MAGNETISM AND SUPERCONDUCTIVITY

Lectures by Sabina Lewińska on **Fridays, 9:00 - 11:00**

beginning 28 February, 2025; the end: 13 June 2025

hall D, Institute of Physics PAS

The course of 15 lectures is:

- Directed at students of International PhD Studies of the Institute of Physics of the Polish Academy of Sciences
- Aimed at familiarizing participants with fundamentals of magnetism and superconductivity.

After completing the course, the participants:

- Should be able to understand basic ideas of papers on magnetism and superconductivity.
- Should be prepared to study magnetic and superconducting materials.

Syllabus

I. Lectures on magnetism

1. Introduction, basic terms.
   Magnetic moments (orbital, spin, nuclear).
   Spin-orbit coupling.
   Magnetic elements in the periodic table.
   Many electron ions (part I).
2. Many electron ions (part II): adding angular momentum operators, Hund rules.
   Hyperfine interactions.
   Atomic moments in an external magnetic field (classical and quantum approach).
   A set of localized magnetic moments, magnetic susceptibility.
3. Diamagnetism, theory of perturbation without degeneracy.
   Paramagnetism, theory of perturbation with degeneracy (quantum and classical approach).
4. Influence of a nonmagnetic surrounding on a magnetic ion.
   Origin of crystal fields.
   Orbital quenching.
   The Jahn-Teller effect.
   Interactions between magnetic moments: direct exchange interactions.
5. Interactions between magnetic moments: indirect exchange interactions.
   Dipol-dipol interactions.
   Systems of coupled magnetic moments: basic models (Ising, Heisenberg, XY).
   Molecular field approximation.
   Ferromagnetism, antiferromagnetism, ferrimagnetism, helical order.
6. Demagnetizing field, magnetic anisotropy, magnetostriction
   Magnetic domains, formation of magnetic domains, domain walls.
   Magnetization processes, hysteresis, soft and hard materials.
7. Superparamagnetism.
   Spin glasses, frustration.
8. Magnetism in metals.
   The free electron model. Pauli paramagnetism. Itinerant magnetism. Landau diamagnetism (Landau quantization).

9. Stoner model of ferromagnetism.
   Systems of strongly correlated electrons: Hubbard model, Kondo effect.
10. Family of Hall effects.
11. Phase transitions: classification (old by Ehrenfest and contemporary).
    Critical phenomena.
    Landau theory of continuous (2^{nd} order) transitions.
    Scaling hypothesis, renormalization group theory, universality classes.
    Quantum phase transitions.

II. Lectures on superconductivity

12. Basic terms, phenomenological theory.
    Main attributes of superconducting state (zero resistance, Meissner effect).
    Superconductors of the I and II type.
    Phase transition to superconducting state.
    Isotope effect.
    Model by Londons.

13. Ginzburg-Landau theory (phase transitions in a system of non-uniform distribution of order parameter).
    Magnetic flux quantization, vortex matter.

14. Elements of the BCS theory.
    Order parameter.
    Physical interpretation of the Ginzburg-Landau $\psi(x)$ function.
    Josephson effect.

15. Measurement techniques in magnetism and superconductivity.
    dc and *ac* magnetic susceptibility measurements; SQUID and VSM magnetometers.
    Electron spin resonance. Mössbauer spectroscopy.
    Two basic magnetic unit systems: CGS Gauss and SI.

Literature:

- *The Physical Principles of Magnetism)* H. Morrish
- *Magnetism in condensed matter*, S. Blundell
- *Suprconductivity, superfluids, and condensates*, J.F. Annett
- *Kwantowa teoria magnetyzmu* (*Quantum theory of magnetism*), R.M. White
- *Magnetzm i nadprzewodnictwo*, A. Szewczyk, A. Wiśniewski, R. Puźniak, H. Szymczak
- *Introduction to Superconductivity and High Tc Materials*, M. Cryot, D. Pavuna

Registration for the course by email to lewinska@ifpan.edu.pl, please, provide name, surname, and name of your institution upon registration.