



SPA5302 NUCLEAR PHYSICS & ASTROPHYSICS 2019
 HOMEWORK SET 4 HAND IN: FRIDAY 22 NOVEMBER BY 4PM

*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. (a) Calculate the Q values for a free proton to undergo β^+ decay, and for a proton in ${}^1\text{H}$ to undergo electron capture. Comment on your answers.
 (b) By considering Q values, show that it could be energetically possible for a nuclei to undergo electron capture but not β^+ decay. Explain why the converse is not true.
2. (a) ${}^{196}\text{Au}$ can β -decay in all 3 possible ways. Calculate the Q value for each possible decay.
 (b) Explain, with the aid of a diagram, why there are no stable odd-odd nuclei.
3. Use the semi-empirical mass formula to show that the condition for β^- decay to occur in odd- A nuclei is

$$Z < \frac{2(A-1)a_A + 0.391A \text{ MeV}}{A^{2/3}a_C + 4a_A}.$$

On an isotone in the nuclear landscape, what does this say about where β^- decay will occur?

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

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

Shells: Neutrons

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

$\frac{e^2}{4\pi\epsilon_0}$	= 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
Neutrino 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 $^{233}_{92}\text{U}$	= 233.043930 u
Mass of $^{235}_{92}\text{U}$	= 235.045568 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/>