Complete diagonalization studies of doped Heisenberg spin rings

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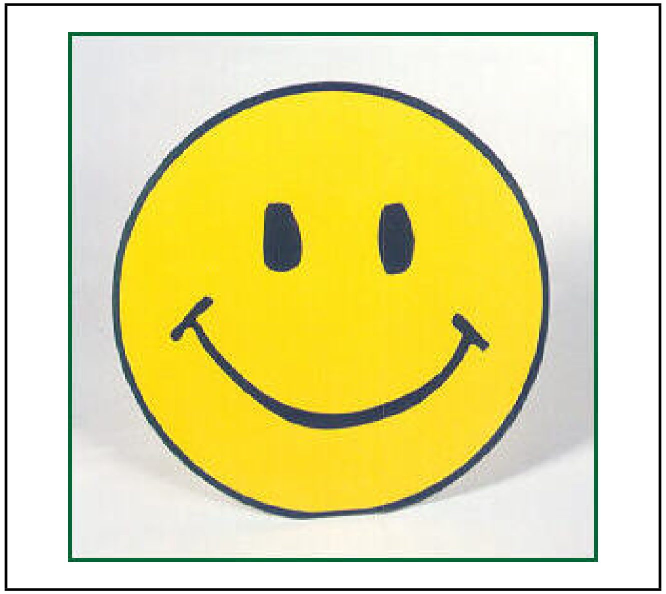
Sorry, I am a bloody beginner on cuprates

A good strategy for a beginner certainly is to ignore everything that was done before!



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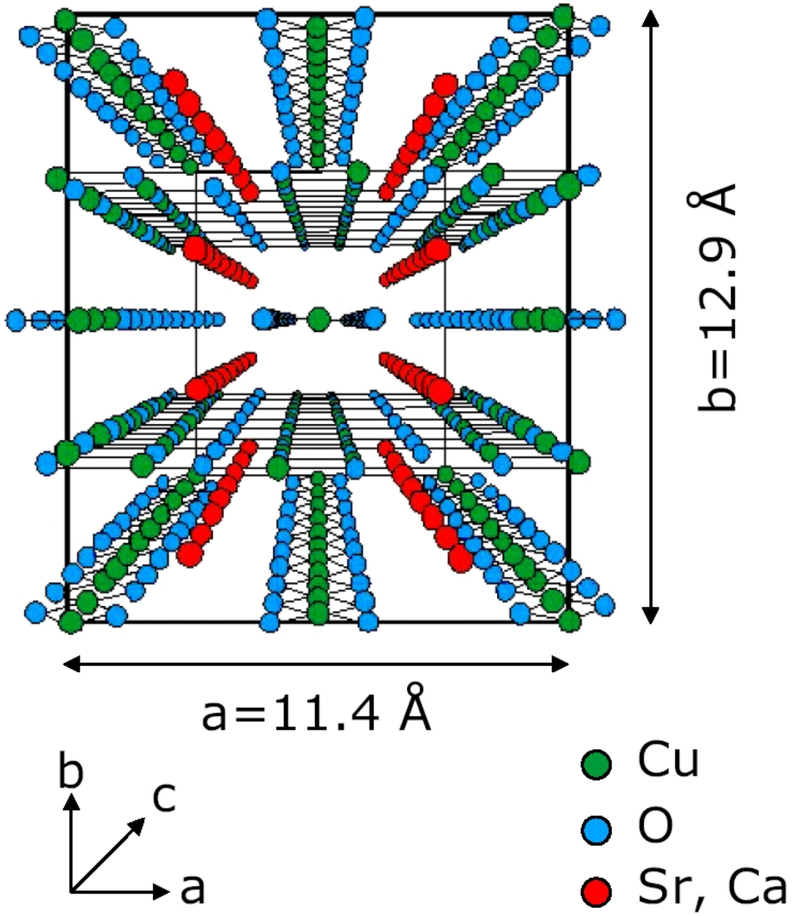

$Sr_{14-x}Ca_xCu_{24}O_{41}$

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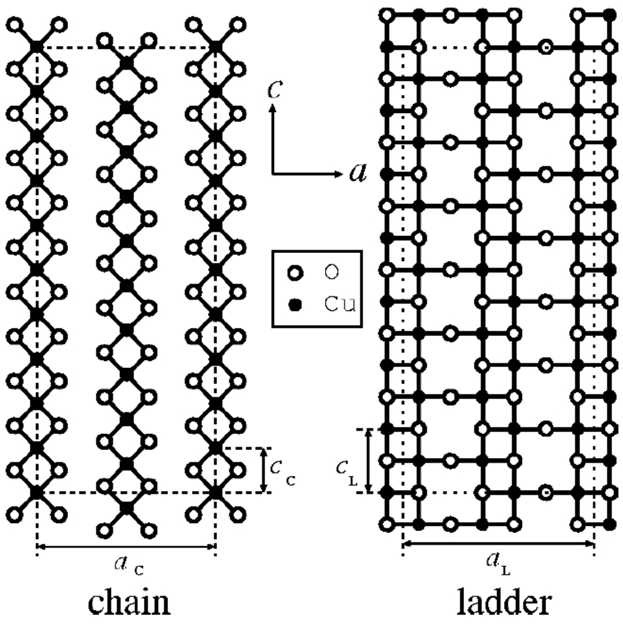
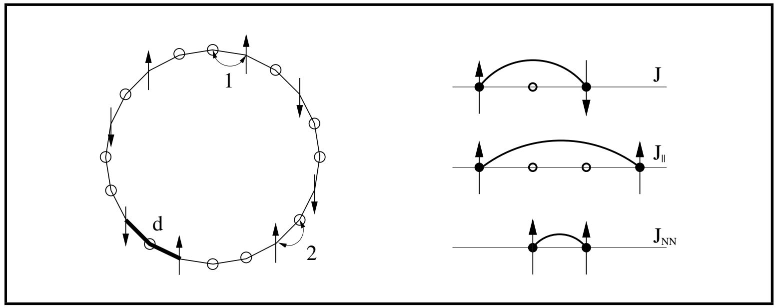
Introduction



Fukuda, Mizuki, Matsuda

- “telephone number compound” $Sr_{14}Cu_{24}O_{41}$ contains two magnetic one-dimensional structures, chains and ladders;
- at low T ladder subsystems magnetically inactive due to a large spin gap;
- investigate magnetic properties of the chain subsystems with the help of a Heisenberg Hamiltonian that depends parametrically on hole positions;
- screened electrostatic hole-hole repulsion is taken into account;
- assume 60 % holes in the chain for the undoped compound;

Model



Heisenberg Hamiltonian depends on spin-hole configuration $\vec{c}$

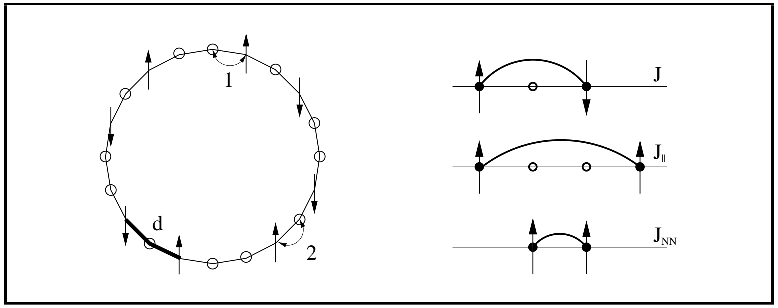
$$\underset{\sim}{H} = \sum_{\vec{c}} \left(\underset{\sim}{H}(\vec{c}) + V(\vec{c}) \right) \quad , \quad \underset{\sim}{H}(\vec{c}) = - \sum_{u,v} J_{uv}(\vec{c}) \; \underset{\sim}{\vec{s}}(u) \cdot \underset{\sim}{\vec{s}}(v)$$

$J = (-64, -67, -70)$ K, $J_{\|} = 5.8$ K, $J_{NN} = 8.7$ K

Debye-screened electrostatic hole-hole repulsion ($\lambda_D = \infty$ in the following)

$$V(\vec{c}) \quad = \quad \frac{e^2}{4\pi\epsilon_0 \, \epsilon_r \, r_0} \frac{1}{2} \sum_{u \neq v} \frac{\exp\left\{-r_0|u-v|/\lambda_D\right\}}{|u-v|}$$

Discussion of the model



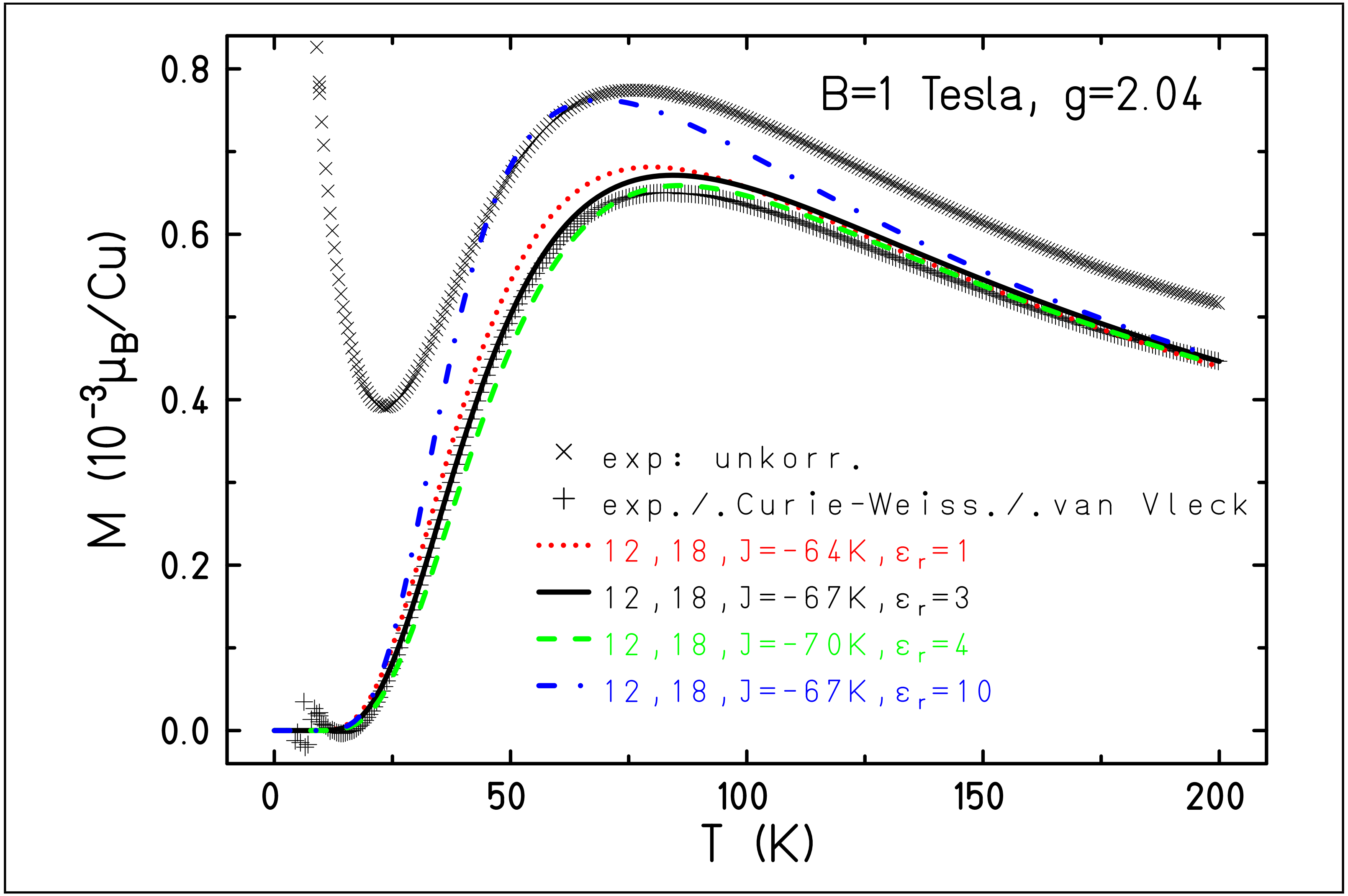
- Ansatz is similar to a simple Born-Oppenheimer description where the electronic Hamiltonian (here spin Hamiltonian) depends parametrically on the positions of the classical nuclei (here hole positions);

- Heisenberg Hamiltonian can be diagonalized for each spin-hole configuration;

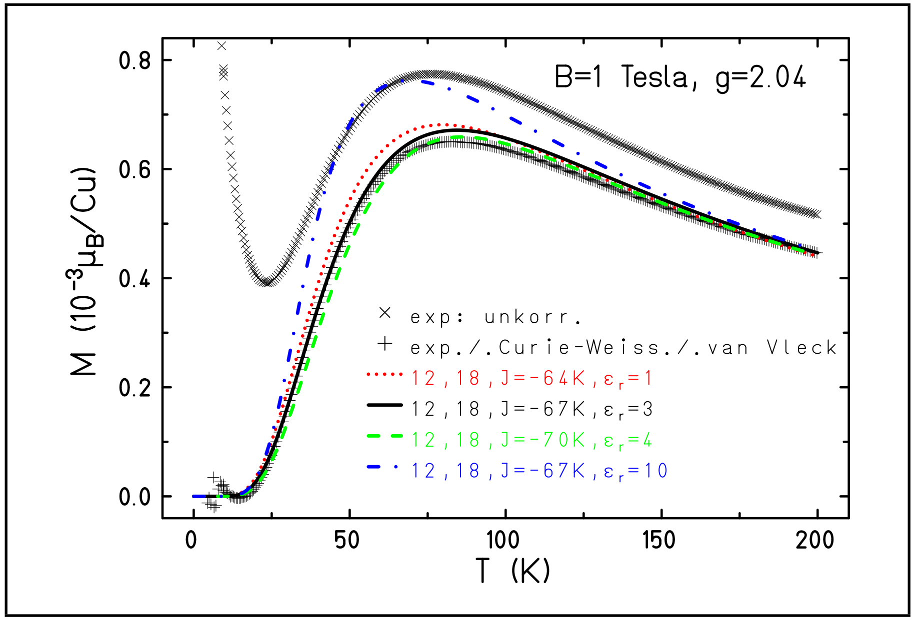
- Screened electrostatic potential energy is the additional energy offset: $E_\nu(\vec{c}) = E_\nu^{\text{Heisenberg}}(\vec{c}) + V(\vec{c})$;

- All thermodynamic quantities can be evaluated without further approximation. Various spin-hole configuration may contribute according to the Boltzmann weight of their energy levels.

60 % holes on the ring



60 % holes on the ring – discussion

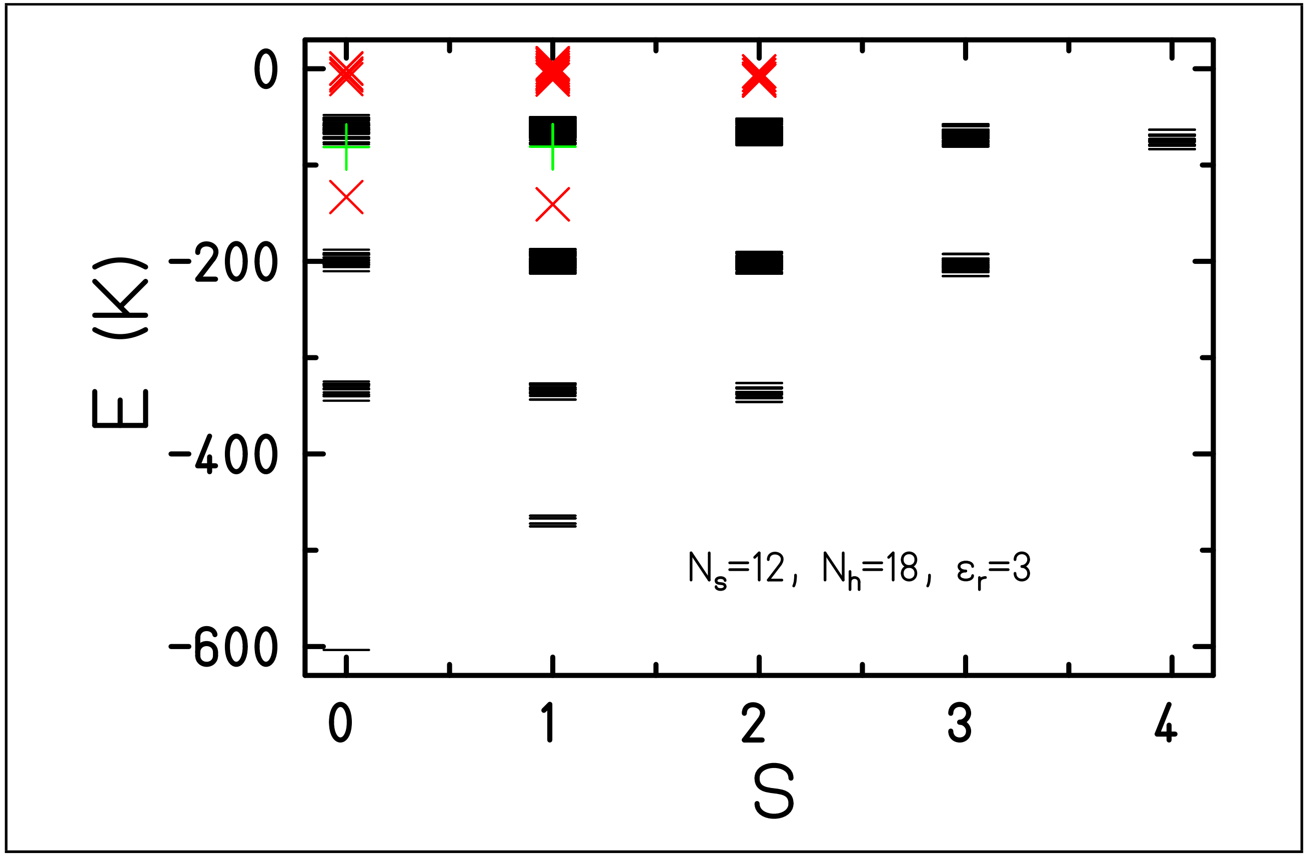


- Ground state indeed dimer-configuration; nearest-neighbor Coulomb repulsion wouldn't be sufficient;
- Magnetization curve strongly dependent on J and ϵ_r;
- For $\epsilon_r = 1$ only the dimer configuration contributes; for $\epsilon_r \gtrsim 3$ several hole configurations contribute with their respective magnetic spectra.

- It seems that $\epsilon_r \approx 3$, which is in good agreement with a dielectric constant of 3.3 found in Ref. [1];

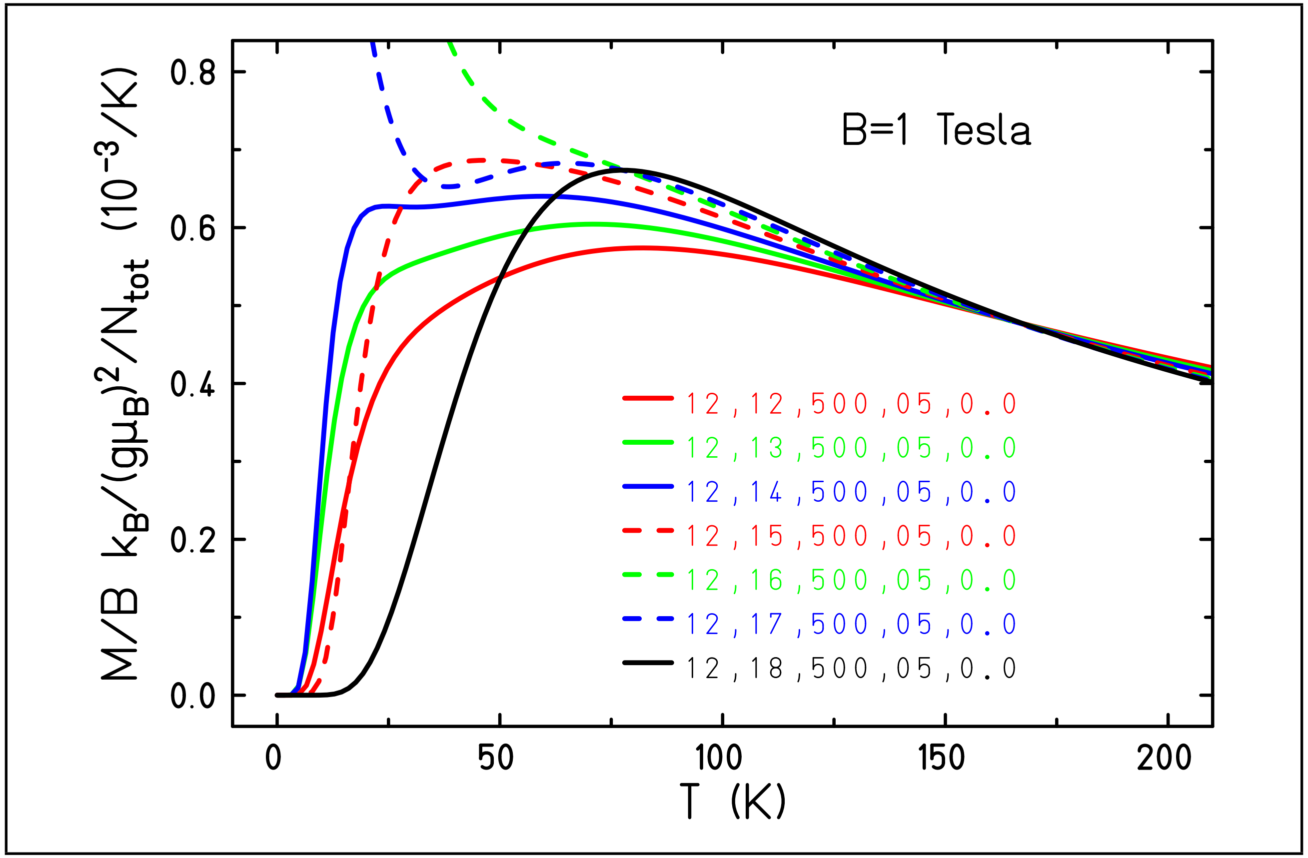
[1] Y. Mizuno, T. Tohyama, and S. Maekawa, Phys. Rev. B **58** (1998) 14713

Low-lying excited hole configurations

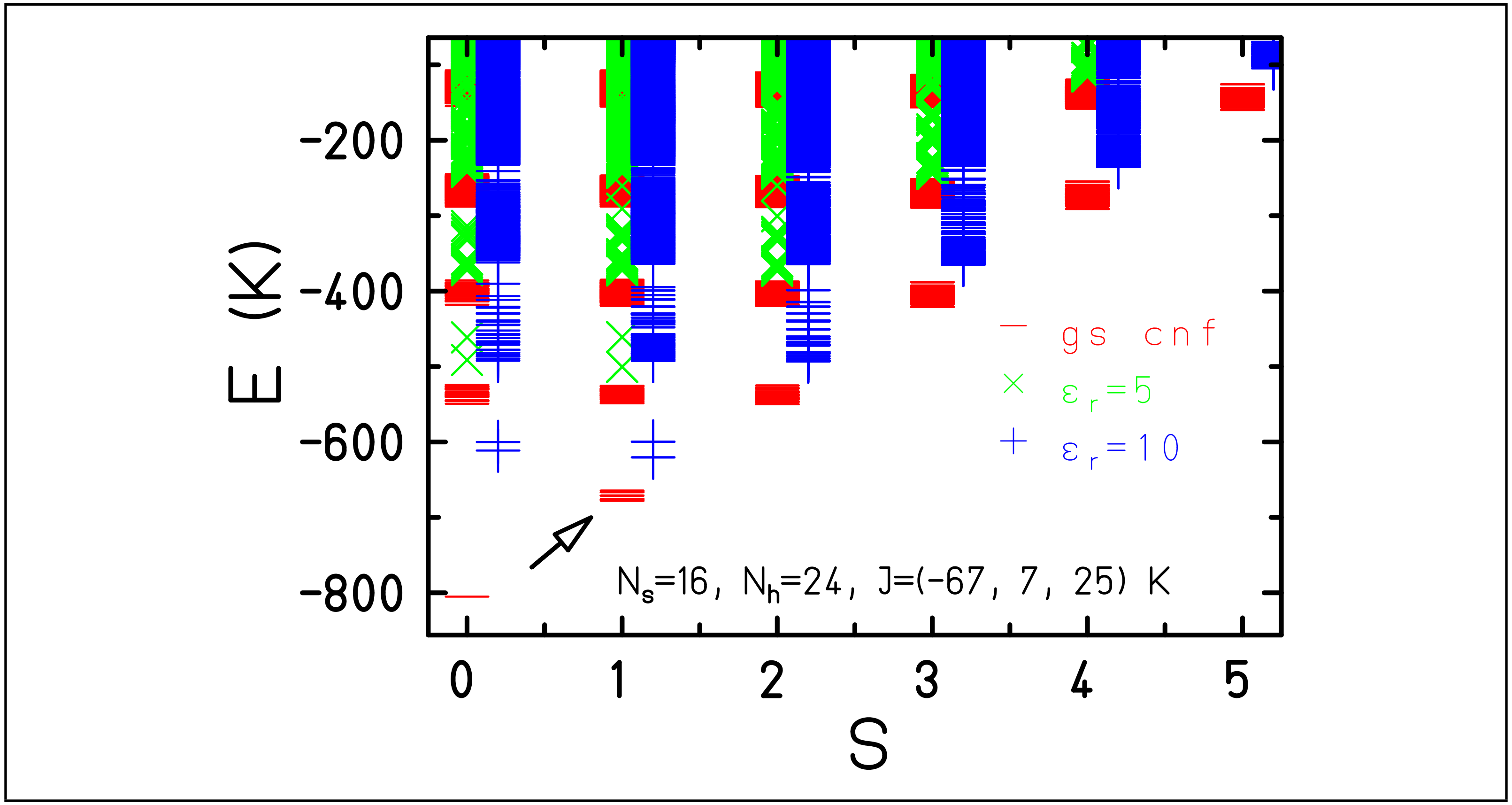


black dashes – dimer configuration, red x-symbols – one hole moved, green crosses – two holes moved

50 % – 60 % holes

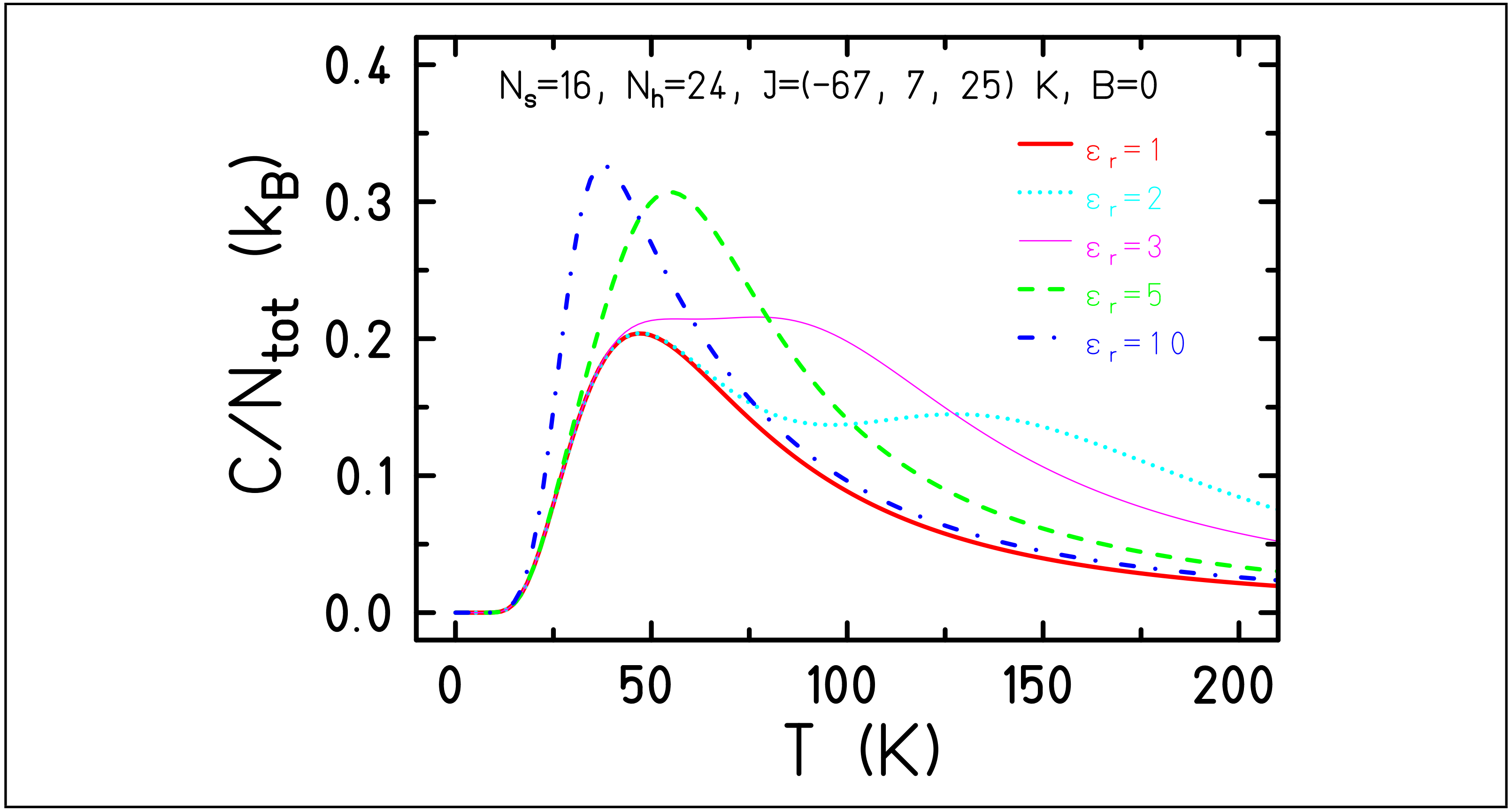

B=1 Tesla
12,12,500,05,0.0
12,13,500,05,0.0
12,14,500,05,0.0
12,15,500,05,0.0
12,16,500,05,0.0
12,17,500,05,0.0
12,18,500,05,0.0
M/B $k_B/(g\mu_B)^2/N_{tot}$ $(10^{-3}/K)$
T (K)
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200

Coulomb effects – levels



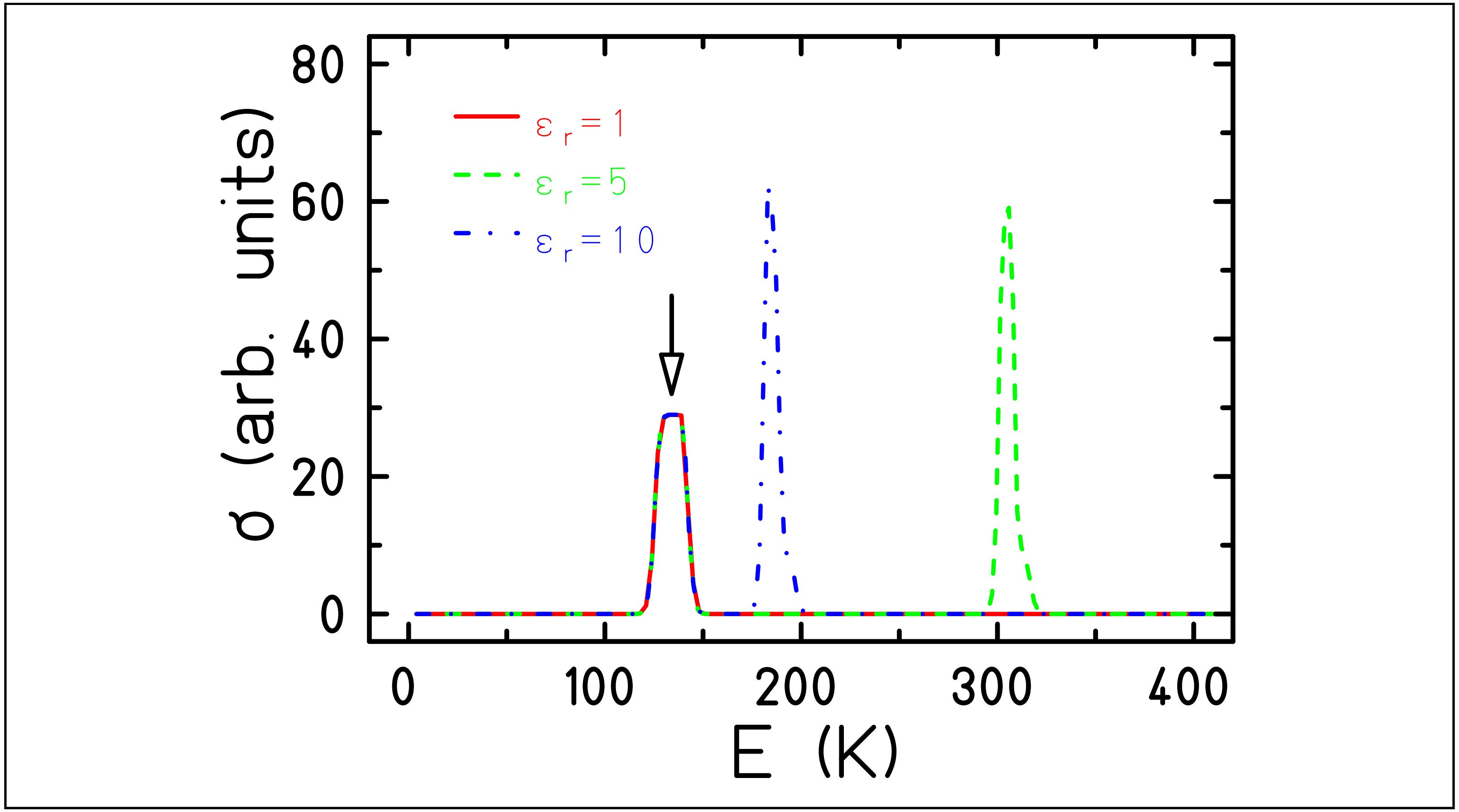
$\lambda_D = \infty$, dielectric constant ϵ_r is the only free parameter.

Coulomb effects – specific heat



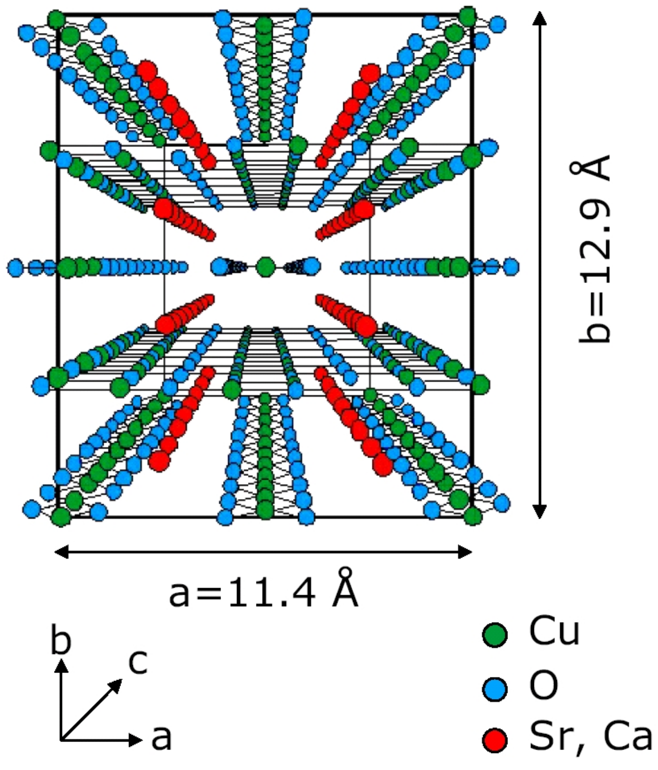
The high degeneracy of excited hole configurations plays an important role, since they substantially contribute to observables at low temperature although lying rather high in energy.

Coulomb effects – inelastic neutron scattering



Rough sketch of the lowest transitions observable with inelastic neutron scattering. The arrow marks the singlet-triplet transition at about 135 K.

Outlook



$Sr_{14-x}Ca_xCu_{24}O_{41}$

- Model depends on four parameters $(J, J_{\|}, J_{NN}, \epsilon_r)$;
- Refine model using the wealth of accumulated magnetization data;
- A direct measurement of the energy needed to excite hole movements would be very valuable since it would put additional restrictions on the range of the dielectric constant ϵ_r – INS?;
- Intermodel comparison with Hubbard and $t{-}J$ model (Fatiha Ouchni). First results show that a strong Coulomb repulsion indeed leads to localized holes on the chain.

Thank you very much for your attention.

Special thanks to

- Dr. Rüdiger Klingeler for endless discussions and for providing magnetization data;
- Prof. Dr. Bernd Büchner for valuable discussions;
- Fatiha Ouchni for drawing my attention to the existing literature and for challenging my ideas.