2022

PHYSICS — HONOURS

Paper : DSE-A2

[(a) Nanomaterials and Applications]

Full Marks : 65

The figures in the margin indicate full marks.

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

Group – A

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

(a) How does band gap of a semiconductor change as it is reduced from bulk dimension to nanodimension?

(b) Use Scherrer equation to calculate size of nanocrystallite, when diffraction peak is obtained at $\theta = 30°$ having FWHM : 0.8, using radiation of wavelength $\lambda = 0.154$nm (Scherrer constant = 0.9).

(c) Distinguish between shallow and deep level trap states.

(d) Determine density of states of infinitely deep potential well of width 1nm corresponding to energy E = 3eV.

(e) Quantum dots are considered as artificial atoms. — Explain.

(f) State basic principle of NEMS.

(g) Discuss use of ball milling technique in ceramic processing very briefly.

Group – B

2. Answer ***any three*** questions : 5×3

(a) Briefly describe Chemical Vapour Deposition (CVD) process for synthesis of nanomaterials.

(b) What is the effect of size quantization on the emission and absorption spectra of a material?

(c) Compare SEM and TEM for the study of surface of thin film with brief description of operational difference. Also, state the effectivity of the techniques to study distribution of nanoparticles.

(d) Show that quantized conductivity in 1-D channel is $2e^2/h$.

(e) Why are K-selection rules relaxed in a nanosystem? What is its effect on the probability of electron transition?

Group – C

Answer ***any four*** questions.

3. Define density of states. Derive its expression corresponding to quantum well (2D) and quantum wire (1D). Represent it graphically in the same plot for both the systems. 2+(3+3)+2

4. (a) Distinguish between exciton and polaron. Explain why excitons do not contribute to electrical conduction. State the conditions to observe exciton.

   (b) Distinguish between direct tunnelling and trap-assisted tunnelling. State temperature dependence of the two processes. {(2+2)+2}+(2+2)

5. (a) Give brief outline of sol-gel method for the synthesis of nanoparticles. Discuss its limitations.

   (b) Describe the basic working principle of Molecular Beam Epitaxy (MBE). (4+2)+4

6. (a) What do you understand by Coulomb blockade effect? State the conditions to observe it.

   (b) Calculate the maximum temperature at which Coulomb blockade is observed in a tunnel junction having $C = 1\text{pF}$. Also, estimate the maximum dimension of the device to observe Coulomb blockade at room temperature (300K). (2+3)+(3+2)

7. (a) Give qualitative description of single electron transfer device (SED). Mention some applications.

   (b) How can photoluminescence (PL) be used to characterize nanomaterials and briefly mention the technique to record the response. (3+2)+(3+2)

8. Write short notes on : 5+5

   (a) Photolithography for nanofabrication

   (d) CNT (Carbon nanotube) based transistors.

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Paper : DSE-A 2

[(b) Advanced Classical Dynamics]

Full Marks : 65

The figures in the margin indicate full marks.
Candidates are required to give their answers in their own words as far as practicable.

Group - A

1. Answer *any five* questions : 2×5

(a) Establish the symmetry that leads to the conservation of angular momentum in Lagrangian formalism.

(b) Calculate the Poisson brackets $\{x, L_z\}$ and $\{y, L_z\}$, where L_z is the z-component of the angular momentum of a particle.

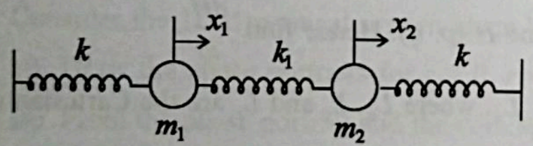
(c) Show that for an inverse square field the virial theorem takes the form $2\langle T\rangle+\langle V\rangle=0$, where the symbols have their usual meanings.

(d) What do you mean by a dissipative dynamical system? Explain with an example.

(e) Find the nature of the fixed point $x = 0$ in case of the dynamical system represented by $\dot{x} = \sin x$.

(f) A particle of mass 'm' moves with constant velocity in a straight line. Justify if it has an angular momentum.

(g)



For the above system, set up the Lagrangian.

Group - B

2. Answer *any three* questions : 5×3

(a) Show that the geodesics on a circular cylinder are helices as $az + b\theta$ = constant.

(b) A flexible chain of fixed length is suspended between two fixed points. Find the curve that will minimize the gravitational potential energy of the system.

(c) What is a conservative dynamical system? An oscillator is described by the equation

$$\ddot{x} - k\,(1 - x^2)\,\dot{x} + \omega^2 x = 0$$

Convert it to a dynamical system and check whether it is dissipative.

(d) If a Lagrangian $L(q, \dot{q})$ has no explicit dependence on time, prove that $\left(L - \dot{q}\dfrac{\partial L}{\partial \dot{q}}\right)$ is a constant of motion.

(e) A bead of mass 'm', suspended by an extensible string from a rigid support is executing small oscillations. Use Lagrange multiplier to determine the tension in the string at an angle θ from the vertical, using Lagrangian formulation.

Group - C

Answer ***any four*** questions.

3\. (a) The Lagrangian of a spherical pendulum is given by $L = \frac{1}{2} ma^2 \left(\dot{\theta}^2 + \dot{\varphi}^2 \sin^2\theta\right) - mga\cos\theta$, where '$\theta$' and '$\varphi$' represent the spherical polar coordinates of the bob of mass 'm' on a sphere of radius 'a'. Find the canonical momenta conjugate to 'θ' and 'φ' and obtain the Hamiltonian of the system.

(b) The Lagrangian of a particle of charge 'q' and mass 'm' moving under a magnetic field characterized by a time-independent vector potential '$\vec{A}$' is given by $L = \frac{1}{2} mv^2 - q\,\vec{v}.\vec{A}$

Derive the Lorentz force equation from this. (2+4)+4

4\. (a) Find the conditions on the real parameters α, β, γ and δ, such that $\dot{q} = \alpha q + \beta p$ and $\dot{p} = \gamma q + \delta p$ are Hamilton's equation of motion for some $H(p, q)$. Hence find $\dfrac{dH}{dt}$.

(b) Show that the Poisson bracket $\{L_x, L_y\} = L_z$, where L_x, L_y and L_z are the Cartesian components of the angular momentum $\vec{L}$.

Hence show that $\{L_x, \{L_y, L_z\}\} + \{L_y, \{L_z, L_x\}\} + \{L_z, \{L_x, L_y\}\} = 0$ (3+2)+(2+3)

5\. (a) Find the planar curve C having the given perimeter L, that encloses the largest area.

(b) The moment and product moment of inertia of a rigid body with respect to a Cartesian coordinate system are I_{xx}, I_{yy}, I_{zz} and I_{xy}, I_{yz}, I_{zx} respectively. Prove that the moment of inertia of the rigid body about an axis making angles α, β and γ with the x, y and z axes respectively is given by $I = I_{xx}\cos^2\alpha + I_{yy}\cos^2\beta + I_{zz}\cos^2\gamma + 2I_{xy}\cos\alpha\cos\beta + 2I_{yz}\cos\beta\cos\gamma + 2I_{zx}\cos\gamma\cos\alpha$. 4+6

6\. (a) Consider a linear triatomic molecule with two outer atoms of mass 'm' connected to the central atom of mass 'M' by two identical massless springs of spring constant 's'. Show that the normal frequencies of small oscillations are '0' $\sqrt{\dfrac{s}{m}}$ and $\sqrt{\dfrac{s}{m} + \dfrac{2s}{M}}$.

(b) Consider a forced linear harmonic oscillator given by

$$m\ddot{x} + m\omega^2 x = \tau f\,\delta(t - t_0)$$

where τ is a quantity having a dimension of time. Discuss qualitative the behaviour of $x(t)$ and $\dot{x}(t)$ immediately before and after $t = t_0$. (2+2+2)+(1+1+1+1)

7. (a) Find out the fixed points of the 1D dynamical system described by

$$\dot{x} = x - x^3$$

Draw the phase portrait and the flow of x. Hence ascertain the nature of the fixed points.

(b) Consider the 2D dynamical system

$$\dot{x} = y$$

$$\dot{y} = x$$

(i) Write down the fixed point and the stability matrix.

(ii) Determine the eigenvalues of the stability matrix and hence conclude about the nature of the fixed point.

(iii) Find the eigendirections and draw the flow lines with respect to these directions. (1½+2+1½)+(1+2+2)

8. (a) Consider the map $x_{n+1} = \cos x_n$ that has a fixed point at $x^* \approx 0.74$. Check analytically that the fixed point is stable. Show graphically how the stable point is approached if one starts from a nearby point.

(b) Consider the 1D dynamical system given by $\dot{x} = rx - x^2$.

(i) Draw the phase portraits for $r > 0$, $r = 0$ and $r < 0$.

(ii) From the phase portrait and the corresponding flows determine the nature of the fixed points in the 3 cases. (2+2)+{(1+1+1)+(1+1+1)}

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