Stellar Astrophysics, Fall 2024

Problem Set VI

Deadline: 5PM of Thursday, November 28, 2024

1. **Fusion probabilities (15%).** In class, we show that the quantum-mechanical penetration of a Coulomb barrier plays a crucial role in thermonuclear fusion.

   (a) (5%) Find the classical distance of closest approach for two protons with an energy of approach equal to 2 keV.

   (b) (5%) Estimate the probability that the protons penetrate the Coulomb barrier tending to keep them apart. *Hint:* The Gamow energy for the fusion of two protons is $E_G = 493$ keV.

   (c) (5%) Estimate the probability for two ^{4}He nuclei with the same energy of approach and compare with the result from (b). *Hint:* The Gamow energy for the fusion of two ^{4}He nuclei is $E_G = 31.6$ MeV.

2. **The CNO cycle (25%).** Consider hydrogen burning by the CNO cycle as discussed in class.

   (a) (10%) Show that, at a temperature of 1.5×10^7 K, the slowest reaction in the cycle is

   $$p + {}^{14}\mathrm{N} \rightarrow {}^{15}\mathrm{O} + \gamma.$$

   (b) (10%) Estimate the temperature dependence of the CNO cycle.

   (c) (5%) It is thought that about 1.6% of the solar luminosity is generated by the CNO cycle. Estimate by how much this would change if the central temperature of the Sun were increased by 1%.