Exam on “Fundamental Properties: Magnetism”

Lecturer: Graeme Blake

Friday January 27, 2017
5118.-152 and 5118.-156
9:00 – 10:30

Exam drafted by Graeme Blake, exam reviewed by Ron Tobey

Name:……………………………………………………………………………….

Student Number: ………………………………………………………………..

This exam paper contains 3 questions on 7 pages.

For administrative purposes; do NOT fill the table

	Maximum points	Points scored
Question 1	11	
Question 2	8	
Question 3	11	
Homework	Grade 1.0	
Total		

The exam grade for the magnetism part is calculated as 1 + 9 × (exam points/30)
The final grade for the magnetism part is (0.9 × exam grade) + (homework grade).

Final grade: _________

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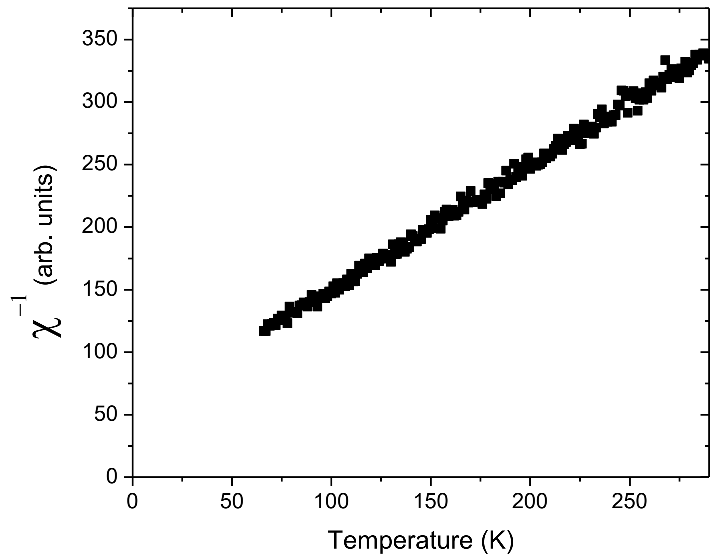
Question 1 (11 points)

a. The figure below shows a plot of the inverse magnetic susceptibility of an unspecified material which at some low temperature shows magnetic ordering.

i. Is this compound ferromagnetic or antiferromagnetic? (1 point)

ii. From the plot, estimate the approximate magnetic ordering temperature. (1 point)

iii. Sketch on the plot how you expect the inverse magnetic susceptibility to evolve below 75 K. (1 point)



b. i. Sketch a plot of magnetization versus applied magnetic field (up to high fields) for the same material, assuming that the magnetic field is applied in the same direction as that of the spins. (1 point)

ii. Make a similar sketch for the situation where the field is applied perpendicular to the spins. (1 point)

c. The compound $LaMnO_3$ shows a phase transition at 750 K in which the structure changes from cubic symmetry on the high temperature side, to an orthorhombic phase on the low temperature side in which the MnO_6 octahedra in the structure are distorted.

i. What kind of phase transition is this?
Explain, using an energy diagram for the d-levels of Mn^{3+} why this happens. (Note: here La has a formal charge of 3+ and Mn^{3+} has the electronic configuration $[Ar]3d^4$). (2 points)

ii. Would you expect a similar transition in $CaMnO_3$? Why/Why not? (Note: here Ca has a formal charge of 2+). (1 point)

iii. For the mixed-valence compound $La_{0.6}Ca_{0.4}MnO_3$, would you expect a ferromagnetic or an antiferromagnetic interaction between the moments on the Mn ions? Briefly explain the mechanism of this exchange interaction. Briefly explain whether you expect the compound to be a metal or an insulator. (3 points)

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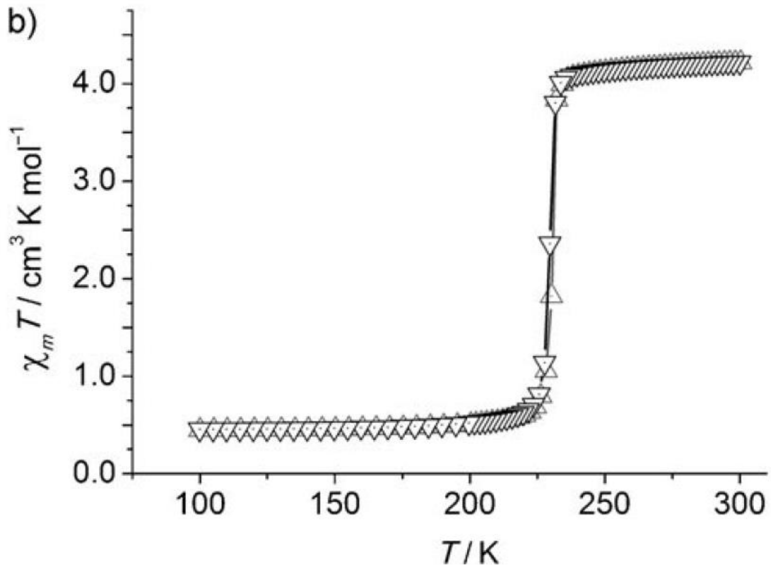
Question 2 (8 points)

The figure below shows a plot of the measured magnetic susceptibility versus temperature (in the form χT versus T) of a paramagnetic complex containing Fe^{3+} cations (electronic configuration $[Ar]3d^5$), each of which is coordinated by 6 ligands in octahedral geometry.



a. Using Hund's rules, predict the term symbol of the ground state of Fe^{3+} (2 points)

b. Give a possible explanation for the sudden change in magnetic susceptibility at 225 K. Is the measured magnetic susceptibility consistent with the predicted ground state of Fe^{3+}? Explain your answer. (2 points)

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c. The effective magnetic moment of a magnetic ion is given by the formula $\mu_{eff} = g_J \mu_B \sqrt{J(J+1)}$

However, this predicted effective moment does not always agree well with experiment.

i. For Ni^{2+} (electronic configuration $[Ar]3d^8$) the predicted μ_{eff} is 5.59 μ_B whereas the measured μ_{eff} is 3.12 μ_B. Explain briefly why. (2 points)

ii. For Eu^{3+} (electronic configuration $[Xe]4f^6$) the predicted μ_{eff} is 0 μ_B (zero) whereas the measured μ_{eff} is 3.4 μ_B. Explain briefly why. (2 points)

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Question 3 (11 points)

a. Explain why Fe, Co and Ni are ferromagnetic whereas all other metallic elements are not. (2 points)

b. Palladium (Pd) and platinum (Pt) are metals that are often said to be on the verge of ferromagnetism. Their paramagnetic susceptibility is greater than that predicted by the formula for Pauli paramagnetism, $\chi_P = \dfrac{3n\mu_0\mu_B^2}{2E_F}$ Explain why. (2 points)

c. Why do ferromagnetic samples form magnetic domains in the absence of a magnetic field? Explain the difference between Néel walls and Bloch Walls. (2 points)

d. Ferromagnetic iron has a cubic crystal structure with lattice constant 2.856 Å. Its magnetic moment is 2.14 μ_B per atom, the exchange constant is equal to $k_B T_C$ where T_C = 1043 K, and the easy axis anisotropy is $K = 4.8\times10^4$ J/m^3. Calculate the domain wall thickness (assume Bloch walls). (2 points)
(Note: $k_B = 1.381 \times 10^{-23}$ J/K)

e. For iron the magnetic easy axis is the [100] direction. Sketch the magnetization as a function of applied magnetic field when the field is applied along the easy axis and when the field is applied along the [110] direction. (2 points)

f. The interaction between the magnetic layers in an alternating non-magnetic metal/ferromagnetic metal multilayer structure can be either ferromagnetic or antiferromagnetic, depending on the thickness of the non-magnetic layers. Explain briefly in words why this is so. (1 point)