Physics 197 **Summer 2009** **Problem Set 6**

Show all calculations. Explain all assumptions. Answer in standard MKS units.
Explicitly substitute units into your symbolic equations to verify solution.
Express answers in 5 or fewer digits. Use scientific notation as appropriate.

Conceptual Questions: Answer in the space provided. Write legibly.

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1. Atoms can absorb photons, with the result that the electron 'wave' is 'lifted' from a lower energy state (smaller radius) to a higher energy state (larger radius). The emission of a photon accompanies the transition of the electron to a lower energy state. In the lowest energy (smallest radius) state, the electron cannot radiate any energy because

   a) it has zero kinetic energy
   b) the wave will not fit in a lower, smaller orbit
   c) both of the above
   d) none of the above

   Explain:

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2. For the principle quantum number n=4, how many different combinations of l and m_l can occur?

   a) 4
   b) 3
   c) 7
   d) 16
   e) 25

   Explain:

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Due on or before 7/27

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3. Using the triplet of numbers (n, l, m_l) to represent an electron with principal quantum number n, an orbital quantum number l, and a magnetic quantum number m_l, which of the following transitions are allowed?

a) (5, 2, 2) → (3, 1, 2)

b) (2, 0, 0) → (3, 0, 1)

c) (4, 3, -2) → (3, 2, 0)

d) (1, 0, 0) → (2, 1, -1)

e) (2, 1, 0) → (3, 0, 0)

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4. The Zeeman effect was instrumental in allowing physicists to manipulate the way electrons orbited atoms. The effect of this manipulation is to split the spectral lines. The spectral lines are split because…

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a) a magnetic force can slightly shift the color of a photon.
b) the magnetic force attracts some gas atoms and repels others.
c) the magnetic force alters the way electrons move in atoms.
d) the magnetic force splits photons.

Explain

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Calculation Questions: **Use** homework format. Make sure pages are in order.

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1. A neutron ($m=1.6749 \cdot 10^{-27}$ kg) is trapped in an infinite, two-dimensional potential well $15 \cdot 10^{-10}$m in length and $5 \cdot 10^{-10}$m in width. The potential energy of the system is zero everywhere inside the well, and infinite everywhere else. The particle's state is described by $\Psi_{m,n}(x,y)= [\Psi_m(x)][\Psi_n(y)]$ where $\Psi_m(x)=A_m\sin(k_m x)+B_m\cos(k_m x)$ and $\Psi_n(y)=A_n\sin(k_n y)+B_n\cos(k_n y)$ are the wave equations for x and y. The wave numbers k_n, k_m are given by the relationship

$$k = \frac{\sqrt{2m(E-U)}}{\hbar}$$

a) Apply the boundary conditions that $\Psi_m(x)=0$ at $x=0$, $x=15 \cdot 10^{-10}$ to simplify the $\Psi_m(x)$ equation and to obtain the quantized energy levels in the x dimension as a function of m.
b) Apply the boundary conditions that $\Psi_n(y)=0$ at $y=0$, $y=5 \cdot 10^{-10}$ to simplify the $\Psi_n(y)$ equation and to obtain the quantized energy levels in the y dimension as a function of n.
c) Determine the wavelength of the photon emitted when the neutron makes a transition from the state described by $\Psi_{4,3}(x,y)$ to the $\Psi_{2,1}(x,y)$ state.

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2. Show that $\psi_{100} = \frac{1}{\sqrt{\pi}}\left(\frac{Z}{a_0}\right)^{\frac{3}{2}} e^{-\frac{Zr}{a_0}}$ satisfies the time independent Schroedinger equation

$$-\frac{\hbar^2}{2m}\left(\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}\right)+U\psi = E\psi \text{, when } U(r) = \frac{-kZq^2}{r} \text{ and } E = \frac{-Z^2mk^2q^4}{2\hbar^2n^2}$$

Hint: Use spherical coordinates.

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3. In any stable two-object bound system, the two objects orbit the center of mass of the system. In the center of mass frame, the two particles have equal and opposite momentum and both have kinetic energy. To account for the relative motion, it is necessary to make a correction.

a) Writing the total energy K_{Total} as $K_1 + K_2$, where $K = p^2/2m$, show that it is possible to construct a quantity called the "*reduced mass*" [$M_{Reduced} = (m_1m_2)/(m_1 + m_2)$] and write K_{Total} as $p^2/2M_{Reduced}$.

Use the reduced mass in all following calculations involving the Bohr model. A muonium atom is composed of a proton and a μ^- particle. The μ^- particle has the same charge as an electron, but is 207 times more massive.

b) Generate an expression for the energy of this system in terms of the principle quantum number *n*. Why can you ignore the quantum numbers *l*, m_l ?
c) Identify which, if any, of the 'Balmer Series' transitions of muonium are within the 400-700nm range.

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