TUNKU ABDUL RAHMAN UNIVERSITY OF MANAGEMENT AND TECHNOLOGY

FACULTY OF APPLIED SCIENCES

ACADEMIC YEAR 2024/2025

OCTOBER EXAMINATION

BACH2153 MATERIALS SCIENCE

FRIDAY, 11 OCTOBER 2024 TIME: 3.00 PM – 5.00 PM (2 HOURS)

BACHELOR OF SCIENCE (HONOURS) IN ANALYTICAL CHEMISTRY

Instructions to Candidates:

Answer **ALL** questions. All questions carry equal marks.

BACH2153 MATERIALS SCIENCE

Question 1

a) You were hired as a nanomaterials specialist last month by a company based in Shah Alam. One of your customers requested you to give them a suggestion on how to determine whether they had successfully synthesized gold nanoparticles (10-20 nm in diameters) in water. They have only a functioning UV-VIS spectrophotometer in their lab. Based on these information, **explain** to your customer how they may use UV-VIS spectroscopy to estimate the size of gold nanoparticles they produced. (5 marks)

b) Magnetic storage of data has transformed human life in the past few decades and it involves the use of magnets. It is also known that a non-zero net magnetic moment is due to the presence of an unpaired electron. **Explain** why ferromagnetic materials can be permanently magnetized whereas paramagnetic ones cannot. (5 marks)

c) The electrical conductivity performance of metal wires is crucial in modern electricity grids. Check out the values of electrical conductivity of metals in Figure 1. **Name and describe** a rule which could be used to explain the different values observed in Figure 1. **Devise** a simple experiment which could be used to differentiate a piece of pure Cu, a piece of brass and a piece of deformed brass from each other. (2, 3 marks)

Metal	Electrical Conductivity $1x10^7[(\Omega\cdot m)^{-1}]$ at room temperature
Ag	6.8
Cu	6.0
Au Fe	4.3 1.0
Brass (70%Cu 30% Zn)	1.6
Stainless Steel	0.2

Figure 1. Electrical conductivity values and chemical compositions.

d) For nanoparticles of iron (Fe), **state** clearly whether you expect them to exhibit diamagnetism or paramagnetism. **Give** a reason for your expectation. For bulk iron metal, **confirm** that there are ~2 Bohr magnetons associated with each iron atom, given that the saturation magnetization is 1.70×10^6 A/m, iron has a Body-Centred-Cubic crystal structure, and also the unit cell edge length is 0.2866 nm. The value of one Bohr's magneton is 9.27×10^{-24} Am^2. (2, 2, 6 marks)

[Total: 25 marks]

BACH2153 MATERIALS SCIENCE

Question 2

a) Nanoparticles of Si could be mixed into paint-like liquids to produce inks with special properties suitable for printable electronics.

(i) The Si nanoparticles in the inks are best described as "semi-crystalline". **Explain** how a semicrystalline material is different from a single crystalline material in the context of microstructure. (5 marks)

(ii) To apply the Si inks on a substrate, which of the flow behavior (A, B, C) in **Figure 2** is the most suitable? **Give** your reasons. (5 marks)

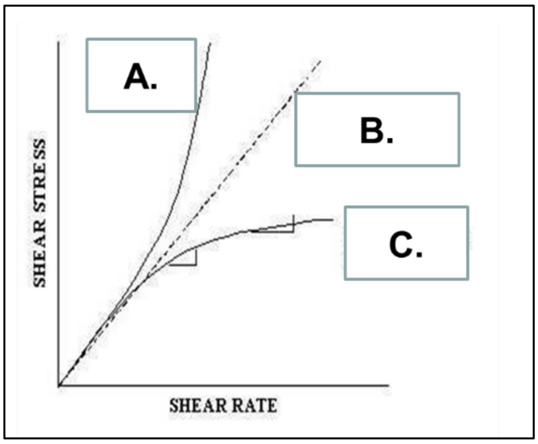

Figure 2. Shear Stress as a dependent variable of Shear Rate for 3 flow behaviours.

(iii) In metallic iron such as cast iron, Si may be present as an unwanted contaminant and it may affect the mechanical strength of iron. If a bar of cast iron (120 mm long and having a square cross section 25 mm on an edge) is pulled in tension with a load of 90,000 N and it experiences an elongation of 0.10 mm, assuming that the deformation is entirely elastic, what would be the elastic modulus of the iron? (5 marks)

b) A cylindrical rod, 100 mm long and having a diameter of 10.0 mm, is to be deformed using a tensile load of 27,500 N. It must not experience either plastic deformation or a diameter reduction of more than 7.5×10^{-3} mm. Of the alloys listed below, steel is considered the best candidate. **Prove** with calculations it is the case. (10 marks)

Material	*Modulus of Elasticity (GPa)*	*Yield Strength (MPa)*	*Poisson's Ratio*
Aluminum alloy	*70*	*200*	*0.33*
Brass alloy	*101*	*300*	*0.34*
Steel alloy	*207*	*400*	*0.30*
Titanium alloy	*107*	*650*	*0.34*

[Total: 25 marks]

Question 3

a) Tin ores were once one of the many valuable resources present in Malaysia. Tin ores mining activities contributed to the economic growth of the country. Tin metal has many usages but pure tin suffers from the "tin disease". **Discuss** the microscopic reason behind the "tin disease". **Recommend** a way to avoid the tin disease. **Hint**: The purity of the tin may not necessary be 100% for certain applications. (3, 2 marks)

b) **Propose** a synthetic method suitable for the fabrication of 10-nm gold nanoparticles which could be readily coated on a flat substrate to function as a solid state catalyst. **List** all reagents and conditions needed. **Explain** briefly the functions of all reagents and conditions involved. (5 marks)

c) Porcelain, a type of ceramic, slowly evolved in China, was fully developed around 2,000 to 1,200 years ago. It is still being used today and may be found in many modern applications. Briefly **discuss** the **two** processes from which porcelain materials gain their hardness. (5 marks)

d) Figure 3 reveals three different regions related to the electrical conductivity of a n-type phosphorus-doped Si semiconductor. Use a simple diagram to **explain** (in terms of chemical bondings and electrons) how *n*-type extrinsic semiconductors can be created to better conduct electricity. **Identify** regions A, B and C. **Specify** which region is involved in modern semiconductor-based devices with a justification. (5, 3, 2 marks)

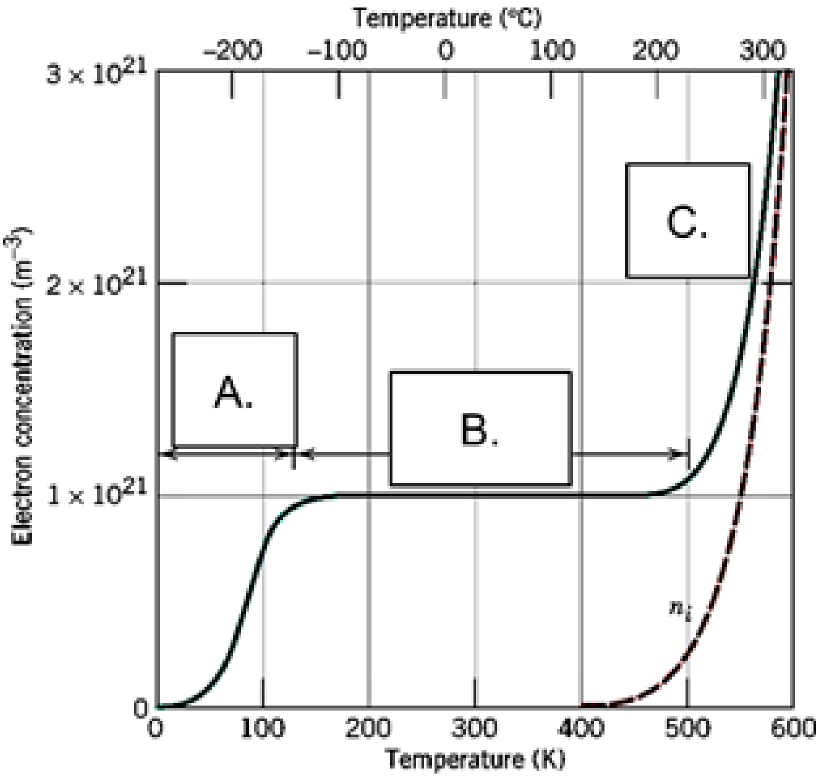

Figure 3. Electron concentration in *n*-type Si as a function of temperature.

[Total :25 marks]

Question 4

The following questions are related to the material shown in Figure 4.

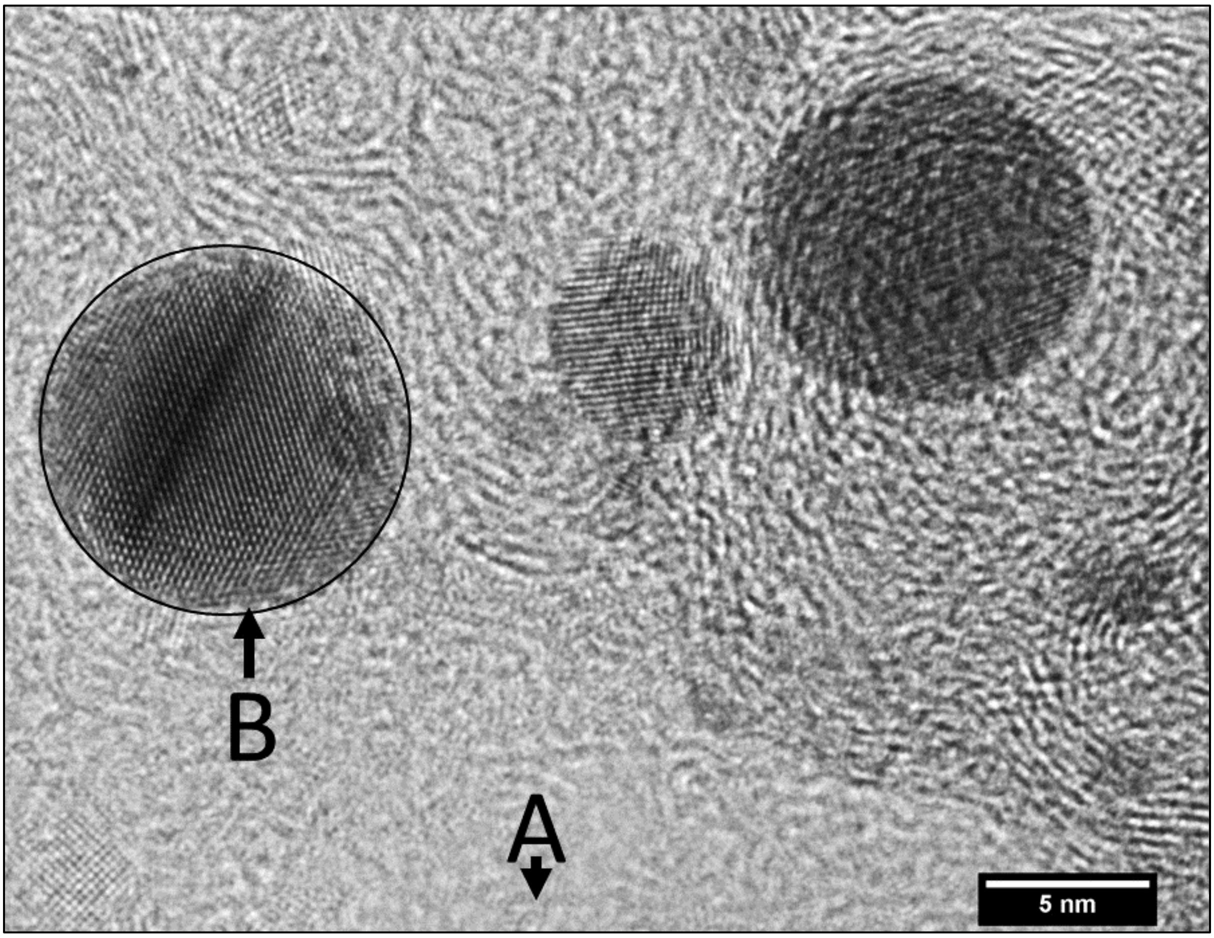

Figure 4. An image of a piece of gold material.

a) Figure 4 shows an image of a few gold particles. **Deduce** the type of microscopy used to produce Figure 4. Support your answer by **giving** three pieces of evidence from examining Figure 4. (2, 3 marks)

b) **Evaluate** if Particle B fits the definition of bulk material. **Show** your work on size calculation. **Compare** A and B in Figure 4 in terms of their contrast and give reasons why a difference is observed. (5, 5 marks)

c) It was reported that the sample analysed in Figure 4 may be contaminated with indium oxide. **Suggest** a material analysis technique which would allow you to confirm the presence of indium oxide impurities while imaging. With the help of a simple diagram, **explain** the working mechanism and relevant law behind the selectivity of the technique suggested. (10 marks)

[Total: 25 marks]

BACH2153 MATERIALS SCIENCE

Appendix 1

Fundamental constants

Avogadro constant = 6.022×10^{23} mol^{-1}
Planck constant, h = 6.62608×10^{-34} Js
Speed of light = 3×10^{8} ms^{-1}
Charge of an electron q =1.602×10^{-19} C
1 eV =1.6021×10^{-19} J
1 Bohr Magneton = 9.27×10^{-24} A.m^2

List of Formulae

	Symbol	Formula	
Current	i	$\frac{V}{R}$	V = voltage; R = resistance
Power	P	$i^2R = iV$	V = voltage; R = resistance; i = current
Electrical resistivity	ρ	$\frac{RA}{l}$	A = cross-sectional area R = resistance l = length
Electrical conductivity	σ	$n_i q(\mu_n + \mu_p)$ $\sigma_0 \exp \frac{-E_g}{2kT}$	n_i = intrinsic concentration q = electronic charge μ_n = mobility of electron μ_p = mobility of hole σ_0 =constant k = Boltzmann constant E_g = energy band gap T = temperature
Poison ratio	ν	$-\frac{\frac{\Delta d}{d_o}}{\frac{\Delta l}{l_o}}$	Δd = diameter change d_o =initial diameter Δl =length change l_o =initial length
Stress	σ	$\frac{F}{A}$	F = force A = cross-sectional area
Strain	ε	$\frac{l_f - l_0}{l_0}$	l_f =final length l_0=initial length
Modulus of elasticity	E	$\frac{\sigma}{\varepsilon}$	σ = stress ε = strain
Resolved shear stress	τ_r	$\sigma \cos\lambda \cos\phi$	σ =shear stress λ =angle between the axial force and the slip direction ϕ =angle between the uniaxial force and the normal to the slip plane

Appendix 1 (Continued)

Fraction of light exiting after the light absorption	I	$I_0 e^{-\alpha t}$	I_0 =fraction of light entering α = linear absorption coefficient t = thickness
Energy	ΔE	$\frac{hc}{\lambda}$	h = Planck's constant c = speed of light λ = wavelength
Reflectivity (Fraction of light reflected)	R	$\left(\frac{n-1}{n+1}\right)^2$	n = refractive index
Magnetic field strength	H	$\frac{ni}{l}$	n = Number of turn in a coil i =current l =length
Magnetic permeability	μ	$\frac{B}{H}$	B = magnetic induction H = magnetic field strength
Relative permeability	μ_r	$\frac{\mu}{\mu_0}$	μ = Magnetic permeability μ_0 = Magnetic permeability in free space
Induced magnetic moment per unit volume	M_s	$\left(\frac{atom}{volume}\right)\left(\frac{\text{number of Bohr magneton}}{\text{atom}}\right)\mu_B$	μ_B = magnitude of a Bohr magneton
Thermal conductivity	k	$\frac{Q\Delta x}{A\Delta T}$	Q = heat transferred A = cross-sectional area ΔT = temperature gradient Δx = distance
Linear coefficient of thermal expansion	α	$\frac{l_f - l_0}{l_0(T_f - T_0)}$	l_f =final length l_0=initial length T_f = final temperature T_0 = initial temperature