$c = 3.00 \times 10^8$ m/s, $h = 4.14 \times 10^{-15}$ eV·s; $\hbar = 6.58 \times 10^{-16}$ eV·s; hc =1240 eV·nm.

1. Please answer the following questions.

   (a) What is Fermi energy? What are the similarities and differences between photons and phonons? (5%)

   (b) Why do we specify that the foil be thin experimentally intended to check the Rutherford scattering formula? Explain why the scattering of α particles at very small angles disagree with the Rutherford formula? (5%)

   (c) Describe the phenomena of stimulated and spontaneous emissions of photons from an atom in the excited state. (5%)

   (d) Using mercury atom as an example, whose first excited state is 4.9 eV above the ground state, describe the setup of the Franck-Herz experiment and how the results can prove that atomic energy states are quantized. (5%)

2. The wave function of an simple harmonic oscillator at t = 0 is given by $\Psi(x,0) = \sqrt{\frac{4}{7}}\psi_0(x) + \sqrt{\frac{2}{7}}\psi_1(x) - i\sqrt{\frac{1}{7}}\psi_2(x)$, where $\psi_0(x), \psi_1(x)$ and $\psi_2(x)$ are the ground state, first excited state and second excited states of the system. ($\psi_0(x) = A_0 e^{-y^2/2}, \psi_1(x) = A_1 2y e^{-y^2/2}, \psi_2(x) = A_2(4y^2-2)e^{-y^2/2}$, and $y = [(km)^{1/4}/\hbar^{1/2}]x$

   (a) Normalize each eigenfunction $\psi(x)$ to determine A_0, A_1 and A_2.

   (b) Write down the wave function $\Psi(x,t)$ at time t.

   (c) Suppose you measure the energy of the oscillator at $t = 0$. Write down the possible values of the energy and the probability of measuring each.

   (d) Calculate the expectation value of the energy in the state $\Psi(x,t)$ (20%)

3. Consider a sample of noninteracting lithium atoms (Li, $Z = 3$) with the third (outer) electron in the $3p$ state in a uniform 4.0 T magnetic field. (a) Determine the fraction of the atom in various (m_s, m_l) states at 300 K. (b) In the $3p \to 2s$ transition, what will be the relative intensities of the lines of the Paschen-Bach effect? (c) How many different wavelengths will you see? (20%)

4. Two relativistic rockets move toward each other. As seen by an observer on Earth, rocket A, of proper length 500 m, travels with a speed of $0.8c$, while rocket B, of

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proper length 1000 m, travels with a speed of $0.6c$. (a) What is the speed of the rockets relative to each other? (b) The earthbound observer sets her clock to $t = 0$ when the two noses of the rockets just pass each other. What will the observer's clock read when the tails of the rockets just pass each other? (20%)

5. (Neutrons ($m = 1.67 \times 10^{-27}$ kg= 939 MeV/c^2) pass through a crystal and exhibit an interference pattern. If the neutrons have a kinetic energy of 1.7 eV, and the separation between successive maxima in the interference patter is 6.4×10^{-2} rad, what is the separation of the crystal planes that produce the interference pattern? (10%)

6. A black spherical satellite of radius 1 m orbits the Sun at a distance $D = 3.5 \times 10^{12}$ m from the center. The Sun radiates approximately as a blackbody at a temperature of about 6000 K and has a radius of $R_s = 7 \times 10^8$ m. The satellite receives radiation from the Sun and at the same time radiates this energy as a blackbody. If there is no internal energy generation and no mechanism for energy loss other than via blackbody radiation, what is the temperature of the satellite? (10%)

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