CCE(M)/PHY–I/10/2024

PHYSICS

(PAPER—I)

Time : 3 hours] [Full Marks : 250

Please read each of the following instructions carefully before attempting the questions :

(i) There are **eight** questions divided in **two Sections**.

(ii) Candidate has to attempt **five** questions in all.

(iii) Question Nos. **1** and **5** are compulsory and out of the remaining, **three** are to be attempted choosing at least **one** question from each Section.

(iv) The number of marks carried by a question/part is indicated against it.

(v) Word limit in questions, wherever specified, should be adhered to.

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SECTION—A

1. Answer *any* **five** of the following questions : 10×5=50

(a) A force applied on a body of mass 20 g is $(5\vec{i}+15\vec{j})$ N. If the body starts from the rest, then what will be its position at time $t=10$ s?

(b) A solid heavy ball is dropped from a gas filled balloon going up with a constant velocity of 10 ms^{-1}. When the balloon was at 100 m high, the ball was dropped. Find the height of the balloon when the ball hits the ground. The acceleration due to gravity $g = 9{\cdot}8\ ms^{-2}$.

(c) Mass of the earth is $6{\cdot}4\times10^{24}$ kg and the mass of the moon is $7{\cdot}2\times10^{22}$ kg. The distance between earth and moon is $5{\cdot}0\times10^{5}$ km. Find the distance of a point from the center of the earth where the resultant gravitational field due to the earth and the moon is zero.

(d) A flywheel of mass 10 kg and radius of 8 cm is revolving at 180 r.p.m. A constant force applied tangentially to its rim reduces its speed to 150 r.p.m. in 20 seconds. Find the force.

(e) The displacement of a point on a damped oscillator is expressed as :

$$x = 4e^{-\frac{1}{4}t} \sin\left(\frac{\pi}{2}\right)t$$

Calculate the velocity of the oscillation at $t = T/4$ and $t = T$, where T is the time period of the oscillation.

(f) In a biprism experiment, fringes for light of wavelength 50 μm are observed 0·2 mm apart at a distance of 150 cm from the prism. The refractive index of the glass of the biprism is 1·50 and it is placed at a distance of 20 cm from the illuminated slit. Calculate the angle at the vertex of the biprism.

(g) Find the speed of a rocket, which moves relative to an observer in order that its length may appear to him to be 98% of its proper length.

2. (a) State Bernoulli's theorem and deduce Bernoulli's equation. How can the upward lift of an aeroplane be explained from the Bernoulli's theorem?

A cylindrical pipe is running full of water. At a certain point X it tappers from 0·6 m diameter to 0·2 m diameter at point Y. The pressure difference between X and Y is 2·0 m of water column. Calculate the rate of flow of water through the pipe. 10+5+5=20

(b) The position of moving particle at any instant is given by $\vec{r} = A\cos\theta\hat{i} + A\sin\theta\hat{j}$. Show that the force acting on it is conservative. Also calculate the total energy of the particle. 15

(c) Derive the expression for the law of addition of relativistic velocities. Show that the resultant velocity of a material particle cannot be greater than velocity of light c. 15

3. (a) Deduce the expression for the equivalent focal length of two thin co-axial lenses separated by a finite distance. Two co-axial thin convex lenses having focal lengths 10 cm and 4 cm are separated by 6 cm. Find the equivalent focal length and position of the principal points. 20

(b) Write the differential equation for simple harmonic motion of a body and show that time period T is given by

$$T = 2\pi \sqrt{\frac{\text{displacement}}{\text{acceleration}}}$$

Calculate the average kinetic energy and total energy of a body executing simple harmonic motion. 15

(c) Explain the formation of fringes in a Fabry-Perot interferometer and discuss the effect of reflection coefficient on the sharpness of the fringes. 15

4. (a) Discuss the theory of plane transmission grating. Deduce the expressions for dispersive power and resolving power of the plane transmission grating. 20

(b) Explain the phenomenon of double refraction in a calcite crystal. What is a quarter wave plate? Deduce its thickness for a given wavelength in terms of its refractive indices.

Quartz crystal has refractive indices 1·552 and 1·542. Calculate the thickness of quarter wave plate for sodium light of wavelength 5890 Å. 15

(c) Explain the terms 'population inversion' and 'stimulated emission'. Describe the He-Ne gas laser. How is the population inversion achieved in this type of laser? 15

SECTION—B

5. Answer *any* **five** of the following questions : 10×5=50

(a) What is the origin of domains in ferromagnetic materials? Why is hysteresis loop observed in B-H curve of a ferromagnetic material?

(b) Explain the self-induction and mutual induction phenomena. A magnetic flux ϕ linked with a coil at any instant of time t is given by $\phi = 20t^2 + 5t + 8$. The magnetic flux ϕ and time t are measured in weber and second, respectively. Find out the e.m.f. induced in the coil at $t = 2$ s.

(c) A uniform plane wave in free space is given by

$$E = 100\exp(-i0{\cdot}2z)\hat{a}_x \text{ V/m}$$

Find the instantaneous value of Poynting vector at $t = 0$ and $z = 10$. (Impedance of free space $Z_0 = 377\Omega$)

(d) What is entropy? Why is a reversible adiabatic change isentropic? One mole of a perfect gas is isothermally expanded to thrice its initial volume. Find the change in entropy. $R = 8{\cdot}313\ \text{JK}^{-1}\text{mol}$.

(e) Explain the Stefan-Boltzmann law of thermal radiation. Light from sun arrives at the earth at the rate of $1{\cdot}2\ \text{kW m}^{-2}$ when sun is directly overhead. The radius of sun is $6{\cdot}0\times10^5$ km and the average radius of earth's orbit is $1{\cdot}5\times10^8$ km. Find the surface temperature of earth, assuming the radiation is like blackbody. (Stefan's constant $\sigma = 5{\cdot}67\times10^{-8}\ \text{Wm}^{-2}\text{K}^4$)

(f) A circuit consists of a resistance of 50 Ω, an inductance of 0·3 H and a capacitor of 50 μF in series and it is supplied with 200 V at 50 Hz. Calculate the power factor, apparent power and true power in the circuit.

(g) A capacitor is being charged from a d.c. source through a resistance of 2 MΩ. If it takes 0·5 second for the charge to reach 3/4 times of its final value, then find out the capacitance of the capacitor.

6. Answer the following questions :

(a) Discuss the reason for the failure of Dulong-Petit's law to predict the specific heat at low temperature. Why should the law be valid at high temperature? Show that the molar specific heat at constant volume C_v for the Einstein model of a solid is given by

$$C_v = 3R\left(\frac{h\nu}{KT}\right)\frac{e^{\frac{h\nu}{KT}}}{\left(e^{\frac{h\nu}{KT}}-1\right)^2}$$

(Symbols have their usual meanings) 5+15=20

(b) What do you understand by a linear electric quadrupole? Show that the electrostatic potential due to linear electric quadrupole varies inversely as the cube of the distance r. Here r is the distance between a point and central of the quadrupole. 15

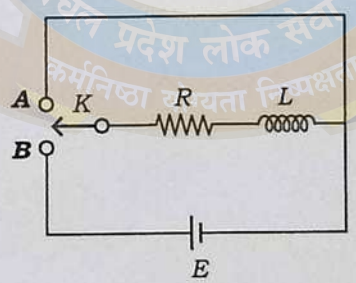
(c) What do you understand by 'local electric field' and 'dielectric polarizability' in a dielectric material? Derive the following Clausius-Mossotti relation :

$$\frac{\varepsilon - 1}{\varepsilon + 2} = \frac{1}{3\varepsilon_0} \sum_j N\alpha_j$$

Here, ε is dielectric constant of the crystal, ε_0 is permittivity of free space, N_j is the number of j^{th} types of atoms in unit volume of the crystal and α_j is polarizability of j^{th} type of atom. 15

7. (a) Write Biot-Savart law in the form of vectors. Using Biot-Savart law, obtain the expression for magnetic field due to a current carrying thin straight wire of finite length. Extend the derivation to obtain the expression for magnetic field due to the wire of infinite length. 20

(b) As shown in the following figure, an inductor L is connected in series with a resistor R and the combination gets connected or disconnected from the battery of e.m.f. E as key K is in position **A** or **B**.



Find the expression for growth and decay of current. 15

(c) What is displacement current? How is it different from conduction current? Why was one of the Maxwell's equations modified introducing the displacement current and how?

A parallel plate capacitor with plate area of 5 cm^2 and separation of 3 mm has a voltage $V = 50\sin 10^3 t$ volt applied to its plate. Calculate the displacement current assuming $\varepsilon = 2\varepsilon_0$. 15

8. *(a)* Deduce the Maxwell's thermodynamic relation :

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

Obtain Clausius-Clapeyron equation from the above relation.

Find the depression in the melting point of ice for an increase in external pressure of 2 atmosphere. Specific volume of ice and water at 0 °C are $1{\cdot}09\times10^{-3}\ m^3kg^{-1}$ and $1\times10^{-3}\ m^3\,kg^{-1}$. Specific latent heat L is $3{\cdot}4\times10^5\ J\ kg^{-1}K^{-1}$. (1 atmosphere = $1{\cdot}01\times10^5\ Nm^{-2}$). 20

(b) Draw the P–V diagram of Carnot cycle and describe the operation of Carnot's engine. A Carnot's engine is operating between a high temperature reservoir at T_1 and low temperature reservoir at T_2. Show that the efficiency of the engine (η) is expressed as $\eta = 1 - \frac{T_2}{T_1}$. 15

(c) Find out the expression for Molecular Energy Distribution of an ideal gas from the Maxwell-Boltzmann distribution function. Show that average molecular energy $E = 3/2\ NkT$, where N is total number of molecules, k is Boltzmann constant and T is absolute temperature. 15

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SECTION—A

1. Answer *any* **five** of the following questions : 10×5=50

(a) Consider a particle of mass m confined in a cubic potential box of side of length L. Calculate the quantum states and their degeneracy for the energy that is three times that of the ground state.

(b) The spin state of an electron is given by the eigen state of operator $\frac{h}{2\sqrt{2}}(\sigma_x + \sigma_y)$, σ_x and σ_y are Pauli spin matrices. What is the probability that z-component of its spin is $\frac{h}{2}$?

(c) A free particle moving in x-direction has the time-dependent wave function $\psi(x,t) = \frac{1}{20} e^{t(10x-10\pi t)}$. Calculate the wavelength and velocity of the particle.

(d) Find the expectation values in the state $|l,m\rangle$ for $\langle \hat{L}_+ \hat{L}_- \rangle$ and $\langle \hat{L}_x \rangle$.

(e) Provide the experimental pieces of evidence for the electron spin.

(f) What do you mean by fluorescence and phosphorescence? Write down three differences between fluorescence and phosphorescence.

(g) Draw the allowed transitions between the $n = 2$ and $n = 1$ levels of atomic hydrogen occurring in the presence of a weak magnetic field.

2. (a) Find the energy eigenvalues and eigen wave functions of a one-dimensional potential box. Show that the wave functions are orthonormal. Find out the expectation values of linear momentum and kinetic energy operators. 20

(b) Derive the expression for reflection and transmission coefficients for one-dimensional step potential V_0, when the energy of the incident particle E is greater than V_0. 15

(c) Calculate the Compton wavelength of a proton (fm unit). 15

3. (a) The wave function of a particle executing linear harmonic motion in the lowest eigen state is $\psi(x) = \left(\frac{\alpha^2}{\pi}\right)^{\frac{1}{4}} e^{\frac{-\alpha^2 x^2}{2}}$, where α is a constant. Calculate the uncertainties in position and momentum of the particle and verify that it follows the uncertainty principle. 20

(b) Lead has an atomic weight of 207·3 amu and density of 11·34 gm per cc.

I. Calculate the number of atoms per cc in the lead.

II. What is the total number of energy vacancies per cc at 500 K if the energy of vacancy formation in lead is 0·55 per atom? 15

(c) Calculate the Landé g-factor and degeneracy of the $^3D_3$ level. 15

4. (a) Write down the ground state wave function for hydrogen atom and verify that it follows the virial theorem. 20

(b) Write down the effective potential of an atom having one electron and draw it for the hydrogen atom having $l = 0$ and $l = 1$. 15

(c) Write down the Hamiltonian for spin-orbit interaction in hydrogen atom and calculate an expression for the energy shift due to it for $l = 1$ state. 15

SECTION—B

5. Answer *any* **five** of the following questions : 10×5=50

(a) Explain the nuclear forces are charge independent. Give two experimental evidences to support your answer.

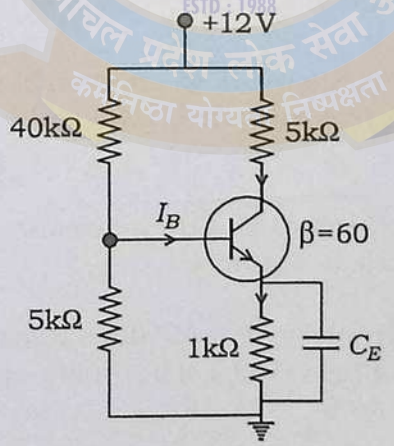
(b) Write down the equation of alpha decay of element, $^{238}_{92}U$ having *Q*-value of 4·28 MeV. Also find the energy emitted alpha particle and Coulomb potential barrier.

(c) Identify the elementary particles correspond to *sss*, *uus* and *uds* quarks composition.

(d) Write down four similarities and four differences between a photon and a neutrino.

(e) Prove that for the Kronig-Penney potential with the momentum $p << 1$, the energy of lowest energy band at $k = 0$ is, $E = \frac{h^2 p}{ma^2}$. (Symbols have their usual meanings)

(f) Calculate the dc bias voltages and currents for the following circuit. Assume $VBE = 0{\cdot}3$ V and $\beta = 60$ for the transistor used.



(g) Simplify the following Boolean expression and show that :

- $(A + C)(\bar{A} + B) = AB + \bar{A}C$
- $\overline{\overline{A + B} + \overline{A.B.C}} = AB + C$

6. Answer the following questions :

(a) Explain the structure and function of enhancement and depletion-type MOSFETs. Draw their output and transfer characteristic curves. Compare briefly the *p*-channel and *n*- channel MOSFETs and show their symbols. 20

(b) Describe the Meissner effect in superconductors. Drawing the M–B curves, differentiate between Type-I and Type-II superconductors. 15

(c) Based on the band theory of solids, discuss the difference amongst conductors, insulators and semiconductors. 15

7. *(a)* Show how to determine Miller indices of a crystal plane. Show that in a cubic crystal the spacing between consecutive parallel planes of Miller indices $(h\,k\,l)$ is given by

$$d_{hkl} = \frac{a}{\sqrt{h + k^2 + l^2}}$$ 20

(b) Draw the simple band diagrams to distinguish the *n*-type and *p*-type semiconductors. From the following expressions for electron and hole densities :

$$n_e = N_C e^{-(E_c - E_F)/kT} \text{ and } n_h = N_V e^{-(E_F - E_v)/kT};$$

find the expressions for the exact positions of Fermi levels of *n*-type and *p*-type semiconductors. 15

(c) Drawing the suitable diagrams, show how op-amp can be used as differentiator, integrator and voltage to current converter. 15

8. *(a)* Derive an expression for the *Q*-value using the kinematics of a nuclear reaction, assuming that the target nucleus is at rest. 20

(b) What do you mean by mirror nuclei? Provide three examples of mirror nuclei. Also, derive the expression for the *Q*-value of beta-plus emitters of mirror nuclei using the semi-empirical mass formula. 15

(c) What are fissile and fertile nuclear materials? Provide two examples of nuclear reactions or decays that convert fertile materials into fissile materials. 15

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