Magnetic Interactions: Basic concepts and simple models

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The elementary Hamiltonian describing the quantum mechanical nature of electrons does not contain the spin explicitly, yet magnetic phases can emerge. This is an example of magnetism being an emergent phenomenon hidden in the antisymmetric nature of the many body wavefunction of electrons being fermions. I will derive on the basis of simple models and principles the essential features of the different magnetic interactions. The lecture is divided into magnetism of localized spins (1. – 4.) and metallic magnetism (5. – 8.)

1. Dipolar interaction: I estimate its strength and show that is cannot be the origin of magnetic phases we know. Instead magnetic ordering is due to exchange interactions, a combined effect of
    1. Pauli principle
    2. Coulomb and/or kinetic energy (Heisenberg)
2. Direct exchange is explained for the example of one atom with 2 valence electrons
3. Superexchange will be discussed on the basis of a simplified H_2 molecule. The concept of downfolding is introduced and the Heisenberg model is derived. The effect of intermediate anions (e.g. as in MnO) is discussed.
4. Double exchange (Zener model) relevant for dilute magnetic semiconductors will be introduced.
5. As simplest model for metals, the direct exchange is applied to the homogeneous electron gas. Concepts like exchange hole, and exchange energy density is discussed. Relation to exchange correlation energy in density functional theory is drawn. Pauli susceptibility is introduced
6. The model for metals is extended to the Stoner Model, which I develop out of model to the density functional theory. Stoner criterium is derived. Susceptibility is discussed. It time permits model is extended to metallic antiferromagnets.
7. Magnetic impurities are discussed in the Anderson impurity model.
8. The interaction of the magnetic impurities immersed in a homogeneous electron gas is discussed on the basis of a simplified Greenfunction method.
9. The extension of the model to a Rashba electron gas leads to the Dzyaloshinskii-Moriya interaction
10. The Dzyaloshinskii-Moriya interaction is also introduced on the basis a minimal model of two magnetic and one non-magnetic atom that carries spin-orbit interaction.

I do not introduce the magneto-crystalline anisotropy. I assume this done in the lecture MM-4 of A. Kalshnikova.

There are many good books on magnetism that cover this part of the lecture. Examples are:

[1] Daniel Charles Mattis, *The Theory of Magnetism Made Simple*, World Scientific Publishing Company, ISBN 9812385797
[2] Daniel Charles Mattis *The Theory of Magnetism*, Springer Verlag, ISBN 0387106111
[3] Robert M. White, *Quantum Theory of Magnetism* Springer Verlag, ISBN 3540651160
[4] Kübler, J., *Theory of itinerant magnetism*, Oxford University Press.