Name:_______________________

PHYSICS 250

May 4, 1999

Final Exam

**Instructions:** Work all 13 problems. You may use a calculator and two pages of notes you may have prepared. There are problems of varying length and difficulty. If you have trouble with one problem, go onto another problem.

Hope you enjoyed the class.

Have a nice summer!
1. (10 pts.) The frequencies of spectral lines in light from a distant galaxy are found to be two thirds as great as those of the same lines in light from nearby stars. Find the recession speed of the distant galaxy.

2. (10 pts.) How much time does a meter stick moving at \( v = 0.3c \) relative to an observer take to pass the observer? The meter stick is parallel to its direction of motion.

3. (10 pts.) The helium-4 nucleus is composed of two neutrons and two protons. Its mass is \( M = 3728 \text{ Mev}/c^2 \). How much energy is required to break up a helium-4 nucleus into its constituent neutrons and protons?
4. (15 pts.) The sun’s mass is \( M = 2 \times 10^{30} \text{ kg} \), its radius is \( R = 7.0 \times 10^8 \text{ m} \), and its surface temperature is \( T = 5.8 \times 10^3 \text{ K} \). How long will it take for the sun to lose 1% of its mass by radiation?

5. (20 pts.) Calculate the de Broglie wavelength of

(a) A neutron with kinetic energy \( K = 10 \text{ MeV} \).

(b) An electron with kinetic energy \( K = 1 \text{ MeV} \).
6. (20 pts.) A particle is confined to the one-dimensional finite potential well of depth $V_0$ as shown in the figure below.

(a) Which of the wavefunctions shown in figures (a)-(d) is an acceptable wavefunction for a particle with energy $E_1 < V_0$?

(b) Which of the wavefunctions shown in figures (a)-(d) is an acceptable wavefunction for particle with energy $E_2 > V_0$?
7. (5 pts.) Three wavefunctions for a particle confined by a one-dimensional potential are shown below. Circle the wavefunction with the highest kinetic energy.

![Wavefunctions](image)

(a) (b) (c)

8. (20 pts.) Helium-3 is a spin-1/2 Fermion with \( M = 3.72 \times 10^3 \text{ MeV}/c^2 \). A noninteracting gas of these atoms has number density \( N/V = 6 \times 10^{21}/\text{cm}^3 \). Calculate

(a) its Fermi wavenumber \( k_F \),

(b) its Fermi energy \( E_F \).
9. (15 pts.) An electron in a hydrogen atom is in a \( 1p \) state with \( m_I = -1 \). Calculate the probability that the particle lies in the cone \( 2\pi/3 < \theta < \pi \).

10. (15 pts.) A beam of electrons with energy \( E = 1.0\,\text{eV} \) is incident on a barrier 6.00eV high and 0.200nm wide. Estimate the fraction of electrons that is transmitted through the barrier.

\[
V_0 = 6\,\text{eV} \\
E = 1\,\text{eV} 
\]
11. (20 pts.) This problem concerns the Li$^{2+}$ ion ($Z = 3$).

(a) Draw an energy level diagram for its electron states showing all states with principal quantum number $n \leq 3$. Indicate the energies, quantum numbers $n$ and $l$, and degeneracies of the states. Draw arrows showing which transitions are permitted. Ignore electron spin.

(b) What wavelength photons appear in the emission spectrum from these states?
12. (20 pts.) The Manganese atom has a total spin of $5/2$ and a total orbital angular momentum of zero.

(a) A beam of these atoms is passed through a Stern-Gerlach apparatus with average magnetic field at its center of 1.2T. How many beams of Mn atoms should be detected at the output of the apparatus?

(b) What is the wavelength of electromagnetic radiation that will flip Mn spins at the center of the apparatus? (Recall the selection rule for spin systems with zero orbital angular momentum: $\Delta m_s = \pm 1$.)

(c) If $N$ of these atoms are in equilibrium at temperature $T = 4K$ in the center of the apparatus, find the ratio of the number of atoms in the highest energy magnetic state to the lowest energy magnetic state.
13. (20 pts.) Six non-interacting electrons are placed in a 2D square well potential with sides of length 0.3nm. Calculate

(a) the ground state energy

(b) the energy and degeneracy of the first excited state. You may find it helpful to show occupancy of energy levels in an energy level diagram.