Evaluation G0S93A
Electron Correlations: Superconductivity and Magnetism
13 June 2016
15 June 2016

NAME:..

INSTRUCTIONS:

- *No course notes, textbooks or any other course or text material is allowed during the exam, except for the formularium that will be handed out during the exam.*
  DON'T WRITE ON THE FORMULARIUM, PLEASE.
- *Please write clearly and be as complete as possible. Answers on scratch paper will not be considered.*
- *Write your name on every answer page (blue paper) of your exam.*
- *This exam form contains 5 pages: one instruction page and 4 questions.*
- *Questions 1 and 2 should be prepared written and will be discussed during the oral examination. Oral examinations will be taken by Prof. M.J. Van Bael (question 1) and Prof. L. Pereira (question 2). The evaluation of these questions will be based both on your written answers and on the oral discussion.*
- *Questions 3 and 4 should be answered fully written and will not be discussed during the oral examination. The evaluation for these questions will be based only on your written answers.*
- *The oral examination starts 1 hour after the beginning of the exam.*

SUCCES !!

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QUESTION 1 (WRITTEN preparation (English or Dutch) – ORAL discussion Prof. M.J. Van Bael)

LETTER

doi:10.1038/nature14964

Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system

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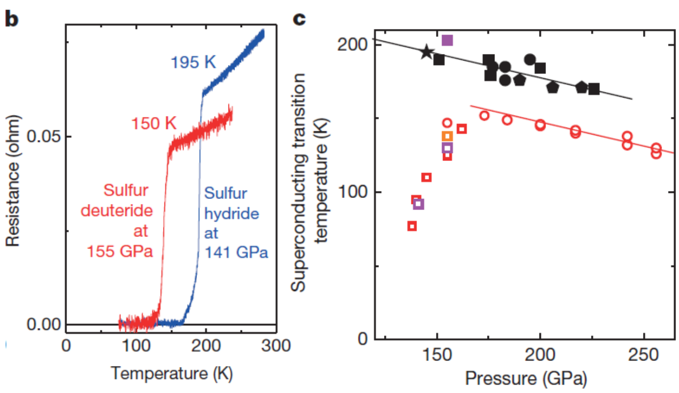

b) Typical superconductive transitions for sulfur hydride (blue trace) and sulfur deuteride (red trace). …
c) Dependence of T_c on pressure; …. Open coloured points refer to sulfur deuteride, and filled points to sulfur hydride. …

The above recent publication of September 2015 reports on the signatures of superconductivity in sulfur hydride under high pressure at a surprisingly high temperature up to 203K.

a) The blue curve in the left figure shows the superconducting resistive transition of H_2S.
How does this proof that the material becomes superconducting and is it sufficient proof of superconductivity?
b) Explain the specific effect that is demonstrated in the given figures and clarify what is the relevance to investigate it. Relate to a superconducting theory or model.
c) What class of superconducting materials currently has the highest critical temperature at ambient pressure?
d) In view of applications, what else is important beside a high critical temperature?

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QUESTION 2 **(WRITTEN preparation (English) – ORAL discussion Prof. L. Pereira)**

What are the main differences between a typical paramagnetic system and a typical superparamagnetic system? Answer this general question by answering the questions (a-e) below.

a) Between these two systems:
   i) dilute Fe ions in a nonmagnetic matrix
   ii) Fe nanoparticles (few nm in diameter) in a non-magnetic matrix
   Which one is more likely to behave as a typical paramagnet and which as a typical superparamagnet?

b) Draw typical magnetization curves for each of them (qualitative, no calculations required):
   i) $M(H)$ at 5 K and 300 K, for $\mu_0 H$ between 0 and 5 T.
   ii) $M(T)$ between 5 K and 300 K, in a low field H ($\mu_0 H \approx 1 \times 10^{-3}$ T), after cooling in field.

c) Under certain conditions, the magnetization curves of paramagnets and superparamagnets can be described (to a reasonable approximation) by the same theory/function, and only one parameter/quantity is responsible for the differences highlighted in your answer to (b). Identify this parameter/quantity and comment on the difference that it originates in the magnetization curves drawn in (b).
   (you can explain it in about 3 lines of text; no equations are explicitly required, but simple expression(s) may help your discussion)

d) The Langevin function is a good approximation to describe superparamagnetic systems, but a poorer description to describe a typical paramagnet. Comment on the fundamental reason for that. (hint: quantum mechanics)
   (you can explain it about 4 lines of text; no equations are explicitly required, but simple expression(s) may help your discussion)

e) Furthermore, even typical superparamagnets often deviate from Langevin function behavior at low temperature and low field. Describe this effect and its origin.
   (you can explain it in about 4 lines of text)

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QUESTION 3 **(ONLY WRITTEN – English or Dutch)**

a) Discuss in detail the Ginzburg-Landau (GL) theory. Explain how to arrive at the GL equations, discuss the physical meaning of the coefficients and parameters in the GL-equations.

b) Explain how the characteristic length scales appear from the GL theory and how to understand their physical meaning. Explain also their temperature dependence according to the GL theory.

c) Which characteristic length scale does not directly evolve from the GL theory? What is its physical meaning?

d) Compare the GL theory with other theories and models for superconductivity.

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QUESTION 4 (ONLY WRITTEN - English)

a) Calculate the magnetic susceptibility of GaN (SI units), assuming that there are no free carriers and no local magnetic moments.

b) Now consider that 10% of the Ga atoms were replaced by Mn atoms (assume, for simplicity, that the number of atoms per unit volume does not change). Assume that Mn atoms are in a 3+ charge state ($3d^4$), that you can apply the Russel-Saunders coupling scheme, and that there is no magnetic interaction between the Mn atoms.
Calculate the paramagnetic susceptibility at 300 K (SI units) associated with the local Mn moments, still assuming that there are no free carriers, for two different scenarios:
   i) without orbital quenching
   ii) with orbital quenching

c) Calculate the total magnetic susceptibility of the system described in (b), at 300 K, for scenario (ii). Convert that value to mass susceptibility (in $m^3\ Kg^{-1}$). Convert both quantities to the cgs unit system.

d) Now consider that the system in (b) orders ferromagnetically with a T_C of 10 K, with the moment per Mn atom being the same as in the paramagnetic regime (calculated in (b)).
Estimate the magnitude of the molecular field in units of Tesla.

Some constants and parameters that you may need to use, but not necessarily all):
ρ(GaN) = 6150 kg m^{-3}
Avogadro constant = 6.02×10^{23} mol^{-1}
relative atomic mass of Ga is 69.7 and of N is 14.0
$\boldsymbol{e}$ = 1.6×10^{-19} C
$\boldsymbol{\mu_0}$ = $4\pi \times 10^{-7}$ N A^{-2}
$\boldsymbol{m_e}$ = 9.11×10^{-31} kg
Z(Ga) = 31; **Z(N)** = 7; **Z(Mn)** = 25
$\langle r^2 \rangle_{av}$**(Ga)** = 1.69×10^{-20} m^2
$\langle r^2 \rangle_{av}$**(N)** = 4.22×10^{-21} m^2
$\langle r^2 \rangle_{av}$**(Mn)** = 2.56×10^{-20} m^2
$\boldsymbol{\mu_B}$ = 9.27×10^{-24} J T^{-1}
$\boldsymbol{k_B}$ = 1.38×10^{-23} m^2 kg s^{-2} K^{-1}