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# MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY

## UNIVERSITY EXAMINATIONS
## 2021/2022 ACADEMIC YEAR

## SECOND YEAR SECOND SEMESTER SPECIAL / SUPPLEMENTARY EXAMINATIONS

## FOR THE DEGREE
## OF
## MASTER OF SCIENCE IN PHYSICS

**COURSE CODE:** SPH 822E

**COURSE TITLE:** ENERGY BANDS, MAGNETISM AND AMORPHOUS MATERIALS

**DATE:** MONDAY 1ST AUGUST, 2022 **TIME:** 8 AM -11 AM

**INSTRUCTIONS TO CANDIDATES**

- Question ONE is compulsory and carries 30 marks
- Attempt any TWO of the remaining questions. Each carries 20 marks.
- Symbols used here hear their usual meaning
- All symbols used have their usual meaning.
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**TIME:** 3 HOURS



*This paper consists of 4 printed pages. Please Turn Over*

**QUESTION ONE** **[14 Marks]**

(a) **Describe** in some detail how the characteristic shape of the magnetization curve (**M** versus **H**) of a ferromagnet can be qualitatively understood in terms of the domain model of ferromagnetism proposed by P. Weiss. [5 marks]

(b) **Show**, with reference to a ferromagnetic sample of regular shape, how a stable domain configuration can develop. **Explain** the role of the magnetostatic energy, the anisotropy energy and the exchange energy in this development [5 marks]

(c) The Bloch domain walls in ferromagnetic cobalt are 128 Å (12.8 nm) wide. **Estimate** the angle between the magnetic moment directions on neighbouring cobalt atoms within a domain wall. [4 marks]

**QUESTION TWO** **[14 Marks]**

a) **Apply** Hund rules to determine the ground state of $Dy^{3+}$ in configuration of $5s^2p^6\,4f^9$. Express your answer in standard atomic notation. [1 mark]

b) The Curie constant C is given as

$$C = \frac{Ng^2[J\{J+1\}]\mu_B^2}{3k_B}$$

for f - electrons. **Estimate** the Curie constants for $Dy^{3+}$. Avogadro's number is given as $6.022 \times 10^{23}\ mol^{-1}$. Note that the g - factor is given by the Lande equation: [3 marks]

$$g = 1 + \frac{J(J+1)+S(S+1)-L(L+1)}{2J(J+1)}$$

c) The susceptibility of $MnF_2$ was measured in the paramagnetic region above the Neel temperature with the following results

| Temperature (K) | 300 | 200 | 160 | 90 |
|---|---|---|---|---|
| Susceptibility, $\chi$ (SI) | 0.0059 | 0.0079 | 0.0091 | 0.0123 |

(i) By **plotting** a suitable graph, show that $MnF_2$ is antiferromagnetic and **determine** the Curie-weiss parameter $\Theta$. [5 marks]

(ii) **Calculate** the effective number of Bohr magnetons and **verify** the result by comparing with the free ion value for the configuration $3d^5$ of $Mn^{2+}$. $MnF_2$ crystallizes in a body-

centred tetragonal cell with a = b = 0.487 nm; c = 0.331 nm and the two formula units per unit cell. [5 marks]

**QUESTION 3** **[14 Marks]**

a) Name two electronic properties of metals that the free electron model can not account for [2 marks]

b) Derive the Curie-Weiss law for the ferromagnets using the mean field theory [4 marks]

c) A ferromagnet has fcc structure with lattice parameter 3.84 Å (cubic cell side) and magnetic moment $1.2\,\mu_B$ per atom at 0 K. Well above the Curie temperature the magnetic susceptibility data in the table below was recorded. Analyze this data in a suitable way and determine the Curie temperature, C, and the exchange field $B_E$ at 0 K, in the mean field approximation (Weiss approximation) [8 marks]

| T (K) | 1350 | 1650 | 1900 |
|---|---|---|---|
| $\chi$ (dimensionless) | 0.00165 | 0.00125 | 0.00103 |

**QUESTION 4** **[14 Marks]**

a) How are amorphous materials prepared and characterized ? [5 marks]

b) Give five physical properties of different amorphous materials [5 marks]

c) Describe any four applications of amorphous materials [4 marks]

**QUESTION 5** **[14 Marks]**

(a) **Explain** what is meant by the term "Pauli paramagnetism". [2 marks]

(b) **Discuss** the paramagnetism in a sample metal which can be described by the free electron model. Include in the **discussion** diagrams showing the electronic density of states. [5 marks]

(c) Hence **show** that the susceptibility of a Pauli paramagnet is given by

$$\chi = \mu_0 \mu_B^{\,2} \rho(E_F),$$

Where $\mu_0$ is the permeability of free space, $\mu_B$ is the Bohr magneton and $\rho(E_F)$ is the density of states at the Fermi level. [3 marks]

(d) **Give** a short qualitative account of Stoner's itinerant electron theory for ferromagnetism. **Describe** the competing interactions which occur and **explain** what is meant by the "Stoner criterion". [4 marks]

**QUESTION 6** **[14 Marks]**

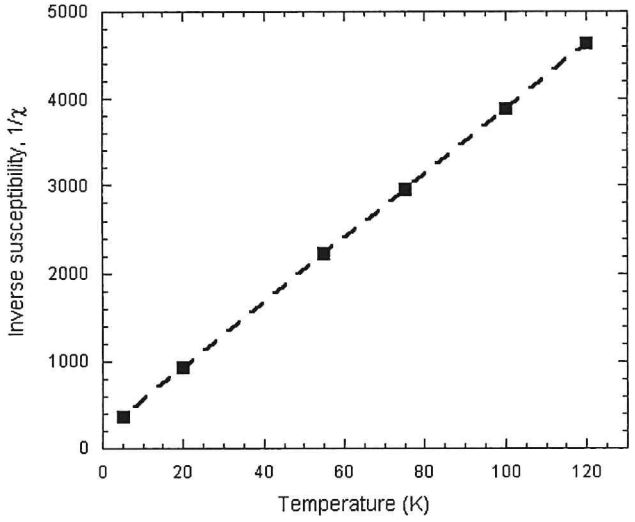
a) By considering the different electron models, outline briefly some of the shortcomings of each of the following in explaining the behaviour of electrons in the crystal lattice

(i) Free electron model [2 marks]

(ii) Nearly free electron model [3 marks]

(iii) Orthogonalized plane wave method [4 marks]

b) The figure shows the inverse magnetic susceptibility ($1/\chi$) (dimensionless) as a function of temperature for a paramagnetic material.




(i) Calculate the concentration of magnetic ions, if they are assumed to be $Co^{2+}$ with configuration $3d^7$. [3 marks]

(ii) Why does the extrapolated curve cut the T-axis, for $T \rightarrow 0$, at a negative value of T? [2 marks]