PHY 251 Fall 2009: homework problem set 5, due in the PHY 251 drop box in room A-129 by noon on Friday, Oct. 16.

1. A hydrogen atom is photoexcited from the $n = 1$ state to the $n = 20$ state. Calculate the photon energy needed to do this, and the photon energy needed to instead ionize the atom completely.

2. The Lyman alpha line refers to the $n = 1$ to $n = 2$ transition in hydrogen, corresponding to the absorption of a photon. For light from a distant star, we see an absorption dip due to hydrogen in the periphery of the star at a wavelength of 421 nm. How fast is the galaxy moving away from us?

3. Calculate the wavelengths of the ground state to first excited state transition for hydrogen, deuterium, and tritium. Do this with enough precision to show the differences accurately.

4. Consider a muonic atom, where a muon (charge of an electron, but with a mass 207 times larger) is captured by a proton. What's the orbital radius, binding energy of the ground state, and wavelength of radiation required to go to the first excited state? Remember reduced mass...

5. Do Serway problem 4.37: Use Bohr's model of the hydrogen atom to show that when the atom makes a transition from the state n to the state $n-1$, the frequency of the emitted light is given by
$$f = \frac{2\pi^2 m_e k^2 e^4}{h^3}\left[\frac{2n-1}{(n-1)^2 n^2}\right]$$
where $k = 1/(4\pi\epsilon_0)$. Show that as $n \to \infty$, the preceeding expression varies as $1/n^3$ and reduces to the classical frequency one would expect the atom to emit. (*Hint:* To calculate the classical frequency, note that the frequency of revolution is $v/(2\pi r)$, where r is given by Equation 4.28.) This is an example of the correspondence principle, which requires that the classical and quantum models agree for large values of n.

6. Do Serway problem 4.38: An electron with kinetic energy less than 100 eV collides head-on in an elastic collision with a massive mercury atom at rest. (a) If the electron reverses direction in a collision (like a ball hitting a wall), show that the electron loses only a tiny fraction of its initial kinetic energy, given by
$$\frac{\Delta K}{K} = \frac{4M}{m_e(1+M/m_e)^2}$$
where m_e is the electron mass and M is the mercury atom mass. (b) Using the accepted values for m_e and M, show that
$$\frac{\Delta K}{K} \simeq \frac{4m_e}{M}$$
and calculate the numerical value of $\Delta K/K$.

7. Calculate the de Broglie wavelength of a 5 eV electron, a 100 keV electron, a 1 TeV proton, and a Volkswagen Beetle covered with daisy stickers traveling at 20 m/s.

8. Serway problem 5.14: Show that the formula for low-energy electron diffraction (LEED) , when electrons are incident perpendicular to a crystal surface, may be written as

$$\sin\phi = \frac{nhc}{d\sqrt{2m_e c^2 K}}$$

where n is the order of the maximum, d is the atomic spacing, m_e is the electron mass, K is the electron's kinetic energy, and ϕ is the angle between the incident and diffracted beams. (b) Calculate the atomic spacing in a crystal that has consecutive diffraction maxima at $\phi = 24.1°$ and $\phi = 54.9°$ for 100 eV electrons.

9. Imagine making an "atom" where a nucleus of 20 neutrons has in its orbit a single neutron, where gravitational attraction rather than electrostatic attraction holds the "atom" together. Calculate the energy and radius of the ground state.