Astro 112 – Physics of Stars
Problem Set #3, Spring 2017
Due in class on Monday, May 8, 2017

1) Calculate the amount of energy released or absorbed in the following reactions. Express your answers in MeV:

a) $^{12}C + ^{12}C \rightarrow ^{24}Mg$

b) $^{12}C + ^{12}C \rightarrow ^{16}O + 2\ ^{4}He$

c) $^{19}F + ^{1}H \rightarrow ^{16}O + ^{4}He$

The mass of ^{12}C is 12.0000 amu, and ^{4}He=4.0026, ^{16}O=15.9949, ^{19}F=18.9984, ^{24}Mg=23.9850. 1 amu=1.6605 x 10^{-27} kg. (*10 points*)

2) Consider a star with radiative outer layers in hydrostatic equilibrium, meaning that equations 3.69/3.70 hold. We are investigating conditions fairly close to, *but just below the surface*, such that the local luminosity ("little l," or "L_r," what the books calls F) is constant, at the surface value of the star (L), and that the local enclosed mass (little m) is equal to M. Assume that at the outer boundary $T = 0$ and $P = 0$ at radius $r = R$ and $m(r) = M$. Find an expression for how T depends on r within the star, assuming opacity κ and μ are constant. Recall that ρ will be a function of r. The gas is ideal. (*14 points*)

3) The Sun's luminosity is a known, 3.8 x 10^{26} W. That energy/sec is currently entirely supplied by nuclear reactions. Assume 26.7 MeV per nuclear reaction for $^{1}H \rightarrow ^{4}He$. (*10 points*)

a) How many reactions per second are taking place in the Sun right now?

b) How much mass is lost from the Sun in one second?

c) How much mass is lost from the Sun in 10^{10} years, and what fraction of the Sun's total mass is this?

d) Two neutrinos are created for every reaction. What is the flux of neutrinos at 1 AU? Express your answer in # per second per cm^2. (1 cm^2 is about the area of your thumbnail)

e) The PPI chain actually yields 26.2 MeV per reaction and PP3 yields 19.2 MeV, because neutrinos steal some energy. If the Sun, for whatever, reason, needed to switch entirely from PP1 to PP3, would your answers to a)-d) increase, or decrease, and why? Assume the L_{Sun} stays the same.

4) The centers of massive stars are hot enough for radiation to provide a significant fraction of the total pressure. We therefore want to understand the equation of state for gas in this regime. We will limit our attention to fully ionized gasses of solar composition where the gas and radiation field are at the same temperature, and the ideal gas law holds. Derive an expression for $\beta = P_{gas}/(P_{gas} + P_{rad})$, the fraction of the total pressure provided by gas, in terms of the gas density ρ and temperature T. Using this result, obtain the relationship between density and temperature in a gas for which $\beta = 0.5$, i.e. gas provides 50% of the total pressure. Evaluate the temperature required to satisfy this condition for $\rho = 10$ g/cm^3. (*6 points*)