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Peer Review

Review of: "Anomalous Scaling and Magnetization Temperature Dependence in Cubic Ferromagnetic Crystals"

Pavel Pokhilko[1]

1. University of Michigan - Ann Arbor, United States

The preprint is very interesting! I enjoyed reading it, especially the appendix. The work can be very useful in the future since it allows comparisons with alternative approaches in quantum magnetism for the Heisenberg model, such as the high-temperature expansion, QMC, exact diagonalization, etc.

The overall calculation of the critical phenomena is a very difficult problem due to several issues:

1. The model validity is often unclear.
2. An accurate determination of the model parameters can be difficult.
3. Within the given model, accurate predictions of critical phenomena can also be difficult due to diverging terms, slowly converging corrections, and finite-size effects.

The authors address mainly point 3 and go beyond the mean-field approximation with a specific operator diagrammatic technique. While on its own it is an impressive achievement, I would like to point out that the connection between the real system and the model could be more complex due to the following complications:

a) The properties of EuO are sensitive to stoichiometry and present defects. I don't have access to the original Soviet paper in Russian, but, hopefully, the translation is good enough:

http://jetp.ras.ru/cgi-bin/dn/e_042_02_0288.pdf

This paper shows that conductivity, heat capacity, and critical parameters depend strongly on the presence and concentration of defects. Experimental critical exponents from the low-temperature and from the high-temperature sides are quite different from each other.

A nearly metallic conductivity of the oxygen-deficient samples may open other mechanisms of magnetic exchange since the conductive electrons can carry magnetic interactions to longer distances.

b) Determination of the model, even without defects for insulators, may not be trivial. First, it is unclear how large the higher-order terms are. The presence of a biquadratic exchange, for example, can lead to the formation of new phases. Second, the superexchange through oxygen changes local configurations on Eu^{2+} slightly from the f^7 configurations. This charge transfer is affected by the strong spin-orbit interaction on Eu centers, which leads to a small on-site anisotropy (and anisotropic local g-tensors) and to an anisotropic exchange tensor. Even for 3d elements, this effect is noticeable, while one would expect it to be stronger for the 4f compounds.

c) Even the signs of effective exchange constants in EuO are debated:

https://doi.org/10.1103/PhysRevB.86.224408

Different signs for the NN and NNN interactions are not uncommon and are signatures of geometric dependence.

Different signs of interactions may cause complications in the subsequent calculations within a quantum magnetic model since there is a competition between antiferromagnetic and ferromagnetic orderings. For example, this competition slows down the convergence of the high-temperature series. I would expect that 1/Z corrections are also sensitive to the relative signs of NN and NNN.

d) Accurate evaluation of J is very difficult due to the correlated nature of superexchange. DFT, for example, can be wrong by an order of magnitude.

Declarations

Potential competing interests: No potential competing interests to declare.