UNIVERSITY OF KANSAS
Department of Physics and Astronomy
Physical Astronomy (ASTR 391) — Prof. Crossfield — Spring 2022

Problem Set 6
Due: Monday, April 6, 2022, 11am Kansas Time
This problem set is worth **50 points**.

As always, be sure to: show your work, circle your final answer, and use the appropriate number of significant figures.

1. **Nuclear binding energies [15 pts]**

   For each of the following nuclear reactions, look up the mass of each of the following nuclei (e.g., on Wikipedia) and calculate ΔM, the change in mass from the ingredients to the products, in atomic mass units (amu). Then, via $\Delta E = \Delta M c^2$ (and/or by noting that $[1\mathrm{amu}\ c^2 \approx 931.494\ \mathrm{MeV}]$) compute the amount of energy released or absorbed by each reaction ($\Delta E > 0$ means energy is released).

   (a) $4\ p \rightarrow {}^{4}_{2}\mathrm{He}$ (the total p-p chain)
   (b) $3\ {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}\mathrm{C}$ (the triple-α reaction)
   (c) ${}^{12}\mathrm{C} + {}^{12}\mathrm{C} \rightarrow {}^{24}\mathrm{Mg}$
   (d) ${}^{12}\mathrm{C} + {}^{12}\mathrm{C} \rightarrow {}^{16}\mathrm{O} + 2{}^{4}\mathrm{He}$
   (e) ${}^{19}\mathrm{F} + {}^{1}\mathrm{H} \rightarrow {}^{16}\mathrm{O} + {}^{4}\mathrm{He}$
   (f) ${}^{1}\mathrm{H} + {}^{1}\mathrm{H} \rightarrow {}^{2}\mathrm{H} + e^{+} + \nu$
   (g) $56\ p \rightarrow {}^{56}\mathrm{Fe}$ (the full process, occurring only in the most massive stars)

2. **Final Fates of Stars [20 pts].** Starting with its life on the main sequence, enumerate and describe the main stages in the life of a star with an initial (main-sequence) mass of:

   (a) $0.2 M_{\odot}$
   (b) $1 M_{\odot}$
   (c) $2 M_{\odot}$
   (d) $10 M_{\odot}$
   (e) $20 M_{\odot}$
   (f) $40 M_{\odot}$

3. **Compact Objects [15 pts].**

   (a) What are the typical mass and size of a **white dwarf**? From these numbers, calculate (in SI units) a typical white dwarf's average density, surface gravity, and roughly estimate (via $dP/dr \sim P_c/R = \rho g$) its central pressure P_c.
   (b) What are the typical mass and size of a **neutron star**? From these numbers, calculate (in SI units) a typical neutron star's average density, surface gravity, and roughly estimate (via $dP/dr \sim P_c/R = \rho g$) its central pressure P_c.
   (c) What is a typical mass of a stellar-remnant **black hole**? What is the size of its event horizon? From these numbers, calculate (in SI units) the surface gravity at the event horizon. Describe how the surface gravity would change if the black hole were more massive.