PHYS 354 — Problem Set 4

Due Jan. 17

1. The photosphere of the Sun is at a temperature of 5770 K.

a) Calculate the ratio of number of hydrogen atoms with electrons in n=2 to those in the ground state and calculate the same ratio for n=3 and the ground state.

b) The spectral line arising from the transition from n=2 to n=3 is expected to be “Doppler broadened” due to the motion of the hydrogen atoms. Calculate the width of this line expressed in nm and as a fractional broadening, that is the width divided by the wavelength of the line.

2. Calculate the temperature at which the number of hydrogen atoms in the n=2 state is equal to the number in the n=1 state. Compare your result to the temperature at which stars show the strongest hydrogen absorption lines in the visible spectrum. Discuss.

3. The density at the core of the sun is about 1.6x105 kg/m3 and the temperature is about 1.5x107K. Estimate the ratio of radiation pressure to gas pressure. What temperature would the core have to be for the two to be equal?

4. Carroll & Ostlie 8.12

5. Could the sun’s luminosity be powered by gravitational collapse? Calculate the total energy content in the sun and then determine the rate at which the radius would be changing for the sun to have its current luminosity. Would the size change in the sun be detectable? Assuming the sun always had its current luminosity how old could it be?

6. Carroll and Ostlie 10.3

7. Repeat the above calculation for nuclear fission. First, assume the Sun is made entirely of thorium-232 (?!?) and that the thorium is being converted to lead-208. What would the fission lifetime be? Of course, the Sun doesn't appear to be made of thorium, so assume only the inner 10% of the mass is Thorium and that this thorium is producing the energy that is transported to the hydrogen layer above. Calculate the fission lifetime in under these conditions. Is there enough energy released to account for Sun's luminosity in either case? This is a bizarre model since we don't see all that much thorium on Earth or anywhere else and we would have to account for the radioactive lifetimes of the various nuclei in the decay chain.

8. A better model would be to assume that fusion is occurring in a Sun made entirely of hydrogen. First, calculate the fusion lifetime assuming all the hydrogen becomes iron. Repeat, the calculation taking the hydrogen only as far as helium. The most realistic model says that only 10% of the hydrogen is at high enough pressure to fuse into helium so repeat the calculation only allowing 10% of the mass to be converted from hydrogen to helium. In all of these models can fusion support the Sun's luminosity?

9. We will derive an expression for the energy of the Gamow peak by differentiating the integrand (f(E)) in the nuclear reaction rate expression and setting the result equal to zero. a) Do a second-order Taylor series expansion of f(E) around the Gamow energy E0 to approximate f(E) as a Gaussian. Determine the width of the Gamow peak, , taking it as the standard deviation of the Gaussian approximation of f(E). b) Express the width of the Gamow peak as a fraction of the Gamow peak energy and evaluate this fractional width numerically for the sun. c) Use the Gaussian approximation of f(E) to find an expression for the integral of f(E)dE over all energies in terms of f(E0) and .

10. Carroll and Ostlie 10.4