## Course Syllabus

### 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)
Bobkova, Irina

### Is this syllabus complete, or do you plan to edit it again before sending it to the Education Office?
The syllabus is a final draft waiting for form approval

### Contact Person
Irina Bobkova

### Contact Person's E-mail
ivbobkova@mail.ru

### 1. Annotation

#### Course Description

Objectives of this course are as follows: the mastery of the fundamental concepts, laws, experimental results and theories of the rapidly developing field of spintronics. Spintronics involves study of active control and manipulation of spin degrees of freedom in solid-state systems. The primary focus of the course is on basic physical principles underlying the generation of carrier spin polarization, spin-polarized transport in metals, semiconductors and insulators and spin dynamics. The basic principles are illustrated by direct calculations in the framework of simple and transparent physical models. A number of problems are suggested for individual work followed by subsequent group discussions.

### Course Prerequisites / Recommendations

General Physics (BSc course, electromagnetic phenomena). This course belongs to MIPT-Skoltech net program. The students graduated from other universities than MIPT are required to pass the test one week before this course starts. Please, contact Prof. Galina Tsirlina tsir@elch.chem.msu.ru to apply.

### 2. Structure and Content
<table>
<thead>
<tr>
<th><strong>Course Academic Level</strong></th>
<th>Master-level course suitable for PhD students</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of ECTS credits</strong></td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Topic</strong></th>
<th><strong>Summary of Topic</strong></th>
<th><strong>Lectures (# of hours)</strong></th>
<th><strong>Seminars (# of hours)</strong></th>
<th><strong>Labs (# of hours)</strong></th>
</tr>
</thead>
</table>
| Magnetoelectronics         | 1. Spin current and spin accumulation  
2. Magnetoelectronic circuits and devices  
3. Calculations of spin-dependent transport in metallic systems  
4. GMR                                                  | 3                         | 3                        |                       |
| Spin-orbit interaction     | 1. Microscopic or intrinsic spin-orbit interaction in an atom  
2. Macroscopic or extrinsic spin-orbit interaction: Rashba interaction, Dresselhaus interaction  
3. Magneto-electric subbands in the presence of the spin-orbit interaction  
4. The spin Hall effect  
5. The spin galvanic and direct magnetoelectric effects | 4                         | 3                        |                       |
| Spin relaxation mechanisms | 1. Elliott-Yafet mechanism  
2. D'yakonov-Perel' mechanism  
3. Bir-Aronov-Pikus mechanism  
4. Hyperfine interactions with nuclear spins | 2                         | 3                        |                       |
| Spin-transfer torques      | 1. Principle of spin transfer torque  
2. Magnetization dynamics, LLG equation  
3. Spin-transfer torque and magnetization dynamics in spin valves  
4. Current-induced spin transfer torque and spin-orbit torque in textured magnets  
5. Current-induced vs magnetic field-induced domain wall motion  
6. Spin torque and domain wall motion in antiferromagnets  
7. Applications of current-induced magnetization dynamics | 6                         | 3                        |                       |
| Magnonics                  | 1. Spectra of magnons in ferromagnetic materials  
2. Interconversion between electric signals and magnonic spin currents at interfaces of ferromagnetic insulators  
3. The spin Peltier Effect for magnetic insulators | 3                         | 3                        |                       |
| Spin caloritronics         | 1. The spin-dependent and spin Seebeck effects  
2. Giant spin Seebeck effect in Zeeman-split superconductors | 3                         | 3                        |                       |

### 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 the framework of various theoretical models, as well as subsequent group discussions</td>
</tr>
</tbody>
</table>

4. Grading

**Type of Assessment**

- Graded

**Grade Structure**

<table>
<thead>
<tr>
<th>Activity Type</th>
<th>Activity weight, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Set</td>
<td>75</td>
</tr>
<tr>
<td>Final Project</td>
<td>25</td>
</tr>
</tbody>
</table>

**Grading Scale**

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

**Attendance Requirements**

- Mandatory with Exceptions

5. Basic Information

**Maximum Number of Students**

<table>
<thead>
<tr>
<th>Maximum Number of Students</th>
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<tbody>
<tr>
<td>Overall: 10</td>
</tr>
<tr>
<td>Per Group (for seminars and labs): 10</td>
</tr>
</tbody>
</table>
Course Stream | Science, Technology and Engineering (STE)
---|---
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>Mathematical and Theoretical Physics</td>
<td></td>
</tr>
<tr>
<td>Photonics and Quantum Materials</td>
<td></td>
</tr>
</tbody>
</table>

Course Tags | Physics

### 6. Textbooks and Internet Resources

**Required Textbooks**

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Magnetism and magnetic materials. J.M.D. Coey. Cambridge. 2010. 9780511845000</td>
</tr>
</tbody>
</table>

**Recommended Textbooks**

|---|
https://doi.org/10.1103/RevMod Phys.76.323

https://doi.org/10.1016/j.physrep.2006.01.001

J. Grollier, A. Chanthbouala, R. Matsumoto, A. Anane, V. Cros, F. Nguyen van Dau, Albert Fert, Magnetic domain wall motion by spin transfer, C. R. Physique, 12 309 (2011)  
10.1016/j.crhy.2011.03.007

https://doi.org/10.1038/nature08876

https://doi.org/10.1002/pssr.201700022

https://doi.org/10.1038/s41567-018-0049-4

0.1140/epjb/e2002-00316-5

7. Facilities

<table>
<thead>
<tr>
<th>Software</th>
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<tbody>
<tr>
<td>Matlab</td>
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<tr>
<td>Mathcad</td>
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8. Learning Outcomes
<table>
<thead>
<tr>
<th>Knowledge</th>
<th></th>
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<tbody>
<tr>
<td>Fundamental concepts underlying the field of spintronics: generation of carrier spin polarization, spin-polarized transport in metals, semiconductors and insulators, spin dynamics</td>
<td></td>
</tr>
<tr>
<td>Main directions (magnetoelectronics, spin-orbitronics, spin torques and control of magnetization dynamics, antiferromagnetic spintronics, spin caloritronics and magnonics) and modern trends in spintronics</td>
<td></td>
</tr>
<tr>
<td>Knowledge of related experimental results: as classical, so as reported in the modern literature</td>
<td></td>
</tr>
<tr>
<td>Knowledge of existing theoretical approaches and models developed for description of basic spintronic phenomena</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Skill</th>
<th></th>
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<tbody>
<tr>
<td>To perform calculations describing basic spintronic phenomena in the framework of simple physical models</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Experience</th>
<th></th>
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<tbody>
<tr>
<td>Analysis, formulation and solution of particular problems being of interest for the fundamental science and practice.</td>
<td></td>
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</tbody>
</table>

9. Assessment Criteria

Input or Upload Example(s) of Assignment 1:

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.

Input or Upload Example(s) of Assignment 2:

Select Assignment 2 Type: Problem Set
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.

**Input Example(s) of Assignment 2 (preferable)**

**Assessment Criteria for Assignment 2**

Qualitative discussion should be accompanied by some estimates related to applicability limits.

**Input or Upload Example(s) of Assignment 3:**

**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.

**Input or Upload Example(s) of Assignment 4:**

**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 

\[ E_a = K_1 \sin^2(\phi) + K_2 \sin^4(\phi), \ 4K_2 > K_1 > 0. \]

**Assessment Criteria for Assignment 4**

Correct expression should be derived.

**Input or Upload Example(s) of Assignment 5:**

**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
Assessment Criteria for Assignment 5

Correct plot should be presented.

10. Additional Notes

Free Style Comments (if any)

The course is presented in the Institute of Solid State Physics RAS (Chernogolovka, Moscow region). Transportation will be arranged.

Upload a File (if needs to be)

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