“Magnetic Physics” Course Syllabus

《磁性物理学（英文)》课程教学大纲

I. Basic Information

Name	Magnetic Physics	Course Code	PHYS3116
Course Category	Required course	Majors	Physics
Credit	2	Total Hours	36
Instructors	Tianyi Cai(蔡田怡) Sheng Ju(睢胜)	Date	2021.9
Textbooks	Magnetism in Condensed Matter, Stephen Blundell, Oxford University Press, 2001		

II. Teaching aim

1) Overall objectives:

This course will introduce the fundamental concepts that underly the practical use of magnetic materials. The interesting magnetic effects found in condensed matter systems have two crucial ingredients: first, that atoms should possess magnetic moments and second, that these moments should somehow interact. We will discuss the different types of magnetic materials, and the basic energies that drive their physical behaviors. A particular focus will also be on the dynamic properties of magnetic materials and their interactions with electrical excitations. These concepts will be reinforced via a micromagnetic simulation project, which allows to directly explore the intricate interplay between different magnetic interactions. The course will discuss these magnetic phenomena in the context of different applications, ranging from biomedical applications to current information technologies. At the same time, we will discuss frontiers of magnetism research, which will be reinforced through the literature review of recently published results.

2) Course objectives:

1. Understand the key concepts of magnetic physics;
2. Know properties and applications to demonstrate the implications of all

these ideas for real materials;

3. Explain the underlying ideas in real measurements and experimental techniques.

3) Corresponding relationship between curriculum objectives, graduation requirements and curriculum content

Table I. Correspondence between course objectives, course contents and graduation requirements

Course objectives	**Corresponding course content**	**Corresponding graduation requirements**
Course objective 1	Chapter 5 Order and magnetic structures Chapter 6 Order and broken symmetry Chapter 8 Competing interactions and low dimensionality	Graduation requirement 3: understand the frontier and development of physics, the physical thought in new technology, and be familiar with the impact of new discoveries, theories and technologies in physics on society. Graduation requirements 8: have the awareness of independent learning and lifelong learning and the ability to adapt to the society.
Course objective 2	Chapter 1 Introduction Chapter 2 Isolated magnetic moments Chapter 4 Interactions Chapter 5 Order and magnetic structures	Graduation requirement 2: master the basic knowledge, basic physical experiment methods and experimental skills related to mathematics and physics, and have the ability to solve problems, explain or understand physical laws by using physical theories and methods.

		Graduation requirements 8: have the awareness of independent learning and lifelong learning and the ability to adapt to the society.
Course objective 3	Chapter 3 Environments Chapter 4 Interaction Chapter 7 Magnetism in metals	Graduation requirement 2: master the basic knowledge, basic physical experiment methods and experimental skills related to mathematics and physics, and have the ability to solve problems, explain or understand physical laws by using physical theories and methods. Graduation requirements 7: have the ability of subject research, design, data processing and academic exchange. Graduation requirements 8: have the awareness of independent learning and lifelong learning and the ability to adapt to the society.

III. Contents

Chapter One: Introduction

1. Teaching aims

Understand the concept of magnetic moments;

Explain some facts about magnetic moments from elementary classical and quantum physics

2. Keypoints and Difficulties

Keypoints: Magnetic moments

Difficulties: The classical and quantum understanding of the magnetic moments

3. Contents

1.1 Magnetic moments

1.1.1 Magnetic moments and angular momentum

1.1.2 Precession

1.1.3 The Bohr magneton

1.1.4 Magnetization and field

1.2 Classical mechanics and magnetic moments

1.2.1 Canonical momentum

1.2.2 The Bohr-van Leeuwen theorem

1.3 Quantum mechanics of spin

1.3.1 Orbital and spin angular momentum

1.3.2 Pauli spin matrices and spinors

1.3.3 Raising and lowering operators

1.3.4 The coupling of two spins

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems：

(1.1) Calculate the magnetic moment of an electron (with $g = 2$). What is the Larmor precession frequency of this electron in a magnetic field of flux density 0.3 T? What is the difference in energy of the electron if its spin points parallel or antiparallel to the magnetic field? Convert this energy into a frequency.

(1.2) Using the definition of spin operators in eqn 1.43, prove eqn 1.53 and the commutation relations, eqns 1.54 and 1.55.

(1.3) Using the definition of the raising and lowering operators in eqns 1.57, prove eqns 1.58, 1.61.

(1.4) Using the commutation relation for spin, namely that

$$[\hat{S}_x, \hat{S}_y] = \mathrm{i}\hat{S}_z$$

(and cyclic permutations), prove that

$$[\hat{\mathbf{S}} \cdot \mathbf{X}, \hat{\mathbf{S}}] = \mathrm{i}\hat{\mathbf{S}} \times \mathbf{X},$$

where X is a vector.

(1.5) Using eqns 1.58 and 1.61, show that

$$\hat{S}_{\pm}|S, S_z\rangle = \sqrt{S(S+1) - S_z(S_z \pm 1)}|S, S_z \pm 1\rangle,$$

where \S, SZ> represents a state with total spin angular momentum S(S + 1)h2 and z component of spin angular momentum Szh. Hence prove the following special cases of eqn 1.76:

$$\hat{S}_{-}|S, S\rangle = \sqrt{2}S|S, S-1\rangle$$
$$\hat{S}_{+}|S, S-1\rangle = \sqrt{2}S|S, S\rangle$$

(1.6) The kinetic energy operator for an electron is p2/2m. Use eqn 1.41 to show that this can be rewritten

$$\frac{(\boldsymbol{\sigma} \cdot \hat{\mathbf{p}})^2}{2m_e}.$$

If a magnetic field is applied one must replace p by p +eA. With the aid of eqn 1.40, show that this replacement substituted into eqn 1.79 leads to kinetic energy of the form

$$\frac{(\hat{\mathbf{p}} + e\mathbf{A})^2}{2me} + g\mu_{\mathrm{B}}\mathbf{B} \cdot \mathbf{S}$$

where the g-factor in this case is g = 2. (Note that in this problem you have to be careful how you apply eqn 1.40 and 1.41 because p is an operator and will not commute with A.)

Chapter Two: Isolated magnetic moments

1. Teaching aims

   Explain the properties of isolated magnetic moments;

   Understand the concepts of paramagnetism and Diamagnetism;

   Determine the magnetic ground of 4f ions by using the Hund' s rules.

2. Keypoints and Difficulties

   Keypoints: susceptibility; paramagnetism; Diamagnetism; Hund' s Rule; SC coupling; JJ coupling

   Difficulties: the classical and quantum theory of paramagnetism; determine the magnetic ground of 4f ions by using the Hund' s rules

3. Contents

   2.1 An atom in a magnetic field

   2.2 Magnetic susceptibility

   2.3 Diamagnetism

   2.4 Paramagnetism

   2.4.1 Semiclassical treatment of paramagnetism

   2.4.2 Paramagnetism for J = 1/2

   2.4.3 The Brillouin function

   2.4.4 Van Vleck paramagnetism

   2.5 The ground state of an ion and Hund's rules

   2.5.1 Fine structure

   2.5.2 Hund's rules

   2.5.3 L-S and j-j coupling

4. Teaching method

   Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

   Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

(2.1) Calculate the diamagnetic orbital susceptibility of a gas of hydrogen atoms (with number density 1020 m^{-3}) in the ground state, and compare this with the paramagnetic spin susceptibility at 100 K.

(2.2) Estimate the diamagnetic susceptibility of a duck (assume it is composed entirely of water). What magnetic field would be necessary to induce the same magnetic moment in the duck as is contained in a magnetized iron filing? Repeat the calculation for a cow.

(2.3) Calculate the paramagnetic moment of a crystal (with dimensions 2 mm x 2 mm x 2 mm) of CuSO4 5H20 (see Table 2.1, density 2286 kg m- 3 , relative molecular mass 249.7 g) in a field of 1 T at 10 K.

(2.4) Using the expressions for the partition function and the Helmholtz function of a spin-1/2 particle in a magnetic field B from eqns 2.29 and 2.30 respectively, show that for n such non-interacting particles per unit volume, the energy E per unit volume is given by

$$E = -n\mu_B B \tanh\left(\frac{\mu_B B}{k_B T}\right),$$

the heat capacity per unit volume is given by

$$C = nk_B \left(\frac{\mu_B B}{k_B T}\right)^2 \operatorname{sech}^2\left(\frac{\mu_B B}{k_B T}\right),$$

and the entropy per unit volume is given by

$$S = nk_B \left[\ln\left(2\cosh\left(\frac{\mu_B B}{k_B T}\right)\right) - \frac{\mu_B B}{k_B T}\tanh\left(\frac{\mu_B B}{k_B T}\right)\right]$$

(2.5) Show that Hund's rules for a shell of angular momentum l and containing n electrons can be summarized by

$$S = \frac{2l+1-|2l+1-n|}{2}$$

$$L = S\,|2l+1-n|$$

$$J = S\,|2l-n|.$$

(2.6) Find the term symbols for the ground states of the ions (a) Ho3+ (4f10), (b) Er3+ (4f11), (c) Tm3+ (4*f* 12), and (d) Lu3+ (4f14).

Chapter Three: Environments

1. Teaching aims

    Understand the physical picture of the interactions between an atom and its immediate surroundings;

    Determine the magnetic ground of 3d ions under an octahedral or tetrahedral crystal field.

2. Keypoints and Difficulties

Keypoints: crystal field; orbital quenching; Jahn-Teller effects

Difficulties: crystal field; orbital quenching; Jahn-Teller effects

3. Contents

3.1 Crystal fields

3.1.1 Origin of crystal fields

3.1.2 Orbital quenching

3.1.3 The Jahn-Teller effect

3.2 Magnetic resonance techniques

3.2.1 Nuclear magnetic resonance

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

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Problems:

(3.1) A Sc++ ion has one electron in the 3d shell. It is in an anisotropic crystal and the crystal field can be written as a potential acting on the 3d electron as Al^2z. What are the lowest orbital states of the Sc ion if A > 0 and if A < 0? The spin-orbit coupling A.1 • s is much smaller than the crystal field. When this is included, what are the approximate ground states of the ion, for A < 0 and A > 0? Discuss the effect on these states of applying a small magnetic field along the z axis and perpendicular to the z axis, and sketch the temperature dependence of the susceptibility.

(3.2) Equal point positive charges are placed on each of the six comers of an octahedron. Taking the origin of a set of cartesian coordinates to be at the centre of the octahedron, show that the potential close to the centre is given by

$$V = \frac{q}{4\pi\epsilon_0 a}\left[6 + \frac{35}{4a^4}\left(x^4 + y^4 + z^4 - \frac{3}{5}r^4\right) + O\left(\frac{r^6}{a^6}\right)\right]$$

where q is the magnitude of each charge and a is the distance between the origin and each charge.

(3.3) An ion, whose nucleus has zero nuclear spin, has a ground state comprising two degenerate levels corresponding to an effective spin S = 1/2. The application of a magnetic field of flux density B produces a separation of the levels which is linear in B. A single electron paramagnetic resonance line is observed for the ion at a frequency of 30 GHz and a magnetic flux density of 0.6 T. An isotope with non-zero nuclear spin I gives rise to a hyperfine structure (described in the spin-Hamiltonian by a term AI S) comprising four approximately equally spaced resonance lines, with separation 10^{-2} T, symmetrically disposed about the line due to the isotope with zero nuclear spin. What information does this give about (a) the nuclear spin and (b) the nuclear magnetic moment of the isotope? Calculate the value of the parameter A. Why is it sometimes necessary to perform these measurements at low temperature?

(3.4) An NMR spectrometer operates at a frequency of 60 MHz. At what applied magnetic field would you expect to observe the resonance of 1H, 2H, 13C and 19F nuclei? (Use the data in Table 2.3.)

(3.5) An ESR spectrometer operates at a frequency of 9 GHz (known as X-band). What magnetic field would be required to observe a signal from the unpaired electron in DPPH (an organic molecule used to calibrate ESR spectrometers which gives a sharp signal at g = 2).

Chapter Four: Interactions

1. Teaching aims

   Understand the different types of magnetic interaction

2. Keypoints and Difficulties

   Keypoints: Direct exchange

   Difficulties: Indirect exchange in ionic solids: superexchange

3. Contents

4.1 Magnetic dipolar interaction

4.2 Exchange interaction

4.2.1 Origin of exchange

4.2.2 Direct exchange

4.2.3 Indirect exchange in ionic solids: superexchange

4.2.4 Indirect exchange in metals

4.2.5 Double exchange

4.2.6 Anisotropic exchange interaction

4.2.7 Continuum approximation

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

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Problems:

(4.1) Show that two magnetic dipoles u1 and u2 separated by r have a dipolar energy equal to

$$E = \frac{\mu_0}{4\pi r^3}\left[\boldsymbol{\mu}_1 \cdot \boldsymbol{\mu}_2 - \frac{3}{r^2}(\boldsymbol{\mu}_1 \cdot \mathbf{r})(\boldsymbol{\mu}_2 \cdot \mathbf{r})\right].$$

(4.2) Calculate the magnitude of the magnetic field 1 A and 10 A from a proton in a direction (a) parallel and (b) perpendicular to the proton spin direction.
(4.3) Estimate the ratio of the exchange and dipolar coupling of two adjacent Fe atoms in metallic Fe. (The exchange constant in Fe can be crudely estimated by setting it equal to k_BTc where TC is the Curie temperature. For Fe, TC =1043 K.)
(4.4) Provide a rough estimate of the size of the exchange constant in a magnetic oxide which is coupled by superexchange using the measured value of the electronic bandwidth (determined by inelastic neutron scattering) of 0.05 eV. Take the Coulomb energy to be ~1 eV, Hence estimate the antiferromagnetic ordering temperature.
(4.5) Consider the case of two interacting spin-1/2 electrons. The good quantum numbers are S = 0 and 1 so that there is a triplet state and a singlet state which will be separated by an energy gap A. We define the sign of A so that when A > 0 the singlet state (S = 0) is the lower state and when A < 0 the triplet state is the lower state. These situations are shown in Fig. 4.6(a) and (b). Show that the susceptibility in this model is given by

$$\chi = \frac{2Ng\mu_B^2}{k_B T(3 + e^{\Delta/k_B T})},$$

which is known as the Bleaney-Bowers equation. It is plotted in Fig. 4.6(c).

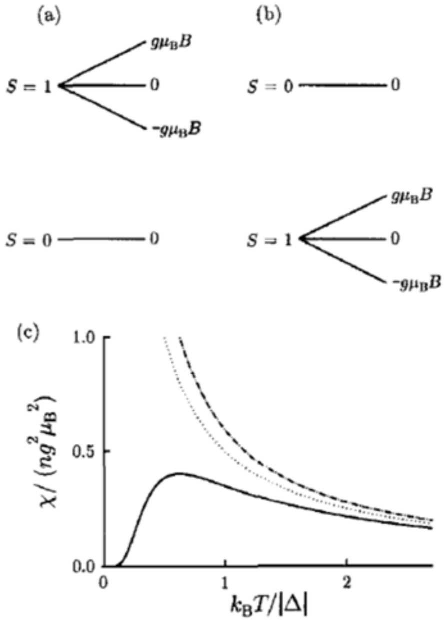
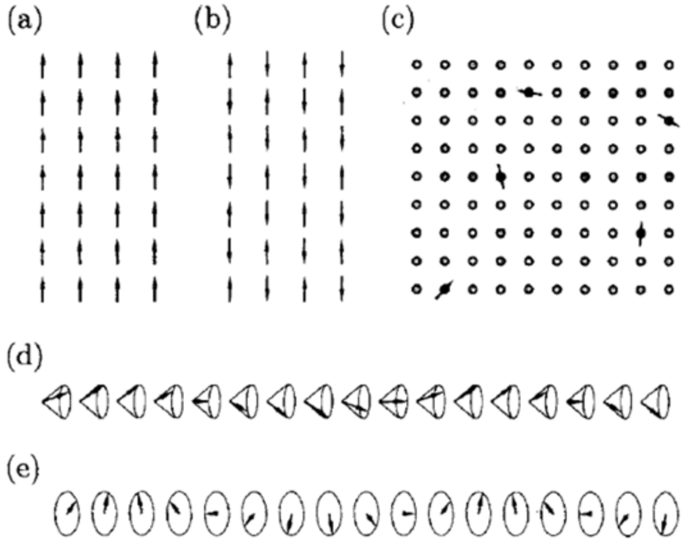


Fig. 4.6 Two spins coupled by Δ give rise to a singlet and triplet state. The energy levels for the case when (a) $\Delta > 0$ and (b) $\Delta < 0$. (c) The susceptibility which is given by the Bleaney–Bowers equation. It is plotted for $\Delta > 0$ (lower curve), $\Delta = 0$ (middle curve), and $\Delta < 0$ (upper curve).

Chapter Five: Order and magnetic structure

1. Teaching aims

   Know the different types of magnetic ground state which can be produced by these interactions



2. Keypoints and Difficulties

   Keypoints: The Weiss model of a ferromagnet; Weiss model of an antiferromagnet

Difficulties: The Weiss model of a ferromagnet

3. Contents

5.1 Ferromagnetism

5.1.1 The Weiss model of a ferromagnet

5.1.2 Magnetic susceptibility

5.1.3 The effect of a magnetic field

5.1.4 Origin of the molecular field

5.2 Antiferromagnetism

5.2.1 Weiss model of an antiferromagnet

5.2.2 Magnetic susceptibility

5.2.3 The effect of a strong magnetic field

5.2.4 Types of antiferromagnetic order

5.3 Ferrimagnetism

5.4 Helical order

5.5 Spin glasses

5.6 Nuclear ordering

5.7 Measurement of magnetic order

5.7.1 Magnetization and magnetic susceptibility

5.7.2 Neutron scattering

5.7.3 Other techniques

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

(5.1) Estimate the size of the molecular field, Bmf in iron in units of Tesla. Compare this with uOM, the contribution to the S-field due to the magnetization.

Hence explain why the concept of exchange is necessary to explain the ferromagnetism of iron. The density of Fe is 7873 kg m-3, the relative atomic mass is 55.847, the Curie temperature TC is 1043 K and each atom carries a moment of approximately 2.2uB .

(5.2) Generalize the Weiss model for spins S > 2. Show that the magnetization M just below TC is given by

$$\frac{M}{M_s} = \left(\frac{10(S+1)^2(T_C - T)}{3[(S+1)^2 + S^2]T_C}\right)^{1/2}$$

and that there is a discontinuity in the heat capacity at TC equal to

$$\Delta C = \frac{5}{2} n k_B \frac{(2S+1)^2 - 1}{(2S+1)^2 + 1}.$$

You will need the relation

$$\begin{aligned} B_S(y) = {} & \left[\frac{(2S+1)^2 - 1}{(2S)^2}\right]\frac{y}{3} \\ & - \left[\frac{(2S+1)^4 - 1}{(2S)^4}\right]\frac{y^3}{45} + O(y^5) \quad y \ll 1. \end{aligned}$$

(5.3) MnF_2 has a tetragonal crystal structure in which the Mn ions are situated at the corners of the tetragonal unit cell a = b =0.5 nm and c =0.3 nm, and at the body-centred position in the unit cell. Below 70 K the spins of the Mn ions become antiferromagnetically aligned along the c axis with the spins of an ion at the centre of the unit cell aligned opposite to those at the corners. The neutron scattering from a powdered sample of MnF_2 is measured using an incident neutron wavelength of 0.3 nm and an angle of scattering between 0° and 90° . Sketch the results you would expect to observe at (a) 100 K and (b) 10 K. You can neglect the scattering from the F ions.

Chapter Six: Order and broken symmetry

1. Teaching aims

   Know the different types of magnetic ground state which can be produced by these interactions

2. Keypoints and Difficulties

   Keypoints: Broken symmetry; Phase transitions; Domains

   Difficulties: Broken symmetry; Domains

3. Contents

6.1 Broken symmetry

6.2 Models

6.2.1 Landau theory of ferromagnetism

6.2.2 Heisenberg and Ising models

6.2.3 The one-dimensional Ising model (D = 1, d = 1)

6.2.4 The two-dimensional Ising model (D = 1, d = 2)

6.3 Consequences of broken symmetry

6.4 Phase transitions

6.5 Rigidity

6.6 Excitations

6.6.1 Magnons

6.6.2 The Bloch T3/2 law

6.6.3 The Mermin-Wagner-Berezinskii theorem

6.6.4 Measurement of spin waves

6.7 Domains

6.7.1 Domain walls

6.7.2 Magnetocrystalline anisotropy

6.7.3 Domain wall width

6.7.4 Domain formation

6.7.5 Magnetization processes

6.7.6 Domain wall observation

6.7.7 Small magnetic particles

4. Teaching method

   Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

   Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

(6.1) A one-dimensional ferromagnetic chain of N spins is described by the Ising Hamiltonian (The last term is used to give periodic boundary conditions.) Show that the partition function Z of this system can be obtained by introducing new operators which have eigenvalues +1 or -1, and hence show that the partition function is Z = (2 cosh(J/2KBT))N. Using these results obtain an expression for the heat capacity per spin of the chain as N —> oo. Deduce the low and high temperature behaviour of the heat capacity and sketch the heat capacity as a function of temperature. Discuss the result.

(6.2) A uniaxial ferromagnet is described by the Hamiltonian

$$\hat{\mathcal{H}} = -\sum_{ij} J_{ij}\,\hat{\mathbf{S}}_i \cdot \hat{\mathbf{S}}_j - \sum_{ij} K_{ij}\,\hat{S}_i^z \hat{S}_j^z.$$

(a) Show that the state with all spins fully aligned along the z axis is an eigenstate of the Hamiltonian.

(b) Obtain an expression for the spin wave spectrum as a function of wave vector q.

(c) Simplify the expressions for the case where Jij and Kij are restricted to nearest neighbours, Jo and K0, and the ferromagnet is (i) a one-dimensional chain, (ii) a twodimensional
square lattice and (iii) a three-dimensional body-centred cubic material.

Chapter Seven: Magnetism in metals

1. Teaching aims

   Know the derivations of the magnetic properties of the electron gas which include Pauli paramagnetism, Landau diamagnetism, the origin of RKKY interactions, instabilities of the electron gas such as spindensity wave formation, and the Kondo effect which occurs when localized moments interact with the electron gas.

2. Keypoints and Difficulties

   Keypoints: free electron model; Pauli paramagnetism; Landau diamagnetism; RKKY interactions
   Difficulties: Pauli paramagnetism; Landau diamagnetism

3. Contents

7.1 The free electron model

7.2 Pauli paramagnetism

7.2.1 Elementary derivation

7.2.2 Crossover to localized behaviour

7.2.3 Experimental techniques

7.3 Spontaneously spin-split bands

7.4 Spin-density functional theory

7.5 Landau levels

7.6 Landau diamagnetism

7.7 Magnetism of the electron gas

7.7.1 Paramagnetic response of the electron gas

7.7.2 Diamagnetic response of the electron gas

7.7.3 The RKKY interaction

7.8 Excitations in the electron gas

7.9 Spin-density waves

7.10 The Kondo effect

7.11 The Hubbard model

7.12 Neutron stars

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

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Problem

(7.1) (a) Show that the paramagnetic susceptibility of a nondegenerate electron gas containing N electrons is identical to that of N independent localized electrons whose

orbital motion is quenched.

(b) Consider a semiconductor with 3 x 1022 electrons per cubic metre in its conduction band and an effective mass m* = 0.1me. Estimate the temperature below which the magnetic susceptibility is independent of temperature. Below this temperature, calculate the magnitude of the Pauli paramagnetism and the Landau diamagnetism

(7.2) Show that the Fourier transform of the Fermi sphere is related to a function related to the RKKY function in eqn 7.89, namely that

$$\int_{|\mathbf{k}|<k_{\mathrm{F}}} \mathrm{d}^3\mathbf{k}\, \mathrm{e}^{\mathrm{i}\mathbf{k}\cdot\mathbf{r}} = \int_0^{k_{\mathrm{F}}} 2\pi k^2\, \mathrm{d}k \int_0^{\pi} \mathrm{e}^{\mathrm{i}kr\cos\theta} \sin\theta\, \mathrm{d}\theta$$

$$= \frac{4\pi}{r^3}\left[\sin k_{\mathrm{F}}r - k_{\mathrm{F}}r\cos k_{\mathrm{F}}r\right] \quad (7.95)$$

Chapter Eight: Competing interactions and low dimensionality

1. Teaching aims

   Know some of the ways in which competing interactions and low dimensionality can lead to some extremely subtle, complex, and sometimes even useful magnetic behaviour in solids.

2. Keypoints and Difficulties

   Keypoints: Spin glasses; Superparamagnetism
   Difficulties: Spin glasses

3. Contents

   8.1 Frustration

   8.2 Spin glasses

   8.3 Superparamagnetism

   8.4 One-dimensional magnets

   8.4.1 Spin chains

   8.4.2 Spinons

   8.4.3 Haldane chains

   8.4.4 Spin-Peierls transition

   8.4.5 Spin ladders

   8.5 Two-dimensional magnets

   8.6 Quantum phase transitions

   8.7 Thin films and multilayers

   8.8 Magneto-optics

   8.9 Magnetoresistance

   8.9.1 Magnetoresistance of ferromagnets

   8.9.2 Anisotropic magnetoresistance

   8.9.3 Giant magnetoresistance

   8.9.4 Exchange anisotropy

   8.9.5 Colossal magnetoresistance

   8.9.6 Hall effect

   8.10 Organic and molecular magnets

8.11 Spin electronics

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

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IV. Class hour allocation

Table II. Specific contents of each chapter and class hour allocation table

章节 Chapter	章节内容 Chapter content	学时分配 Class hour allocation
Chapter One	Introduction	Two Weeks, 4 Hours
Chapter Two	Isolated magnetic moments	Two Weeks, 4 Hours
Chapter Three	Environments	Two Weeks, 4 Hours
Chapter Four	Interactions	Two Weeks, 4 Hours
Chapter Five	Order and magnetic structure	Two Weeks, 4 Hours
Chapter Six	Order and broken symmetry	Two Weeks, 4 Hours
Chapter Seven	Magnetism in metals	Two Weeks, 4 Hours
Chapter Eight	Competing interactions and low dimensionality	Two Weeks, 4 Hours

V. Teaching progress

Table III. Teaching schedule

Week	Date	Chapter	Content	Teaching hours	Requirements	Remarks
1		Chapter One	Introduction; Magnetic moments; Classical mechanics	Two	Problem	
2		Chapter One	Quantum mechanics	Two	Problem	
3		Chapter Two	Magnetic susceptibility; Diamagnetism	Two	Problem	
4		Chapter Two	Paramagnetism; Hund’s Rule; SC coupling; JJ coupling	Two	Problem	
5		Chapter Three	Crystal field;	Two	Problem	
6		Chapter Three	Orbital quenching; Jahn-Teller effects	Two	Problem	
7		Chapter Four	Magnetic dipolar interaction; Exchange interaction; Direct exchange	Two	Problem	
8		Chapter Four	Indirect exchange; Double exchange; Anisotropic exchange interaction	Two	Problem	

9		Chapter Five	Ferromagnetism	Two	Problem	
10		Chapter Five	Antiferromagnetism	Two	Problem	
11		Chapter Six	Broken symmetry; Heisenberg and Ising models	Two	Problem	
12		Chapter Six	Phase transitions; Excitations; Domains	Two	Problem	
13		Chapter Seven	The free electron model; Pauli paramagnetism	Two	Problem	
14		Chapter Seven	Landau diamagnetism; RKKY interactions	Two	Problem	
15		Chapter Eight	Spin glasses	Two	Problem	
16		Chapter Eight	Superparamagnetism	Two	Problem	

VI. Textbook and References

Textbooks：Stephen Blundell, Magnetism in Condensed Matter, Oxford University Press, 2001

References：

1. B. I. Bleaney and B. Bleaney, Electricity and Magnetism, OUP 1989, contains a comprehensive treatment of electromagnetism

2. A. I. Rae, Introduction to Quantum Mechanics, IOP Publishing 1992 is a clear exposition of Quantum Mechanics at an introductory level.

3. A good account of quantum angular momentum can be found in Chapters 1-3 of volume 3 of the Feynman lectures in Physics, R. P. Feynman, Addison-Wesley 1975.

4. An excellent description of quantum mechanics may be found in J. J. Sakurai, Modern Quantum Mechanics, 2nd edition 1994, Addison-Wesley.

5. B. H. Bransden and C. J. Joachain, Physics of atoms and molecules, Longman 1983, provides extensive information on isolated atoms.

6. Useful background information may also be found in P. W. Atkins, Molecular quantum mechanics, OUP 1983.

7. Also useful is the comprehensive book by A. Abragam and B. Bleaney, Electron paramagnetic resonance of transition ions, Dover 1986.

8. D. J. Griffiths, Introduction to electromagnetism, Prentice Hall 1989 provides a readable account of magnetostatic fields in matter.

9. A discussion of the merits of classical versus quantum mechanical derivations of diamagnetism is given in S. L. O'Dell and R. K. P. Zia, American Journal of Physics 54, 32(1986).

10. A good introduction to NMR may be found in P. J. Hore, Nuclear magnetic resonance OUP 1995. Also extremely useful is B. Cowan, Nuclear magnetic resonance and relaxation CUP 1997. The classic text on NMR is A. Abragam, Principles of nuclear magnetism OUP 1961.

11. A. Abragam and B. Bleaney, Electron Paramagnetic Resonance of Transition Ions, Dover 1986, provides extensive information about crystal fields and ESR experiments in paramagnetic salts.

12. The crystal field can be considered using the so-called Stevens operators, see K. W. H. Stevens, Proc. Phys. Soc. A 65, 209 (1952) and M. T. Mulchings, Solid State Physics 16, 227 (1966).

13. For further information on the M6ssbauer effect see Mossbauer spectroscopy, edited by D. P. E. Dickson and F. J. Berry, CUP 1986.

VII. Teaching method

1. Give full play to the educational role of theoretical physics courses, consolidate mathematical and physical foundations, and emphasize the addition of cutting-edge scientific and technological content, keeping the teaching materials updated. Integrate magnetic physics with solid-state physics, quantum mechanics, and other courses, focusing on complex quantum model systems at the forefront of interdisciplinary research, and sharpening scientific thinking and research innovation abilities.

2. Combine blackboard writing and PowerPoint presentations, taking advantage of both traditional and modern teaching methods. Adopt a comprehensive approach that includes lectures, discussions, and flipped classrooms.

3. Integrate relevant innovation projects, train students' ability to solve complex problems through thematic seminars, literature research, and group collaboration, among other activities.

4. Utilize information technology: Create an information-based teaching environment that combines offline classroom teaching, making the teaching format interactive. For example, use an online platform to distribute quizzes in real-time to assess teaching effectiveness and assist in activities such as flipped classrooms and thematic seminars.

VIII. Assessment method and evaluation method

[1] Corresponding relationship between curriculum assessment and curriculum objectives

Table IV. Correspondence between course assessment and course objectives

Course objectives	Key points of assessment	Assessment method
Course objectives1	Related teaching content	Regular learning performance evaluation + Process-oriented assessment + The final exam
Course objectives2	Related teaching content	Regular learning performance evaluation + Process-oriented assessment + The final exam
Course objectives3	Related teaching content	Regular learning performance evaluation + Process-oriented assessment + The final exam

[2] Appraising method

[1] Appraising method

Multifaceted assessment: from in-class to out-of-class, from final exams to process-oriented assessments, from in-class activities to project-based assessments, etc. Utilize an information-based app to export pre-class, in-class, and post-class learning data, along with out-of-class thematic discussions, process-oriented assessments, and closed-book exams. Calculate the final grade based on weighted scores.

The regular assessment accounts for 10% of the total grade, with four formative assessments contributing 60% (15% each), and the final assessment accounting for 30% of the total grade.

[2] Analysis of assessment proportion and achievement degree of curriculum objectives

Table V. Analysis of assessment proportion and achievement degree of curriculum objectives

考核占比 课程目标	平时	过程化考核	期末	总评达成度
Course objectives1	30%	30%	30%	Degree of achievement for Course Objective 1 = {0.1 x regular performance score for Objective 1 + 0.6 x process-oriented exam score for Objective 1 + 0.3 x the final exam score for Objective 1} / Total score for Objective 1. Degree of achievement for Course Objective 2 = {0.1 x regular performance score for Objective 2 + 0.6 x process-oriented exam score for Objective 2 + 0.3 x the final exam score for Objective 2} / Total score for Objective 2. Degree of achievement for Course Objective 3 = {0.1 x regular performance score for Objective 3 + 0.6 x process-oriented exam
Course objectives2	30%	30%	30%	
Course objectives3	40%	40%	40%	

				score for Objective 3 + 0.3 x the final exam score for Objective 3} / Total score for Objective 3. Overall degree of achievement = 0.3 x Degree of achievement for Course Objective 1 + 0.3 x Degree of achievement for Course Objective 2 + 0.4 x Degree of achievement for Course Objective 3.

[3] Scoring criteria

Course objectives	Scoring criteria				
	90-100	80-89	70-79	60-69	＜60
	优	良	中	合格	不合格
	A	B	C	D	F
Course objectives 1	Demonstrate a deep and comprehensive understanding of the key concepts in magnetic physics, showcasing the ability to explain complex ideas, apply them to various scenarios, and analyze their implications.	Display a solid understanding of the key concepts in magnetic physics, with the ability to provide clear explanations and apply them to basic scenarios.	Show a satisfactory understanding of the key concepts in magnetic physics, able to explain them to a certain extent and apply them in simple contexts.	Exhibit a basic understanding of some key concepts in magnetic physics, but with limited ability to explain or apply them accurately.	Lack a sufficient understanding of the key concepts in magnetic physics, unable to provide accurate explanations or apply them effectively.
Course objecti	Demonstrate a comprehensive	Show a solid grasp of the	Display a satisfactory	Exhibit a basic understanding	Lack a sufficient

Course objectives	Scoring criteria				
	90-100	80-89	70-79	60-69	＜60
	优	良	中	合格	不合格
	A	B	C	D	F
ves 2	understanding of the properties and applications, effectively illustrating the implications of these ideas for real materials.	properties and applications, effectively explaining the implications of these ideas for real materials.	understanding of the properties and applications, with some ability to explain the implications of these ideas for real materials.	of the properties and applications, with limited ability to explain the implications of these ideas for real materials.	understanding of the properties and applications, unable to demonstrate the implications of these ideas for real materials.
Course objectives 3	Provide a comprehensive and thorough explanation of the underlying ideas in real measurements and experimental techniques, demonstrating a deep understanding of the principles, methodologies, and applications involved.	Offer a clear and coherent explanation of the underlying ideas in real measurements and experimental techniques, showcasing a solid understanding of the principles and methodologies involved.	Provide a satisfactory explanation of the underlying ideas in real measurements and experimental techniques, demonstrating a basic understanding of the principles and methodologies involved.	Exhibit a limited or superficial explanation of the underlying ideas in real measurements and experimental techniques, with some gaps in understanding the principles and methodologies involved.	Lack a sufficient explanation of the underlying ideas in real measurements and experimental techniques, showing a lack of understanding of the principles and methodologies involved.