



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.

- (a) Calculate the potential energy in MeV due to Coulomb repulsion of: a gold nucleus ($Z = 79$) and an α -particle with centres 10 fm apart. 5

(b) Calculate the binding energies of ${}^2_1\text{H}$, ${}^4_2\text{He}$ and ${}^6_3\text{Li}$, and hence the energy released in the fusion reaction ${}^2_1\text{H} + {}^6_3\text{Li} \rightarrow 2{}^4_2\text{He}$. 5
- Use the SEMF to predict the *atomic* mass of ${}^{238}\text{U}$ in atomic mass units. Compare this to the real value and calculate the difference in MeV. Hence estimate the percentage error. 10
- Mirror nuclei are pairs of nuclei with the same mass number A but with the number of protons and neutrons 'swapped', e.g., ${}^{14}_8\text{O}$ and ${}^{14}_6\text{C}$. By considering the mirror nuclei ${}^{19}\text{Ne}$ and ${}^{19}\text{F}$, use measured values of their binding energies and the SEMF to estimate the value of the constant multiplying the Coulomb term, a_C . Compare with the value quoted over the page, and comment on your answer. 10
- Consider isobars of nuclei with $A = 75$. Look up the atomic masses of these nuclei in the range $Z = 28$ to $Z = 38$. Make an accurate sketch of atomic mass versus Z for this isobar (you can plot the data on a computer if you like). Now do the same for the isobar with $A = 76$. With reference to the SEMF, discuss the qualitative difference between the figures. 10

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

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

Shells: Neutrons

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

$\frac{e^2}{4\pi\epsilon_0}$	= 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 $^{235}_{92}\text{U}$	= 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/>