1. Which of the following phenomena most clearly demonstrates the particle nature of light? (Choose one answer) (5%)
   (A) diffraction
   (B) polarization
   (C) the photoelectric effect
   (D) refraction
   (E) interference

2. Which of the following phenomena most clearly demonstrates the wave nature of electrons? ( Choose one answer) (5%)
   (A) the photoelectric effect
   (B) blackbody radiation
   (C) the Compton effect
   (D) diffraction of electrons by crystals
   (E) none of these answers

3. The working principle of STM is by detecting the tunneling current through a conductive sample. Suppose a tunneling current in an electronic device goes through a potential-energy barrier. In which case, will the tunneling current be increased? (Choose one best answer.) (5%)
   (A) Reduce the width of the barrier.
   (B) Reduce the energy height of the barrier.
   (C) Both choice (A) and (B) will increase tunneling current.
   (D) Neither choice (A) or (B) will increase tunneling current.

4. Consider the $n = 3$ energy level in a hydrogen atom. How many electrons can be placed in this level? (Choose the best response.) (5%)
   (A) 1
   (B) 2
   (C) 8
   (D) 9
   (E) 18

5. The Fermi energy corresponds to (5%)
   (A) the maximum energy electrons can have in a metal at T = 0 K.
   (B) the maximum energy electrons can have in a metal at T = 0 C.
   (C) (the minimum energy electrons can have in a metal at T = 0 K.
   (D) the number of electrons per unit volume between E and E + dE.
   (E) the minimum energy electrons can have in a metal at T = 0 C.

6. The work function for platinum is 6.35 eV. Ultraviolet light of wavelength 155 nm is incident on the clean surface of a platinum sample. We wish to predict the stopping voltage we will need for electrons ejected from the surface.
   (A) What is the photon energy of the ultraviolet light? (5%)
   (B) What is the minimum required energy of the light to eject electrons from platinum? (5%)

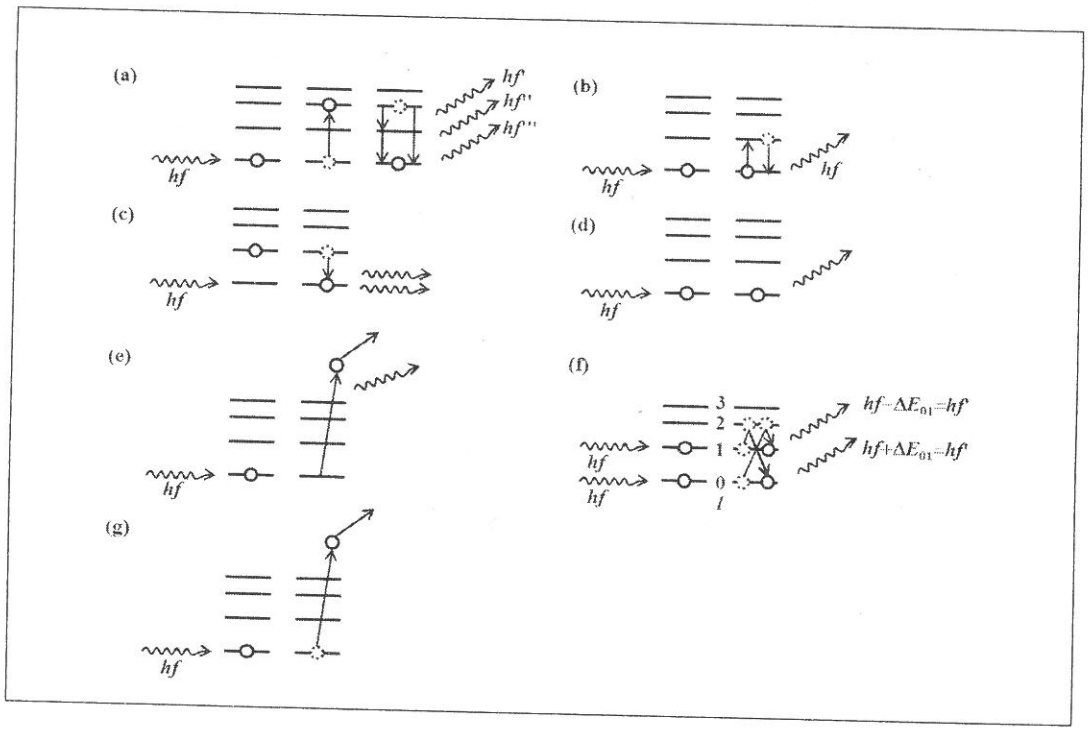
7. As the electron of a hydrogen atom undergoes a transition from the n = 3 state to the n = 2 state, a photon is emitted. (a) Calculate the energy of the emitted photon. _____eV (5%) (b) Calculate the wavelength of the emitted photon. (hint: 13.6eV is the energy required from n=1 to vacuum) ____nm. (5%)

8. The energy-wavevector dispersion relation for free electrons is

$$E = \frac{(\hbar k)^2}{2m}.$$

From this Derive the energy density of states D(E) for 2 dimensions. (5%)

9. The following figure shows 7 kinds of interaction of radiation with atomic or molecular systems residing on certain states. (a) The photon is absorbed and the atom, excited to a state of higher energy, later emits one or more photons as it decays to a state of lower energy. (b) The fact that the energy of the incident photon matches one of the excitation energies of the atom results in the absorption by this atom. (c) The atom, at an excited state, is stimulated to make a downward transition to a lower state by an incident photon of proper energy. (d) The molecule is stimulated to emit a photon of the same energy as the incident photon. (e) The atom originally at level 1 is stimulated to emit a photon of higher energy than the incident photon; the molecule originally at level 0 is stimulated to emit a photon of lower energy than the incident photon. (f) The incident X-ray or γ-ray photon makes an electron to escape from the atom accompanied by a photon of lower energy. (g) The incident photon makes the atom escape from the metal.




(A) When each subfigure (a)-(g) respectively pertains to (i) Compton effect, (ii) Raman scattering, (iii) resonance absorption, (iv) fluorescence, (v) stimulated emission, (vi) Rayleigh scattering, and (vii) photoelectric effect, please match (i)-(vii) with (a)-(g) one on one. (20%)

(B) Explain the difference between spontaneous emission and stimulated emission as well as that between Raman scattering and stimulated Raman scattering. (5%)

10. The following is the time-independent Schrodinger equation

$$-\frac{\hbar^2}{2m}\nabla^2\psi(\vec{r})+V(\vec{r})\psi(\vec{r})=E\psi(\vec{r}). \quad (1)$$

(A) Explain if this equation is linear. (5%)

(B) Explain what forms of $V(\vec{r})$ lead to eigenfunctions of the form $\psi(\vec{r})=Ce^{i\vec{P}/\hbar\cdot\vec{r}}$. (5%)

(C) What are the uncertainties of momentum $\langle|\Delta\vec{P}|\rangle$ and position $\langle|\Delta\vec{r}|\rangle$ for $\psi(\vec{r})=Ce^{i\vec{P}/\hbar\cdot\vec{r}}$ ? (5%)

11. Two events occur at the same point $x'_0$ at times $t'_1$ and $t'_2$ in frame $S'$, which moves with speed $v$ relative to frame $S$, What is the spatial separation of these events measured in $S$? (10%)