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Low temperature
properties of solids II

Techniques
and applications

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Proceedings of the 21st International Conference on Low Temperature Physics
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Part S4 - LT Properties of Solids 1: Magnetism (theory)

Low critical temperature structural phase transitions induced by magnetic fields

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1. INTRODUCTION.

Microscopic theory of the structural phase transitions based on the cooperative Jahn-Teller effect approach [1] has lately attracted more and more attention as a possible way to improve the understanding of the fundamental properties of matter. This approach is directly connected to the microscopic mechanisms of ferroelectricity, high temperature superconductivity in Cu-based and C_{60}-based superconductors, colossal magnetoresistance of manganites and other phenomena in modern physics. Studies of the influence of the magnetic field on the structural phase transitions are of great importance for the analysis of the electron-phonon mechanism of structural transitions and of new anomalous properties of the materials.

2. CRYSTALS, HAMILTONIAN AND MECHANISM.

The phenomenon of magnetic field induced structural phase transitions [2] is considered for the dielectric rare earth compounds with zircon structure. The crystals are tetragonal at all temperatures in the absence of an external magnetic field and suffer structural transitions to the orthorhombic phase under critical value magnetic fields oriented at 45^0 to the a, b(=a) axes in the crystal plane.

The Hamiltonian of the systems under consideration contains the electron-phonon and electron-strain interactions, the energy of the electronic subsystem in the crystal field, the Zeeman interaction and the elastic energy of the strained crystal. The shift canonical transformation of the Hamiltonian leads to the effective electron-electron correlations responsible for the possible structural phase transitions.

The possibility for the structural transition to occur depends primarily upon the strength the interelectron interactions and the value of the energy gap between the ground singlet and the first excited doublet of the rare earth ions. The electron correlations are not strong enough to induce a structural transition in the absence of the magnetic field. However sufficiently strong magnetic fields at particular orientations can affect the electronic subsystem changing the interlevel energy gap and the effectiveness of the vibronic mixing of the electronic states. As a result of that the virtual phonon exchange interaction of the electrons becomes sufficiently great for the structural phase transitions to occur in the crystals under consideration.

3. RESULTS , NUMERICAL CALCULATIONS.

The properties of materials with magnetic field induced structural transitions were analyzed for the $Tm_xLu_{1-x}PO_4$

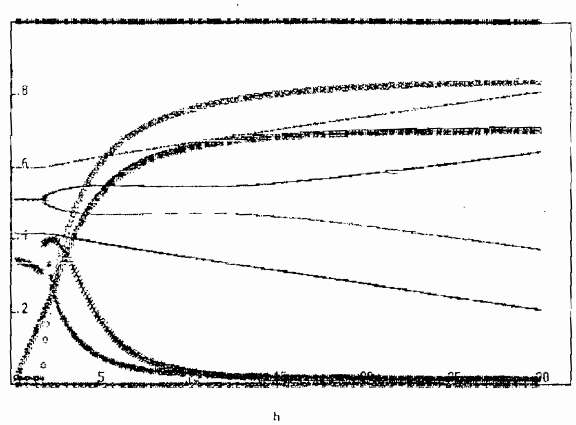

FIGURE 1. The order parameter, its derivative w.r. to h (sharp peak at h=2), the magnetization, and susceptibility are plotted as a function of h. Included are the 4 energy levels as a function of h. One notes that at h=0 the order parameter is 0. There is a discontinuity in the susceptibility at the transition where the order parameter becomes finite. The graph is for Δ =9, A=8.6 and T=0.9

and $Tb_xY_{1-x}VO_4$ crystals. It was shown that depending upon the concentrations of the Jahn-Teller rare earth ions, energy gap between the electronic levels, and the values of the magnetic fields none, one, or two structural phase transitions are possible. In the accompanying figures we show the results of the calculations of the temperature and magnetic field dependence of different magnetic, acoustic and magnetoacoustic properties of the crystals.

We would like to note the unusual magnetic field and temperature dependences of dynamic magnetostriction (static and dynamic)[3] and magnetic susceptibility (magnetic moment). The magnetostriction in the systems under consideration is not only anomalously large, but has, in addition, unusual behavior with the magnetic field (the static striction is not squared in Δ H=H-H$_{cr}$) and unusual behavior with the temperature (the sharp peak of the dynamic striction). The magnetic susceptibility has a very specific anomaly connected with the magnetic nonlinearity caused by the electron-phonon interaction.

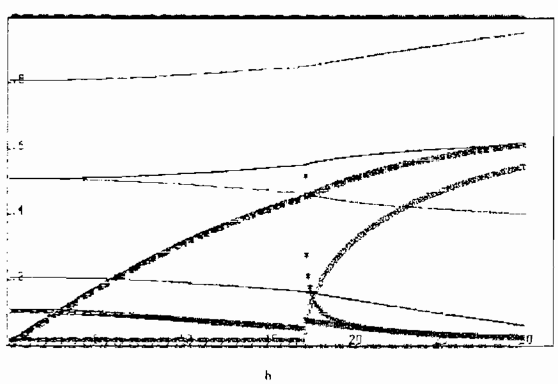

FIGURE 2. Same properties as in Fig. 1 but with Δ =30, A=22.7 and T=3. Again the order parameter of zero at h=0 and becomes finite at much higher h.

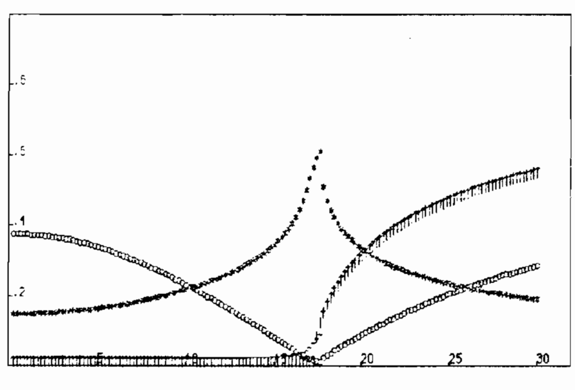

FIGURE 3. Elastic constant, its field derivative (peak), and order parameter as a function of h. Same parameters as in Fig. 2

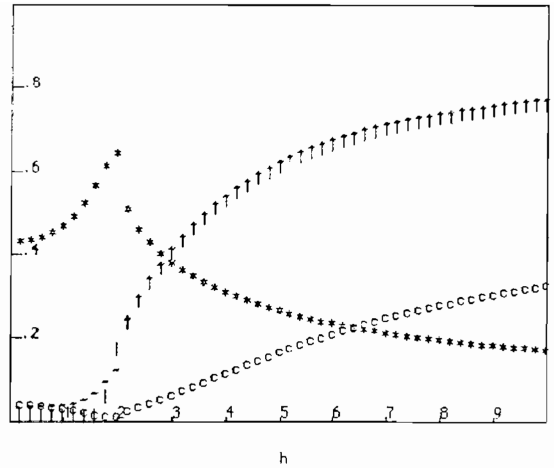

FIGURE 4. Elastic constant, its field derivative (peak), and order parameter as a function of h. The h-axis is magnified. Same parameters as in Fig. 1.

4. CONCLUSIONS

The microscopic mechanism of magnetic field induced structural phase transitions in Jahn-Teller crystals is studied and different properties of the materials are calculated. The phenomenon was experimentally observed at the giant magnetostriction measurements in the impulse magnetic fields and in the Raman scattering for the $TmPO_4$ crystals.

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