Ph 674: Solid state physics – magnetism

Instructor: Tom Giebultowicz (“Dr. Tom”)
Weniger Hall, Room 375 or 424
Ph: 541 737 1707, e-mail: tgiebult@physics.oregonstate.edu
Personal Web page: http://science.oregonstate.edu/~tgiebult/
Office hours: 13:00-14:00, Weniger 424

Dedicated course Web page:
http://science.oregonstate.edu/~tgiebult/COURSES/ph674

Expected student learning outcomes:

After taking this course, students will be able to:

- Explain the theoretical foundations of our current understanding of magnetism in condensed matter;
- Describe the basic classification of magnetic solids;
- Describe the basic types of ordering in solids in which the atomic magnetic moments form a periodic structure;
- Describe and explain the operation principles of certain major experimental tools used for investigating magnetism in solids;
- Describe the temperature-dependent phenomena seen in major types of magnetic solids;
- Describe the dynamics of spin systems in various types of magnetic solids;
- Describe and understand the motivation and the objectives in major research efforts in contemporary studies of solid state magnetism;
- Start studying, on their own, more advanced topics in the theory of magnetism, and published reports on major experimental accomplishments in the area of condensed matter magnetism – in order to get ready for undertaking research projects their own research projects.

Ph 674: Detailed schedule of classes in the first two weeks.

Date (**week**.class)	Topics & Material	Reading
Jan. 3 **1**.1	Organizational issues. Course objectives. Basic definitions: *B*, *H* fields, magnetic moment, magnetization *M*. Orbital and spin angular momenta (***l*** and ***s***), and orbital and spin magnetic moments of a. single electron. Orbitals and their symbols. Many-electron atoms: Pauli exclusion, Madelung's *Aufbau* rule, Hund's rule.	MG: 1.1, 1.2, 2.1, 2.4. JMDC: pp.1-61 (optional), 3.1., 4.1 : .
Jan 5 **1**.2	Atomic term symbols. ***L***, ***S*** and ***J*** momenta for many-electron atoms, and their relation to the net atomic magnetic moment μ: the Lande factor *g*. Magnetic properties of elements up to *Z*=30.	MG: pp 20-21 JMDC: 4.2 EdTdL: 4.2.2., 7.1-7.3 DAMcQ: pp. 312-320
Jan 7 **1**.3	Experimental measurements of the atomic μ: paramagnet in externalfield, Brillouin and Langevin functions. Cooling by adiabatic demagnetization of a paramagnet.	MG: pp 10-19 JMDC: 4.3; EdTdL: 7.4 Notes pp.23-36
Jan 10 **2**.4	Magnetic atoms in crystals: why do the observed μ values for most transition metal ions differ from the free atom/ion values? Orbital momentum “quenching” by crystal (ligand) fields. Single-ion magnetic anisotropy. Interactions between magnetic atoms. Dipole-dipole interactions: why do they play only a marginal role? Exchange interactions: forces of essentially nonmagnetic origin, but playing a dominant role in magnetism!	MG 4.1-4.3, 7.1-7.2 JMDC 4.4, 5.2, 5.2.1,.5.2.2
Jan 12 **2**.5	Exchange interactions continued: direct exchange, superexchange. Basic types of magnetic order resulting from spin-spin exchange: ferromagnets and antiferromagnets. The rich variety of possible antiferromagnetic (AFM) structures – as an example, the AFM structures forming in a FCC spin lattice with nearest-neighbor (NN) and next-nearest-neighbor exchange interactions.Methods of determining the spin structure: primarily, neutron diffraction. Introduction to magnetic neutron diffraction (a Power Point presentation).	MG 5.2 JMDC 6.3.1 Notes 37-48
Jan 14 **2**.6	Magnetic neutron diffraction continued. Diffraction spectra produced by the atomic structure: Bragg reflections and their intensity. The structure factor F_{hkl} . The magnetic structure factor. Characteristic reflections produced by Type I, Type II, and Type III AFM order in a FCC spin lattice. Non-collinear magnetic structu-	MG 5.4 JMDC 6.3.3, 5.2.1 (Eq. 5.27) Notes 49-64

	res. Dzialoshinski-Moriya exchange as one possible (but rare) mechanism leading to non-collinearity. Competition between FM and AFM interactions, or between two different AFM interactions in a given system as a **common** source of non-collinear effects, such as, e.g., a helical spin arrangement. Neutron diffraction spectra from helimagnets. Magnetic ordering continued. Magnetic systems with no long-range order: amorphous ferromagnets, spin glasses.	

Detailed schedule for the third week, and a brief schedule for the last two weeks

Date (**week**.class)	Topics & Material	Reading
Jan. 17 **3**.- no class	Martin Luther King Day	US Modern History
Jan 19 **3**.7	A "true story" of investigating the AFM structure in a real system ($Cd_{0.30}Mn_{0.70}Te$; a PPT slide presentation). Magnetic Excitations I: localized non-dispersive excitation modes – small isolated spin clusters in magnetically diluted systems. Inelastic neutron scattering from such clusters (pair, triads) as a method for precise determination of the spin-spin exchange parameter *J*. Magnetization-step spectroscopy of small spin clusters – another method of precise measuring of *J* values. Electron Paramagnetic Resonance (EPR, a.k.a. Electron Spin Resonance, ESR): yet another method of investigating the excitations of isolated spin-spin pairs. The Mean-Field Theory, MFT (or Approximation, MFA): and old and tired workhorse in the theory of magnetism, but still quite often hired despite it's post-retirement age. A quick overview of the most important MFA results for paramagnetic and ordered phases. The mean-field approximation, for ferro- and antiferromagnets.	Power Point slide presentations (all neutron & Magnetization Step Spectroscopy stuff); notes (ESR stuff); MFA stuff: MG: 5.1-5.2; JMDC: 5.1 More notes (MFA)
Jan 21 **3**.8	MFA continued. Spontaneous magnetization. The MFA approach to antiferromagnetism. AFM sublattices. MFA solutions in the vicinity of the phase transition point. Magnetic Excitations II: collective dispersive modes – spin waves. Semi-classical MFA-based theory of spin waves in ferromagnets. Measurements of the dispersion relations of spin waves (magnons) by inelastic neutron scattering. Magnon dispersion relations as the principal source of information about the spin-spin exchange parameters *J* . The differences between magnon dispersion relations in ferro- and antiferromagnets. Miscellaneous topics: amorphous ferromagnets ("metallic glasses"); "frustrated" AFM spin lattices.	MG 6.5 JMDC 5.4. Notes (inelastic neutron scattering studies of magnon dispersion relations). Amorphous magnets & spin glasses: MG 5.5; JMDC 6.4-6.5.
Jan 24 **4**.9	Systems with localized magnetic moments: insulators and wide-gap semiconductors. Itinerant electrons: the "band theory" of magnetism.Magnetism and conductivity (Mott theory). Exchange in magnetically	

	diluted alloys (RKKY interaction).	
Jan 26 **4**.10	Magnetic multilayers and superlattices. Giant magnetoresistance (GMR). The advent of spintronics.	
Jan 28 **4**.11	Magnetic semiconductors. Half-metals. Prospects for semiconductor spintronics: chances and challenges.	
Jan. 31. **5.**12	Miscellaneous topics of current interest: frustrated spin lattices again, low-dimensional magnetism, orbital ordering, and other.	
Feb. 02 **5.**13	Reserve	
Feb. 04 **5.**14	Review of the material for final exam.	

Textbooks:

MG – Mathias Getzlaff, *Fundamentals of Magnetism*, Springer, 2010 (main).

JMDC – J. M. D. Coey, *Magnetism and Magnetic Materials*, Cambridge University Press, 2010.

EdTdL – *Magnetism.Fundamentals*, edited by E. du Tremolet de Lacheisserie, D. Grigoux, and M. Schlenker, Springer, 2005.

DAMcQ – D. A. McQrrle, *Quantum Chemistry*, University Science Books, 1983.

Course objectives (more personal instructor's thoughts)

Suppose that someone asked me a question: *Tom, I'd like you to give a course on solid state magnetism. A course that would cover all essential fundamental aspects, and also would give the students a good overview of "state-of-the-art" research that is currently conducted in this area. How many lecture hours would you need for that?* I would answer: *At least one hundred, perhaps even more.*

However, all time we have in the present Ph 674 course is 14x1.5 = 21 lecture hours. Squeezing all essential information into such a short block is really a big challenge for the instructor. Some sacrifices have to be done – many topics that are highly interesting, but not absolutely necessary, have to be skipped. And there will be no time for "in-depth" explanations of many things – you will have to "accept them without proof". But you already have much background in electrodynamics and quantum mechanics, so in many cases you may not need a "formal proof", because you have already dealt with similar problems.

My goal in this course is to give you a "packet of fundamental information" that would allow you to read and understand (at least, partially) research papers that are currently published in the area of solid state magnetism. Over years, scientist working in this field have created a specific vocabulary that includes a large number of terms not much used in other areas of physics. Here are some examples: *exchange, superexchange, RKKY exchange, crystal field anisotropy, orbital momentum quenching, orbital ordering, itinerant magnetism, superparamagnetism, mean field theory, spin waves, 3d material, 4f metals, Neel temperature, g-factor, spin glass, spin ice, frustrated lattice, easy axis, Mott two-current model,…* -- the list may be continued over many more lines – I can bet that you don't have a clear idea what is the exact meaning of most of them! But take any article on solid state magnetism from "Physical Review B", and you will find such "magic words" in every other sentence. Because this is the "professional jargon" used by the magnetic scientific community. Each of these terms refer to an effect, idea or notion that are all of importance. So, my goal would be to teach you that "language" – so that you not only know the words, but you also have a clear idea what they mean and why a given effect, idea or notion is of importance.

Learning those "fundamentals" will take about 60% of out time. Then, I'd like to give you an overview of research topics in solid state magnetism that are of considerable current importance. One of such "hot topics" is, for instance, the novel spin-controlled electronics, a.k.a. "spintronics" – a research area that emerged after the discovery of Giant Magnetoresistance (for which the 2007 Nobel Prize in physics was awarded).

So, in conclusion: I hope that the Ph 674 course will give you a sufficient "potential" for reading and understanding current scientific reports in the area of solid state magnetism – and will also offer you "guidelines" of what topics in this research field are especially worth paying attention to.