PARLIAMENT OF INDIA
(JOINT RECRUITMENT CELL)

MAIN EXAMINATION FOR POSTS OF EXECUTIVE/LEGISLATIVE/COMMITTEE/PROTOCOL OFFICER AND RESEARCH/REFERENCE OFFICER IN LOK SABHA SECRETARIAT

26th AUGUST, 2008

PHYSICS - Paper-I

INSTRUCTIONS : Answers must be written in English only. Candidates should attempt at least 2 questions from each section and total 5 questions. The number of marks carried by each question is indicated against the same.

Time: 3 hours Marks: 300

SECTION - A

1. (a) Considering a beam of alpha particles incident on an atomic nucleus obtain an expression for Rutherford scattering cross section. Integrate this expression over the entire solid angle to obtain total cross section. What value do you get for the total cross section? What does this value of cross section reveal about the nature of the force that acts between the nucleus and the alpha particles? (45 marks)

(b) Mention the characteristics of the centre-of-mass (cm) system. For the non-relativistic elastic collision of a moving particle of mass m_1 with a stationary target of mass m_2, show that the velocity of the cm (in lab system) is given by

$$\vec{V}_{cm} = \frac{m_1}{m_1 + m_2} \vec{u}_1$$

where $\vec{u}_1$ is the velocity of the incident particle in lab system. (15 marks)

2. (a) Explain Eulerian angles by using appropriate figures. What for are these angles used? If B, C and D transformations are given by

60/8 (2)

$$B = \begin{pmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$C = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{pmatrix}$$

$$D = \begin{pmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

M8 x4 = 60/5 (36)

Find the product matrix $A = BCD$ for the complete transformation. (30 marks)

(b) Describe Michelson-Morley experiment in brief giving all its essential features. What for was this experiment designed and what was its result? (20 marks)

(c) Show that the total energy of a relativistic particle can be written as

$$E^2 = p^2c^2 + m_0^2c^4$$

where the symbols have their usual meanings. What form does it assume for photons? (10 marks)

3. (a) What do you understand by stationary waves? How are these waves produced on a string of fixed length? Obtain an equation of a stationary wave on a string of fixed length. Mention the characteristic features of stationary waves. (35 marks)

(b) Obtain the laws of reflection and refraction of light from Fermat's principle. (15 marks)

(c) Mention the characteristics of Laser light. Explain the spatial and temporal coherence. Mention the types of lasers that are available at present. (10 marks)

4. (a) What do you understand by the phenomenon of interference of light? Describe Young's experiment for observation of interference pattern. Obtain an expression for the fringe width. (20 marks)

(b) Explain the phenomenon of diffraction of light. What is a diffraction grating? How do you use a diffraction grating to measure the wavelengths corresponding to different colours (of light) observed in the grating spectrum. How is the resolving power of a grating defined? (25 marks)

(c) What do you understand by polarization of light? How do you achieve polarization by reflection? Explain Brewster's law. How would you detect the linearly polarised light? (15 marks)

(4)

5. (a) Mention the postulates of special theory of relativity. Derive the following Lorentz transformation equations:

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}$$

$$y' = y$$

$$z' = z$$

$$t' = \frac{t - \left(\frac{v}{c^2}\right)x}{\sqrt{1 - v^2/c^2}}$$

where the symbols have their usual meanings. (40 marks)

(b) Discuss various attenuation mechanisms of an optical beam in an optical fiber. What do you understand by pulse dispersion in step index fiber? (20 marks)

SECTION - B

6. (a) Deduce the multipole expansion of the scalar potential of an arbitrary charge distribution. Mention the significance of dipole potential and dipole moment, and quadrupole potential and quadrupole moment. (30 marks)

(b) Obtain the resonance condition in a series LCR circuit energised by a sinusoidal voltage of frequency ω. How is the resonance frequency related to L and C? What is the value of current in the resonance condition? (20 marks)

(c) Explain the principle of transformer. Explain the step-up and step-down transformers. (10 marks)

7. (a) Write down general form of Maxwell's equations. What form do these equations assume in empty space? Show that an electromagnetic disturbance travelling at speed c is compatible with Maxwell's equations. (30 marks)

(b) What are vector and scalar potentials? What do you understand by gauge invariance? Explain Lorentz and Coulomb gauges, and the electromagnetic field tensor. (20 marks)

(c) Discuss the physical significance of displacement current by taking the example of flow of current through a capacitor. (10 marks)

8. (a) What do you understand by black body radiation? Obtain the expression for Planck's law of radiation. Deduce Stefan-Boltzmann law from Planck's law of radiation. (35 marks)

(b) Obtain Van der Waal's equation of state for a real gas. How can one obtain the constants a and b in terms of measurable constants T_c, P_c and V_c? The symbols have their usual meanings. (25 marks)

9. (a) What is Bose-Einstein condensation? For an ideal Bose-gas obtain the condition for Bose-Einstein condensation. (30 marks)

(b) What do you understand by thermal ionization of a monatomic gas? Obtain Saha ionization formula (Saha's equation) for such a gas. (20 marks)

(c) State and prove equipartition and virial theorems. (10 marks)

10. (a) Consider a dielectric sphere of radius a and dielectric constant ϵ placed in a uniform electric field. Obtain expressions for the electric field inside the dielectric, and for polarization throughout the volume of the sphere. (30 marks)

(b) Obtain the Maxwell-Boltzmann distribution of molecular velocities that gives the probability of finding a molecule with velocity $\bar{v}$ in the gas under equilibrium conditions. (30 marks)

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26th AUGUST, 2008

PHYSICS - Paper-II

INSTRUCTIONS : **Answers must be written in English only. Candidates should attempt at least 2 questions from each section and total 5 questions. The number of marks carried by each question is indicated against the same.**

Time: 3 hours

Marks: 300

SECTION - A

1. (a) The wavefunction of a particle of mass m at time t=0, is given as

$$\psi(x,0) = \sqrt{\frac{\alpha}{\pi}} \exp(-\alpha x^2/2 + ikx)$$

The particle is confined to move along x-axis. (i) Find the probability density for the momentum of the particle.
(ii) Calculate the expectation values for the momentum and energy of the particle.

(30+10 Marks)

(b) Using time-dependent Schrödinger equation in one dimension, show that the probability density $\rho(x,t) = |\psi(x,t)|^2$ obeys the equation,

$$\frac{\partial \rho(x,t)}{\partial t} + \frac{\partial J(x,t)}{\partial x} = 0$$

Find $J(x,t)$, and give the physical significance of this equation. (20 Marks)

2. (a) Find the eigenvalues and eigenfunctions of a particle confined to a cubic box of side L. The potential inside the box is unifrmly zero. Explain the notion of the density of states, and obtain it for this problem as the size $L \to \infty$. Also consider the similar problem in two dimensions, and obtain the density of states for a particle confined to a square of size L in the limit $L \to \infty$.

(30 Marks)

(b) For an electron in a uniform magnetic field $\vec{B}$, the spin Hamiltonian can be written as,

$$H = -g\vec{\sigma} \cdot \vec{B}$$

where $\vec{\sigma}'s$ are the Pauli matrices. Write down the Hamiltonian as a matrix, using the explicit forms of the Pauli matrices. Work out the eigenvalues of the Hamiltonian and show that they are independent of the direction of $\vec{B}$. Explain physically why should this be so.

(30 Marks)

3. (a) Write down the Schrödinger equation for a particle of mass m in a spherically symmetric potential V(r). Separate it in spherical polar coordinates.

(20 Marks)

(b) What is the physical quantity associated with the angular part of the equation. What are the eigenvalues and eigenfunctions of the angular operator? (The derivation is not required)

(20 Marks)

(c) Suppose a uniform magnetic field is applied to the system, what happens to these eigenvalues?

(10 Marks)

(d) Obtain the value of the commutator, $[L_z, L^2]$, where $\vec{L}$ denotes the angular momentum.

(10 Marks)

4. (a) An electron in Hydrogen atom is excited to the level n=3 and l=2. Which are the lower levels to which it can go to, according to the dipole selection rule?

(10 Marks)

(b) Write down the electronic configuration of Co^{27}. From this obtain its total angular momentum using Hund rules. Express its state in spectroscopic notation.

(25 Marks)

(c) The doublet line seen in sodium lamp arises from hyperfine interaction, $-A\vec{I}\cdot\vec{J}$. Here $\vec{I}$ and $\vec{J}$ denot respectively the nuclear spin and the electronic angular momentum. Assuming that, I = 3/2, work out the splitting of the 3s level in Sodium.

(25 Marks)

5. (a) Describe the quantum theory of binding of two Hydrogen atoms using Heitler-London picture. Explain clearly how the wavefunction of two electrons depend on the their spin state, and thereby show that the binding occurs when the electrons are in a siglet state.

(30 Marks)

(b) A diatomic molecule is composed of two atoms of masses m_1 and m_2. The mean distance between the atoms is r_0, and the spring constant of the binding force between them is k_0. First obtain the eigenenergies of the rotational states of the molecule assuming that the distance between the atoms is fixed. Next describe what modifications to the energy spectrum arise due to nonrigidity of the molecule, under the assumption that the vibrational excitation energy is much larger than the rotational energy. (You are not required to derive the eigenvalues of the differential equations occurring in the problem.)

(30 Marks)

SECTION - B

6. (a) The binding of two nucleons in a Deutron has the following features. (i)Deutron is weakly bound in l=0 stae and has no excited states. (ii)It has spin 1, and has a small quadrupole moment.
Using these facts, deduce that the nuclear force is spin dependent and noncentral. On this basis how do we understand the absence of a bound state for two neutrons or two protons.

(25 Marks)

(b) Using the empirical plot of binding energy per nucleon with mass number

of the nucleus, explain why heavy nuclei are prone to fission with the release of energy. (15 Marks)

(c) Explain the concept of fission barrier and describe the fission process in terms of the liquid drop model. Bring out the role of surface energy and Coulomb energy in this process clearly. (20 Marks)

7. (a) Explain the concept of magic numbers of nuclear stability and give their values. (10 Marks)

(b) Illustrate how does the Shell model explain the existence of magic numbers using isotropic harmonic oscillator potential. (30 Marks)

(c) Describe Yukawa's theory of nuclear force. Explain physically how the mass of the exchanged meson is related to the range of the force. Given that the mass of the π-meson is 140 Mev.work out the range of the force. (20 Marks)

8. (a) Explain why the existence of Neutrino had to be postulated to understand a basic feature of beta decay. (15 Marks)

(b) Describe the experiment that established the existence of more than one kind of Neutrino. (15 Marks)

(c) The results of deep inelastic electron-proton scattering experiments were crucial to establish the existence of Quarks. Describe briefly the results and the analysis that led to such a conclusion (15 Marks)

(d) Isolated quarks are never seen. Explain with some examples, how does the idea of the colour force explain this property. (15 Marks)

9. (a) Write down and plot in a schematic form the manner in which the specific heat of insulators and metals vary with temperature at low temperatures. Explain the physical origin of all the terms and bring out the basic difference between metals and insulators in this regard. (20 Marks)

(b) Write down and plot in a schematic form the manner in which the specific resistance of insulators and metals vary with temperature at low temperatures. Explain the physical origin of all the terms and bring out the basic difference between metals and insulators in this regard. (20 Marks)

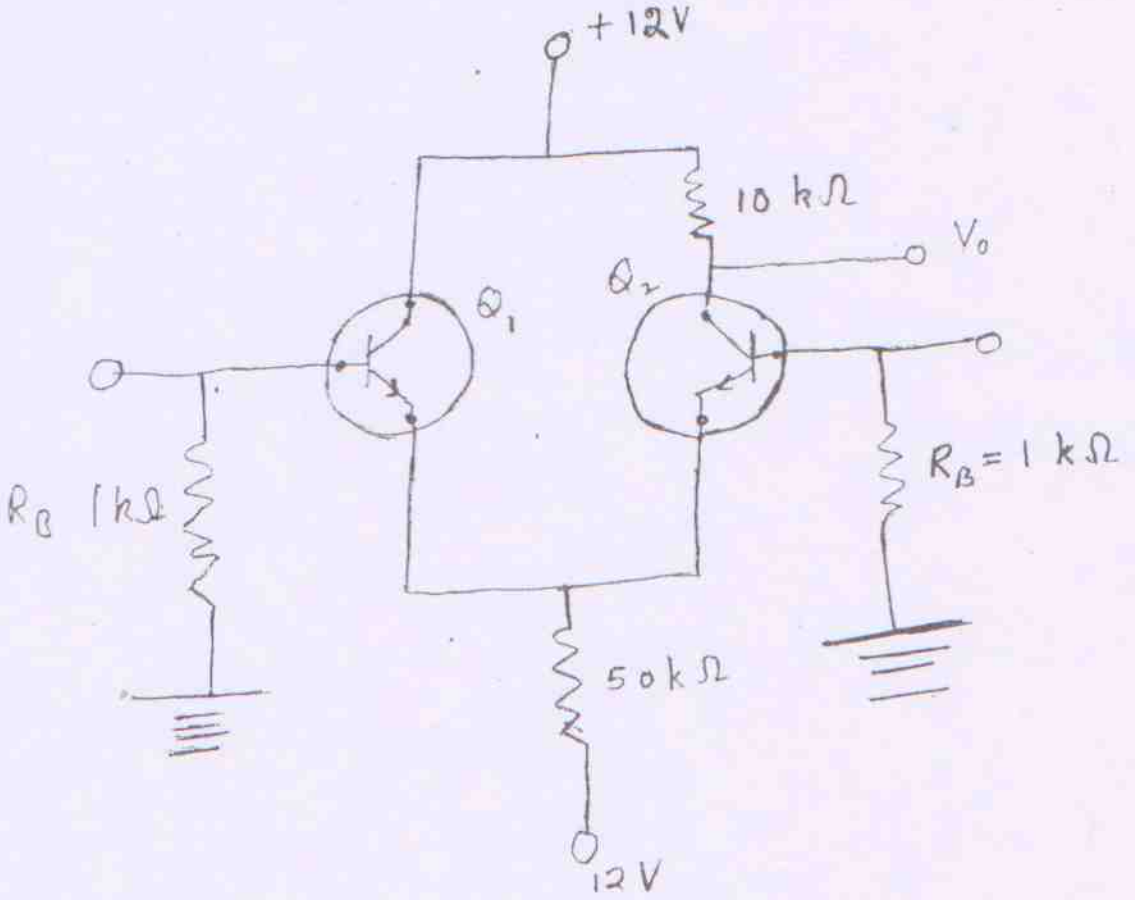
(40)

(c) Explain Meissner effect. Draw the phase diagram of Type-I superconductor in Magnetic field-Temperature plane. What is the value of magnetic suceptibility in the superconducting phase? (10 Marks)

(d) What is the Isotope effect? What clue did it give towards the mechanism of superconductivity? (10 Marks)

10. (a) Write down any three equivalent Boolean expressions for an Exclusive-OR circuit, and implement them using logic block diagrams. (20 Marks)

(b) A circuit is shown below.



Assuming that Q_1 and Q_2 have identical $\beta_{dc} = 100$, find the emitter currents I_B and input bias currents I_E in each of the transistors. Using the Ebers-Moll equation $I_c(V_{BE})$, find the differential gain and common mode gain of the above amplifier.

(30 marks)

(c) Find the AC gain for the following source-follower circuit. The transconductance of the JFET is 2000 μS.

(10 marks)