# MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY

## UNIVERSITY EXAMINATIONS

## 2021/2022 ACADEMIC YEAR

## FIRST YEAR SECOND SEMESTER EXAMINATIONS

## FOR THE DEGREE

## OF

## MASTER OF SCIENCE IN PHYSICS

**COURSE CODE:** SPH 822 E

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

**DATE: FRIDAY 22ND APRIL, 2022** **TIME: 9:00 AM – 12:00 PM**

**INSTRUCTIONS TO CANDIDATES**

- Answer ANY FIVE Questions
- Speed of light, $c = 3 \times 10^{8}$ m/s Electronic charge, $e = -1.6 \times 10^{-19}$ C
- Paramagnetic Susceptibility, $\chi_{Para} = \frac{\mu_0 N p^2 \mu_B^2}{3 k_B T} = \frac{C}{T}$ Curie's law
- Total magnetic susceptibility, $\chi_{Total} = \chi_{Para} + \chi_{Diamagnetic} = \frac{C}{T} + \chi_{Diamagnetic}$
- Boltzman Constant, $k_B = 1.38 \times 10^{-23}$ J K$^{-1}$ Avogadro Constant $N = 6.022 \times 10^{23}$ mol$^{-1}$
- Bohr magneton $\mu_B = 9.274 \times 10^{-24}$ J T$^{-1}$

## QUESTION ONE [14 Marks]

a) Explain how **a diamagnetic material** responds to an externally applied magnetic field $H$. Define the magnetization $M$, the susceptibility $\chi$ and the relative permeability $\mu_r$ of a diamagnet and comment on their magnitudes. [2 marks]

b) What is the significance of the fact that all materials have a contribution to their susceptibility which is diamagnetic? [1 mark]

c) Give a detailed account of the model proposed by **Langevin for the diamagnetic state**. Show that the susceptibility $\chi$ per unit volume of a material of atomic number Z is given by,

$$\chi = -\mu_0 N Z \frac{e^2}{6m} < \rho^2 >$$

Where $\mu_0$ is the permeability of free space, $N$ is the number of atoms per unit volume, $e$ and $m$ are the charge and mass of the electron respectively and $< \rho^2 >$ is the mean square radius of the electron orbits. [8 marks]

a) Given that the **diamagnetic susceptibility** of Hydrogen is $-1.2 \times 10^{-11}$ per mole, find the value of the mean square radius of the first Bohr orbit in the Hydrogen atom. [3 marks]

## QUESTION TWO [14 MARKS]

a) What do you understand by the term "**Pauli paramagnetism**" ? [2 marks]

b) Explain with the aid of diagrams showing the electron density of states, how Pauli paramagnetism arises in a simple metal which can be described by the free electron model. Hence, or otherwise, show that the susceptibility of the Pauli paramagnet is given by

$$\chi_p = \mu_0 \mu_B^2 \rho(E_F)$$

where $\mu_0$ is the permeability of free space, $\mu_B$ is the Bohr magneton and $\rho(E_F)$ is the density of electron states at the Fermi level. [7 marks]

c) How does the value of $\chi_p$ compare with the value of $\chi$ predicted by the Curie-Weiss law ? [3 marks]

d) How does $\chi_p$ vary with temperature ? [2 marks]

## QUESTION THREE [14 Marks]

a) What are amorphous materials ? [1 mark]

b) Briefly describe how amorphous materials are prepared and characterized [4 marks]

c) Briefly Explain any five physical properties of different amorphous materials [5 marks]

d) Mention any four applications of amorphous materials [4 marks]

## QUESTION FOUR [14 Marks]

(a) What are the characteristic bulk magnetic properties of **a ferromagnet** ? **[3 mark]**

(b) Draw a graph of the **magnetisation curve *M versus H*** of a typical ferromagnet and identify its salient features.

Hence explain what is meant by the terms

(i) Remnant Magnetisation,

(ii) Coercive Field,

(iii) Hysteresis Loop,

illustrating your answer with suitable graphs. **[5 marks]**

(c) P. Weiss gave a qualitative description of the magnetisation curve of a ferromagnet on the assumption that it consisted of small regions called domains, which are spontaneously magnetised. What mechanisms have been proposed to account for the spontaneous magnetisation of a ferromagnet on an atomic scale, and what success have they achieved?

**[4 marks]**

(d) Gadolinium has a Curie temperature of 292 K and a magnetic moment of 7.63 $\mu_B$ per atom. For Gadolinium, $J = S = 7/2$ ; $g = 2$; $N = 3.0 \times 10^{28}$ $m^{-3}$ Estimate the magnitude of the so-called "internal field" that is responsible for the spontaneous magnetisation of gadolinium.

**[2 marks]**

## QUESTION FIVE [14 Marks]

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.

a) Free electron model [4 marks]
b) Nearly free electron model [5 marks]
c) Orthogonalized plane wave method [5 marks]

## QUESTION SIX [14 Marks]

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 |

a) By plotting a suitable graph, Show that $MnF_2$ is antiferromagnetic and determine the Curie-Weiss parameter, $\theta$. [9 marks]

b) Calculate the effective number of Bohr magnetons and verify the result by comparing with the free ion value for the configuration $3d^5$ of $Mn^{2+}$. MnF2 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 7 [14 Marks]

The molar susceptibility of paramagnetic chromiumsulphate, ($CrK(SO_4).12H_2O$) sample has been measured at $20^0 C$ with the result: $\chi_m = 7.94 \times 10^{-5} m^3/kmol$.

a) Determine the experimental effective number of Bohr magnetons for the chromium ion. [4 marks]

b) Find the corresponding theoretical value for $Cr^{3+}$ with the configuration $3d^3$. [4 marks]

c) The magnetic susceptibility $\chi$ of a diamagnetic sample is measured to check for a suspected manganese (paramagnetic) impurity. The following results are obtained.

| Temperature, T (K) | 300 | 180 | 145 | 115 |
|---|---|---|---|---|
| Susceptibility, $\chi$ (*SI Units*) | -8.88 | -8.50 | -8.24 | -7.86 |

(i) Use a suitable diagram to show that the sample contains a paramagnetic impurity []

(ii) Calculate the concentration of the impurity, assuming that it is $Mn^{2+}$ ions with the configuration $3d^5$.

(iii) Estimate the diamagnetic susceptibility of the pure substance.