Multiple Choice

_____A1) A spin-zero particle has the angular wavefunction

$$\Psi = \frac{1}{\sqrt{2}}\left(Y_{32}(\theta,\phi) + Y_{21}(\theta,\phi)\right)$$

where $Y_{lm}(\theta,\phi)$ are the normalized spherical harmonics. The expectation value of the total angular momentum L^2 is closest to:

A) $\frac{5\hbar^2}{2}$ B) $3\hbar^2$ C) $2\hbar^2$ D) $9\hbar^2$ E) $18\hbar^2$.

Explain:

_____A2) For the wavefunction in A1), the expectation value of L_z is closest to:

A) $\frac{3\hbar}{2}$ B) $\frac{9\hbar}{2}$ C) $\frac{13\hbar}{2}$ D) $\frac{\hbar}{2}$ E) $zero$.

Explain:

_____A3) Positronium is the bound state of an electron and a positron (anti-electron). The energy of a photon emitted in transitions of positronium from the first excited state to the ground state is closest to:

A) 10.2 eV. B) 3.4 eV. C) 5.1 eV D) 6.8 eV E) 13.6 eV

Explain:

_____A4) Light of wavelength 488 nm is observed when a hydrogen atom decays from one state to another state. This most likely is the result of a transition between which of the following states?

A) n=2 to n=1 B) n=3 to n=1 C) n=3 to n=2

D) n=4 to n=2 E) n=4 to n=3.

Explain:

_____A5) ψ_a and ψ_b denote momentum eigenfunctions with different eigenvalues a and b, respectively. What is the value of $\int \psi_a^* p_{op} \psi_b dx$?

A) a B) b C) |ab| D) $|ab|^{1/2}$ E) zero.

Explain:

____A6) A two-dimensional square well of side length L contains two identical non-interacting particles in two different energy eigenstates ψ_A and ψ_B. For which of the following space eigenfunctions is the average distance between the particles the smallest?

A) $\frac{1}{\sqrt{2}}\left(\psi_A(1)\psi_B(2) + \psi_A(2)\psi_B(1)\right)$

B) $\frac{1}{\sqrt{2}}\left(\psi_A(1)\psi_B(2) - \psi_A(2)\psi_B(1)\right)$

C) Neither, they are the same.

D) Depends on whether they are fermions or bosons.

Explain:

Free response (pts as marked):

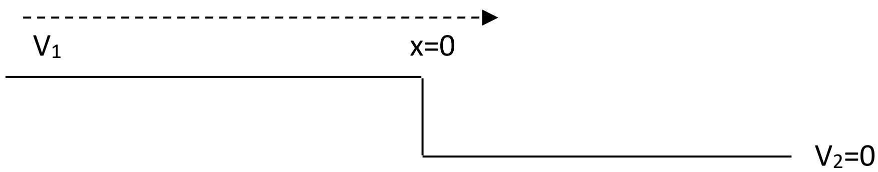
B1) A particle in a three-dimensional potential has the wavefunction:

$$\psi(r) = \begin{cases} 0 & for\ 0 \leq r \leq a \\ \dfrac{\sqrt{3a^3}}{r^3} & for\ r > a \end{cases}$$

a) What is the expectation value of r for the particle in this state?

b) What is the expectation value of the angular momentum for the particle in this state?

B2) A stream of electrons of energy $E>V_1$ is incident from the left onto a step-down potential at x=0 as shown below.



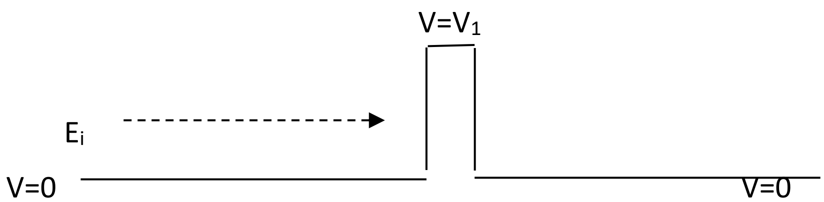
a) Write the general form of the wavefunctions for relevant spatial regions.

b) Simplify this general form using physical and boundary condition arguments. Do not solve the equations at this point. Clearly state your assumptions and arguments.

c) Deduce the mathematical relationship between transmitted probability current and incident current as a function of E, V_1, and V_2.

B3) Calculate the commutator $[\hat{p}^2,\ \hat{x}]$. What can you conclude about eigenstates of $\hat{p}^2$ and $\hat{x}$.

B4) A beam of positrons (m=electron mass), each with energy E_i, is incident from the left on a potential barrier (sketched below). Assume $E_i<V_1$. It is measured that 1% of the incident current is observed on the other side.



i) What is the energy E_t of a transmitted positron? Explain your answer.

ii) Is there any current inside of the barrier? Explain your answer.

iii) Assume that, instead of positrons, the incident beam is made up of protons of the same energy. Is the transmitted current much greater than, slightly greater than, equal to, slightly less than, or much less than the transmitted current for positrons? Explain your answer.