# Homework #7

$p$-nuclei formation, $r$-process

Assigned: April 19, 2021 Due: April 26, 2021

*Percentages for each problem of the total grade (100%) as given. Sub-problems, if present, split the problem's percentage equally. Please show your work!*

## Problem 1 The Distance of Gamma-Ray Bursts (20%)

Assume that the measured energy fluence of a gamma-ray burst is $10^{-7}\,\mathrm{J\,m^{-2}}$. Calculate the energy of the original event assuming that:

a. The source is in the Oort cloud of comets within our Solar System at a distance of 50 kAU.

b. The source is extragalactic at a distance of 1 Gpc.

Compare these energies to each other and to other stellar events.
*(Problem adopted after example 4.1 in Carroll & Ostlie (2017), "An Introduction to Modern Astrophysics", 2nd edn. (Cambridge University Press)[1])*

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## Problem 2 Uranium in the Early Solar System (20%)

Natural uranium consists of two isotopes that are long-lived enough to have survived the 4.567 Ga since the formation of the Solar System. These are $^{235}$U with a half-life of $7.038 \times 10^8$ a and $^{238}$U with a half-life of $4.468 \times 10^9$ a. The current abundance of these uranium isotopes is 0.00724 and 0.992742, respectively.

a. Calculate the uranium isotopic composition in the early Solar System.

[1] doi: 10.1017/9781108380980

b. Assuming that the $r$-process makes $^{235}$U and $^{238}$U in equal proportions, when did the $r$-process take place that formed our uranium?

c. Bonus 5%: Would the $^{235}$U enrichment in the early Solar System be enough to drive a nuclear power plant without further enrichments? How about a nuclear weapon?

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### Problem 3 Primary vs. Secondary Processes (20%)

Explain the difference between a primary versus a secondary nucleosynthesis process. Discuss for the $s$- and $r$-process the category they fall into. Are the $p$-nuclei formed in a primary or secondary process? Explain.

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### Problem 4 *s*-, *r*-, and *p*- nuclei (20%)

Give examples of 5 nuclei each that are $s$-only, $r$-only, and $p$-only and state why these nuclei cannot be made by other processes. Hint: You can assume that $^{100}$Mo is almost exclusively an $r$-only nucleus.

A chart of the nuclides might help with this exercise. If you don't have a paper copy, you can find many free, online versions. A very detailed chart can be found on the website of the International Atomic Energy Agency (IAEA).[2]

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### Problem 5 Neutron Density in *r*-Process (20%)

The neutron density in the $r$-process is variable, but a typical value would be $\rho_n \sim 10^{22}\,\mathrm{cm}^{-3}$. One neutron has a mass of $m_n = 1.674 \times 10^{-27}\,\mathrm{kg}$. Calculate the density of the neutrons and compare to water, which has a density of $1\,\mathrm{g\,cm}^{-3}$. Why does the $r$-process not take place in the ocean?

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[2] https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html