

# PHYSICS

## PAPER – I SECTION A

1. Answer any four of the following: (10 × 4 = 40)
- (a) Moon revolves around Earth making a complete revolution in 27.3 days. Assume that the orbit is circular and has a radius of 4,00,000 kms. What is the magnitude of acceleration of Moon towards Earth?
- (b) Does the frequency of sound emitted by one moving frame of reference as heard on the other frame of reference depend on the velocities of the moving frames?  
Discuss this aspect when both the frames are moving in opposite directions to each other with uniform velocities  $V_1$  and  $V_2$  respectively. The first frame emits the sound and the other receives it.
- (c) A vertically suspended 2 m length of string is given a tension equal to the weight of a 0.80 kg mass. The string is found to resonate in four equal segments to a frequency of 520 Hz. What is the mass per unit length of the string? Take the value of acceleration due to gravity of Earth to be  $9.8 \text{ ms}^{-2}$ .
- (d) What do you understand by the terms 'Spatial coherence' and 'Temporal coherence'? Illustrate by giving one example for each.  
Deduce the relationship between coherence time and coherence length.
- (e) What is double refraction? Taking calcite crystal as an example, explain the phenomenon of double refraction.
2. (a) What is a Foucault's pendulum? Show that the plane of vibration of the pendulum at north pole executes one complete rotation in one day but it does not rotate at all at the Equator. (13)
- (b) Derive an expression for the Rutherford scattering cross-section and show that it varies as the square of the  $K.E.$  of the particle. (13)
- (c) A mass of 1 kg is placed on a smooth horizontal plane and attached by a string to another mass 1 kg hanging over a mass less and frictionless pulley. Find the acceleration of the system and tension in the string. (14)
3. (a) Bring out clearly how the Lorentz transformation equations explain Time dilation and Length contraction. (13)
- (b) State Huygens' principle. How does Huygens theory explain the laws of refraction of light in a transparent medium? Deduce the path difference between two waves of wave lengths  $\lambda_1$  and  $\lambda_2$ , traveling in a transparent medium. (14)

- (c) If  $s$  is the minimum distance between an object and its real image formed by a thin converging lens of focal length  $f$ , then show that  $s = 4f$  (13)
4. (a) Distinguish between Fraunhofer and Fresnel diffractions. What is a Cornu's spiral? With the help of a neat diagram, explain its significance. (13)
- (b) Explain the operation of a He-Ne laser with the help of relevant energy level diagram. What is the role of Ne atoms in the laser? (13)
- (c) In a Young's experiment, light of two wavelengths, 520 nm and 650 nm, are used to form the interference fringes. The distance between the plane of the slits and the screen is 120 cm. Find the
- Distance of 5th bright fringe from the central maximum for the wavelength 650 nm;
  - Least distance from the central maximum at which the bright fringes due to both the wavelengths coincide.
- (14)

### SECTION II

5. Answer any four of the following: (10 × 4 = 40)
- State Biot-Savart's law. Explain how the magnetic field produced at the centre of a current-carrying circular wire can be obtained.
  - A quarter-wave plate is made of thin sheets of mica whose birefringence for sodium light ( $\lambda = 589$  nm) is 0.0041. What is the thickness of the quarter-wave plate?
  - Deduce Maxwell's fourth equation in the differential form, i.e.,
 
$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$
  - Show that the efficiency of a Carnot engine using an ideal gas as the working substance and operating between  $T_1$  K and  $T_2$  K is given by
 
$$\eta = \frac{T_2 - T_1}{T_1}$$
  - A 50 gm block of copper taken from a furnace is dropped into a 200 gm glass beaker containing 100 gm of water. The temperature of water rises from 15°C to 30°C. What was the temperature of the furnace?
6. (a) A thin plastic rod of length  $L$  has positive charge of uniform linear density  $\lambda$ . Find the electric potential due to it at P at a perpendicular distance from one end of the rod. (13)
- (b) (i) In a single-loop circuit containing a battery of e.m.f.  $E$  and a resistance  $R$ , find the value of the current, by applying the energy principle. (5)

- (ii) Three resistors  $R_1$ ,  $R_2$  and  $R_3$ , are connected in parallel. One battery of e.m.f.  $E_1$  is connected between  $R_1$  and  $R_2$  such that the current in the battery flows anti-clockwise. Another battery having e.m.f.  $E_2$ , is connected between  $R_2$  and  $R_3$ , on the same line as  $E_1$ . The current through  $E_2$ , flows clockwise. Calculate the currents through  $R_1$ ,  $R_2$ , and  $R_3$ . Assume  $R_1 = R_2 = R_3 = 2\Omega$ ;  $E_1 = 4V$  and  $E_2 = 2V$ .

(9)

- (c) What is an ideal transformer? Explain the theory of a transformer taking into account the requirements of energy transmission.

(13)

7. (a) Explain the technique of holography. Mention some of its important applications. (13)

- (b) Deduce Maxwell's second equation in the differential form, i.e.  $\Delta \cdot \vec{B} = 0$  (13)

- (c) A magnetic field of  $2.6 \times 10^5 \text{ Am}^{-1}$  is applied to an optically active medium whose Verdet's constant for Sodium-D light is  $0.104 \text{ arc mm/A}$ . If the light traverses a path  $10 \text{ cm}$  long, through which angle will the plane of oscillation turn? (14)

8. (a) Write brief but comprehensive notes on the following: (20)

(i) Saha ionisation formula

(ii) Bose-Einstein condensation

- (b) Show that for an ideal gas undergoing an adiabatic process  $pV^\gamma = \text{constant}$ .

Calculate the change in entropy when  $1 \text{ kg}$  of ice at  $0^\circ\text{C}$  melts to water at the same temperature. The latent heat of melting of ice is  $79.6 \text{ cal. gm}^{-1}$ .

(20)

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# PHYSICS

## PAPER - II

### SECTION A

#### LIST OF USEFUL CONSTANTS

Mass of proton	= $1.673 \times 10^{-27}$ kg	Atomic mass unit (amu)	= $1.660 \times 10^{-27}$ kg
Mass of neutron	= $1.675 \times 10^{-27}$ kg		931 MeV
Mass of electron	= $9.11 \times 10^{-31}$ kg	Mass of $^{14}\text{N}$	= $14.007550$ amu
Mass of constant	= $6.626 \times 10^{-34}$ Js	Mass of $^{11}\text{B}$	= $11.01281$ amu
Boltzmann constant	= $1.380 \times 10^{-23}$ JK $^{-1}$	Mass of Alpha particle	= $4.003879$ amu
Bohr Magneton	= $9.273 \times 10^{-24}$ A/m $^2$	Mass of $^{16}\text{O}$	= $15.99493$ amu
Electronic charge	= $1.602 \times 10^{-19}$ C	Velocity of light in vacuum	= $3 \times 10^8$ ms $^{-1}$

1. Answer any four of the following:

(a) Can an electron stay inside a nucleus? Justify your answer using quantum mechanical principles. (10)

(b) Show that the density of states for a particle of mass  $\mu$ , inside a cuboid of side L is

$$p(k) = \frac{\mu L^3}{8\pi^3 h^2} k \sin \theta d\theta d\phi.$$

This particle has momentum  $p = \hbar k$  with spherical co-ordinates of  $\vec{k}$  given by  $(k, \theta, \phi)$ . (10)

(c) What is the polarisability of a molecule? How does it lead to an explanation of Raman effect? (10)

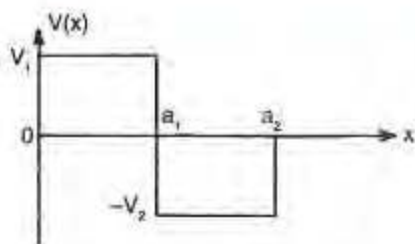
(d) Explain the meanings of the following in atomic spectroscopy:  
Electron configuration, equivalent electron, term symbol, level symbol, degeneracy. (10)

(e) What is Lamb shift? How much has it been measured for an atom with atomic number one? Can it be explained using Dirac's relativistic wave equation for an atom? (10)

2. Consider the one-dimensional potential

$$V(x) = \begin{cases} 0 & \text{for } x < 0 \text{ (Region I)} \\ V_1 & \text{for } 0 \leq x \leq a_1 \text{ (Region II)} \\ -V_2 & \text{for } a_1 \leq x \leq a_2 \text{ (Region III)} \\ 0 & \text{for } x > a_2 \end{cases}$$

Here both  $V_1, V_2 > 0$ . Assume that a particle of mass  $\mu$  and energy E is incident from left on this potential.



- (a) Write time-independent Schrödinger equations and their respective solutions for each region, taking  $0 < E < V_1$ . (13)
- (b) Apply boundary conditions (do not solve the consequent equations). (12)
- (c) Obtain the normalization integral for the wave function in the whole region. Simplify it as much as you can without performing integration. (15)
3. Let  $H_{fs}$  represent the interaction potential in the Hamiltonian of a hydrogen atom which gives rise to the fine structure splitting.
- (a) Write the explicit form of  $H_{fs}$ . (6)
- (b) Show that it commutes neither with  $\hat{L}$  nor with  $\hat{S}$  (the total orbital and spin angular momenta, respectively). (8)
- (c) Define the angular momentum operator  $\hat{J}$  that commutes with  $H_{fs}$  and prove your statement. (6)
- (d) Obtain an expression for  $H_{fs}$  in terms of  $L^2$ ,  $S^2$ , and square of the new angular momentum operator  $\hat{J}$  you have defined. (6)
- (e) Which degeneracy in the spectrum of an atom is removed by the presence of  $H_{fs}$ ? (6)
- (f) Calculate  $H_{fs}$  for a 3d electron (leave your answer in terms of radial function). (8)
4. (a) Explain the meanings of the terms (O, P, Q, R, S) branches, bands, and of progression in molecular spectroscopy. Which spectrum contains only branches, both branches and bands, branches and progression? (25)
- (b) High resolution laser spectroscopy can resolve lines that can not be resolved by conventional spectroscopy. Justify this statement. (15)

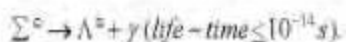
## SECTION B

5. Attempt any four of the following:

(a) Estimate the packing fraction of  $^{16}\text{O}$  nucleus.

(10)

(b) Which of the fundamental interactions is present in the following nuclear process? Use the conservation laws to arrive at the conclusion:



(10)

(c) What is the structure of sodium chloride? How many unit cells of NaCl are there in each cube? What are the positions of Na and Cl ions in each cell?

(10)

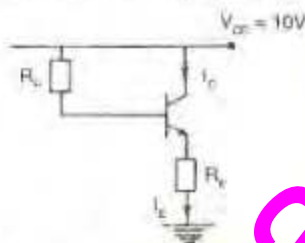
(d) Simplify the logic expression

$$Y = A\bar{B} + \bar{A}B$$

by drawing up truth tables.

(10)

(e) For the circuit designed as in diagram below:



Determine

(i) The type of BJT used,

(ii) The resistance value  $R_B$ ,

(iii) The value of resistor  $R_E$ .

to set the emitter-earth voltage at 5 V when  $I_C$  is nominally 2 mA and  $\beta = 200$ .

Given,  $V_{BE} = 0.65$  V

(10)

(a) What is Kurie plot? In what way it finds use in nuclear decay?

(10)

(b) (i) Differentiate between K-capture and inverse beta decay.

(5)

(ii) What are the properties of neutrino?

(5)

(iii) What is the principle used in the experiment conducted by Reines and Cowan?

(7)

(c) Explain why is it that a U-235 is fissile with a thermal neutron whereas U-238 requires a fast neutron to undergo fission. Given: Binding energies of the added neutrons for U-235 and U-

238 are 6.8 MeV and 5.9 MeV respectively. Estimate the critical energies for the two nuclei to support your answer (13)

7. (a) What are quarks? List the various types of them. Give the concept of coloured quarks. (20)
- (b) Discuss the motion of electrons in a one dimensional crystalline lattice according to band theory. (6)
- (c) On the basis of answer to (b), plot schematically, the energy, velocity and effective mass of electrons as a function of wave vector  $k$ . (6)
- (d) How does band theory leads to distinction between metals, insulators and intrinsic semiconductors? (6)
- (e) 'What is the concept of 'hole'?' (2)

8. (a) Referring to the circuit diagram given below, the following data hold good:

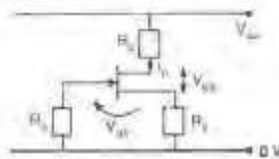
$$I_{DSS} = 8\text{mA}$$

$$V_p = -4\text{V}$$

$$R_D = 2.2\text{k}\Omega$$

$$R_S = 1\text{k}\Omega$$

$$V_{DD} = 10\text{V}$$



$V_{GS}$ (V)	$I_D$ (mA)
0	8.0
-1	4.5
-2	2.0
-3	0.5
-4	0.0

- (i) What is the type of device used? (2)
- (ii) Draw the transfer characteristic. (2)
- (iii) Draw the load line. (2)
- (iv) Obtain an approx. value for  $I_D$ . (2)
- (v) Obtain an approx. value for  $V_{DS}$ . (2)
- (b) What are the characteristics of a practical OP-AMP?
- How does the open loop gain of a 741 OP-AMP vary with frequency? Use graphical illustration. What is CMRR? (15)
- (c) (i) What is the principle used in "half adder"? (5)
- (ii) Draw the truth table for a half-adder. (5)
- (iii) What are the Boolean expressions for 'sum' and 'carry' outputs of a half-adder? (5)