Physics 777: Introduction to Astrophysics

Problem Set 3

Due: —

1 Stellar Evolution

1. Consider the life cycle of a star that has roughly the mass of the Sun. The star will go through several distinct evolutionary stages. Copy the following table and fill it up, indicating for each of the listed stages the approximate surface temperature of the star, its approximate radius and luminosity, the primary source of energy during this stage (if nuclear fusion, indicate both the element that is being fused and the final product of the fusion), the approximate duration of the stage, and a brief (one or two sentences) description of your answers.

Stage Name	**Temperature [K]**	**Radius [$R_\odot$]**	**Luminosity [$L_\odot$]**	**Source of Energy**	**Duration [yr]**	**Brief Description**
Protostar						
Main Sequence						
Horizontal Branch						
White Dwarf						

2. A star has a luminosity that is 10^4 times that of the Sun, and a mass that is roughly ten times that of the Sun.
   (a) What is the approximate lifetime of this star?
   (b) What process will mix the contents of the material in the core of this star?
   (c) Will this star enter a red giant phase at the end of main sequence hydrogen burning at its core? Why or why not?
   (d) What will be the final endpoint in the evolution of this star?

2 Stellar Remnants

1. A failed star is called a brown dwarf. These objects are not massive enough to develop the conditions necessary to fuse hydrogen in their cores. Assuming that hydrogen fusion requires central temperatures of $\geq 10^7$ K, estimate the mass below which electron degeneracy pressure provides core support before fusion begins.

2. Consider an exotic substance that exerts a pressure that is proportional to the square of its density–i.e. it has an equation of state that is given by:

$$P = K\rho^2$$

   where K is some constant. Show that a uniform-density sphere made from this substance must maintain one specific size, regardless of its mass.

3. Show that the equation of state for electron degenerate matter can be written as,

$$P = \frac{\pi m_e^4 c^5}{3h^3} f(x) \tag{1}$$

   where $x = p_F/m_e c$ and,

$$f(x) = x(2x^2 - 3)\sqrt{x^2 + 1} + 3\sinh^{-1}(x) \tag{2}$$

4. Using the equation of state for degenerate electron matter, numerically solve for the mass-radius relation for a star supported by electron degeneracy pressure (make a plot of this relation). Show that the radius goes to zero at the Chandrasekhar mass.