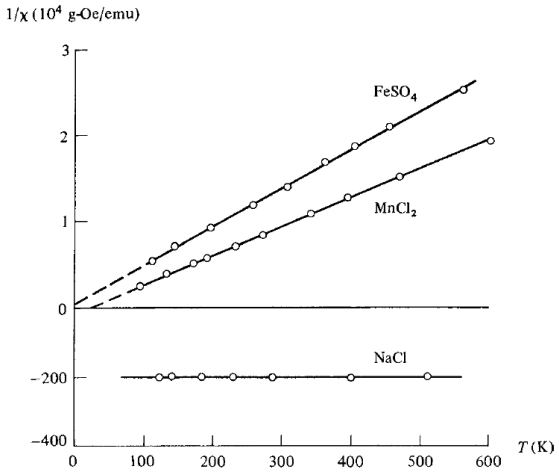
Tutorial 7

1. Magnetic Susceptibility

a) The figure below shows the magnetic susceptibility of three compounds. Explain the behavior and mention the likely dominating source of magnetism.

b) For $FeSo_4$ and $MnCl_2$. Assuming equal density, estimate the ratio of effective magnetic moments per Fe/Mn atom (this assumption is not so bad: $FeSo_4$: 2,84 g/cm3 and $MnCl_2$ 2.977 g/cm3)

c) Both compounds show an offset from zero. Explain the reason behind the offset and the difference that a positive or a negative offset makes.



(*Taken from Cullity, Graham: Introduction to Magnetic Materials*)

2. Spin waves

Spin waves provide a mechanism that governs the magnetization of ferromagnets at low temperatures. They form wave like excitations between localized spins at atomic lattice sites. We here want to derive the dispersion relaxation of 1D spin waves in a semiclassical approach.

a) Show that the equation of motion of a 1D spin wave can be written as

$$\frac{d\boldsymbol{S}_j}{dt} = -\frac{g\mu_B}{\hbar}\left(\boldsymbol{S}_j \times \boldsymbol{B}_{\text{ext}}\right) + \frac{J_A}{\hbar^2}\left[\boldsymbol{S}_j \times (\boldsymbol{S}_{j-1} + \boldsymbol{S}_{j+1})\right]$$

(Hint: use a mean field approach with an effective field $B_{\text{eff}} = B_{\text{ext}} + B_{A,i}$ and an exchange field $B_{A,i} = -\frac{J_A}{g\mu_B\hbar}(\boldsymbol{S}_{i-1} + \boldsymbol{S}_{i+1})$, then write down the equation of motion for the Larmor precession).

b) Now, linearize the equation by assuming $|S_{i,x}|, |S_{i,y}| \ll |S_{i,z}|$ and $\boldsymbol{B}_{\text{ext}} || \hat{\boldsymbol{z}}$ (→ neglect terms quadratic in $|S_{i,x}|, |S_{i,y}|$ and assume $|S_{i,z}| \sim -S$).

c) Solve the linearized equation by a plane wave ansatz of the form

$$S_{i,x} = S_x \exp\left(i[qia - \omega t]\right)$$
$$S_{i,y} = S_y \exp\left(i[qia - \omega t]\right)$$

Here, a is the lattice constant and ω the Larmor frequency. Solve for $\hbar\omega$

d) Plot $\hbar\omega$ as a function of q in the case of $B_{\text{ext}} = 0$.

e) What is the relation between S_x and S_y? What physical picture is connected with that?

f) The dispersion relation of an antiferromagnet is given by

$$\hbar\omega = \frac{2J_A S}{\hbar} |\sin qa|$$

Add this to the plotted result for the ferromagnet. What do they have in common? What is different?

3. Test exam

As promised, we will do a peer exam, so that you will get familiar with presenting in an exam setting.

Prepare to answer the following question:

Exam Question 1: What is Pauli paramagnetism? What parameters does it depend upon? Make a sketch for illustration.

Exam Question 2: What forms of exchange interactions did you encounter? Be prepared to go into detail for one of them.

Exam Question 3: What Models of charge screening do you know about (Thomas-Fermi model, Lindhard response function)? What are the differences and what do they depend on?

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discussion date: February 11th

Rules

- We divide into pairs of 3 that go into different parts of the room (ideally people that you do not know).
- In each round (~5min) one person is the „student“ and the other two the „examiner“.
- The examiners ask one of the three questions from the list and the student answers. You should sit together at a table and drawings on a piece of paper are allowed. The examiners can ask follow-up questions.
- After the answer, briefly discuss how you liked the answer and what could be improved.
- Participation trophy: if you participate in the peer exam, you get the point for the exercise independent of performance.
- After three rounds, we brainstorm all together what are good strategies to answer in an exam