**UNIVERSITY OF KANSAS**
Department of Physics and Astronomy
Physical Astronomy (ASTR 391) — Prof. Crossfield — Spring 2024

**Problem Set 5**
**Due**: Monday, February 26, 2024, 10am Kansas Time
This problem set is worth **35 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 $\Delta M$, 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 $[1\mathrm{amu}\, c^2 \approx 931.494\,\mathrm{MeV}]$): (i) compute the amount of energy released or absorbed by each reaction, (ii) state explicitly whether energy is released or absorbed ($\Delta E > 0$ means energy is released), and (iii) calculate the overall efficiency of each reaction.

   **WARNING:** don't just read the masses of these nuclei off of the periodic table — the masses listed there are averages over all isotopes of that particular element. Instead, you need to look up the mass of the particular isotope of the particular element listed below. For example: carbon on the periodic table is listed as having a mass of 12.011 amu... but the mass of Carbon-12 ($^{12}$C) is *exactly* 12.0000..., by definition. These small differences are important when it comes to nuclear reactions!

   (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-$\alpha$ 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) $40 M_\odot$