Course Title (in English) | Magnetic phenomena at macro-, micro- and nanoscales  
Course Title (in Russian) | Магнитные явления на макро-, микро- и наномасштабах  
Lead Instructor(s) | Uspenskaya, Lyudmila  
| Uspenskaya, Lyudmila  
Status of this Syllabus | The syllabus is a final draft waiting for form approval  
Contact Person | Lyudmila Uspenskaya  
Contact Person’s E-mail | uspenska@issp.ac.ru  

1. Annotation

Course Description

Objectives of this course are as follows: the mastery of the fundamental concepts, laws and theories of physics of magnetic phenomena; introduction to basic experimental techniques to characterize magnetic materials; modern applications of magnetics. The importance of these topics results from application of thin magnetic films as the layers in heterostructures which control the operation of micro- and cryoelectronics devices. The straightforward scaling is impossible when one goes from the bulk magnetic materials to micro- and nm-size systems because of the principle difference in dynamic behavior and appearance of new types of excitations.

Course Prerequisites

General Physics (BSc course, electromagnetic phenomena).

2. Structure and Content

Course Academic Level

Master-level course suitable for PhD students  
Number of ECTS credits | 3

<p>| Topic | Summary of Topic | Lectures (# of hours) | Seminars (# of hours) | Labs (# of hours) |</p>
<table>
<thead>
<tr>
<th>Section</th>
<th>Content</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferromagnetism</td>
<td>Anisotropy, exchange, magnetostrictive, and magnetostatic energies. Demagnetization factor. Magnetic domain structure. Methods of observation and their applicability.</td>
<td>3</td>
</tr>
<tr>
<td>Applications</td>
<td>Applications of magnetic materials. Magnetic properties of some particular important for cryoelectronics magnetic material (from bulk to nanofilms).</td>
<td>3</td>
</tr>
<tr>
<td>Spin-orbit interaction and some spin phenomena</td>
<td>Microscopic or intrinsic spin-orbit interaction in an atom Macroscopic or extrinsic spin-orbit interaction: Rashba interaction, Dresselhaus interaction Magneto-electric subbands in the presence of the spin-orbit interaction The spin Hall effect The spin galvanic and direct magnetoelectric effects The spin capacitor The spin Hanle effect The spin Seebeck effect The spin Peltier effect</td>
<td>3</td>
</tr>
<tr>
<td>Spin field-effect transistors; Spin accumulation, injection and detection; Spin relaxation mechanisms</td>
<td>Spin field-effect transistors Spin accumulation Spin injection across a ferromagnet/metal interface and spin detection Spin transport in nonlocal spin devices Spin injection into a ferromagnetic insulator Elliott-Yafet mechanism D'yakonov-Perel' mechanism Bir-Aronov-Pikus mechanism Hyperfine interactions with nuclear spins</td>
<td>3</td>
</tr>
</tbody>
</table>
Spin-transfer torques

- Principle of spin transfer torque
- Current-induced adiabatic spin transfer torque and spin-orbit torque
- Current-induced magnetization dynamics, LLG equation
- Magnetization dynamics in spin valves
- Current-induced domain wall motion
- Spin torque in antiferromagnets
- Applications of current-induced magnetization dynamics

3. Assignments

<table>
<thead>
<tr>
<th>Assignment Type</th>
<th>Assignment Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Set</td>
<td>Problems assuming calculation of various quantities in frames of theoretical models, as well as qualitative problems to discuss the trends observed experimentally for various magnetic materials.</td>
</tr>
</tbody>
</table>

4. Grading

- Type of Assessment: Graded

<table>
<thead>
<tr>
<th>Grade Structure</th>
<th>Activity Type</th>
<th>Activity weight, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Homework Assignments</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Final Exam</td>
<td>60</td>
</tr>
</tbody>
</table>

Grading Scale

- A: 80
- B: 65
- C: 55
- D: 45
- E: 35
- F: 0

5. Basic Information

- Attendance Requirements: Mandatory with Exceptions

<table>
<thead>
<tr>
<th>Maximum Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall:</td>
</tr>
<tr>
<td>Per Group (for seminars and labs):</td>
</tr>
</tbody>
</table>
Course Term (in context of Academic Year)

Term 2

Course Delivery Frequency

Every year

Students of Which Programs do You Recommend to Consider this Course as an Elective?

<table>
<thead>
<tr>
<th>Masters Programs</th>
<th>PhD Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials Science</td>
<td>Physics</td>
</tr>
<tr>
<td>Photonics and Quantum Materials</td>
<td></td>
</tr>
</tbody>
</table>

Course Tags

Physics

6. Textbooks and Internet Resources

<table>
<thead>
<tr>
<th>Required Textbooks</th>
<th>ISBN-13 (or ISBN-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetism and magnetic materials. J.M.D. Coey. Cambridge. 2010.</td>
<td>9780511845000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recommended Textbooks</th>
<th>ISBN-13 (or ISBN-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetism. Etian de Treomote de LaCheissere, Daniel Gignoux, Michael Ssclenker. CNRS, Granoble, France, 2005.</td>
<td>9780387699103</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Web-resources (links)</th>
<th>Description</th>
</tr>
</thead>
</table>

7. Facilities

Software

- Mathlab
- Mathcad

8. Learning Outcomes

Knowledge

Basics of classical and quantum theory of magnetism, basic experimental data on the properties of magnetic materials, the difference in the properties of ferromagnetic and antiferromagnetic, ferrimagnetic and other magnetic structures.

The origin of the domain structure, the structure of the domain boundaries and their behavior in the constant and variable magnetic fields; theory of magnetic hysteresis, resonance phenomena in magnetic materials, magneto-optical effects, especially the properties of thin films and nanostructured samples.

Fabrication techniques and modern experimental methods of research in physics of magnetic phenomena.

Skill

To identify the main characteristics of the magnetic material (magnetization, coercivity, remanence, permeability.

To give definitions of basic physical concepts and quantities; to formulate the basic laws of physics and describe physical phenomena and processes using physical scientific terminology to describe physical phenomena and the proper physical models.
Experience
Analysis, formulation and solution of particular problems being of interest for the fundamental science and practice.

Do you want to specify outcomes in another framework?
Knowledge-Skill-Experience is good enough

9. Assessment Criteria

Select Assignment 1 Type
Problem Set

Input Example(s) of Assignment 1 (preferable)
Consider a close-packed lattice composed of atoms of 0.1 nm radius with an orbital magnetic moment of one Bohr magneton per atom. What is the spontaneous magnetization?

Assessment Criteria for Assignment 1
Correct magnetization value should be reported.

Select Assignment 2 Type
Problem Set

Input Example(s) of Assignment 2 (preferable)
Comment on techniques which can be applied to determine (A) magnetic permeability of certain material, (B) its saturation magnetization, and (C) coercivity. Explain the applicability limits for each technique.

Assessment Criteria for Assignment 2
Qualitative discussion should be accompanied by some estimates related to applicability limits.

Select Assignment 3 Type
Problem Set

Input Example(s) of Assignment 3 (preferable)
Predict the changes of EPR, NMR, FMR frequencies when going from a spherical shape to thin plate.

Assessment Criteria for Assignment 3
The formulas should be proposed, as well as quantitative estimates for certain geometries.

Select Assignment 4 Type
Problem Set

Input Example(s) of Assignment 4 (preferable)
Derive an expression for the coercivity of a spherical particle with anisotropy energy $E_a = K_1 \sin^2(\phi_1) + K_2 \sin^4(\phi_1)$, $4K_2 > K_1 > 0$.

Assessment Criteria for Assignment 4
Correct expression should be derived.

Select Assignment 5 Type
Problem Set

Input Example(s) of Assignment 5


Calculate and plot the dispersion relations of spin-split subbands in a 1D quantum wire with a magnetic field directed along the axis of the wire (x-axis). Assume that there is a symmetry-breaking electric field along the y-axis, which induces the Rashba spin-orbit interaction. Furthermore, the quantum wire has a crystallographic inversion asymmetry along the x-direction, which induces the Dresselhaus spin-orbit interaction.

Investigate the spin structure of the subbands as a function of the wavevector. When the problem is solved for a general case consider special cases:

a. no magnetic field
b. Rashba interaction is absent
c. Dresselhaus interaction is absent

Correct plot should be presented.

The course is presented in the Institute of Solid State Physics RAS (Chernogolovka, Moscow region), magnetic corp, room 115. Spintronics: Dr. I. Bobkova. Wednesdays, 11.00, starting from 31.10.2018.

https://ucarecdn.com/1d382b06-f84c-4541-96e3-fa02602d907f/