**Problem 1:**

A particle of mass $M$ is in an infinitely deep square well potential $V$ where

$V = 0$ for $-a \leqq x \leqq a$, and

$V = \infty$ for $x < -a$, $a < x$.

A very small perturbing potential $V'$ is superimposed on $V$ such that

$V' = \epsilon\left(\frac{a}{2} - |x|\right)$ for $\frac{-a}{2} \leqq x \leqq \frac{a}{2}$, and

$V' = 0$ for $x < \frac{-a}{2}$, $\frac{a}{2} < x$.

If $\psi_0, \psi_1, \psi_2, \psi_3, \ldots$ are the energy eigenfunctions for a particle in the infinitely deep square well potential, with $\psi_0$ being the ground state, which of the following statements is correct about the eigenfunction $\psi_0'$ of a particle in the perturbed potential $V + V'$?

(A) $\psi_0' = a_{00}\psi_0$, $a_{00} \neq 0$

(B) $\psi_0' = \sum_{n=0}^{\infty} a_{0n}\,\psi_n$ with $a_{0n} = 0$ for all odd values of $n$

(C) $\psi_0' = \sum_{n=0}^{\infty} a_{0n}\,\psi_n$ with $a_{0n} = 0$ for all even values of $n$

(D) $\psi_0' = \sum_{n=0}^{\infty} a_{0n}\,\psi_n$ with $a_{0n} \neq 0$ for all values of $n$

(E) None of the above

**Problem 2:**

Consider a system of $N$ noninteracting particles confined in a volume $V$ at a temperature such that the particles obey classical Boltzmann statistics. If the temperature is lowered to the point at which quantum effects become important, the pressure of the gas may differ depending on whether the particles are fermions or bosons. Let $P_F$ be the pressure exerted by the particles if they are fermions, $P_B$ be the pressure if they are bosons, and $P_C$ be the pressure the particles would exert if quantum effects are ignored. Which of the following is true?

(A) $P_F = P_B = P_C$

(B) $P_F > P_C > P_B$

(C) $P_F > P_B > P_C$

(D) $P_F < P_B < P_C$

(E) $P_F < P_C < P_B$

**Problem 3:**

The configuration of the potassium atom in its ground state is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$. Which of the following statements about potassium is true?

(A) Its $n = 3$ shell is completely filled.

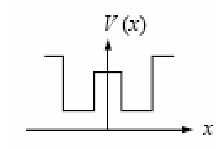
(B) Its $4s$ subshell is completely filled.

(C) Its least tightly bound electron has $\ell = 4$.

(D) Its atomic number is 17.

(E) Its electron charge distribution is spherically symmetrical.

**Problem 4:**
The sketch below shows a one-dimensional potential for an electron. The potential is symmetric about the *V*-axis.




Which of the following statements correctly describes the ground state of the system with one electron present?
(A) A single electron must be localized in one well.
(B) The ground state will accommodate up to four electrons.
(C) The kinetic energy of the ground state will be one-half its potential energy.
(D) The wave function of the ground state will be antisymmetric with respect to the *V*-axis.
(E) The wave function of the ground state will be symmetric with respect to the *V*-axis.

**Problem 5:**
A second electron is now added to the system. If the electrons do not interact, which of the following statements is correct?
(A) The second electron must be localized in the well not previously occupied.
(B) In the ground state of the system, each of the two electrons will have the same spatial wave function.
(C) In the ground state of the system, one electron will be in a spatially symmetric state and one will be in a spatially antisymmetric state.
(D) The second electron will not be bound.
(E) Pair annihilation will occur.

**Problem 6:**
An electron with energy E and momentum $\hbar$k is incident from the left on a potential step of height V > E at x = 0 . For x > 0 the space part of the electron's wave function has the form
(A) $e^{ikx}$.
(B) $e^{ik'x}$, where k'< k.
(C) $e^{-\alpha x}$, where $\alpha$ is real and positive,
(D) sin(kx).
(E) identically zero.

**Problem 7:**
Photons of energy 4.98 eV are incident on a metal with a work function of 4.73 eV. What is the maximum kinetic energy of an electron emitted from the metal?
(A) 0.25 eV
(B) 1.05 eV
(C) 4.85 eV
(D) 9.71 eV
(E) 4.73 eV

## Problem 8:

Given that the binding energy of the hydrogen atom ground state is $E_0 = 13.6$ eV, the binding energy of the $n = 2$ state of positronium (positron-electron system) is

(A) $8\,E_0$

(B) $4\,E_0$

(C) $E_0$

(D) $\frac{E_0}{4}$

(E) $\frac{E_0}{8}$

## Problem 9:

The energy levels of the hydrogen atom are given in terms of the principal quantum number $n$ and a positive constant $A$ by the expression

(A) $A\left(n+\frac{1}{2}\right)$

(B) $A(1-n^2)$

(C) $A\left(-\frac{1}{4}+\frac{1}{n^2}\right)$

(D) $A\,n^2$

(E) $-\frac{A}{n^2}$

## Problem 10:

A Gaussian wave packet travels through free space. Which of the following statements about the wave packet are correct for all such wave packets?

I. The average momentum of the wave packet is zero.
II. The width of the wave packet increases with time, as $t \to \infty$.
III. The amplitude of the wave packet remains constant with time.
IV. The narrower the wave packet is in momentum space, the wider it is in coordinate space.

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

## Problem 11:

The ground state configuration of a neutral sodium atom $(Z = 11)$ is

(A) $1s^2 2s^2 2p^5 3s^2$

(B) $1s^2 2s^3 2p^6$

(C) $1s^2 2s^2 2p^6 3s$

(D) $1s^2 2s^2 2p^6 3p$

(E) $1s^2 2s^2 2p^5$

## Problem 12:

If a singly ionized helium atom in an $n = 4$ state emits a photon of wavelength 470 nanometers, which of the following gives the approximate final energy level, $E_f$, of the atom, and the $n$ value, $n_f$, of this final state?

| | $E_f$ (eV) | $n_f$ |
|---|---|---|
| (A) | −6.0 | 3 |
| (B) | −6.0 | 2 |
| (C) | −14 | 2 |
| (D) | −14 | 1 |
| (E) | −52 | 1 |

## Problem 13:

Which of the following atoms has the lowest ionization potential?

(A) $^{2}_{4}$He

(B) $^{7}_{14}$N

(C) $^{8}_{16}$O

(D) $^{18}_{40}$Ar

(E) $^{55}_{133}$Cs