Tutorial 6

1. Repetition I

a) Which type of magnetism dominates in noble gases?

b) What are the 3 types of cooperative magnetism we have learned about?

c) What are the values of μ_B and k_B when expressed in $\mu eV/T$ and $\mu eV/K$, respectively?

d) To which magnetic field do you need go to observe a significant change in the occupancy of a simple electron system ($s = 1/2$, $1\ \mu_B$) at room temperature? How much would this change if you cooled with liquid helium?

e) Which microscopic mechanisms of magnetism for bound electrons have you learned about so far?

f) Which one is typically the largest? Which one only has contributions from the orbital angular momentum?

2. Repetition II

a) Describe in one sentence the effects of Pauli paramagnetism and Landau diamagnetism.

b) How large is the "Fermi temperature" typically for metals?

c) Explain, using this concept, why Pauli paramagnetism is temperature-independent, in contrast to Langevin paramagnetism.

d) What dominates for a free electron gas when considering only Landau diamagnetism and Pauli paramagnetism?

3. Hund's rules

a) The electron configuration of elementary Chromium Cr is [Ar]$3d^5 4s$. In ionic bonding Chromium donates at first its electron of the outer 4s shell. Afterwards, if more electrons have to be donated to reach the intended valence, they are taken from the 3d shell. The experimentally determined value of the magnetic moment of the Cr^{3+} ion is $\mu = 3.8\ \mu_B$. Determine the quantum numbers S, L and J of the Cr^{3+}-ion in its ground state. Using the determined quantum numbers, calculate the magnetic moment μ in units of μ_B. How does this compare?

b) Using Hund's rules, give the electronic ground state J of the following ions (**note**: here we require that you are able to derive the configuration without your notes during the exercise class!)

(1) Pr^{3+}
(2) Eu^{2+} in configuration [Xe]$4f^7$
(3) Eu^{3+} in configuration [Xe]$4f^6$
(4) Tb^{3+}

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State the corresponding terms in spectroscopic notation $^{2S+1}L_j$.

4. Magnetic Dipole Interaction

The potential energy between two magnetic dipoles μ_1 and μ_2 is given by:

$$E_{DD} = -\frac{\mu_0\mu_1\mu_2}{4\pi r^3}[3(\boldsymbol{S}_1\cdot\hat{r})(\boldsymbol{S}_2\cdot\hat{r}) - \boldsymbol{S}_1\cdot\boldsymbol{S}_2]$$

a) Express the energy as an effective magnetic field acting on one of the spins.

b) Calculate the maximum strength of the magnetic field that is produced by an atom of magnetic moment μ_1=μ_B at the site of a neighboring atom (nearest neighbor only). Typical nearest neighbor distances r_0 for the ferromagnets Fe can be calculated by the following information: Fe has a bcc lattice with a = 2.866 Å

c) Compare the maximum energy of the dipole-dipole interaction to the thermal energy at the Curie temperature of Fe.

d) Can we explain cooperative interaction with magnetic dipole interaction? If not, what could be?