2024

PHYSICS — HONOURS

Paper : DSE-A-2.1 and DSE-A-2.2

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

DSE-A-2.1

(Nanomaterials and Applications)

Full Marks : 65

Group - A

1. Answer ***any five*** questions : 2×5

(a) Quantum dots are considered as artificial atoms. – Explain.

(b) What do you mean by polaron?

(c) An X-ray beam of wavelength 0.71Å is diffracted by a cubic rock salt (a = 0.281 nm). Calculate the glancing angle for the second-order reflection from (110) planes.

(d) Using Scherrer equation, calculate the crystallite size of nanoparticle with full width at half maximum (FWHM) = 0.1 radians, λ = 0.154 nm and θ = 30°. (Scherrer constant = 0.9).

(e) Show that the quantum size (Δx) effects become observable under the condition $\Delta x \leq \frac{\hbar}{\sqrt{mkT}}$.

(symbols have their usual meaning).

(f) State the basic principle of NEMS.

(g) Why is the sample covered by gold in SEM study?

Group - B

2. Answer ***any three*** questions :

(a) (i) An electron is confined between two impenetrable walls 5Å apart. Determine the energy levels for the states n = 1 and 3.

(ii) Find the speed of the electron in the n = 1 state. 3+2

(b) (i) What do you mean by density of states?

(ii) Determine the density of states of a two-dimensional nanomaterial. Sketch the same as a function of energy. 1+(3+1)

(c) (i) Briefly outline the spin coating and dip coating techniques using sol-gel method.

(ii) Mention two advantages and two disadvantages of sol-gel method. 3+2

Please Turn Over

(d) (i) What information can X-ray diffraction reveal about the structure of nanomaterials?

(ii) Derive the Scherrer formula for determining the average particle size of nanocrystals. 2+3

(e) (i) What are excitons?

(ii) What are the different types of excitons? Distinguish between them. 2+(1+2)

Group - C

Answer ***any four*** questions.

3. (a) What is scanning electron microscopy (SEM)? Draw the schematic diagram and mention the essential components of a Scanning Electron Microscope.

(b) What are the various signals produced by SEM regarding microstructure and chemical analysis of a nanomaterial?

(c) How many atoms does a spherical gold nanoparticle of radius 1 nm contain given bulk gold has *fcc* structure with lattice constant 4.08 Å? (2+2)+2+4

4. (a) Chemical vapour deposition (CVD) is a bottom-up approach. – Explain.

(b) What are the different types of CVD processes?

(c) Describe the principle of operation of a CVD process.

(d) What are the differences between chemical and physical vapour deposition techniques?

2+2+3+3

5. (a) What are the differences between Schottky and Frenkel defects?

(b) Find an expression to show how the number of Schottky defects depend on temperature.

(c) What are F centres? Explain with an example. 3+4+(2+1)

6. (a) What do you mean by magnetic quantum well? How does it differ from a traditional quantum well?

(b) What are the major differences between conduction at the macroscale and nanoscale levels?

(c) Distinguish between an exciton and a polaron. Explain why excitons do not contribute to electrical conduction. (2+2)+2+(2+2)

7. (a) Explain the Coulomb blockade effect. What conditions must be satisfied for this effect to be observed?

(b) Show that a potential $\frac{e}{c}$ is required to transfer a single electron across a tunnel junction.

(c) Calculate the size of a sphere-shaped quantum dot of Si that would produce observable single electron effect at room temperature (300 K).

(The dielectric constant of silicon = 11.5, and the permittivity of vacuum, $\epsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}).

(3+2)+2+3

8. (a) What do you mean by photoluminescence (PL)?

(b) Mention briefly the use of nanostructured materials in solar cells, LEDs, optical data storage devices, and medical technology. 2+(2×4)

DSE-A-2.2

(Advanced Classical Dynamics)

Full Marks : 65

Group - A

1. Answer ***any five*** questions : 2×5

   (a) A bob of mass 'm' hangs from a rigid support with a massless inextensible chord and executes SHM. Use Lagrangian formulation to find the tension in the string.

   (b) If I_1, I_2 and I_3 be the principal moments of inertia of a rigid body, then show that $I_3 \leq I_1 + I_2$.

   (c) Calculate the Poisson brackets $\{x, L_x\}$, where L_x is the x-component of the angular momentum of a particle.

   (d) For a particle having a Lagrangian $L = \dot{x}^2/(2x) - V(x)$, find the Hamiltonian H.

   (e) Show that for inverse square central force field, Virial theorem takes the form $2< T > + < V > = 0$, where the symbols have their usual meanings.

   (f) Find the fixed points for the dynamical system represented by $\dot{x} = \sin x$ and classify their stability.

   (g) What do you mean by dissipative dynamical system? Explain with one example.

Group - B

2. Answer ***any three*** questions :

   (a) A particle is moving along a straight line under the action of a potential $V(x)$. Show that the Lagrange's equation of motion remains invariant under the transformation $x = c + x'$, where c is a constant. 5

   (b) Using Fermat's principle, find the path followed by light ray in a medium whose refractive index n is proportional to $1/y$. 5

   (c) State Virial theorem in classical mechanics. Derive the equation of state $PV = NK_BT$ for ideal gas from the concept of Virial theorem. 2+3

   (d) What are fixed points? Discuss the stability character of the fixed point for the system $\dot{x} = x(1-x)$ using the concept of flow. 2+3

   (e) Find the fixed points for the map $x_{n+1} = x_n^3$ and determine their stability. 5

Please Turn Over

Group - C

Answer ***any four*** questions.

3. (a) Given $S = \int_0^1 \frac{\dot{x}^2}{t^3}\, dt$. Extremize S to find $x(t)$ with conditions $x\,(t = 0) = 1$ and $x\,(t = 1) = 2$.

(b) If $f(q, p)$ and $g\,(q, p)$ are constants of motion, then show that their Poisson bracket $\{ f, g \}$ is also a constant of motion.

(c) Using Poisson bracket, show that $F = \frac{pq}{2} - Ht$ is a constant of motion if the Hamiltonian of the system is given by $H = \frac{p^2}{2m} - \frac{1}{2q^2}$. 4+3+3

4. (a) Consider a particle of mass m moving under the action of uniform gravity on the surface of a sphere of radius R. Show that the critical angle (θ_c) at which the particle sliding off from the surface of sphere is given by $\theta_c = \cos^{-1}(2/3)$. [Assume that the particle starts off from the North Pole]

(b) A particle of charge 'q' and mass 'm' moves with velocity $\vec{v}(t)$ in a region containing both electric field $\vec{E}(\vec{r}, t)$ and magnetic field $\vec{B}(\vec{r}, t)$. Show that the Lagrangian of the charged particle is given by

$$L = \frac{1}{2}mv^2 + q(\phi - \vec{A} \cdot \vec{v}),$$

where $\phi(\vec{r}, t)$ and $\vec{A}\,(\vec{r}, t)$ are electric scalar potential and magnetic vector potential, respectively. 5+5

5. (a) Show that the Poisson bracket of $\{L_x, L_y\} = L_z$, where L_x, L_y and L_z are the cartesian components of angular momentum.

(b) For a system, kinetic energy $T = \frac{1}{2}m\dot{r}^2$ and potential energy $V = \frac{1}{r}\left(1 + \frac{\dot{r}^2}{c^2}\right)$.

(i) Find the Hamiltonian (H) of the system.

(ii) Determine whether $H = T + V$.

(iii) Show that $\frac{dH}{dt} = 0$.

(c) Show that if the Lagrangian of a system does not depend on time explicitly, its Hamiltonian is a constant of motion. 3+3+4

6. (a) Consider a linear triatomic molecule with two outer atoms of mass m connected to central atom of mass M by two identical massless springs of spring constant s. Show that the normal frequencies of small oscillation are

$$0, \ \sqrt{s/m}, \ \sqrt{(s/m)+(2s/M)}.$$

(b) Find the moments and products of inertia of a uniform square plate of side 'a' and mass 'm' about x, y, z axes, x, y being taken as the adjacent sides of the plate and z is perpendicular to its plane. Also calculate the principal moments of inertia. 5+(3+2)

7. (a) What do you mean by a 'dynamical system'? Cast the equation of Newton's laws of motion for a particle moving along x-axis, $m\ddot{x} = f(x)$, into a dynamical system. What is its dimensionality?

(b) Find the fixed points of the dynamical system represented by $\dot{x} = x^2 - 1$. Draw the phase portrait and the flow of x. Hence, ascertain the nature of the fixed points. (2+1+1)+(2+2+2)

8. (a) Consider two models for the population growth (i) $\dot{N} = rN$, and (ii) $\dot{N} = rN\left(1 - \frac{N}{k}\right)$.

Find the fixed point(s) in each case. Use the linear stability analysis to study the nature of the fixed points.

(b) Consider the map $x_{n+1} = \cos x_n$. Using the quadratic MacLaurin expansion for the cosine function, find the approximate values for the fixed point(s) of the system. How many fixed point does the system has? (1+2+3)+(3+1)