SPECIFIC HEAT OF THE ONE-DIMENSIONAL COMPRESSIBLE ISING MAGNET WITH THE EINSTEINIAN PHONON SPECTRUM

S.Milošević* and M.Mijatović**

*Department of Physics and Meteorology, Faculty of Science, Belgrade and Institute of Physics, Belgrade

**Faculty of Physics, Skopje

The Einstein's specific heat theory[1] was the first application of the Planck quantum theory to the condensed matter physics. It was done with a quite clear motivation: "If Planck's theory of radiation contains any seed of truth, then we should expect that in other parts of the heat theory we can find such discrepancies, between the current kinetic theory of heat and experiments, which could be unravelled in the same way. To my mind this actually is the case, as I will show in what follows"[1]. Einstein represented a crystal composed of N particles by 3N non-interacting, quantum-mechanical oscillators, all having the same characteristic frequency ν (a strict monochromatic approximation). Thereby he obtained the average energy of crystal, at the ambient temperature T, and the corresponding specific heat. The latter had the desired virtue of being temperature-dependent. It approached the classical Dulong-Petit law at high temperatures, and vanished (exponentially) as Z goes to zero.

Experimental investigations of W.Nernst showed that the Einstein's specific heat formula was qualitatively correct, but a systematic deviation from the experimental data was observed. Einstein explained that this deviation was due to the fact that oscillations in a crystal are "far from being monochromatic"[2]. Today we know that it was a correct explanation, but in those days even Nernst did not agree with

Einstein [3]. It fact, soon aftewards P. Debye [4] proposed a virtually exact polychromatic model, which acquired excellent confirmations from experiments, in particular at low temperatures where it predicts that the spceific heat vanishes as T^3 rather than exponentially.

Nowadays, at least one paragraph in any textbook on statistical physics, or solid state theory, is devoted to the Einstein model. Here we want to point out that this model has retained its heuristic character as well. We consider the recently discovered spin-Peierls transition, which can be defined as a progressive spin-lattice dimerization occurring in certain quasi-one-dimensional magnetic chains[5]. Within the scope of this interesting phenomenon we study the one-dimensional Ising spin system interacting with a single phonon mode of the harmonic lattice. The Hamiltonian of the system is

$$= -J_0 \sum_l S_l S_{l+1} - J_1 \Delta \sum_l (-1)^l S_l S_{l+1} - J_2 \sum_l S_l S_{l+2} + N\omega_0 \Delta^2 \qquad (1)$$

where J_0 and J_2 are the exchange coupling constants of the nearest and next-nearest neighbour interactions, whereas J_1 is the first derivative of the exchange energy with respect to the distance (taken at the average distance a). The lattice distortion parameter is Δ, and ω_0 is the characteristic latice frequency. S_l is the conventional Ising variable ($S_l = \pm 1$), and N is the number of spins.

The Hamiltonian (1) differs from that one treated previously[6,7] by presence of the second term. Consequently, it turns out that a relatively strong spin coupling J_0 should not necessarily push the appearance of lattice distortions to lower temperatures and eventually destroy it, as it was concluded[6,7] in the case $J_2 = 0$. We have established this result by an exact derivation of the spin system free energy, and by an analysis of the corresponding self-consistent equations for the lattice distortion parameter and the two-spin correlation functions[8,9]. In particular, we have shown that the specific heat anomaly persists at higher temperatures if $J_2 \neq 0$ is taken into account[8]. Thus, the overall picture, based upon the simple Einsteinian phonon spectrum, makes us believe that a magnetoelastic phase transition similar to the spin-Peierls transition can take place in the quasi-one-dimensional Ising chains.

REFERENCES

1 A.Einstein, Ann. Phys. 22, 180 (1907)

2 A.Einstein, Ann. Phys. 35, 679 (1911)

3 A.Einstein, in "Conseil de Physique, Institute Solvay, 1911. Raports", (Paris, Gauthier 1912), p. 407.

4 P. Debye, Ann. Phys. 39, 789 (1912)

5 I.S. Jacobs et al., J. Magn. Magn. Mater. 15-18, 332 (1980)

6 K.A.Penson, A. Hotz and K.H.Bennemann, Phys. Rev. B 13, 433 (1976)

7 A.Oguchi, Progr. Theor. Phys. 57, 1102 (1977)

8 M.Mijatović and S.Milošević, J. Magn. Magn. Mater. 15-18, 1029 (1980)

9 M.Mijatović and S.Milošević, Phys. Letters 79A, 196 (1980)