Tutorial: Nuclear Reactions

Equations and Relations:

Half life: The number of remaining atoms after x half-lives is $N = N_0/2^x$

Energy $E = mc^2$
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$1\ u = 931.502\ MeV/c^2$

1. Energy from nuclear fission.

A. The uranium atom can also fission into Rb and Cs atoms. Fill in the missing term in the following nuclear reaction: $U^{235} + n \rightarrow Rb^{93} + Cs^{141} +$ _____

B. Given that $m(U^{235}) = 235.043924$ u, $m(Rb^{93}) = 92.92172$ u, $m(Cs^{141}) = 140.91949$ u, and m(n) = 1.00866501 u, find the energy released in this reaction.

C. In uranium-235 there are (6.022×10^{23} atoms/mole) / (235.043924 g/mol) = 2.562074 atoms/g.

A. How many atoms of U^{235} are there in 1.00 kg of material?

B. How much energy (in MeV) is released from fission for 1 kg of U^{235}?

C. How much energy is this in Joules? ($1\ eV = 1.602 \times 10^{-19}$ J)?

Check Point

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2. Nuclear decay half-life.

A supernova produces heavy elements like U^{235} and U^{238}. Since the masses of these two elements are very similar (as compared to say Co^{59}) they were produced in equal amounts. For a two element system, the initial ratio r(0) of an element (N_1) to the total number ($N_{tot} = N_1 + N_2$) can be found by $r(0) = \frac{N_1}{N_1 + N_2}$.

A. What was the original ratio r(0) of U^{235} for a sample containing U^{235} and U^{238}?

Suppose the age of the formation of these elements (the supernova out of which our solar system formed) to be measured at approximately 6 billion years (6×10^9 yr.)[1].

B. The half-life for U^{235} is 7.0×10^8 yr. About how many U^{235} half-lives ago was the supernova?

C. The half-life for U^{238} is 4.5×10^9 yr. About how many U^{238} half-lives ago was the supernova?

The ratio at a given time is: $r(t) = \frac{N_1 e^{-\lambda_1 t}}{N_1 e^{-\lambda_1 t} + N_2 e^{-\lambda_2 t}}$, but by using our relation for the half-life we can approximate this equation as

$$r(t) = \frac{\left(\frac{1}{2^{(Number\,U^{235}\ half-lives)}}\right)}{\left(\frac{1}{2^{(Number\,U^{238}\ half-lives)}}\right) + \left(\frac{1}{2^{(Number\,U^{235}\ half-lives)}}\right)}.$$

D. Determine the approximate current ratio of U^{235} for a sample containing U^{235} and U^{238}.

The natural abundance as measured from a variety of mineral sources has a ratio r(t) of 0.00720.

D. What is the percentage difference of the calculated and measured ratios?

E. What conclusion can be made from this?

[1] Data from K. Krane, *Introductory Nuclear Physics*, (Wiley, 1988).
Random answers: 0.00658, 0.5, 1.33, 2, 8.57, 8.6, 180.757, 7.419×10^{13}, 4.63113×10^{26}.