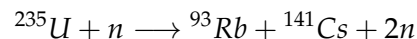


Please write your answers clearly and neatly. **Include your working!** Answers without proper reasoning will receive no marks. For some questions you will need to look up atomic masses, periodic tables etc.

Hand in solutions to ALL questions. ONE of these will be marked and will count towards your class record.

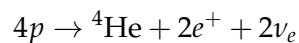
1. The isotopes Plutonium-240 and -241 have activation energies 6.3 MeV and 6.0 MeV respectively. Compare these to the excitation energy after absorbing a neutron. Which will fission from just a thermal neutron and why? For the case that would not fission, what would be the velocity (in m/s) a neutron would need to possibly induce fission? 10

2. The bomb dropped on Hiroshima 'Little Boy' had a blast yield of 15 kilotons of TNT. The main fissile material in the bomb was ^{235}U . Assume that the fission reaction 10



was a typical reaction in the explosion. How many ^{235}U nuclei underwent fission? How much ^{235}U underwent fission in the bomb, in kg? (You can use the energy released in 1 ton of TNT as $4 \times 10^9\text{J}$)

3. In the sun, one of the dominant fusion reaction is the PPI chain, which has the net reaction 10



Calculate the Q value for this reaction. The energy output from the sun is about $3.846 \times 10^{26}\text{ W}$. How many protons per second are converted into Helium assuming this is the main reaction taking place?

Some (potentially) useful information:

The radius of a nuclei may be approximated by $R \approx 1.2A^{1/3}$ fm.

The semi-empirical mass formula (SEMF) for the binding energy of a nucleon is

$$B(Z, A) = a_V A - a_S A^{2/3} - a_C \frac{Z(Z-1)}{A^{1/3}} - a_A \frac{(A-2Z)^2}{A} + \delta(Z, A).$$

Constants in the SEMF: $a_V = 15.56, a_S = 17.23, a_C = 0.697, a_A = 23.28, a_P = 12.0$ where each number is in MeV.

Nuclear Shells: Protons

$$1s_{\frac{1}{2}} \downarrow_2 \quad 1p_{\frac{3}{2}} \downarrow_4 \quad 1p_{\frac{1}{2}} \downarrow_2 \quad 1d_{\frac{5}{2}} \downarrow_6 \quad 1d_{\frac{3}{2}} \downarrow_4 \quad 1d_{\frac{1}{2}} \downarrow_2 \quad 1f_{\frac{7}{2}} \downarrow_{10} \quad 2p_{\frac{3}{2}} \downarrow_4 \quad 1f_{\frac{5}{2}} \downarrow_6 \quad 2p_{\frac{1}{2}} \downarrow_2 \quad 1g_{\frac{9}{2}} \downarrow_{10} \quad 1g_{\frac{7}{2}} \downarrow_8 \quad 2d_{\frac{5}{2}} \downarrow_6 \quad 1h_{\frac{11}{2}} \downarrow_{10} \quad 2d_{\frac{3}{2}} \downarrow_4 \quad 3s_{\frac{1}{2}} \downarrow_2 \quad 1h_{\frac{9}{2}} \downarrow_8 \quad 2f_{\frac{7}{2}} \downarrow_8 \quad \dots$$

Shells: Neutrons

$$1s_{\frac{1}{2}} \downarrow_2 \quad 1p_{\frac{3}{2}} \downarrow_4 \quad 1p_{\frac{1}{2}} \downarrow_2 \quad 1d_{\frac{5}{2}} \downarrow_6 \quad 1d_{\frac{3}{2}} \downarrow_4 \quad 1d_{\frac{1}{2}} \downarrow_2 \quad 1f_{\frac{7}{2}} \downarrow_{10} \quad 2p_{\frac{3}{2}} \downarrow_4 \quad 1f_{\frac{5}{2}} \downarrow_6 \quad 2p_{\frac{1}{2}} \downarrow_2 \quad 1g_{\frac{9}{2}} \downarrow_{10} \quad 2d_{\frac{5}{2}} \downarrow_6 \quad 1g_{\frac{7}{2}} \downarrow_8 \quad 1h_{\frac{11}{2}} \downarrow_{10} \quad 2d_{\frac{3}{2}} \downarrow_4 \quad 3s_{\frac{1}{2}} \downarrow_2 \quad 2f_{\frac{7}{2}} \downarrow_8 \quad 1h_{\frac{9}{2}} \downarrow_8 \quad \dots$$

$\frac{e^2}{4\pi\epsilon_0}$	= 1.439965 MeV fm
Boltzmann's constant	$k_B = 8.6173303 \times 10^{-5}$ eV/K
Planck's constant	$h = 4.135668 \times 10^{-15}$ eV s
Speed of light	$c = 2.99792 \times 10^8$ m/s
Neutron mean lifetime	881 s
Atomic mass unit	$1 u = 931.4940954 \text{ MeV}/c^2 = 1.66054 \times 10^{-27}$ kg
Mass of electron	$m_e = 5.4858 \times 10^{-4} u = 0.51099895 \text{ MeV}/c^2$
Mass of proton	$m_p = 1.00727646688 u = 938.27208 \text{ MeV}/c^2$
Mass of neutron	$m_n = 1.00866491578 u = 939.56541 \text{ MeV}/c^2$
Mass of ^1_1H	= 1.00782503 u
Mass of ^2_1H	= 2.01410178 u
Mass of ^3_1H	= 3.01604927 u
Mass of ^3_2He	= 3.01602932 u
Mass of ^4_2He	= 4.00260325 u
Mass of $^{232}_{90}\text{Th}$	= 232.038055 u
Mass of $^{234}_{90}\text{Th}$	= 234.043601 u
Mass of $^{235}_{92}\text{U}$	= 235.043930 u
Mass of $^{236}_{92}\text{U}$	= 236.045568 u
Mass of $^{238}_{92}\text{U}$	= 238.050788 u
Mass of $^{239}_{92}\text{U}$	= 239.054293 u
Mass of $^{240}_{94}\text{Pu}$	= 240.053811 u
Mass of $^{241}_{94}\text{Pu}$	= 241.056849 u
Mass of $^{242}_{94}\text{Pu}$	= 242.058741 u
Mass of the Sun	$M_{\odot} = 1.988 \times 10^{30}$ kg
Gravitational constant	$G = 6.67408 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$

Nuclei masses given are atomic masses.

You can look up other nuclear data from websites

<https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html>

<http://www.nndc.bnl.gov/nudat2/>

<http://atom.kaeri.re.kr/nuchart/>

<http://people.physics.anu.edu.au/~ecs103/chart/>