CIVIL SERVICES EXAMINATION (MAINS) 2022
PHYSICS PAPER - II:QUANTUM MECHANICS
TUTORIAL SHEET: 1
Foundations of Quantum Mechanics

1. Derive Bohr's angular momentum quantization condition in Bohr's atomic model from the concept of de Broglie waves. **(2010)**

2. Calculate the wavelength of De Broglie waves associated with electrons accelerated through a P.D. of 200 Volts. **(2011)**

3. Estimate the size of the hydrogen atom and the ground state energy from the uncertainly principle. **(2011)**

4. Use the uncertainly principle to estimate the ground state energy of a linear harmonic oscillator **(2012)**

5. In a series of experiments on the determination of the mass of a certain elementary particle, the results showed a variation of _+ (plus-minus) 20 m(e), where m(e) is the electron mass. Estimate the lifetime of the particle. **(2013)**

6. Find the deBroglie wave length of (i) a neutron (ii) and electron moving with kinetic energy of 500 eV .(1 eV = 1.602 x 10 ^-19 J) **(2014)**

7. The mean life of Lambda particle is 2.6 x 10^-10 s. What will be the uncertainty in the Determination of its mass in eV? **(2014)**

8. Find the energy, momentum and wavelength of photon emitted by a hydrogen atom making a direct transition from an excited state with n=10 to the ground state. Also find the recoil speed of the hydrogen atom in this process. **(2016)**

9. An electron is confined to move between two rigid walls separated by 10^{-9} m. Compute the de Broglie wavelengths representing the first three allowed energy states of the electron and the corresponding energies. **(2016)**

10. A typical atomic radius is about 5 x 10^{-15} m and the energy of β-particle emitted from a nucleus is at most of the order of 1 MeV. Prove on the basis of uncertainty principle that the electrons are not present in nuclei. **(2016)**

11. Using uncertainty principle, calculate the size and energy of the ground state hydrogen atom. **(2016)**

12. A beam 4.0 keV electrons from a source is incident on a target 50.0 cm away. Find the radius of the electron beam spot due to Heisenberg's uncertainty principle. **(2017)**

13. Estimate the de Broglie wavelength of the electron orbiting in the first excited state of the hydrogen atom. **(2017)**

14. Show that the mass and linear momentum of a quantum mechanical particle can be given by $m = h/(\lambda v)$ and $p = h/\lambda$, respectively, where h, λ and v are Planck's constant, wavelength and velocity of the particle, respectively. Comment on the wave-particle duality from these relations. **(2019)**

15. State and express mathematically the three uncertainty principles of Heisenberg. Highlight the physical significance of these principles in the development of Quantum Mechanics. **(2019)**

16. For a free quantum mechanical particle under the influence of a one-dimensional potential, show that the energy is quantized in discrete fashion. How do these energy values differ from those of a linear harmonic oscillator? **(2019)**

17. Using the uncertainty principle $\Delta x \Delta p \geq \frac{\hbar}{2}$, estimate the ground state energy of a harmonic oscillator. **(2020)**

TUTORIAL SHEET: 2
Schrodinger's Wave equation and applications

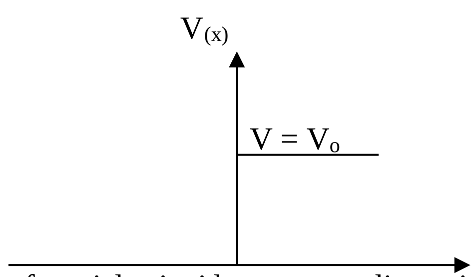
1.Obtain an expression for the probability current for the plane wave $\psi(x,t) = \exp[i(kx - \omega t)]$. Interpret your result. **(2010)**

2. A system is described by the Hamiltonian operator, $H = -\frac{d^2}{dx^2} + x^2$ Show that the function A x $\exp\left(-\frac{x^2}{2}\right)$ is an eigen function of H. Determine the eigen values of H. **(2011)**

3. Solve the Schrodinger equation for a particle of mass m in an infinite rectangular well defined by
$V_{(x)} = 0 \quad 0 \le x \le L = \infty \quad x < 0, x > L$ Obtain the normalized eigen functions and the corresponding eigen values. **(2011)**

4. Normalize the wave function $\psi(x) = e^{-|x|} \sin \alpha x$ **(2011)**

5. (a)



Consider a beam of particles incident on one-dimensional step function potential with energy $E > V_o$as shown in the above figure. Solve the Schrodinger equation and obrain expressions for the reflection and transmission coefficients.
(b) What are the limits of the reflection coefficient for $E \rightarrow V_o$ and $E \rightarrow \infty$?
(c)Discuss the cases $0 < E < V_o$and $E < 0$. **(2013)**

6. Obtain the time independent Schrödinger equation for a particle. Hence deduce the time independent Schrödinger equation. **(2014)**

7. Solve the Schrödinger equation for a particle of mass m confined in one dimensional potential well of the form:V=0 , when 0≤x≤L=infinity , when x<0 , x>L. Obtain the discreet energy values and the normalized eigen functions. **(2014)**

8. An electron is moving in a one dimensional box of infinite height and width 1 A (Angstrom). Find the minimum energy of electron. **(2014)**

9. Normalized wave function of a particle is given: $\psi(x) = A \exp(-x^2/a^2 + ikx)$.Find the expectation value of position. **(2015)**

10. Solve the Schrodinger equation for a step potential and calculate the transmission and reflection coefficient for the case when the kinetic energy of the particle E_0 is greater than the potential energy V (i.e., $E_0 > V$).
(2016)

11. Calculate the lowest energy of an electron confined to move in a 1-dimensional potential well of width 10nm.

12. Using *Schrödinger equation*, obtain the eigenfunctions and eigenvalues of energy for a 1-dimensional harmonic oscillator. Sketch the profiles of eigenfunctions for first three energy states. **(2017)**

13. Calculate the probability of transmission of an electron of 1.0 eV energy through a potential barrier of 4.0 eV and 0.1 nm width. **(2017)**

14.The wave function of a particle is given as $\psi(x) = \frac{1}{\sqrt{a}} e^{-|x|/a}$. Find the probability of locating the particle in the range $-a \le x \le a$. **(2018)**

15. Calculate the zero-point energy of a system consisting of a mass of $10^{-3} kg$ connected to a fixed point by a spring which is stretched by $10^{-2} m$ by a force of $10^{-1} N$. The system is constrained to move only in one direction. **(2018)**

16. The general wave function of harmonic oscillator (one-dimensional) are of the form

$$u_n(x) = \sum_{k=0}^{\infty} a_k y^k e^{-y^2/2}$$

With $y = \sqrt{\frac{m\omega}{\hbar}} x$, and coefficients a_k are determined by recurrence relations

$$a_{k+2} = \frac{2(k-n)}{(k+1)(k+2)} a_k$$

Corresponding energy levels are $E_n = \left(n + \frac{1}{2}\right) \hbar\omega$. Discuss the parity of these wave functions. What happens, if the potential for $x \le 0$ is infinite (half harmonic oscillator)?
(2018)

17. Which of the following functions is/are acceptable solution(s) of the *Schrödinger equation*?

(i) $\psi(x) = A\,e^{-ikx} + B\,e^{ikx}$
(ii) $\psi(x) = Ae^{-kx} + B\,e^{kx}$
(iii) $\psi(x) = A\,sin3kx + B\,cos5kx$
(iv) $\psi(x) = A\,sin3kx + Bsin\,5kx$
(v) $\psi(x) = A\tan kx$

Explain your answer. **(2018)**

18. A beam of particles of energy 9 eV is incident on a potential step 8 eV high from the left. What percentage of particles will reflect back? **(2018)**

19. Write down the Hamiltonian operator for a linear harmonic oscillator. Show that the energy eigenvalue of the same can be given by $E_n = \left(n + \frac{1}{2}\right)\hbar\omega_0$ at energy state n with ω_0 being the natural frequency of vibration of the linear oscillator. Prove that $n = 0$ energy state has a wave function of typical Gaussian form. **(2019)**

20. Estimate the size of hydrogen atom and the ground state energy from the uncertainty principle. **(2019)**

21. Prove that Bohr hydrogen atom approaches classical conditions, when n becomes very large and small quantum jumps are involved.

(2020)

22. Find the probability current density for the wave function

$\Psi(\chi, t) = [\,Ae^{ipx/h} + Be^{-ipx/h}\,]\quad \bar{e}^{ip^2t/2m\hbar}$

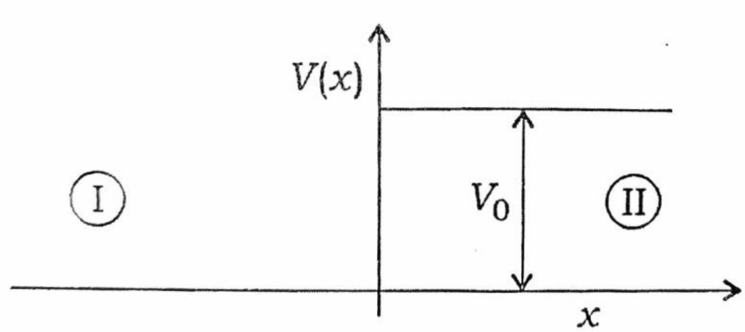
Interpret the result physically. **(2020)**

23. A particle is described by the wave function $\Psi(x) = \left(\frac{\pi}{2}\right)^{-1/4}\ \bar{e}^{ax^2/2}$. Calculate Δx and Δp for the particle , and verify the uncertainty relation $\Delta x\,\Delta p = \frac{\hbar}{2}$. **(2020)**

24. Write the wave functions for a particle on both sides of a step potential, for $E > V_0$:

(2020)

$V(x) = \begin{cases} V_0, & x > 0 \\ 0 & x < 0 \end{cases}$



TUTORIAL SHEET: 3

Quantum Mechanics-II

1. Show that the Pauli spin matrices satisfy the following:

$$\sigma_x^2 = \sigma_y^2 = \sigma_z^2 = 1$$

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

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

$$\sigma_z \sigma_x = -\sigma_x \sigma_z = i\sigma_y$$ **(2010)**

2. The normalized wave function for the electron in hydrogen atom for the ground state is $\psi(r) = \left(\pi a_0^3\right)^{-1/2} \exp\left(-\frac{r}{a_0}\right)$ Where a_0 is the radius of the first Bohr orbit. Show that the most probable position of the electron is a_0 **(2010)**

3. Let $\vec{\sigma}$ be the vector operator with component equal to pauli spin matrices $\sigma_x, \sigma_y, \sigma_z$ if $\vec{a}, \vec{b}$ are vectors in 3D space, prove the identity $(\vec{\sigma}.\vec{a})(\vec{\sigma}.\vec{b}) = \vec{a}.\vec{b} + i\vec{\sigma}.(\vec{a} \times \vec{b})$. **(2011)**

4. For hydrogen atom, ground state is $\psi_{(x)} = \frac{1}{\left([\pi a_0^2)\right]^{\frac{1}{2}}} e^{-\frac{r}{a_0}}$ Calculate $\langle r \rangle$ and $\langle \frac{1}{r} \rangle$. **(2011)**

5. Show (i) Sin $(\sigma_x \phi)$ = σ_x sin ϕ **(2011)**

(ii) Cos ($(\sigma_1 z\phi)$ = cos ϕ **(2012)**

6. What is the degree of degeneracy of the energy – eigen Values. What happened if the spin of the electron is taken into account? **(2012)**

7. Solve the radial part of the time independent Schrodinger Equation for a hydrogen atom. Obtain its expression for energy Eigen values. **(2012)**

8. Using the definition $\vec{L} = r \times p$ of the orbital angular momentum operator , evaluate [L(x) , L(y)] **(2013)**

9. The normalized wave function for the electron for the electron in the ground state of the hydrogen
atom is given by
$\psi(r) = \frac{1}{\sqrt{\pi a_0^3}} e^{-r/a_0}$. Find $\langle r \rangle$ *and* $\langle r^2 \rangle$. **(2013)**

10. If x and p are the position and momentum operators, prove the commutation relation [p^2 , x] = -2ihp
(2014)

11. Write down Pauli spin matrices. Express J(x) , J(y) and J(z) in terms of Pauli spin matrices.
(2014)

12. Using the commutation relations
[x, p(x)] = [y, p(y)] = [z,p(z)]=ih
Deduce the commutation relation between the components of angular momentum operator L.
[L(x), L(y)]=ihL(z)
[L(y), L(z)]= ihL(x) and
[L(z),L(x)]=ihL(y)
(2014)

13. Solve the Schrodinger equation for a particle in a three dimensional rectangular potential barrier. Explain the terms degenerate and non-degenerate states in this context.
(2015)

14. A particle trapped in an infinitely deep square well of width a has a wave function

$\psi = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \sin\left(\frac{\pi x}{a}\right)$. The walls are suddenly separated by infinite distance. Find the probability of the particle having momentum between p and $p + dp$ **(2015)**

15. Write down the matrix representation of the three Pauli matrices σ_x, σ_y and σ_z. Prove that these matrices satisfy the following identities:

- **i.** $[\sigma_x, \sigma_y] = 2\, i\, \sigma_z$
- **ii.** $[\sigma^2 . \sigma_x] = 0$
- **iii.** $(\sigma . A)(\sigma . B) = A . B + i\, \sigma . (A \times B)$
  If A and B commute with Pauli matrices. **(2016)**

16. Calculate the density of states for an electron moving freely inside a metal with the help of quantum mechanical Schrodinger's equation for free particle in a box. **(2016)**

17. Evaluate the most probable distance of the electron from nucleus of a hydrogen atom in its $2p$ state. What is the probability of finding the electron at this distance? **(2017)**

18. Explain why the square of the angular momentum (L^2) and only one of the components (L_x, L_y, L_z) of L are regarded as constants of motion. **(2017)**

19. The ground state wave function for hydrogen atom is

$$\psi(r) = \frac{1}{\sqrt{\pi a_0^3}} e^{-r/a_0}$$

Where a_0 is the Bohr radius. Sketch the wave function and the probability density as a function of the separation distance r. Calculate the probability that the electron in the ground state is found beyond the Bohr radius. **(2018)**

20. Prove the following identities:

(i) $[\hat{p}_x, \hat{L}_y] = i\hbar\hat{p}_z$

(ii) $e^{i(\hat{\sigma}.\hat{n})\theta} = cos\theta + i(\hat{\sigma}.\hat{n})sin\theta$ **(2018)**

21. Show that for free electron gas, the density of states in three dimensions (3D) varies as $E^{1/2}$, and this dependence changes to E^0 for 2D (quantum well), $E^{-1/2}$ for 1D (quantum wire) and δ function for 0D (quantum dot). **(2018)**

22. How do you define density of states? Show that the density of states with wave vector less than $\vec{k}$ in a three-dimensional cubic box of volume V can be given by

$$D(\omega) = \frac{V}{2\pi^2} k^2 \left(\frac{dk}{d\omega}\right)$$

in the frequency spectrum between ω and $\omega + d\omega$. Here, assume that the number of modes per unit range of k is $L/(2\pi)$, L being the length of each side of the cubic box. **(2019)**

23. Define Pauli spin matrices σ_x , σ_y and σ_z. Using these definitions, prove the following:

(i) $\sigma_x^2 = \sigma_4^2 = \sigma_z^2 = 1$

(ii) $\sigma_x\sigma_y = i\sigma_z;\ \sigma_z\sigma_x = i\sigma_y;\ \sigma_y\sigma_z = i\sigma_x$ **(2019)**

24. Define angular momentum of a particle and find out the three components of the angular momentum operator $\hat{L}$ in Cartesian coordinates. Show that

$$\hat{L}^2 = -\hbar^2\left[r^2\nabla^2 - \frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)\right]$$

Prove that the operator $\hat{L}^2$ can also be expressed as

a. $\hat{L}^2 = -\hbar^2\left[\frac{1}{Sin\theta}\frac{\partial}{\partial\theta}\left(sin\theta\,\frac{\partial}{\partial\theta}\right) + \frac{1}{Sin^2\theta}\frac{\partial^2}{\partial\emptyset^2}\right]$ **(2019)**

b. in spherical polar coordinates $(r, \theta, \emptyset)$.

25. If the z-component of an electron spin is $+\frac{\hbar}{2}$, what is the probability that its component along a direction z' (forming an angle θ with z-axis) is $\frac{\hbar}{2}$ or $\frac{\hbar}{2}$? What is the average value of spin along z'? **(2020)**

26. Also Show that $(\vec{L} \times \vec{L}) = i\hbar\vec{L}$. **(2020)**

ATOMIC PHYSICS
TUTORIAL SHEET: 4

1. What is Zeeman Effect? How it can be understood on quantum mechanical basis? Obtain an expression for Zeeman splitting of atomic energy levels in a magnetic field B. Explain the magnetic splitting of sodium D-lines.

(2010)

2. What is spin-orbit interaction? Calculate the energy shift due to spin-orbit interaction term in H-like system. Discuss the significance of this shift in relation to the fine structure of hydrogen spectral lines

(2010)

3. Discuss the fine structure of hydrogen atom spectrum. Draw the compound doublet spectrum arising as a result between 2 p and 2d levels. **(2011)**

4. What do you mean by term symbols? Obtain term symbols for the following sets of values of S andL:

(i) S= $\frac{1}{2}, L = 2$ $(ii) S = 1, L = 1$ $(iii) S = \frac{3}{2}, L = 1$

(2011)

5. Show that $^2S_{\frac{1}{2}}, {}^2P_{\frac{1}{2}}, {}^2P_{\frac{3}{2}}$ levels of sodium spectrum are split in the ratio of 3 : 1 : 2 due to anomalous Zeeman Effect. **(2011)**

6. Sodium doublets are produced by transitions $3^2P_{\frac{1}{2}} \rightarrow 3^2S_{\frac{1}{2}}\ (D_1)$ and $3^2P_{\frac{3}{2}} \rightarrow 3^2S_{\frac{1}{2}}\ (D_2.)$ Calculate the Lande's g- factors for these levels.

(2012)

7. Discuss the fine structure of sodium D line. Draw D_1 and D_2 lines due to the transitions between ^2P and ^2S levels. **(2013)**

8. A sample of certain element is placed in a magnetic field of flux density 0.3 tesla. How far apart is the Zeemen component of a spectral line of wavelength 4500 A?
Given: $e/m = 1.76 \times 10^{11}$ c/kg, $c = 3.0 \times 10^8 ms^{-1}$. **(2014)**

9. Obtain an expression for the normal Zeeman shift. Illustrate the Zeeman splitting of spectral lines of H atom and the allowed transitions for the l = 1 and l = 2 states. **(2014)**

10. What is Zeeman Effect? How can it be understood on the basis of quantum mechanics?

(2015)

11.Obtain Zeeman splitting for sodium D-lines. **(2015)**

12. Find the magnetic moment of an atom in $3P_2$ state, assuming that LS coupling holds for this case. **(2015)**

13. In the Stern-Gerlach experiment using Ag atoms, the oven temperature is 1000 K, l ≈ 25 cm and $\frac{\partial B_z}{\partial z} \simeq 10^{+3}$ Tesla/m. Calculate the separation of the two components. **(2016)**

14. Describe Stern-Gerlach experiment. Discuss how it has explained space quantization and electron spin. Find the value of angle between the spin angular momentum S and its z-component of an electron moving along the external magnetic field B. **(2016)**

15. The series limit wavelength of Balmer series in hydrogen spectrum is experimentally found to be 3646 A. Find the wavelength of the first line of this series. **(2016)**

16. Compute the allowed spectral terms for two non-equivalent p-electrons of the basis of Pauli's exclusion principle. **(2016)**

17. Explain in detail L-S coupling and j-j coupling schemes. **(2016)**

18. What is Lamb shift? What is its significance in determining the fine structure of H_α Balmer line in hydrogen atom?
(2016)

19. Calculate the radius of electron orbit for Li^{++} in ground state. **(2018)**

20. Describe the importance of L-S and J-J coupling in atomic spectroscopy. What are experimental evidences of their existence? **(2018)**

21. What is Zeeman effect? Discuss the factors on which Larmor frequency is dependent.
(2018)

22.Discuss the fine structure of hydrogen spectrum. How is it of importance in the astronomical observations? **(2018)**

23.Define mathematically the Bohr radius of a hydrogen atom and who that the binding energy at state n of this atom can be given by

$$E_n = -\frac{1}{2}\frac{Ze^2}{(a/Z)}\frac{1}{4n^2\pi\varepsilon_0}$$

where Z is the atomic number of H atom. Calculate the numerical values of a and E_1 of H atom. **(2019)**

24. Describe normal and anomalous Zeeman effect. Explain how it lifts the degeneracy in hydrogen atom.

(2019)

25. What is lamb shift? Discuss its significance in determining the fine structure of H_α Balmer line in hydrogen atom. **(2019)**

26. Determine the normal Zeeman splitting of the cadmium red line of 6438 Å, when the atoms are places in a magnetic field of 0.009 T. **(2020)**

27. Explain how the magnetic moments of atoms, the space quantization of angular momentum and the spin of electron are measured using Stern – Gerlach experiment. **(2020)**

PHYSICS PAPER- II: MOLECULAR PHYSICS
TUTORIAL SHEET: 5

1. Calculate, giving necessary steps, the radio frequency at which nuclear magnetic resonance occurs in water kept in a uniform magnetic field of $2\cdot 4T$. The magnetic moment of proton is $2\cdot 793\mu N$ **(2010)**

2. (i) Discuss occurrence of rotational energy levels of a diatomic molecule and show that the pure rotation spectrum of such a molecule consists of a series of equally spaced lines separated by a constant wave number difference 2B. Write down the selection rules.
(ii) Is it possible to obtain pure rotational spectra of H_2, HF, O_2 and NO molecules?
(iii)In CO molecule J = O →J = 1 line occurs at a frequency $1\cdot 153\times 10^{11}$ Hz. Calculate the moment of inertia of CO molecule.
(2010)

3. What is Raman Effect? How does it differ from Rayleigh scattering? Explain Raman Effect on the basis of quantum mechanical theory. How is Raman Effect experimentally studied? What are the advantages of using laser sources in the study of Raman Effect?
(2010)

4. State and explain Franck-Condon principle. Discuss its applications in molecular spectroscopy.
(2010)

5. On the basis of inertia I_A, I_B and I_C each about X, Y and Z axes respectively, how can you classify molecules?
(2011)

6. (a) (i)Treating a diatomic molecule as a simple oscillator, obtain its energy (vibrational) levels.
(ii)The observed vibrational frequency of the Co molecule is 6.42 $\times$ 10^{13} Hz. What is the effective force constant of the molecule? (C= $12u, O = 16u$)
(b) (i) Discuss pure rotational spectra of linear molecules
(ii) What is Lamb shift?
(2011)

7. Why should rotational Raman spectrum show a separation of the first Raman line from the exciting line as 6B cm^{-1}, While the separation between successive lines is equal to 4B c m^{-1}, when B is the rotational constant?
(2012)

8. What will happen to the energy level of an unpaired electron when subjected to an external magnetic field? Find the condition for electron spin resonance. **(2013)**

9. (a) With proper selection rules, construct the energy level diagram and allowed transitions for ESR spectrum of hydrogen atom. (b) Why are Raman active vibrations and infrared vibrations in CO_2molecule complementary to each other? (c) In a Raman spectrum of linear triatomic molecule, the first three lines are 4.86, 8.14 and 11.36cm^{-1}. Calculate the rotational constant, B and the moment of inertia of the molecule. (Given h = 6.626 x 10^{-27}J.s, C = 3.0 x 10^{10}cm/sec.) **(2013)**

10. Discuss the vibrational spectra of a diatomic molecule treating it as an anharmonic oscillator. **(2014)**

11. Explain how the nuclear spin I depends on the mass number A and atomic number Z of atoms. **(2014)**

12. (i) Obtain an expression for the resonance condition in NMR.
(ii)Explain the relaxation processes in NMR spectroscopy.
(2014)

13. Establish that: $hc = 1240\ MeV.\ fm$
(2015)

14. Hydrogen molecule is diatomic. Obtain the rotational energy levels of this molecule. Write down the selection rules. Obtain the smallest energy required to excite the lowest rotational mode. **(2015)**

15. The observed vibrational frequency of CO molecule is $6.42\times10^{13}\ Hz$. What is the effective force constant of the molecule?
(2015)

16. Show that the lines in the absorption spectra corresponding to the rotational transitions from two adjacent energy levels of a medium sized molecule at room temperature have comparable intensities.
(2017)

17. Given the force constant of HC1 molecule = 516 Nm^{-1}, determine the wave number of the fundamental mode of vibration of the molecule. How many transition lines one can expect in the vibration spectra of HC1 molecule at room temperature? **(2017)**

18. Explain Stokes and anti-Stokes Raman scattering with the help of energy level diagram. For a diatomic molecule, obtain expressions for transition energies of its Raman spectra with rotational fine structure and hence the wave numbers of the Stokes lines. **(2017)**

19. Explain why lines in some Raman spectra are found to be plane polarized to different extents even though the exciting radiation is completely unpolarized? **(2017)**

20. State Franck-Condon principle. Define Franck-Condon factors. Using schematic diagram, explain the decay of excited states leading to the phenomena of fluorescence and phosphorescence. **(2017)**

21. Explain the principle of Nuclear Magnetic Resonance (NMR) with the help of an energy level diagram. Give examples of nuclei which exhibit NMR. What major inferences can be drawn from an NMR spectra?

(2017)

22. In an NMR experiment, hydrogen atoms are subjected to a magnetic field of 5.0 T. Determine the difference in energy (kJ/mol) between two spin states of the nuclei of hydrogen atom and the frequency of radiation required for NMR.

(2017)

23. What is nuclear precession? How is it used in the principle of working of NMR?

(2018)

24. Discuss the theory of rotational and vibrational spectra of diatomic molecules. What is the difference between fluorescence and phosphorescence?

(2018)

25. Why are Raman active vibrations and IR vibrations in CO_2 molecule complementary to each other?

(2019)

26. What is Franck-Condon principle? Discuss the intensity distribution in the vibrational electronic spectra of a diatomic molecule on the basis of this principle.

(2019)

27. Write the principle of nuclear magnetic resonance (NMR) . Explain the design and working of NMR, and write its important applications.

(2020)

28. Calculate the frequency of the first Bohr orbit of hydrogen atom. **(2020)**

29. What is Zeeman effect? Explain Zeeman effect on the basis of classical electron theory.

(2020)

TUTORIAL SHEET: 6

NUCLEAR PHYSICS

1. Calculate the packing fraction and the binding energy per nucleon for ${}^{16}_{8}O$ and ${}^{87}_{38}Sr$ nuclei.

(2010)

2. A star converts all its hydrogen to helium, achieving 100% helium. It then converts the helium to carbon via the reaction ${}^{4}_{2}He + {}^{4}_{2}He + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + 7\cdot 27 MeV$ The mass of the star is $5\cdot 0\times 10^{32}$ kg and it generates energy at the rate of 5×10^{30} kg. How long will it take to convert all Helium to carbon at this rate?

(2010)

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

(2010)

4. Predict from the single particle shell model the shell configuration, ground state spin and parity for the following nuclei: ${}^{13}_{7}N$;${}^{17}_{8}O$

(2010)

5. Explain parity violation in β-decay. Describe how parity violation was experimentally detected in the decay of ${}^{60}Co$.

(2010)

6. Find the total kinetic energy of electron and antielectron neutrino emitted in beta decay of free neutron. (The neutron-proton mass difference is 1.30 Mev and mass of electron is 0.51 Mev) **(2010)**

7. What are chain reactions? What do you mean by critical size of the core in which chain reaction takes place? What is critical mass?

(2010)

8. ${}^{235}U$ yields two fragments of A = 95 and A = 140. Obtain the energy distribution of the fission products. Assume that the two fragments are ejected with equal and opposite momentum. **(2010)**

9. Show that nucleus is a quantum system. **(2011)**

10. (a) (i) What is the importance of study of deuteron ? Obtain the solution of Schrodinger equation for ground state of deuteron and show that deuteron is a loosely bound system.
(ii) What do you mean by non- central forces?

(b) (i) What are chain reactions? What do you mean by critical size of the core in which chain
reactions take place? What is critical mass?
(ii) $U\,235$ *yields* fragments of A= 95 and A= 140. Obtain the energy distribution of the fission products. Assume that the two fragments are ejected with equal and opposite moments. **(2011)**

11. (a) Write down the Bethe- Weizsacker Semi-empirical mass formula for a nucleus. Explain the significance of each term. Discuss the stability of a nucleus against $\beta - decay$. What is the effect of pairing term on stability?
(b) What are mirror nuclei? How does the charge independence of nuclear force emerges from this concept?

(2012)

12. Calculate the recoil energy of $^{57}_{26}Fe$ nucleus when it emits a gamma photon of energy 14 KeV.

(2012)

13. Calculate the Q-value of the reaction: $^{9}_{4}Be\left(^{4}_{2}He, n\right)^{12}_{6}C$

Given:
Mass $\left(^{9}_{4}Be\right) = 9.01283\ u$
Mass $\left(^{4}_{2}He\right) = 4.002603\ u$
Mass $\left(^{12}_{6}C\right) = 12.000\ u$
Mass $(n) = 1.0086652\ u$

(2013)

14. Write down the nucleonic configuration of, ^{7}Li, ^{12}C, ^{17}O, and ^{27}Al in the ground state of the nuclear shell model and hence calculate the corresponding ground state angular momenta and parities. How do the observed ground state angular momenta and parities agree with those predicted on the basis ofshell model? **(2013)**

15. What is the role of neutrino in the weak interaction of radioactive nuclides? Explain the experimental detection of neutrino. **(2013)**

16. Explain parity violation in β-decay. Describe how parity violation was experimentally detected in the decay of ^{60}Co. Mention any other decay process in which the parity violation has been demonstrated. **(2013)**

17. Explain why stable light nuclei have equal number of protons and neutrons whereas heavy nuclei have excess of neutron. **(2014)**

18. What are the magic numbers in nuclei? List the experimental evidences indicating their existence. **(2014)**

19. It is possible to estimate the nuclear radius from the study of alpha decay? Explain how. **(2014)**

20. State the basic assumption of single particle shell model. How do the centrifugal and spin-orbit terms remove the degeneracy of a three-dimensional spherical harmonic oscillator? **(2016)**

21. Predict the spin and parity of ground states of the following nuclei on the basis of shell model:

(i) $8^{O^{15}}$

(ii) $8^{O^{16}}$

$17^{CL^{38}}$ **(2016)**

22. Explain why the deuteron has no excited state. **(2016)**

23. Estimate the order of nuclear radius of lead (Z= 82) using the large angle (back) scattering of alpha particles of energy 10 MeV incident on a target (lead).

[Given : $(4\pi \in_o)^{-1} = 9 \times 10^9\ Nm^2C^{-2}$]

(2017)

24. Distinguish between charge independence and charge symmetry of nuclear force. Give one example of each of these. **(2017)**

25. Describe briefly how parity violation in $\beta - decay$ was experimentally observed? What do you understand by the statement, 'neutrinos are left-handed'? **(2017)**

26. Given that the deuteron magnetic moment operator (in units of nuclear magneton) can be expressed as

$$\vec{\mu}_d = \mu_n \vec{\sigma}_n + \mu_p \vec{\sigma}_p + \frac{1}{2}\vec{l},$$

Where $\vec{l}$ is the relative angular momentum between neutron and proton $\vec{\sigma}_n$ and $\vec{\sigma}_p$ are the Pauli spin operators and μ_n and μ_p are the respective magnetic moments. Find out the D-state probability of deuteron wave function.

[Given : $\mu_d = 0.857\, \mu_N, \mu_n = -1.913\, \mu_N$ and $\mu_p = 2.793\, \mu_N$; $\mu_N (nuclear\ magneton)$] **(2017)**

27. Write the semi-empirical mass formula pointing out the role of volume term, surface energy term, coulomb and symmetry energy correction terms. **(2017)**

28. Draw a schematic diagram of the single particle energy levels in a shell model including the effect of spin-orbit coupling. Show how it explains magic numbers in nuclei. Give two examples to show how this scheme predicts the spins and particles of odd A nuclei.

\ **(2017)**

29. Write the semi-empirical mass formula for nuclei and on its basis draw mass parabolas for odd and even isobars. What would be the most stable isobar in each case? **(2018)**

30. Obtain an expression for the magnetic moment of a nucleus having one nucleon outside the closed core. Use this to calculate the magnetic moment of $_8O^{17}$ nucleus. **(2018)**

31. Nuclear forces are mediated by exchange of π-mesons of rest mass 140 MeV. Estimate the range of nuclear forces. **(2018)**

32. Assuming that the neutron-proton interaction has a square well form

$$V(r) = -V_0 \; for\; r \le b$$
$$= 0 \; for\; r > b$$

The ground wave function of deuteron nucleus is given as

$$\psi(r) = A \sin kr \;\; for\; r \le b$$
$$= Ce^{-\gamma r} for\; r > b$$

Where k = $\sqrt{\frac{M}{\hbar^2}(V_0 + W)}$ and $\gamma = \sqrt{\frac{MW}{\hbar^2}}$

Here M is the nucleon mass, W is the binding energy of deuteron and A and C are constants.

(i) Show that for a just bound state of deuteron

$$V_0 b^2 = \frac{\pi^2 \hbar^2}{4M}$$

33. Explain why deuteron is a loosely bound extended structure. **(2018)**

34. Explain the various methods of finding the size of the nucleus. How will you determine the nuclear radius from the observation of beta rays resulting from nuclear transition when the initial and final nuclei are mirror nuclei? **(2019)**

35. Given that the single particle energy separation between 1 $d_{5/2}$ and 1 $d_{3/2}$ in ^{17}O is $5MeV$. Calculate the strength of spin-orbit interaction. It is observed that 1 $d_{5/2}$ level is lower than 1 $d_{3/2}$ level. **(2019)**

36. Why is it not possible to detect the parity violation in weak interaction by observing only the beta decay rate? Justify your answer. **(2019)**

37. In a certain cyclotron, the maximum radius that the path of a deuteron may have before it is deflected out of the magnetic field is 20 cm.

(i) Calculate the velocity of the deuteron at this radius

(ii) What is the energy of deuteron in MeV ?

Given, magnetic field = 1500 gauss and mass of deuteron = 3.34×10^{-27} kg. **(2020)**

38. Calculate in terms of the nuclear magneton, μ_N, the magnetic dipole moment of 3_{S_1} state of deuteron.

Given , $\mu_P = 2.792847\mu_N$ and $\mu_n = -1.913042\mu_N$. **(2020)**

39. Explain the Mössbauer effect. **(2020)**

40. Natural uranium found in the earth's crust contains the isotopes $^{235}_{92}$U, and $^{238}_{92}$U in the ratio 7.3×10^{-3} to 1. Assuming that at the time of formation these two isotopes were produced equally, estimate the time since formation. Given that the mean lives of both the are 1.03×10^9

years and 6.49×10^9 years respectively.

(2020)

41. Write down the Weizsäcker mass formula for the nuclear binding energy Give short justification for each term of the formula.

(2020)

42. List the main reactions in the pp chain leading from hydrogen to helium during stellar nucleosynthesis. Also mention the net effect of the reactions. **(2020)**

TUTORIAL SHEET: 7
PARTICLE PHYSICS

1. State the quantum number I_z, Y and S for the u d s quarks and anti quarks. Which combination of these leads to the formation of (i) proton and (ii) neutron?
(2010)

2. Explain conservation of Baryon Number. Comment on the stability of proton. **(2010)**

3. Which of the following reactions are permitted or forbidden by various conservation laws?
(i) $K^- + P \rightarrow \lambda^0 + \pi^0$
(ii) $K^- + n \rightarrow \Sigma^+ + \pi^0$
(iii) $\pi^- + P \rightarrow K^- + \Sigma^+$
(i) $\pi^+ + n \rightarrow K^- + n^0$
(v) $\pi^- + P \rightarrow \lambda^0 + K^0$
(vi) $\pi^- + P \rightarrow K^- + \Sigma^-$ **(2012)**

3. State the quantum l_z, Y and S for the u d s quarks and antiquarks. Which combination of these leads to the formation of
(i) proton and (ii) neutron? **(2013)**

4. In the following reaction indicate with an explanation, whether they proceed by strong, electromagnetic or weak interaction or they are forbidden:
(i) $x^+ \rightarrow \mu^+ + v_\mu$
(ii) $p \rightarrow n + e^+ + v_e$
(iii) $p + \pi^- \rightarrow K^+ + \Sigma^-$
(2013)

5. (i) What are salient features of nuclear forces?
(ii) Discuss Yukawa's theory of nuclear forces.
(2014)

6. (i) How does liquid drop model explain fission?
(ii)What are the limitations of shell model? **(2014)**

7. Describe grand unification theories (GUT).
(2015)

8. How many types of neutrinos exist? How do they differ in their masses? **(2015)**

9. (i) $\Omega^{-} \rightarrow \wedge^{0} + K^{-}$

(ii) $\wedge^{0} \rightarrow p + \pi^{-}$

(iii) $K^{-} \rightarrow \mu^{-} + \upsilon_{\mu}$

(2015)

10. State the quantum numbers I_z, Y and S for uds quarks and antiquarks. Which combination of these leads to the formation of a (i) proton and (ii) neutron? **(2015)**

11. What are elementary particles and how are they classified? Describe in brief the different types of interactions that can occur between the elementary particles. **(2016)**

12. Explain the various leptonic family members. What is leptonic number conservation? Based on this conservation law, state whether the following reaction are possible or not:

(i) $x^{-} \rightarrow \mu^{-} + \mu_{\tau}$

(ii) $n \rightarrow P^{+} + e^{-} + V_{e}$

(2016)

13. Write down the quark structure of the following hadrons: $\Delta^{++}, \Omega^{-}, \Sigma^{-}$ *and* Λ^{o}

Write down the following decays in terms of quarks:

i. $n \rightarrow P^{+} + e^{-} + V_{e}$

ii. $\Delta^{+} \rightarrow \pi^{+} + n$

iii. $\Sigma^{+} \rightarrow P^{+} + \pi^{o}$

(2016)

14. Explain unification of electromagnetic and weak interactions. What is Z^{o}-boson? What is its relevance in electroweak unification? **(2016)**

15. State the three characteristic properties of strong, weak and electromagnetic forces distinguishing one from the other.

(2017)

16. Point out the interactions in which the following conservation laws are obeyed or violated

(a) Isotopic spin

(b) Hyper charge

(c) Lepton number

(d) Charge conjugation **(2017)**

17. Write down the quark constituents of each of the following:

(e) π^{+}, (b) K^{+}, (c) Δ^{++}, (d) Σ°, (e) Ω^{-} **(2017)**

18. Which of the following elementary particle reactions/decays are allowed under various conservation laws? If allowed , write down the type of interaction and the characteristic time by which it would proceed:

(i) $p + n \rightarrow \Lambda^0 + \Sigma^+$

(ii) $\pi^+ + n \rightarrow \Lambda^0 + K^+$

(iii) $p + n \rightarrow K^+ + \Sigma^+$

(iv) $\pi^0 \rightarrow \gamma + \gamma$

(v) $\bar{n} \rightarrow \bar{p} + e^+ + v_e$ **(2018)**

19. Write down the basic weak interaction processes in the nuclei. Also illustrate the beta decays of (i) neutron and (ii) proton. **(2020)**

20. List in two separate columns, the quantities that are conserved and not conserved in the weak interaction of particles. **(2020)**

TUTORIAL SHEET: 8

Crystal Structure & its Determination

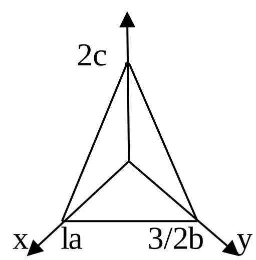
1. Derive Bragg diffraction condition in vectorial form using incident and diffracted wave vectors and reciprocal lattice vector.

(2010)

2. An electron beam of 4 Kev is diffracted through a Bragg angle of 16° for the first maxima. If the energy is increased to 16 keV, find the corresponding Bragg angle for diffraction.

(2010)

3.



A crystal plane is shown in the above figure. Find its Miller indices and interplanar spacing.

(2013)

4. Explain the working of SEM and TEM highlight the major differences in principles. Draw neat schematic diagrams. **(2014)**

5. What is the reciprocal lattice and why is it named so? Derive the relationships for the primitive translation vectors of the reciprocal lattice in terms of those of the direct lattice. **(2014)**

6. How does he energy gap in superconductors differ from the energy gap in insulator? How does it vary with temperature for superconductors? **(2014)**

7. Obtain Laue's equations for X-ray diffraction by crystals. Show that these are consistent with the Bragg's law.

(2016)

8. The primitive translation vectors of a two-dimensional lattice are a = 2 i + j , b = 2 j. Determine the primitive translation vectors of its reciprocal lattice.

(2016)

9. Deduce the Miller indices of the close-packed planes of atoms in the f.c.c. lattice. **(2019)**

PHYSICS PAPER – II : SOLID STATE PHYSICS
TUTORIAL SHEET: 9
Band theory of solids

1. Explain the reduced zone scheme of plotting the energy bands in solids. On the basis of E vs k curve distinguish between conductors, semiconductors and insulators.

(2010)

2. What is nearly free electron approximation? On the basis of this approximation explain the formation of energy bands in solids. **(2010)**

3. Starting with the expression for the density of states for electrons in a band, show that the Fermi energy of an intrinsic semiconductor is at the middle of the band gap. Use these results to estimate the electron density at 300K (Assuming $E_g = 1$ eV and the rest masses of electron and hole as m_e and m_h). **(2013)**

4. Describe the motion of an electron in one dimensional periodic potential and show that it leads to formation of bands of allowed and forbidden states in the electron energy spectrum. How are the conductors, semiconductors and insulators discriminated on the basis of band structure? **(2015)**

5. What is the difference between direct and indirect band gap semiconductors? Which one is suitable for use in solar cells? **(2016)**

6. The Energy (E) and wave vector (k) for a conduction band electron in a semiconductor are related as $E = \alpha \frac{\hbar^2 k^2}{m_0}$ where α is a constant and m_0 is the free electron mass. Calculate the effective mass of the electron.

(2017)

7. Consider a face-centred cubic lattice of side a. Deduce –

(i) The primitive translation vectors;
(ii) The volume of the primitive cell;
(iii) The reciprocal primitive translation vectors;
(iv) The volume of the reciprocal lattice

(2019)

TUTORIAL SHEET: 10

Thermal and Magnetic Properties of Solids

1. Distinguish between Einstein and Debye models of specific heats of solids. Obtain an expression for the specific heat of a solid on the basis of Debye model. Discuss the results for low and high temperature ranges. **(2010)**

2. Distinguish between classical and quantum theory of paramagnetism. Explain the paramagnetism of free electrons on the basis of F.D. distribution. **(2010)**

3. Find an expression for lattice specific heat of solids, and its low and high temperature limits. What is Debye temperature? **(2010)**

4. Find an expression for lattice specific heat of solids and its low and high temperature limits. What is Debye's temperature? **(2011)**

5. The velocity of sound in f.c.c. gold and f.c.c. copper is 2100m/s and 3800 m/s respectively. If the Debye temperature of copper is 348 K, then determine the Debye temperature of gold. Take the densities of gold and copper as 1.93 x 10^4kg/$m^3$and 0.89 x 10^4 kg/m^3 respectively. **(2014)**

6. Find an expression for lattice specific heat of a solid, and its low and high temperature limits. What is Debye temperature? **(2015)**

7. Write down the salient features of the Einstein's theory of lattice heat capacity. Further write down the expression for specific heat in Einstein's theory and explain its high and low temperature limits. **(2016)**

8. In a semiconductor, the effective masses of an electron and hole are 0.07 m_0 and 0.4 m_0 respectively, where m_0 is the free electron mass. Assuming that the average relaxation time for the hole is half of that for the electrons, calculate the mobility of the holes when the mobility of the electrons is 0.8 $m^2 volt^{-1} s^{-1}$. **(2017)**

9. Derive an expression for lattice specific heat in Debye model. Find its low temperature limit (Debye T^3 law). **(2018)**

SOLID STATE PHYSICS
TUTORIAL SHEET: 11
SUPERCONDUCTIVITY

1. Describe the characteristic properties of a superconductor. Derive London equation for a superconductor and hence explain Meissner effect. **(2010)**

2. What is Josephson tunneling? Distinguish between a.c. and d.c. Josephson effects. **(2010)**

3. Describe the Characteristics properties of a superconductor. Derive London equation for a super conductor and hence explain Meissner effect. **(2011)**

4. Explain the variation of Magnetisation of Type I and Type II superconductors as a function of applied magnetic field **(2012)**

5. Cooled to 4 K and then magnetic field is applied. With schematic diagrams, explain path of magnetic field lines in all these situations: **(2013)**

6. Lead in the superconducting state has critical temperature of 6.2 K at zero magnetic field and a critical field of 0.064 Mam^{-1} at 0 K. Determine the critical field at 4 K. **(2014)**

7. Distinguish between a superconductor and perfect conductor. Explain what is a Cooper pair. **(2015)**

8. With the help of a schematic diagram, show how entropy and specific heat vary with temperature for a superconductor. **(2016)**

9. Obtain the expression for penetration depth using London's equation of superconductivity and explain its significance. **(2017)**

10. What are type I and type II superconductors? Give examples. Discuss and compare Meissner effect and perfect diamagnetic behaviors for type I and type II super conductors. **(2018)**

11. Using the two – fluid model of a conductor (normal and superconducting) and the Maxwell's equations , derive the two London equations of superconductivity . **(2020)**

Electronics/ TUTORIAL SHEET: 12

Semiconductors/Solar cell

1. Draw the device structure of a-p-n junction solar cell and explain how light energy is converted into electrical energy. Draw and explain its I-V characteristics.

(2015)

2. A silicon semiconductor sample at T = 300 K having cross-sectional area of 0.5 μm^2 has a pentavalent donor doping profile given by $(x) = 5 \times 10^{16}\ e^{(-x/L_n)}\ cm^{-3}$. Given, the mobility of the electrons in the sample is 1250 $cm^2V^{-1}s^{-1}$ and the diffusion length of the electrons, L_n , is 4 μm. Calculate the diffusion current in the sample at distance $x = 2\ \mu m$.

(2019)

3. A silicon semiconductor sample is doped with $6 \times 10^{16} cm^{-3}$ of aluminium and $7 \times 10^{15} cm^{-3}$ of phosphorus atoms. Given at T = 300 K, the intrinsic carrier concentration, $n_i = 1.5 \times 10^{10} cm^{-3}$; the band gap, $E_g = 1.1\ eV$; the electron mobility, $\mu_n = 1250\ cm^2V^{-1}s^{-1}$ and the hole mobility, $\mu_p = 480\ cm^2V^{-1}s^{-1}$.

Determine in the sample of the following:

(i) The type of the semiconductor, n or p
(ii) The hole carrier concentration
(iii) The electron carrier concentration
(iv) The position of the Fermi level in the sample with respect to the bottom of the conduction band
(v) The conductivity of the sample **(2019)**

4. A 5 cm^2 Ge solar cell with a dark reverse saturation current of 2 nA has solar radiation incident upon it, producing 4×10^{17} electron-hole pairs per second. The electron and hole diffusion lengths are given to be 5μm and 2μm, respectively. Calculate for the cell of the following:

(i) The short-circuit current
(ii) The open-circuit voltage **(2019)**

TUTORIAL SHEET: 13

TRANSISTORS (Amplifiars/Oscillators)

1. Draw the common-base amplifier circuit, using an n-p-n transistor and briefly discuss its working.
(2010)

2. Draw and explain the collector characteristics of a bipolar junction transistor in common emitter configuration. Using the plot, explain how the transistor can be used as an ON-OFF switch. **(2013)**

3. Explain how the circuit shown above can be a source of oscillations. Use this circuit to construct a transistor oscillator and explain its working. What is the frequency of oscillations of this circuit? **(2013)**

4. Differentiate between p-n-p and n-p-n transistors. Give their device structure and biasing circuits when used as an amplifier.
(2015)

5. Design a transistor based Colpitt oscillator which can oscillate at 9 MHz. Explain how the oscillations are created and sustained. **(2015)**

TUTORIAL SHEET: 14

Digital Electronics/Microprocessors

1. Simplify the logical expression AB + AB + ABC using a karnaugh map. **(2010)**

2. Simplify the logical expression (A + B) (B+C) (A + C) and draw the logical circuit to implement it. **(2010)**

3. Construct a digital circuit to add three bits A, B and C and provide their sum and carry as-outputs. Show appropriate Boolean expressions and truth table to justify the outputs. **(2013)**

4. (a) Give the two forms of the De Morgan's theorem.
(b) What is the principle used in 'half –adder'? Give the truth table for it.

(2014)

5. Simplify the logical expression [AB (C + BD) + A B] C.

(2015)

6. Why are NAND and NOR gates called universal gates? Give the logic diagram, Boolean equation and the truth table of NAND gate. **(2016)**