 Final Exam - PHYS 300 - Modern Physics

Mendes, Spring 2009, April 28, 2009

Start time: 11:30 a.m.

End time: 2:00 pm

Open textbook, notes, homeworks, and quizzes

Calculators allowed; no other electronic device allowed

Where it is appropriate, make sure to provide physical units to your numerical answer
1) The distance to the farthest star in our galaxy is of the order of $10^5$ light years (distance travelled by light in $10^5$ years). In principle, it is possible for a human being (which typically lives less than 100 years on the planet Earth) to travel to this star within his/her lifetime. Explain why and calculate the required velocity.
(10 points)

2) Suppose two particles approach the earth from opposite directions, one with a velocity $0.90c$ and the other with a velocity $0.70c$. What is the relative speed of approach of one particle with respect to the other?
(30 points)

3) a) Calculate the average energy of the lowest energy state of 10 non-interacting bosons (spin = integer; assume mass = m) in a one-dimensional box of length L.

b) Calculate the average energy of the lowest energy state of 10 non-interacting fermions (spin = odd/2; assume mass = m) in a one-dimensional box of length L.

c) Given two containers at the same temperature, one with a fermion gas and one with a boson gas, which will have the highest pressure? Give a physical explanation supported by your calculations above.
4) Using 23 as the atomic weight and 0.97 g/cm$^3$ as the density of metallic sodium, compute the Fermi energy (in eV) on the assumption that each sodium atom gives one electron to the conduction band.
5) If the 3s electron in sodium did not penetrate the inner core, its energy would be $-13.6 \text{ eV} / 3^2 = -1.51 \text{ eV}$ with an effective $Z_{\text{eff}} = 1$. Because it does penetrate, it sees a higher effective $Z_{\text{eff}}$ and its energy is lower (deeper in the potential well). Use the measured ionization potential of 5.14 V to calculate the $Z_{\text{eff}}$ for the 3s electron in sodium.
(20 points)

6) A hydrogen atom in the ground state is placed in a uniform magnetic field of strength $B_z = 0.55 \ T$.

a) Compute the energy splitting of the two spin states of the hydrogen atom with respect to the $z$-direction of the magnetic field.

b) If you wish to excite with electromagnetic radiation (photons) the hydrogen atom from the lower to the higher energy state calculated above, what wavelength must the photon have?