

THE “SOFT” PHASE TRANSITION – WHAT IS IT?

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In according with Ehrenfest classification, phase transitions of the first and second orders are distinguished. As to the third order phase transitions, according to [1] they are simply impossible. So, the mentioned classification based on consideration of Gibbs thermodynamic potential and its first and second derivatives seems to be completely full. It is not so, however. The results of our investigations of superparamagnetic particles properties (on the basis of Langevin model modified by the molecular field theory) lead to this conclusion.

In Figs. a and b one can see the most essential results of investigations of temperature-field dependences of magnetic susceptibility for identical superparamagnetic particles ensemble in the Curie point T_C region. In these Figures: χ is the specific magnetic susceptibility, M_0 is the specific magnetization at absolute saturation, N is the “nominal” magnetic moment of a particle expressed in the Bohr magnetons, $\tau (\equiv T/T_C)$ is the reduced temperature, H_{crit} is the critical magnetic field for the phase transition “paramagnetism – induced superparamagnetism” [2], $\Delta\chi$ is the jump of the magnetic susceptibility at this phase transition.

As we see in Fig. a (in the case of nanoparticles with $N = 500$ and $T_C = 300$ K), the nearer the temperature of phase transition “paramagnetism – induced superparamagnetism” to T_C , the smaller the jump of second order derivative of Gibbs potential (whose role the magnetic susceptibility χ plays). In the limit at $\tau = 1$ we have, consequently, the phase transition which is “softer” than the second order one by Ehrenfest.

An analysis of dependence of the jump $\Delta\chi$ on the particle “size” N at $\tau = 1$ (Fig. b) leads to the same conclusion as well. Indeed, the temperature phase transition for ferromagnetic particles ($N > 10^9$) occurs at $\tau = 1$ as usual second order phase transition ($\Delta\chi \neq 0$), whereas for nanoparticles ($N < 10^6$) it is the “soft” transition in the mentioned sense.

[1] I.P. Bazarov, V.V. Bondarenko. On the impossibility of the third and higher order phase transitions. J. Phys. Chem. (Russia). 1996. 70, № 7. P. 1198– 1200.

[2] V.I. Nikolaev, T.A. Bushina, Kim Eng Chan. On magnetic properties of superparamagnets in the Curie point region. J. Magn. and Magn. Mater. 2000. 213, № 1–2. P. 213–218.