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PHYSICS

(Major)

Paper : 5.3

(Quantum Mechanics and Astrophysics)

Full Marks : 60

Time : 3 hours

*The figures in the margin indicate full marks
for the questions*

GROUP—A

(Quantum Mechanics)

(Marks : 40)

1. Choose the correct answer from the given alternatives (any four) : 1×4=4

(a) The magnitude of Compton shift is maximum when the angle of scattering is

(i) 0°

(ii) π

(iii) $\pi/2$

(iv) 45°

(b) In view of the uncertainty principle, the radiation emitted by an atom can have

- (i) a definite frequency
- (ii) a band of frequencies
- (iii) a definite phase
- (iv) a definite wavelength

(c) Schrödinger one-dimensional wave equation is

- (i) first-order in x and second-order in t
- (ii) second-order in x and first-order in t
- (iii) first-order in both x and t
- (iv) second-order in both x and t

(d) If $\hat{A} = \frac{d^2}{dx^2}$ and $\psi(x) = ae^{-2x}$, then the eigenvalue of $\psi(x)$ is

- (i) 2
- (ii) 4
- (iii) $2a$
- (iv) a

(e) If R and T be the reflection and transmission probabilities of a particle through a potential step, then

- (i) $R - T = \text{constant}$
- (ii) $R + T = 0$
- (iii) $R + T = 1$
- (iv) $R + T = \infty$

2. Answer any *three* questions : 2×3=6

- (a) What was the reason for the failure to explain the blackbody radiation spectra? How did Planck overcome this?
- (b) What voltage must be applied to an electron microscope to produce electrons of wavelength 0.40 Å?
- (c) "Quantum mechanics is probabilistic whereas classical mechanics is deterministic." Discuss.
- (d) Suppose the wavelength of incident light in a photoelectric experiment changes from 300 nm to 400 nm. Find the corresponding change in the stopping potential.
- (e) Write down Schrödinger's time-dependent and time-independent equations for a particle of mass m .

3. Answer any *two* questions : 5×2=10

- (a) Give the mathematical statement of the uncertainty principle explaining the terms involved. A proton is confined to a nucleus of radius 5×10^{-15} m. Calculate the minimum uncertainty in its momentum. What is the minimum uncertainty in the kinetic energy of the proton? Given, mass of the proton $m_p = 1.67 \times 10^{-27}$ kg.

1+2+2=5

- (b) What do you mean by expectation value of a dynamical variable? Find the expectation values $\langle p \rangle$ and $\langle p^2 \rangle$ for the wave function

$$\psi(x) = \begin{cases} \sqrt{\frac{2}{L}} \sin\left(\frac{\pi x}{L}\right) & \text{for } 0 < |x| < L \\ = 0 & \text{for } |x| > L \end{cases} \quad 1+2+2=5$$

- (c) What is tunneling? Is there any similar process in classical mechanics analogous to tunneling in quantum mechanics? Discuss. 3+2=5
- (d) Define phase velocity and group velocity. Deduce the relation between phase velocity and group velocity for the de Broglie waves. Which of these two is associated with particle velocity? 2+2+1=5

4. What is a one-dimensional potential step? A particle of mass m is moving in a one-dimensional potential given by

$$V = \begin{cases} 0 & \text{for } x < 0 \\ = V_0 & \text{for } x \geq 0 \end{cases}$$

If the energy E of the incident particle is greater than V_0 , then calculate the coefficient of reflection and transmission. 2+8=10

Or

Discuss briefly the experiment of Davisson and Germer pointing out clearly how it demonstrate the existence of de Broglie matter waves. What is the wave-particle duality? 8+2=10

5. What is the need for normalization of a wave function? Calculate the normalization constant of a wave function (at $t = 0$) given by

$$\psi(x) = ae^{-(a^2x^2/2)} \cdot e^{ikx}$$

known as the Gaussian wave packet. Hence determine the probability density of the wave function. 2+8=10

Or

What are Hermitian operators? Give two examples. What are conjugate variables in quantum mechanics? Give an example of any one pair of conjugate variables and obtain their commutation relations. 2+2+6=10

GROUP—B

(Astrophysics)

(Marks : 20)

6. (a) Answer any *one* question : 1

(i) What is a celestial sphere?

(ii) What is the declination of the north celestial pole?

(b) Answer any *two* questions : 2×2=4

(i) Define ecliptic. What are vernal and autumnal equinoxes?

(ii) What is the difference between sidereal time and solar time?

(iii) Explain the signs of zodiac.

7. Answer any *one* question : 5

(a) The apparent magnitude of a star is found to be +3.3 and its parallax is 0.005". Find its absolute magnitude.

(b) What are Hertzsprung-Russell (H-R) diagram? What is the meaning and importance of the term main sequence in such diagrams?

8. What is the basis of spectral classification of stars? Enumerate the special features of the Harvard spectral sequence. 4+6=10

Or

Write down the sequence of events leading to the formation of a protostar. When does a protostar become a star? Describe briefly the occurrence of helium flash. 5+2+3=10

[The following data can be used when required :

Charge of electron $e = 1.6 \times 10^{-19}$ C

$c = 3 \times 10^8$ m/s, $h = 6.6 \times 10^{-34}$ J-s

$m_e = 9.1 \times 10^{-31}$ kg, $m_p = 1.67 \times 10^{-27}$ kg]
