IFoS 2010

005034

B-JGT-K-QIB

PHYSICS

Paper II

Time Allowed : Three Hours | *Maximum Marks : 200*

INSTRUCTIONS

Candidates should attempt questions 1 and 5 which are compulsory, and any THREE of the remaining questions, selecting at least ONE question from each Section.

All questions carry equal marks. Marks allotted to parts of a question are indicated against each.

Answers must be written in ENGLISH only.

Assume suitable data, if considered necessary, and indicate the same clearly.

Neat sketches may be drawn, wherever required.

List of Useful Constants :

Mass of proton	=	$1{\cdot}673 \times 10^{-27}$ kg
Mass of neutron	=	$1{\cdot}675 \times 10^{-27}$ kg
Mass of electron	=	$9{\cdot}11 \times 10^{-31}$ kg
Planck constant	=	$6{\cdot}626 \times 10^{-34}$ Js
Boltzmann constant	=	$1{\cdot}380 \times 10^{-23}$ JK^{-1}
Bohr magneton	=	$9{\cdot}273 \times 10^{-24}$ A/m^2
Nuclear magneton (μ_N)	=	$5{\cdot}051 \times 10^{-27}$ $JT^{-1}(Nm^2)$
Electronic charge	=	$1{\cdot}602 \times 10^{-19}$ C

Atomic mass unit (u) $= 1{\cdot}660 \times 10^{-27}$ kg

$= 931$ MeV

$g_s^p = 5{\cdot}5855\ \mu_N$

$m(p) = 1{\cdot}00727$ (u)

$m(n) = 1{\cdot}00866$ (u)

$m({}^4_2He) = 4{\cdot}002603$ u

$m({}^{12}_6C) = 12{\cdot}00000$ u

$m({}^{87}_{38}Sr) = 86{\cdot}908893$ u

SECTION A

1. Answer any ***four*** of the following :

(a) State and explain the Heisenberg's uncertainty principle. Show that the natural line width of a spectral line follows from this principle. The lifetime of an excited state of an atom is 10^{-8} s. Calculate the energy width of such a state. *10*

(b) The electron spin operator $\hat{s}$ can be expressed in matrix form in terms of the Pauli spin operator, $\hat{\sigma}$ as $\hat{\sigma} = 2\hat{s}$ where

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix},\ \sigma_y = \begin{pmatrix} 0 & -i \\ +i & 0 \end{pmatrix},\ \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Show that

$$\sigma_x^2 = \sigma_y^2 = \sigma_z^2 = 1 \text{ and}$$

$$\sigma_x\sigma_y = -\sigma_y\sigma_x = i\ \sigma_z$$

$$\sigma_y\sigma_z = -\sigma_z\sigma_y = i\ \sigma_x$$

$$\sigma_z\sigma_x = -\sigma_x\sigma_z = i\ \sigma_y$$

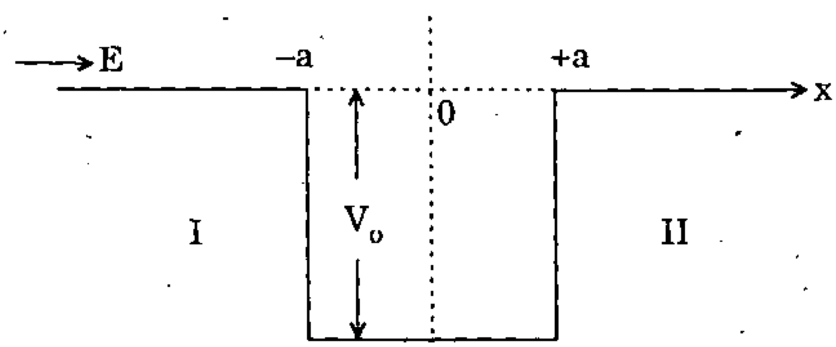
10

(c) Estimate the number of states lying in an energy interval of 0·03 eV above the Fermi level in a potassium crystal of unit volume.
(E_F = 2·12 eV for potassium) *10*

(d) If the magnetic moment of proton is 2·793 μ_N calculate, giving necessary steps, the radio frequency at which nuclear magnetic resonance occurs in water kept in a uniform magnetic field of 2·4 T. *10*

(e) What is Raman effect ? Discuss its application to molecular structure. *10*

2. (a) A stream of particles of mass M and energy E is directed from left to a one-dimensional potential well, as shown below :



The potential is $-V_0$ in the region $a \geq x \geq -a$ and zero elsewhere. Set up a time-independent Schrödinger equation and obtain an expression for the transmission ratio from region I to II. Discuss the result. Show that there is a finite reflection from such a potential well, which is a result of the wave nature of matter. *20*

(b) Set up a time-independent Schrödinger equation for a linear harmonic oscillator and obtain the energy eigen values. Explain the significance of zero point energy. 20

3. (a) Set up the time-independent Schrödinger equation for an electron moving in a Coulomb field, $V(r) = \frac{-ze^2}{4\pi\varepsilon_0 r}$, in polar coordinates. Solve the radial equation to get the energy eigen values. 20

(b) Describe Stern – Gerlach experiment. In performing this experiment, beams of neutral atoms are used. Why are electrons or ion beams not used ? Explain how it demonstrates the discrete nature of the magnetic moment of an atom. 20

4. (a) Consider a diatomic molecule as a rigid rotator. Obtain its rotational energy levels and hence the rotational spectra. 20

(b) Derive the combined vibration – rotation spectrum of a diatomic molecule. What are P and R branches ? 20

SECTION B

5. Answer any ***four*** of the following :

(a) Calculate the binding energy per nucleus for $^{87}_{38}Sr$. *10*

(b) A star converts all its hydrogen into helium, achieving 100% helium. It then converts the helium into carbon via the reaction

$$^{4}_{2}He + ^{4}_{2}He + ^{4}_{2}He \longrightarrow ^{12}_{6}C + 7{\cdot}27 \text{ MeV}$$

The mass of the star is $5{\cdot}0 \times 10^{32}$ kg and it generates energy at the rate of 5×10^{30} W. How long will it take to convert all helium to carbon at this rate ? *10*

(c) Write the quark composition of the following : *10*

(i) Neutron

(ii) Proton

(iii) Λ

(iv) K^-

(v) π^+

(d) In one experiment, a perfect conductor and a superconductor are cooled to below 1 K and then a magnetic field is applied. In another experiment, they are cooled to below 1 K in magnetic field. Describe their responses in these two experiments and explain. *10*

(e) Employing NAND gates, design a half adder circuit which can add two bits A and B and provide a sum S and a carry C as its output. *10*

6. (a) What are magic numbers ? Discuss the shell structure of a nucleus. How is this model able to explain various properties of nuclei ? Discuss the limitations of this model. *28*

(b) Predict from the single particle shell model, the shell configuration, ground state spin and parity for the following nuclei :

$$^{7}_{3}\text{Li}, \quad ^{13}_{7}\text{N}, \quad ^{17}_{8}\text{O}, \quad ^{27}_{13}\text{Al}$$ *12*

7. (a) Discuss the motion of an electron in an allowed energy band under the influence of an external electric field. Obtain an expression for the effective mass of the electron and discuss its variation in the band. *15*

(b) Show the variation of magnetization with applied magnetic field for type I and type II superconductors. Describe their behaviour. Discuss their potential for various applications. *10*

(c) What is a Josephson junction ? Explain the phenomenon of tunneling of charge carriers across such a junction. Discuss DC and AC Josephson effects. Mention some applications of this device. *15*

8. (a) Using the collector characteristics of a bipolar junction transistor, show how you can use it as a switch with one ON and one OFF state. Plot and describe the operation of this circuit for a sinusoidal input. *10*

(b) Describe the essential parts of an oscillator circuit using a block diagram. Design a Colpitts oscillator set to a frequency of 1500 Hz and explain how your design incorporates the essential parts of the oscillator circuit. *15*

(c) What are the advantages of MOSFET over JFET ? Draw and explain the structure and working of a MOSFET which can function both in enhancement and depletion modes. *15*