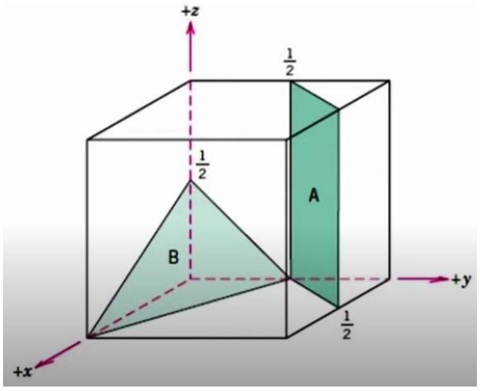
Materials Science and Engineering

Question 1

a) Within a cubic unit cell, sketch following directions and planes: [1 0 1], [3 0 1], [1 $\bar{1}$ 1].

b) Determine the Miller indices of the A and B planes in the right Figure.



Question 2

A tensile strength is to be applied along the long axis of a cylindrical Al 1100 alloy rod with a diameter of 15 mm. Determine the magnitude of the applied load required to produce a 5.5×10^{-4} mm change in diameter if the deformation is entirely elastic. Given: Poisson's ratio (ν) = 0.33 and Elastic modulus (E) = 69 GPa for Al 1100 alloy.

Question 3

a) Calculate the number of free electrons per cubic meter for silver (Ag), assuming that there are 1.3 free electrons per silver atom. The electrical conductivity and density for Ag are 6.8×10^{7} $(\Omega\cdot m)^{-1}$ and 10.5 g/cm^3, respectively.

b) Compute the electron mobility for Ag.

Question 4

Arrange the following materials in ascending order of melting points and explain the reasoning behind your ranking: (a) silver (Ag), (b) Methane (CH_4), (c) Magnesium fluoride (MgF_2), (d) ice (H_2O), and (e) Decane ($C_{10}H_{22}$).

Question 5

a) What is a 0D material? Draw its density of state (DoS) diagram.

b) Why the color of quantum dots (e.g. Gold) appear differently compared to their 3D bulk form?

Question 6

(a) What is glass transition temperature in polymers?

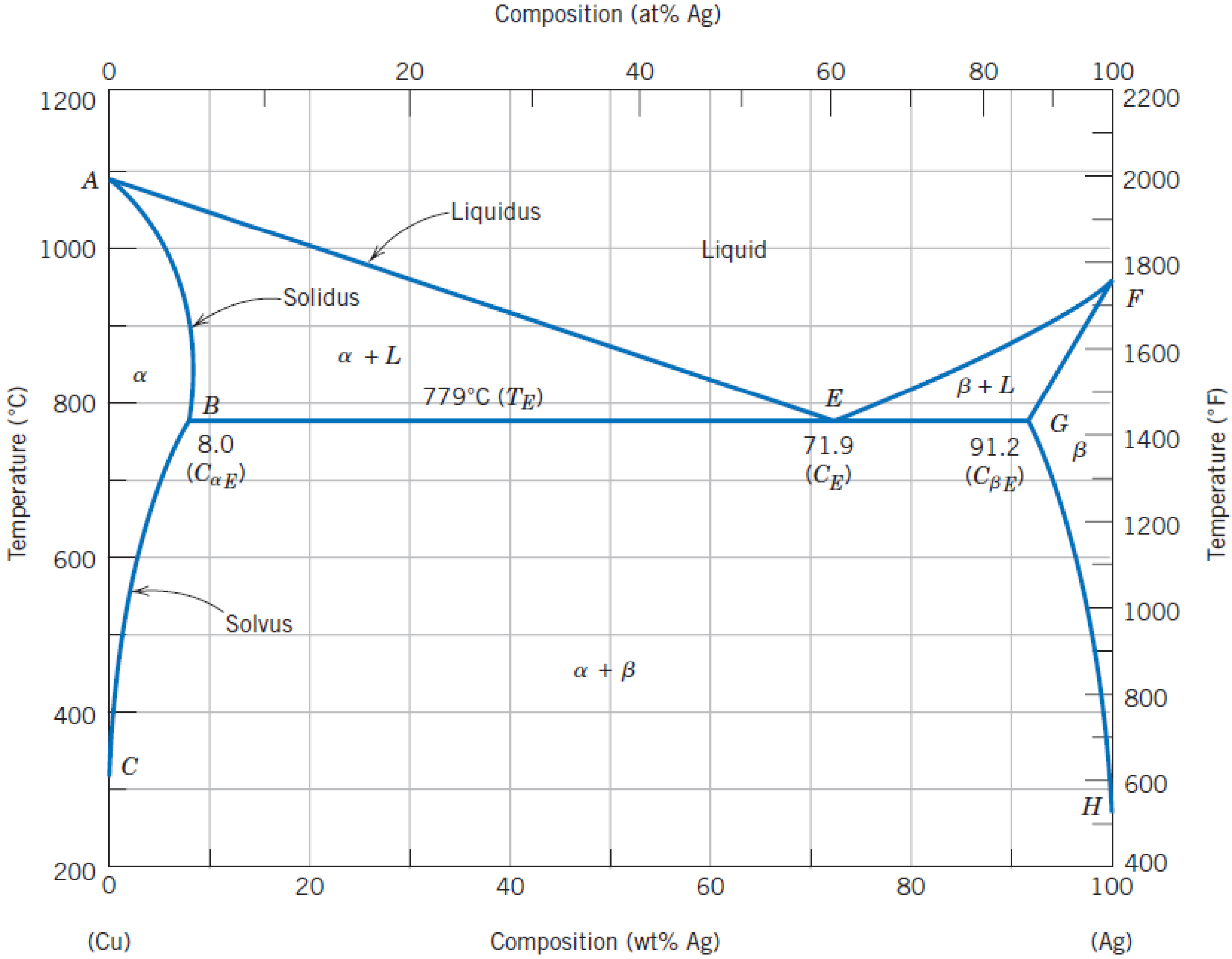
(b) Suggest one experimental method to determine the glass transition temperature of a polymer, for example polystyrene. Briefly explain how the instrument works.

Question 7

a) Is it possible to have a copper-silver alloy of (a) composition 20 wt.%Ag – 80 wt.% Cu (alloy A) that at equilidrium consist of α and liquid phases having mass fractions W_α = 0.8 and W_L = 0.2? If so, what will be the approximate temperature of the alloy? If such the alloy is not possible, explain why.

b) Calculate the mass fractions of W_α and W_L in an alloy B (40 wt.%Ag – 60 wt.% Cu) when it is cooled to a temperature just above 779.1°C at equilibrium.

c) Calculate the mass fractions of W_α and W_β in the alloy B (40 wt.%Ag – 60 wt.% Cu) when it is cooled to a temperature just below 778.9°C at equilibrium.



Question 8

Nickel solidifies via homogeneous nucleation. The latent heat of fusion per unit volume, the solid–liquid surface free energy, and the degree of supercooling are -2.53×10^9 J/m^3, 0.255 J/m^2, and 319 K, respectively.

(a) Calculate the critical radius r* and the critical activation free energy ΔG* for homogeneous nucleation.

(b) Nickel has a face-centered cubic (FCC) crystal structure with a lattice parameter of 0.360nm at its melting temperature [T_m (Ni) = 1455°C]. Determine the number of atoms contained in a critical nucleus.

Question 9

Compare the critical crack length (c_{crit}) for the following materials:

(1) A Ti alloy with σ_y= 550 MPa and K_{1c} = 40 MPa$\sqrt{m}$.

(2) Silicon Carbide with σ_y = 490 MPa and K_{1c} = 4 MPa$\sqrt{m}$.

Comment on the ductility of the two materials.

Question 10

(a) Rewrite the expression for the total free energy change for nucleation for the case of a cubic nucleus of edge length a (instead of a sphere of radius r). Now differentiate this expression with respect to a and solve for both the critical cube edge length, a*, and ΔG*.

(b) Is ΔG* greater for a cube or a sphere? Why?

Question 11

Consider a metal single crystal oriented such that the normal to the slip plane and the slip direction are at angles of 60° and 35°, respectively, with the tensile axis. If the critical resolved shear stress is 6.2 MPa, will an applied stress of 12 MPa cause the single crystal to yield? If not, what stress will be necessary?

Question 12

Consider a single crystal of some hypothetical metal that has the FCC crystal structure and is oriented such that a tensile stress is applied along a [1 1 2] direction. If slip occurs on a (1 1 1) plane and in a [0 1 1] direction, and the crystal yields at a stress of 5.12 MPa, compute the critical resolved shear stress.

Question 13

Using the isothermal transformation diagram for an iron-carbon alloy of eutectoid composition below, specify the nature of the final microstructure (in terms of microconstituents present and approximate percentages of each) of a small specimen that has been subjected to the following time-temperature treatment. In each case assume that the specimen begins at 760 °C (1033 K) and that it has been held at this temperature long enough to have achieved a complete and homogeneous austenitic structure.

a. Cool rapidly to 700°C (973 K), hold for 10^4 s, then quench to room temperature.

b. Reheat the specimen in part (a) to 700°C for 20 h.

c. Rapidly cool to 600°C (873 K), hold for 4 s, rapidly cool to 448°C (721 K), hold for 10 s, then quench to room temperature.

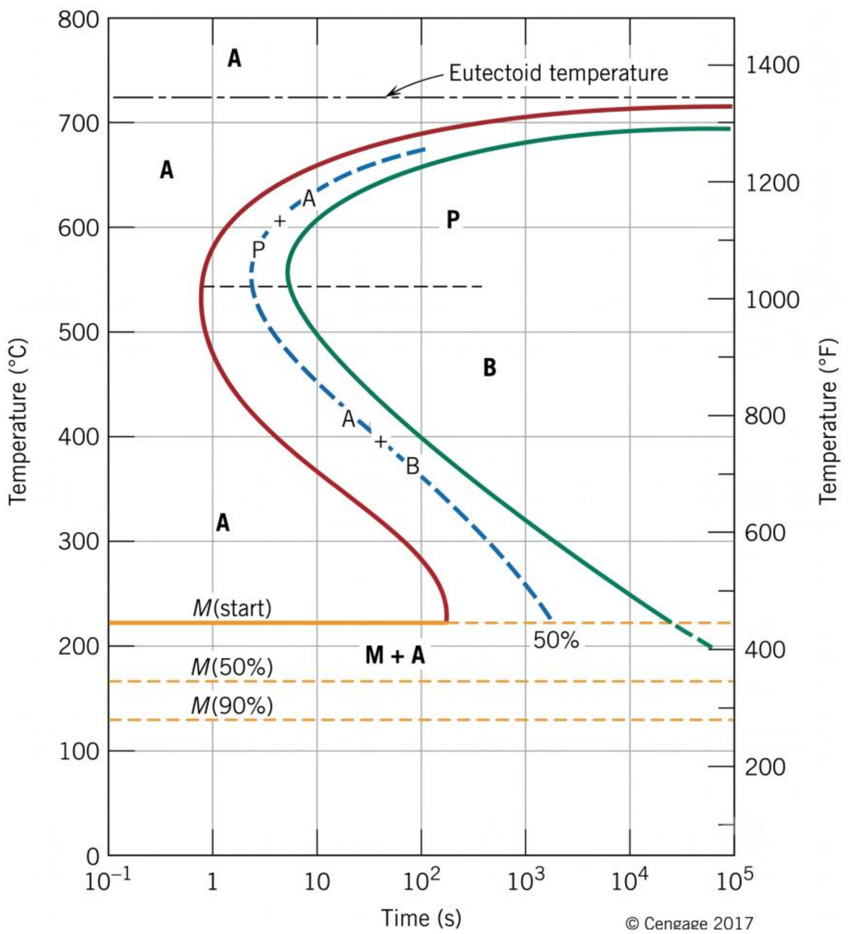
d. Cool rapidly to 398°C (671 K), hold for 2 s, then quench to room temperature.

e. Cool rapidly to 398 °C (671 K), hold for 20 s, then quench to room temperature.

f. Cool rapidly to 398°C (671 K), hold for 200 s, then quench to room temperature.

g. Cool rapidly to 575°C (848 K), hold for 20 s, rapidly cool to 350°C (623 K), hold for 100 s, then quench to room temperature.

h. Cool rapidly to 250 °C (523 K), hold for 100 s, then quench to room temperature in water. Reheat to 315 °C (588 K) for 1 h and slowly cool to room temperature.



Question 14

For some hypothetical metal, the equilibrium number of vacancies at 900°C is 2.3×10^{25} m^{-3}. If the density and atomic weight of a metal are 7.40 g/cm^3 and 85.5 g/mol, respectively, calculate the fraction of vacancies for this metal at 900°C.

Question 15

Calculate the energy for vacancy formation in nickel (Ni), given that the equilibrium number of vacancies at 850°C (1123 K) is 4.7×10^{22} m^{-3}. The atomic weight and density (at 850°C) for Ni are 58.69 g/mol and 8.80 g/cm^3, respectively.

Question 16

(a) Briefly define Burgers vector for a dislocation.

(b) Explain how to distinguish edge, screw and mixed dislocation by their difference in dislocation line and Burgers vector.

Question 17

(a) Describe the formation of depletion layer in a p-n junction.

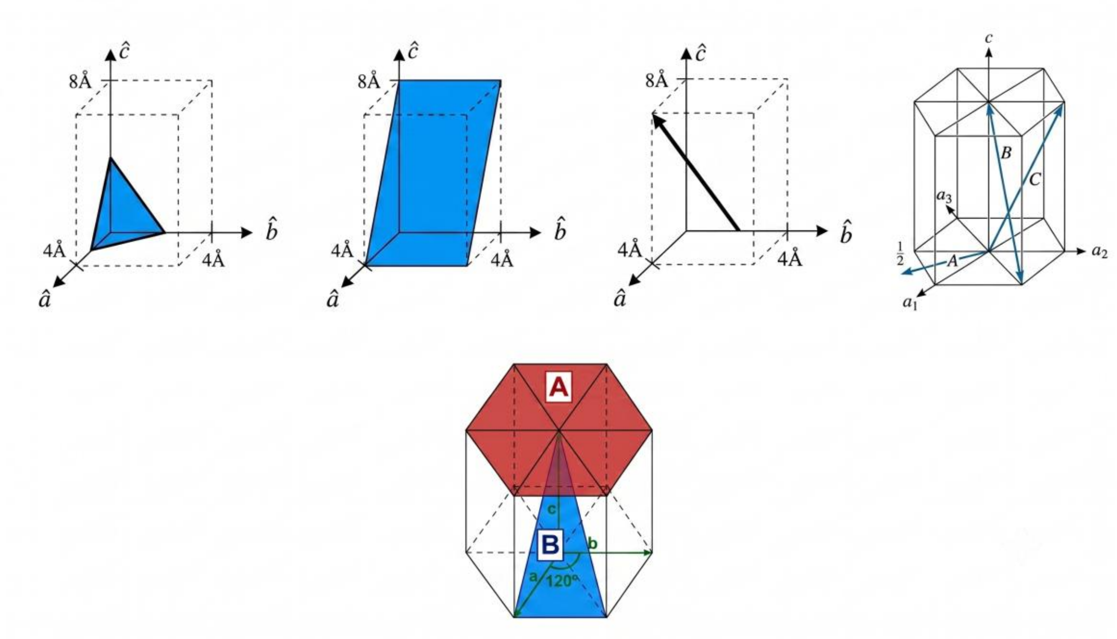
(b) What is the difference in I-V relationship of a p-n junction compared to an Ohmic material under electric conduction?

Question 18

(a) Compute the electrical conductivity of a cylindrical silicon specimen with a diameter of 7.0 mm and a length of 57 mm, through which a 0.25 A current passes in an axial direction. A voltage of 24 V is measured across two probes separated by 45 mm. (b) Compute the resistance over the entire 57 mm length of the specimen.

Question 19

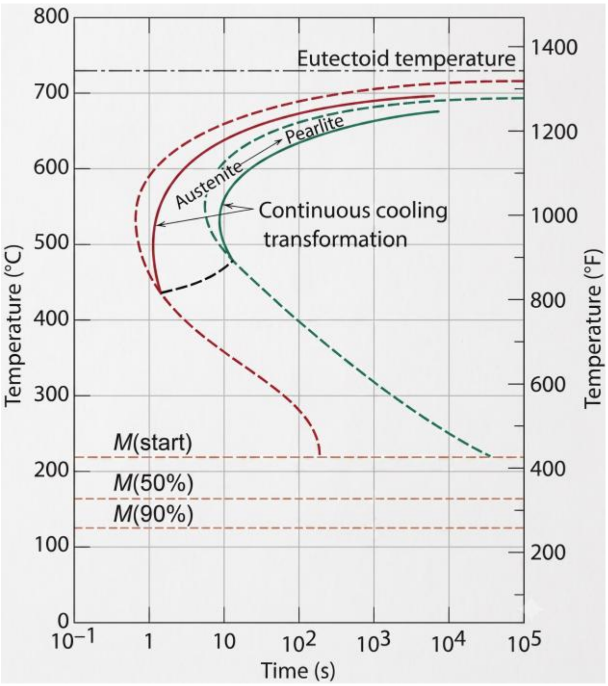
Determine the Miller or Miller-Bravais indices of the following figures.



Question 20

(a) A typical Continuous Cooling Transformation (CCT) Diagram of a steel is shown below. Draw a quenching (i.e. rapid cooling and hardening) curve on the CCT that the steel will result in fully martensitic structure.

(b) Rank the following quenching medium according to the cooling rate for water, oil, and still air.



Question 21

(I) Express the following absorbances in terms of percent transmittance:

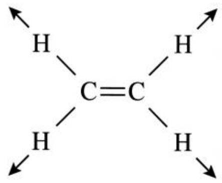
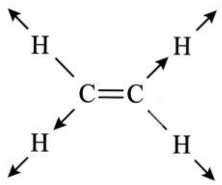
(a) 0.042 (b) 0.917 (c) 0.245

(II) Convert the following transmittance data to absorbances:

(d) 5.38% (e) 39.4%

Question 22

Indicate whether the following vibrations are active or inactive in the IR spectrum.

Molecule	Motion
(a) $CH_3—CH_3$	C—C stretching
(b) $CH_3—CCl_3$	C—C stretching
(c) SO_2	Symmetric stretching
(d) $CH_2{=}CH_2$	C—H stretching: 
(e) $CH_2{=}CH_2$	C—H stretching: 

Question 23

Calculate the absorption frequency corresponding to the –C-H stretching vibration treating the group as a simple diatomic C-H molecule with a force constant of $k = 5.0\times10^2$ N/m. Compare the calculated value with the range found in correlation charts.

Question 24

The XRD pattern of a polycrystalline Bi_2Te_3 film is given in the Figure below. Known that Bi_2Te_3 has a hexagonal structure and the wavelength Cu Kα is 1.5406 Å.

(a) Fitting (006) peak with Pseudo-Voigt1 function yielded $x_c = 17.5$ and $w = 0.215$. Calculate the grain size using the Scherrer equation.

(b) Calculate the d-spacing of (006) plane.

(c) Determine the c-axis lattice constant of Bi_2Te_3.

Question 25

For electrical properties measured by the Hall effect method, the sheet resistance of a film is 290.2 Ω/sq, the sheet carrier concentration is 9.992×10^{14} cm^{-2}, and the film thickness is 140nm, carrier mobility is 21.5 cm^2/Vs. Calculate the resistivity, carrier concentration, and conductivity of the film.

Question 26

a) Prove the Dragg's Law.

b) Describe the XRD method.

c) Describe two measuring modes in AFM method.

Question 27

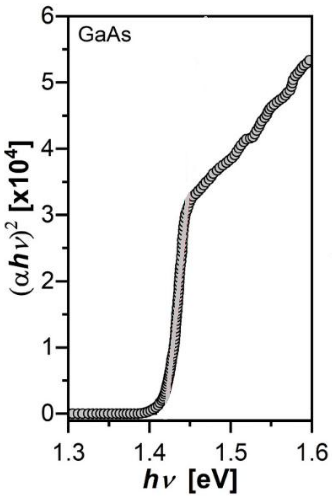
a) Describe the structural and working principles of SEM.

b) Present the Spin-Orbital angular momentum, and write the area relationships for:

(i) $p_{1/2} : p_{3/2} = ?$ (ii) $d_{3/2} : d_{5/2} = ?$ (iii) $f_{5/2} : f_{7/2} = ?$

c) Write a key similarity and some differences between Raman and IR spectra.

d) Given the following Tauc' plot of GaAs (*see the right figure*). Determine the band gap energy of GaAs, and indentify the type of electronic transition for GaAs (direct or indirect band gap)?



Question 28

(a) Please describe the mechanism difference of the following molecular spectroscopy: FTIR, and Raman.

(b) Calculate the approximate wavenumber and wavelength of the fundamental absorption due to the stretching vibration of a carbonyl group C=O.

(c) A molecule exhibits a Raman shift at 1580 cm^{-1}. Calculate the energy of this vibrational mode in electron volts (eV).

Question 29

a) Draw a schematic band diagram for a direct bandgap material and an indirect bandgap material. How can you distinguish between a direct and an indirect bandgap based on the characteristics of their band diagrams?

b) Write the formula and draw schematic of the Tauc'plot for determining the optical band gap of a material using absorption spectrum.

c) Write the formula and draw schematic of the Kubelka-Munk plot for determining the optical band gap of a material using reflectance spectrum.

d) Present the main applications, advantages, and disadvantages of molecular spectroscopy.

Question 30

For the nanoindentation technique, present the following things:

(a) Draw a typical load vs. displacement curve.

(b) Write the formula for calculating the hardness, reduced modulus, and Young's modulus using the Oliver and Pharr method.

(c) Given a nanoindentation result for a SnO_2 film using an ideal Berkovich indenter that maximum force is 473.7 µN, maximum depth is 80.4 nm, and contact stiffness is 21.7 µN/nm. Calculate the hardness and reduced modulus of the film.

Question 31

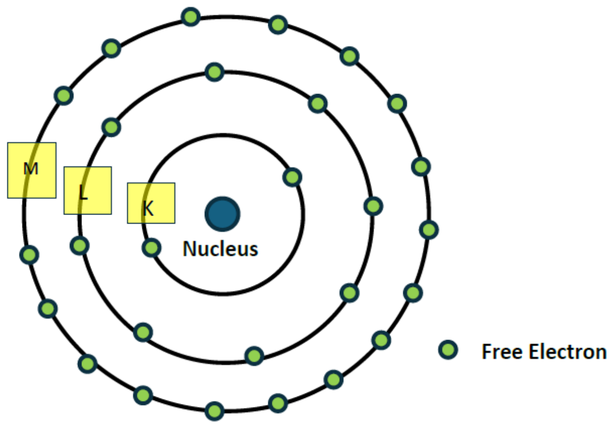
(a) What is bright field (BF) and dark field (DF) in TEM?

(b) In Scanning Transmission Electron Microscopy (STEM), how do High-Angle Annular Dark-Field (HAADF) and Low-Angle Annular Dark-Field (LAADF) imaging differ regarding their detector angles and the types of scattered electrons they collect?

Question 32

(a) Explain the formation of X-ray by using the following atomic model.

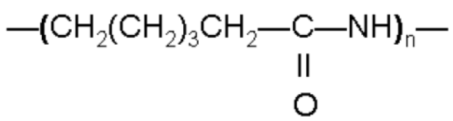
(b) According to your answer, how can you generate an X-ray source for a diffractometer?



(c) Explain the broadening of the diffraction pattern in X-ray diffraction due to (1) crystallite size; (2) lattice distortion?

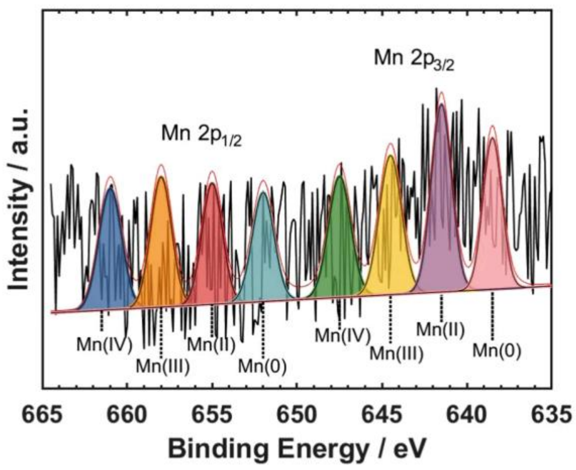
Question 33

(a) How many peaks are expected of C1s XPS spectra of Nylon 6?



(b) In an XPS experiment, the integrated peak area of the C 1s signal at 285 eV is I_C = 5000 counts, and the corresponding sensitivity factor S_C = 1.0. The O 1s peak at 531 eV has an integrated area of I_O = 3000 counts, with a sensitivity factor S_O = 2.93. Calculate the atomic concentration of carbon and oxygen in the sample.

(c) Identify the problem of the following XPS peak fit.



Question 34

(a) A solution containing 3.92 mg/100 mL of A (335 g/mol) has a transmittance of 64.1% in a 1.5-cm cell at 425 nm. Calculate the molar absorptivity of A at this wavelength.

(b) The wavelength of the fundamental N-H stretching vibration is about 1.5 µm. What is the approximate wavenumber and wavelength of the first overtone peak for the N-H stretch?

Question 35

(a) Describe the mechanism of emitted (1s) electron in X-ray photoelectron spectroscopy (XPS) and how it is possible to distinguish between XPS and Auger electron peaks?

(b) Describe the mechanism of the production of a KLM Auger electron and X-ray fluorescence (XRF) photon in Auger electron spectroscopy (AES)?

Question 36

(a) Identify the components labeled (1) through (8) in the SEM schematic and briefly describe the function of each.

(b) What do the Cu Kα and Cu Lα X-ray lines represent in EDS measurements?