Problem 1:

The normalized ground state wave function of hydrogen is $\psi_{100} = \frac{2}{(4\pi)^{1/2} a_0^{3/2}} e^{-r/a_0}$, where a_0 is the Bohr radius. What is the most likely distance that the electron is from the nucleus?

(A) 0
(B) $\frac{a_0}{2}$
(C) $\frac{a_0}{\sqrt{2}}$
(D) a_0
(E) $2a_0$

Problem 2:

True statements about the absorption and emission of energy by an atom include which of the following?

I. An atom can only absorb photons of light that have certain specific energies.
II. An atom can emit photons of light of any energy.
III. At low temperature, the lines in the absorption spectrum of an atom coincide with the lines in its emission spectrum that represent transitions to the ground state.

(A) I only
(B) III only
(C) I and II only
(D) I and III only
(E) I, II, and III

Problem 3:

Consider a single electron atom with orbital angular momentum $L = \sqrt{2}\hbar$. Which of the following gives the possible values of a measurement of L_z, the z-component of L ?

(A) 0
(B) $0, \hbar$
(C) $0, \hbar, 2\hbar$
(D) $-\hbar, 0, \hbar$
(E) $-2\hbar, -\hbar, 0, \hbar, 2\hbar$

Problem 4:

The lifetime for the $2p \rightarrow 1s$ transition in hydrogen is 1.6×10^{-9} s. The natural line width for the radiation emitted during the transition is approximately

(A) 100 Hz
(B) 100 kHz
(C) 100 MHz
(D) 100 GHz
(E) 100 THz

Problem 5:

De Broglie hypothesized that the linear momentum and wavelength of a free massive particle are related by which of the following constants?

(A) Planck's constant
(B) Boltzmann's constant
(C) The Rydberg constant
(D) The speed of light
(E) Avogadro's number

Problem 6:

Which of the following statements about bosons and/or fermions is true?

(A) Bosons have symmetric wave functions and obey the Pauli exclusion principle.
(B) Bosons have antisymmetric wave functions and do not obey the Pauli exclusion principle.
(C) Fermions have symmetric wave functions and obey the Pauli exclusion principle.
(D) Fermions have antisymmetric wave functions and obey the Pauli exclusion principle.
(E) Bosons and fermions obey the Pauli exclusion principle.

Problem 7:

A particle is in an infinite square well potential with walls at $x = 0$ and $x = L$. If the particle is in the state $\psi(x) = A\sin\left(\frac{3\pi x}{L}\right)$, where A is a constant, what is the probability that the particle is between $x = \frac{1}{3}L$ and $x = \frac{2}{3}L$?

(A) 0
(B) $\frac{1}{3}$
(C) $\frac{1}{\sqrt{3}}$
(D) $\frac{2}{3}$
(E) 1

Problem 8:

A spin-$\frac{1}{2}$ particle is in a state described by the spinor

$$\chi = A\begin{pmatrix} 1+i \\ 2 \end{pmatrix},$$

where A is a normalization constant. The probability of finding the particle with spin projection $S_z = -\frac{1}{2}\hbar$ is

(A) $\frac{1}{6}$
(B) $\frac{1}{3}$
(C) $\frac{1}{2}$
(D) $\frac{2}{3}$
(E) 1

Problem 9:

An atom has filled $n = 1$ and $n = 2$ levels. How many electrons does the atom have?

(A) 2
(B) 4
(C) 6
(D) 8
(E) 10

Problem 10:

The Balmer formula for the wavelength of the spectral lines in the visible spectrum of hydrogen may be written as $1/\lambda = R_H (1/2^2 - 1/n^2)$. If the wavelength of the H_α line in the Balmer series is 6563 Angstroms, the wavelength of the series limit is most nearly

(A) 1640 A
(B) 2281 A
(C) 3646 A
(D) 8542 A
(E) 11,813 A

Problem 11:

Which of the following expressions is proportional to the total energy for the levels of a one-electron Bohr atom? (m is the reduced mass, Z is the number of protons in the nucleus, $-e$ is the charge on the electron, and n is the principal quantum number.)

(A) $\frac{mZe^2}{n}$
(B) $\frac{mZe^2}{n^2}$
(C) $\frac{mZ^2e^4}{n^2}$
(D) $\frac{m^2Z^2e^2}{n^2}$
(E) $\frac{m^2Z^2e^4}{n^2}$

Problem 12:

Characteristics of the quantum harmonic oscillator include which of the following?

I. A spectrum of evenly spaced energy states
II. A potential energy function that is linear in the position coordinate
III. A ground state that is characterized by zero kinetic energy
IV. A nonzero probability of finding the oscillator outside the classical turning points

(A) I only
(B) IV only
(C) I and IV only
(D) II and III only
(E) I, II, III, and IV

Problem 13:

A quantum mechanical harmonic oscillator has an angular frequency ω. The Schrödinger equation predicts that the ground state energy of the oscillator will be

(A) $-\frac{1}{2}\hbar\omega$

(B) 0

(C) $\frac{1}{2}\hbar\omega$

(D) $\hbar\omega$

(E) $\frac{3}{2}\hbar\omega$

Problem 14:

In the Bohr model of the hydrogen atom, the linear momentum of the electron at radius r_n is given by which of the following? (n is the principal quantum number.)

(A) $n\hbar$

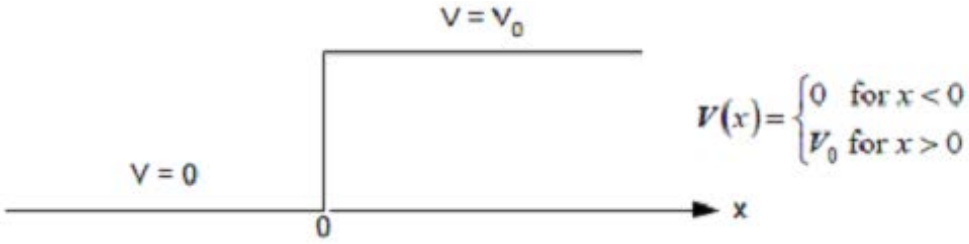
(B) $nr_n\hbar$

(C) $\frac{n\hbar}{r_n}$

(D) $n^2 r_n \hbar$

(E) $\frac{n^2\hbar}{r_n}$

Problem 15:



The figure above represents a step function in potential energy for electrons moving along the x-direction in a one-dimensional problem. A monochromatic beam of electrons of energy E is incident on the barrier from the left. If $E>V_0$, then which of the following is correct?

(A) At x=0, the sum of the incident wave and the reflected wave is equal to the transmitted wave.

(B) At x=0, the transmitted wave is zero.

(C) The wave number of the reflected wave is less than that of the incident wave.

(D) The wave number of the reflected wave is equal to that of the transmitted wave.

(E) Electrons pass over the potential barrier without reflection but with reduced speed.