transfer and the related mechanisms of elastically deforming stresses (partially accounted for in molecular-field models) resulting in structure changes.

The T-P-H effect through the properties of elasticity varies the volume, redistributes the energies, thus forming the structural phase transition and properties in each phase state.

The analyzed processes of a fast (linear) increase of magnetization or magnetostriction in the magnetic field show that particles (sites and bonds in the structure) are a great vector (magnetic moment) of magnetic non-compensation. This phenomenon results from the participation in structure formation of numerous individual non-compensated spins, bound electrons in intermolecular (modal) space. It was not possible completely to explain the interactions or the role of elastically deforming stresses in non-compensative processes in theoretical molecular-field models.

Consequently, the model-theoretical representations of the quantum-mechanical statistics are more preferable for the magnetic non-compensation in structure at $T=0^\circ\text{K}$ and with the maximal energy of the atomic-electronic bond and the minimal energy of elastic stresses. Next, the volume increase with thermo-elastic stresses influences the state of structure sites and bonds due to the expansion, and then the long-range forces start operating and magnetic non-compensation goes to zero.

The analysis of the role of magnetic properties and relation thereof to elastic regularities of T and H effect on structure changes rises a question about the formation of conditions for origination of T_c critical point. As the internal energy is a factor of conformities and interactions between binding energies and internal stresses, then T_c is the temperature of conformity for thermoelastic expansion and magnetoelastic compression.

Numerous results obtained for LaMnO_3 , $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, $\text{Eu}_{0.55}\text{Sr}_{0.45}\text{MnO}_3$, $\text{La}_{0.56}\text{Ca}_{0.24}\text{Mn}_{1.2}\text{O}_3$ are based on new representations, which assume that there exists the direct correlation between structure changes and regularities of elastically deforming stresses. Let us state that there is the redistribution between interactions and conformities of the atomic-electronic binding energy and the energy of elastic stresses in physical processes. In other words, this correlation of structure changes can be treated as the law determining the degree of conformity and correlation between heat flow (heat capacity) and the energy of elastic stresses. As noted, this correlation is always present.

Accounting for direct relationship between structure, regularities of elasticity, electronic and magnetic properties, PT, new approaches make it possible to explain the anomalies, peculiarities, effects through described regularities. The applied analytical methods allowed to determine the role of stresses in the formation of structural phase transitions with the unusual location of critical points and phase states at 0°K . This fact was a reason for finding generalizing principles named secondary indications that determine and fix the position of PT at 0°K . These indications are:

- a) unambiguous location of maxima of thermo-baro-resistive, thermo-baro-magneto-resistive effects at $T_{pp}=0^{\circ}\text{K}$ corresponding to the structural phase transition, Fig. 8.6d;
- b) single-phase influence of T and H on changes of magnetization properties at the initial section of the dependence and the antiphase influence on the same properties after the phase transition, Figs. 8.2a, 8.3c, 8.5c;
- c) the revealed regularity of magnetization properties in the region of structural phase transition into inverse (anomalous) hysteresis effect, Figs. 8.2a, 8.3a, 8.4a, 8.5d;
- d) a sign-alternating effect of temperature on magnetization properties in different phases, Figs. 8.2a, 8.3a, 8.4a, 8.5d;
- e) succession in positions of mentioned points PP_x and P_x and their direct relation to the field-temperature dependence $T_p(H)$, the boundary separating the superconducting and conducting phase states, Figs. 8.6c, 8.4, 8.3b, 8.2b.

The given results (Figs. 8.5a, 8.6a) show that the phase with dielectric properties becomes apparent in physical processes of volume change at the expense of mechanisms of the decrease of stresses down to the temperature of the structural phase transition at 0°K . That is the process that determines the mechanisms of stress concentration preventing the mobility of conduction electrons. The stress concentration is also present in the region of semiconducting phase (Fig. 8.7a) where the parameter changes from the critical point P_x' and the volume starts decreasing. This is observed for the dependence of resistivity with T decrease and P, H increase and change of structure symmetry from a high value down to lower one (Fig. 8.6a). These facts enable us to conclude that the critical point of the structural phase transition at $T=0^{\circ}\text{K}$ meets the requirements of a triple point, i.e. the point of dielectric, superconducting and conducting (metallic) phase convergence.

For a more complete understanding of the laws of bulk elasticity in physical processes it is very important to analyze the significance of the mentioned critical lines and points for the formation of structural phase transitions and properties.

The demonstrative is the result of intersection of approximated dependences at the critical point P_x' (Fig. 8.7a). The presence of three parameters (T-P-H) and the revealed regularities of their influence on the resistance has specified the approaches to substantiate the role of mechanisms of elastically deforming compression in the formation of structural phase transitions and the region of stress concentrators in semiconducting phase. The position of P_x' critical point (Figs. 8.7a, 8.6a) shows the sequence of the physical process forming the region of PT in the form of a jump of resistivity followed by the transition to conducting (metallic) phase where the changes

obey the law of linear elasticity. This result has made it possible to establish a very important factor of conformities in T-P-H ratio ($6.3^\circ\text{K}-1 \text{ kbar}-2.3 \text{ kOe}$) and to assume that the backpressure and H decrease the level of elastic stresses in the structure. This is confirmed by changes (decrease) of resistivity properties by analogy with the thermoelastic compression.

Being the most prominent in regularities of hysteresis, differences of anisotropy, magnetoelasticity and thermoelasticity are shown by linear changes of $T_{ms}(H)$ and $T_{ms}(P)$, Fig. 8.7a.

Here we add the result of distinction of the temperature maxima of magneto-, baro-, magneto-baro-resistive effects $T_{PP}=T_{mc}$ (Fig. 8.7b). This is a straight confirmation of the formed structural phase transition. For this result the physical processes are located in the region of thermoelasticity priorities. This follows from the revealed correspondences between T, H and P.

One more important result adds to the role of bulk elasticity in magnetostriction dependences (Fig. 8.1a), which are linear by definition due to priorities of magnetoelasticity. It became possible to specify P_x , PP_x critical points and the regular changes of the field-temperature dependence $T(H_g)$ (Fig. 8.1b). Those are the regularities of the dependence of complex processes of elastically deforming stresses in the structure that point to the separation of phase states limited by P_x and PP_x . Here we also pay attention to the antiphase effect of temperature and to the formation of structural phase transition in the region where magnetoelastic stresses are of priority for H increasing; the mechanisms of thermoelasticity are involved with T decrease, and this is demonstrated by the revealed regularities. It becomes possible to approximate the magnetostriction properties on the dependences for $T=0^\circ\text{K}$ and to show the role of mechanisms of magnetoelastic stresses under the maximal magnetic non-compensation resulting from the minimal volume for $T=0^\circ\text{K}$. As a result, the position of PT has been determined and the role of magnetoelastic anisotropy has been shown to be defining T_x ($H_x - 205 \text{ kOe}$, $T=0$), Fig. 8.1a,b. It follows that position of T_c is, by definition, a fact of averaged conformity of elastic stresses with the change of priorities, under the realization of structural phase transition between $T_{mc}(H=0, T_{PP})$ and $T_x(H_x, T=0)$.

Positions of critical points are connected with changes in volume; it is also a consequence of chemical composition, technology of preparation and the intrinsic magnetic non-compensation as well as the reaction of volume on T-P-H effect through the mechanisms of elastic stresses. It is worth to note the regularities in the hydrostatic pressure (P) effect (Fig. 8.1a), all the critical points are invariable for the composition under consideration, while the properties and position of PT dependence vary anti-clockwise with respect to $T_x(H_x, T=0)$.

The most demonstrative is the result where regularities in changes of properties and PT allow to register superposition of critical points PP_x and P_x

(Figs. 8.2a, 8.3b, 8.4b, 8.6c). The elastic regularities of T-P-H effect have been revealed. They corresponded to 1°K -4kOe -3kbar by the linear change of magnetization properties.

The analysis of relationship between structure peculiarities and bulk elasticity in a real physical process has shown that the structural phase transition may exist at $T=0^{\circ}\text{K}$. Moreover, the experiment gave the result close to that parameter. This effect is accompanied by a high jump of the properties, including heat capacity and susceptibility. Its parameters are $T_x(H_x=6.5$ for $T=0^{\circ}\text{K}$), Fig. 8.2a,b. This means that the magnetoelastic ($H_x=6.5$ kOe) stresses correct the position of the structural phase transition for $T=0^{\circ}\text{K}$. Next, the field-temperature dependence differentiates the phase states of superconducting and conducting phases. Here we note that $T_P(H)$ dependence (Fig. 8.2a,b) much differs from $T(H_g)$ (Fig. 8.1a,b) first of all by critical line position of different sign [6] and by existence of critical point $P(H_P, T_P)$. This regularity of changes in phase transition is connected with position of point PP_x , in the results under consideration, and this is the defining factor for the formation of superconducting phase. It also shows the role of stresses in the effect of anomalous hysteresis within the region of structural phase transition. These results demonstrate the antiphase effect of the temperature on properties for separate phases.

The critical point of the phase transition at $T=0$ K functions as a triple point. In this region under thermo-elastic compression, the mechanisms concentrating the stresses start operating to realize a jump of properties when the region of phase transition is formed and this hinders the dynamics of the conduction-electron mobility. Subsequently, structural phase transition results in considerable changes of heat capacity, resistivity, magnetization, thus characterizing the superconducting and conducting phases as they are.

Our attention is paid next to numerical parameters of conformal influence of T-P-H. They are equal to 1°K -3 kbar- 4 kOe. We also note the position of the parameter where the region of field-temperature dependences $T_P(H)$ and $T_P(H,P)$ (Fig. 8.2a) is limited by $P(H_P, T_P)$ point. This critical point limits the region of existence of phase states, it can be determined for any structures by investigating properties and PT under the influence of high hydrostatic pressures.

The analysis of the role of P_x' point where resistive dependences intersect each other (Fig. 8.6a, 8.7a) in the physical process of volume change under T-P-H influence through mechanisms of elastic compression is worth mentioning too. These results confirm regular participation of the mechanisms in the effect of colossal magnetoresistance being under study for many years.

By using new approaches to analyze the results of investigations, when the defining role of the effect of thermodynamic parameters T-P-H is considered in view of the mechanisms of elastic stresses, it is possible to explain

numerous anomalies, peculiarities and effects by relationships between structure and elasticity.

The presented generalizing analysis shows the correspondence and interaction of binding energy and elastic energy. The neglecting of this energy [172] in the course of model theoretical analysis results in practical refusal of an important part of the energy that forms and changes the phase transition and properties.