Exam on "Functional Properties: Magnetism"

Lecturer: Graeme Blake

Friday January 26, 2018
Martini Plaza
(half of the 09.00 – 12.00 time slot)

Exam drafted by Graeme Blake, exam reviewed by Caspar van der Wal

Name:……………………………………………………………………………….

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

This exam paper contains 3 questions on 6 pages.
Please answer on the back of the page if you need more space.
A periodic table is supplied at the end of the paper (page 7).

For administrative purposes; do NOT fill the table

	Maximum points	Points scored
Question 1	10	
Question 2	14	
Question 3	11	
Homework	1 point of final score	
Total		

The exam grade for the magnetism part is calculated as 1 + 9 × (exam points/35).
The final grade for the magnetism part is (exam grade) + (homework grade).

Final grade: _________

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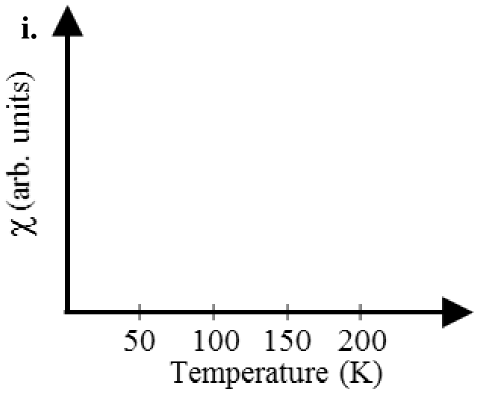
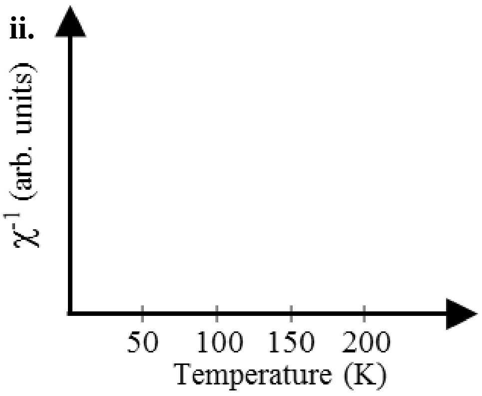
Question 1 (10 points)

a. **i.** On the left-hand plot below, draw a typical magnetic susceptibility versus temperature curve for a *ferromagnet* with T_C = 100 K. (2 points)

ii. On the right-hand plot below, draw a typical *inverse* magnetic susceptibility versus temperature curve for an *antiferromagnet* with T_N = 50 K. (2 points)





b. Propose a suitable order parameter for a paramagnetic to antiferromagnetic phase transition and explain why this order parameter is suitable. (2 points)

c. Describe how the effective magnetic moment in the *paramagnetic* temperature region (above the ordering temperature of the ferromagnet or antiferromagnet) can be experimentally determined. (2 points)

d. $LaBaNiO_4$, in which Ni^{3+} ($3d^7$) is octahedrally coordinated by oxygen, is a paramagnetic insulator. The effective magnetic moment of Ni is μ_{eff} = 1.75 μ_B at 100 K but μ_{eff} = 3.90 μ_B at room temperature. Give a possible explanation for these different values. (2 points)

Question 2 (14 points)

a. i. Using Hund's rules, determine the ground state of the Sm^{3+} cation (electronic configuration $4f^5$). (2 points)

ii. Calculate the effective magnetic moment of ground-state Sm^{3+}. (The Landé g-value for Sm^{3+} is g_J = 2/7.) (2 points)

iii. The measured effective moment of Sm^{3+} is μ_{eff} = 1.74 μ_B. Does this agree with your calculated value? Comment on your answer. (2 points)

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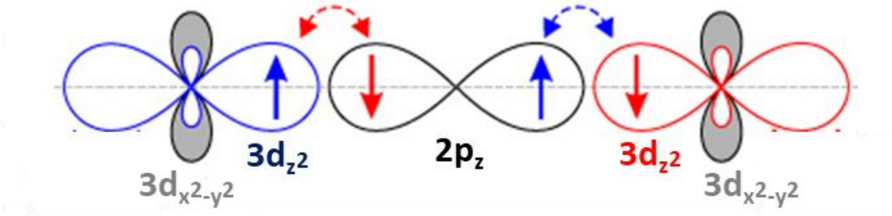
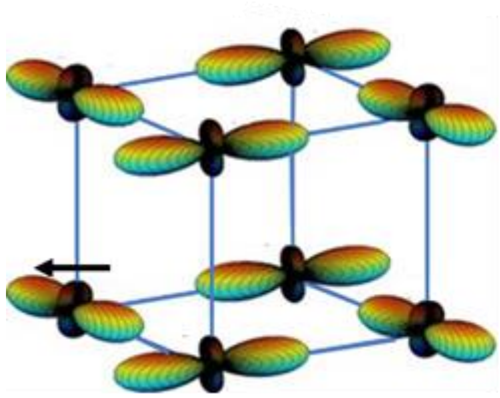
c. Consider a metal oxide in which neighbouring transition metal atoms, both octahedrally coordinated by oxygen, each contain one unpaired electron in the $3d_{z2}$ orbital. Superexchange can take place via the $2p_z$ orbital of a bridging oxygen atom in the geometry shown schematically below. Explain why superexchange in this geometry is antiferromagnetic. (2 points)



d. $LaMnO_3$ possesses one unpaired electron in its manganese $3d_{z2}$ orbital. These orbitals order spatially as shown in the picture below. Explain briefly why this happens. (Here Mn^{3+} has electron configuration $3d^4$ and manganese is octahedrally coordinated by oxygen.) (2 points)



e. The spin associated with one Mn^{3+} cation in $LaMnO_3$ is shown by the arrow (lower left on the diagram above). Indicate on the picture the directions of the other spins. Is the overall spin ordering in $LaMnO_3$ ferromagnetic or antiferromagnetic? (2 points)

f. $LaMnO_3$ is an insulator. When more than 20% of the trivalent La^{3+} in $LaMnO_3$ is replaced by divalent Sr^{2+}, the material becomes metallic. Suggest why. (2 points)

Question 3 (11 points)

a. When a ferromagnetic material is cooled down through its Curie temperature in the absence of an applied magnetic field, it forms ferromagnetic domains. Explain why these domains spontaneously form. (2 points)

b. Sketch a typical magnetization versus applied magnetic field loop for a soft ferromagnet and a hard ferromagnet. Give an example of an application for each type of ferromagnet and explain briefly why its properties are suitable for that application. (4 points)

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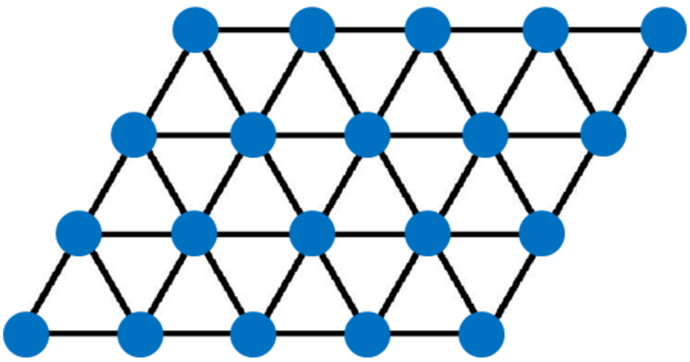
c. Ferromagnetic nickel has a cubic crystal structure with lattice constant 3.524 Å. There are 0.6 spins per atom in the ferromagnetic state, the exchange constant *J* is equal to $k_B T_C$ where T_C = 627 K, and the easy axis anisotropy is K = -0.5×10^4 J/m^3. Calculate the domain wall thickness (assume Bloch walls). (2 points)
(Note: $k_B = 1.381 \times 10^{-23}$ J/K)

d. $YbMgGaO_4$ is an insulator and has a crystal structure in which the magnetic Yb^{3+} cations (S = ½) are arranged in two-dimensional layers with a triangular pattern as shown below by the blue circles. The sign of J for the exchange interaction between neighbouring Yb^{3+} cations is negative (antiferromagnetic). Discuss what the magnetic properties of $YbMgGaO_4$ might be and whether you would expect long-range magnetic ordering to occur in this compound. How could you test your prediction experimentally? (3 points)



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Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.93	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.73	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.09	35 Br Bromine 79.90	36 Kr Krypton 84.80
37 Rb Rubidium 84.49	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium 98.91	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium [208.98]	85 At Astatine 209.98	86 Rn Radon 222.02
87 Fr Francium 223.02	88 Ra Radium 226.03	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.97	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244.06	95 Am Americium 243.06	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium [254]	100 Fm Fermium 257.10	101 Md Mendelevium 258.10	102 No Nobelium 259.10	103 Lr Lawrencium [262]

Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide