List of exam questions **1.02.2025**

Atomic magnetism

1. Elucidate the magnetic response of induced magnetic moments, permanent magnetic moments, and itinerant electrons. What is the magnitude and temperature dependence in each case?
2. Derive the Curie law for a spin-$\frac{1}{2}$ magnetic moment
3. Elucidate the magnetization of a local magnetic moment. What is the difference between the Langevin and Brillouin functions?
4. Compare and contrast temperature dependence of the magnetic susceptibility (at constant field) and field dependence of the magnetization (at constant temperature) for a local magnetic moment. Which value of the magnetic moment can be measured in each case?
5. Elucidate the relation between the orbital moment of a moving charge and its magnetic moment
6. Introduce Bohr magneton. Explain the relation between the spin and orbital moments of an electron and its magnetic moment. How do the spin and orbital moments add up?
7. Introduce the Hund's rules and apply them to determine the ground state and magnetic moment for a $4f$ ion of your choice
8. Explain the electronic configuration of $3d$ ions in octahedral crystal field. Give examples of the low-spin and high-spin states
9. Elucidate Van Vleck paramagnetism. Sketch temperature dependence of the Van Vleck contribution to the magnetic susceptibility
10. Derive the expression for the Pauli paramagnetic susceptibility of a metal

Magnetic order

11. Introduce main types of magnetic interactions. Explain how strong they are, and in which classes of materials they are relevant.
12. Introduce the classification of magnetic structures by their total magnetization, by periodicity, and by the spin direction
13. Explain the meaning of a propagation vector. How is it related to the magnetic structure in real space and to its diffraction pattern in the reciprocal space?
14. Explain the difference between axial and polar vectors. Show transformations of the magnetic moment vector under inversion and mirror symmetry operations.
15. Explain the formation of helical order, for example, in a spin chain with competing magnetic interactions
16. Explain the construction of the mean-field theory for a Heisenberg magnet. Consider ferromagnetis as well as antiferromagnets
17. Introduce the Curie-Weiss law. What information can be extracted from the Curie-Weiss analysis of the magnetic susceptibility?
18. Sketch temperature dependence of the magnetic susceptibility and field dependence of magnetization for an antiferromagnet. What is the spin-flop transition?
19. What is spin wave?

20. Compare and contrast the spin-wave dispersion relations for ferromagnets and antiferromagnets. Discuss their implications for the low-temperature heat capacity.

Quantum magnetism and complex spin states

21. Compare and contrast the energy levels of a spin-$\frac{1}{2}$ dimer in Heisenberg and Ising models
22. Show that the eigenstates of the Heisenberg Hamiltonian can be classified by their total spin (S^2) and its projection (S^z)
23. Derive magnetic susceptibility for a spin-$\frac{1}{2}$ dimer. Elucidate the low-temperature and high-temperature limits
24. What are skyrmions? What are the main preconditions for their formation?
25. What are experimental signatures of a spin glass?

Practical aspects

26. Explain different units of the magnetic field. What is the difference between Tesla, Oersted, and Gauss?
27. Explain how magnetic fields can be generated in the lab
28. Explain how magnetization is measured experimentally
29. How to determine magnetic moment of an ion experimentally?
30. Explain the principle of adiabatic demagnetization refrigeration
31. Elucidate magnetic response of a ferromagnet, including its remanent magnetization, coercive field, and energy product
32. What is the difference between soft and hard ferromagnets? Give examples of materials and their applications
33. Introduce Bloch and Néel types of the domain walls in ferromagnets. What determines their energy and thickness?
34. Explain how magnetic structure can be determined experimentally
35. How to study magnetic excitations of a magnetically ordered state?
36. How to image domain walls and spin textures? Give at least two methods, explain their sensitivity and spatial resolution.