UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 4 Examination in Engineering: February 2020

Module Number: ME 4312 **Module Name: Nanotechnology**

[Three Hours]

[Answer **all questions**, each question carries **12** marks]

Q1. Properties of nanoparticles depend on the quantum confinement along each dimension and therefore quantum mechanical treatment allows us to distinguish the properties of nanoparticles based on the shape.

a) Explain how you would use the simple quantum mechanical models to distinguish 0D, 1D and 2D nanostructures.

[2.0 Marks]

b) The wave function of two dimensional nanoparticle in the quantum confinement region of size l is $\psi = B\sin\left(\frac{n\pi x}{l}\right)$ while in the outside of this region ψ is zero.

i) Find the value of the constant B in terms of l.

[3.0 Marks]

ii) What is the expression for the energy of the n^{th} energy state and hence draw the first four energy states.

[2.0 Marks]

iii) Draw the wave function ψ and $|\psi|^2$ for the first three energy states.

[2.0 Marks]

c) The concept of quantum mechanical tunneling model used to describe the theory of the scanning tunneling microscopic(STM) imaging found that the wave function of the gap between the sample and the needle is $\psi = Be^{-kx}$, where $k\hbar = \sqrt{2m(V_0 - E)}$. In a particular scanning carried out to image a material sample, the system was set to $(V_0 - E)$ = 2. 20 eV. Calculate the percentage of the current drop if the needle is moved from l_1 = 0.5 nm to l_2 = 0.6 nm?

The transition probability $T = \left\{1 + \frac{\left(e^{kl} - e^{-kl}\right)^2}{16\varepsilon(1-\varepsilon)}\right\}^{-1}$ and it can be simplified to $T = 16\varepsilon(1-\varepsilon)e^{-2kl}$ if $kl >>> 1$.

[3.0 Marks]

Q2. The density of states (DOS) calculations allows us to determine the general distributions of energy states as a function of energy and the spacing between energy bands.

a) In the derivation of the expressions for the DOS of nanomaterials, the dimension in the nanoscale is treated quantum mechanically ($k = \frac{n\pi}{L}$) and the other dimensions in free motions are treated by the K-space coordinating system ($k = \frac{2\pi}{L}$).

i) Derive the appropriate DOS functions for both 3D and 0D material.

[3.0 Marks]

ii) Sketch the DOS functions for both cases.

[2.0 Marks]

iii) Compare the behaviour of DOS of 0D and 3D systems.

[1.0 Mark]

b) The nucleation is the most important and the first part of the nanoparticle synthesis. Once the nucleation starts, the growth of the particles increases. The effective control of the nucleation and then the growth is the key to have the particles in the desired size range.

The total change of the chemical potential for the formation of nucleus is given by $\Delta G = \frac{4}{3}\pi r^3 \Delta G_V + 4\pi r^2 \gamma$.

i) What is the major requirement that the mother solution should posses?

[1.0 Mark]

ii) Identify the each term of the above equation.

[2.0 Marks]

iii) Derive the expression for the energy barrier that the nucleation should overcome and the corresponding critical radius.

[3.0 Marks]

You may use following information for Q1 and Q2.
Mass of the electron (m_0) = 9.11×10^{-31} kg
Electron charge (q_e) = 1.602×10^{-19} C
Plank constant ($\hbar$) = 1.054×10^{-34} J.s
vacuum permittivity (ϵ_0) = 8.85×10^{-12} F/m

Q3. a) Economically profitable natural deposits of nanomaterials in large scale are very less. Therefore for the most of the nano technological applications, nano materials have to be synthesized.

i) Discuss briefly the differences between *top down approach* and *bottom up approach* in synthesis of nanopowders and write down any four example for *bottom up approaches* for synthesis of nanopowders.

[3.0 Marks]

ii) Explain main steps in Sol-gel synthesis for producing nanomaterials using appropriate example.

[3.0 Marks]

iii) Describe briefly the *dip-pen nanolithographic technique* to make patterns in atomic/molecular scale.

[2.0 Marks]

b) Characterization of nanomaterials after synthesis is an essential work to be conducted before use for any nanotechnological applications.

i) What do you mean by characterization of nanomaterials?

[1.0 Mark]

ii) Discuss the benefits and limitations of dynamic light scattering spectroscopy (DLS) that use to measure the size of the particle.

[3.0 Marks]

Q4. a) Nanotechnology is revolutionizing both scientific and industrial community due to their applications in the fields of textile, medicine, environmental protection, energy, and space exploration.

i) Discuss briefly the terms ***nano finishing*** and ***smart cloth*** related to the textile industries.

[2.0 Marks]

ii) List two possible nanomaterials that can be used in textile industries and discuss briefly the effect of them.

[2.0 Marks]

b) Write short notes on followings:

i) Allotropes of carbon and their applications.

[2.0 Marks]

ii) Size dependent properties of nanomaterials.

[2.0 Marks]

c) Nature has many materials, objects, and processes which function from the macroscale to nanoscale. Understanding the functions provided by these objects and processes can guide us to imitate and produce nanomaterials, nanodevices, and processes. As a mechanical engineer, discuss the following objects and their functions that can be served as the inspiration for various nanotechnological developments.

i) Plants

ii) Insects, spiders, lizards, frogs

iii) Birds

iv) Aquatic animals

[4.0 Marks]

Q5. a) Size of the nanoparticles is a critical factor for their nanotechnological applications. Researchers use high-powered microscopes to see the surface features of nano structures on the atomic scale, effectively opening the door to modern nanotechnology.

i) Explain why optical microscopes are not possible for nano scale observations.

[2.0 Marks]

ii) Compare the differences between optical microscope and electron microscopes.

[2.0 Marks]

iii) Explain briefly the working principles of scanning tunneling microscopy (STM) with neat sketches.

[2.0 Marks]

b) Despite of the evident benefits of nanoparticles, there are still open questions about the influence of these nanoparticles on human health and environment.

i) What are the potential risks of nanomaterials to human health and the environment?

[2.0 Marks]

ii) Discuss on the potential ways of nanomaterials enter into the human body.

[2.0 Marks]

iii) Propose possible precaution methods that can be taken to minimize risks of nanomaterials to human health and the environment.

[2.0 Marks]