Section 13: Modern Physics II (Quantum Mechanics)

1. Quantum Numbers

For the $n = 3$ energy level in a hydrogen atom, what are the possible values for the quantum numbers l (orbital) and m_l (magnetic)? How many distinct electron states exist for $n = 3$?

2. Energy Scaling

State the general dependence of energy E on the principal quantum number n (i.e., $E \propto n^?$) for:

a) A particle in a one-dimensional infinite potential well.

b) An electron in a hydrogen atom.

3. Photon Energy

Calculate the energy (in eV) of a photon with a wavelength of 500 nm. Use the formula $E = \frac{hc}{\lambda}$ where $h = 4.1357 \times 10^{-15}$ [eVs] and $c = 3.0 \times 10^8$ m/s.

4. Quantum Well Energy

An electron is in a 1D infinite potential well of width $L = 0.5$ nm. It is in the $n = 2$ state. What is the energy of the electron in eV?

5. Quark Model

What is the quark composition of a proton and a neutron? Use this to verify their electric charges (u quark charge = +2/3 e, d quark charge = -1/3 e).

6. Radioactive Half-Life

The half-life of Cobalt-60 is 5.27 years. If a sample initially contains 100 grams of Cobalt-60, how much will remain after approximately 21 years?

7. Alpha Decay

Give a specific, balanced nuclear equation for an alpha decay process, starting with Uranium-238 ($^{238}_{92}$U).

8. Beta Decay

Give a specific, balanced nuclear equation for a beta-minus decay process, starting with Carbon-14 ($^{14}_{6}$C).

9. Pair Annihilation

An electron and a positron, each with a rest mass of 0.511MeV/c^2, annihilate each other, producing two photons of equal energy. What is the energy (in MeV) and wavelength of each photon?

10. Wavefunction Probability

For a particle in a 1D box of length L, the wavefunction for the ground state is $\Psi(x) = \sqrt{2/L}\sin(\pi x/L)$. Calculate the probability of finding the particle in the region $0 \leq x \leq L/4$.