Supplementary Worksheet #9
Binding Energy and the SEMF of the Nucleus

1 Binding Energy

1. What is **binding energy**?
2. What does binding energy tell us about nuclear stability?
3. Show that the binding energy can be written as

$$BE = ZM_H + (A - Z)m_n - M(A, Z).$$

4. Using tabulated masses, calculate the nuclear binding energy of $^{10}_{5}\mathrm{B}$.
   a) Use the proton and neutron masses from the NIST database:
   `https://physics.nist.gov/cgi-bin/cuu/Value`
   b) What do the numbers in parentheses next to the masses mean?
   c) Use the atomic mass of $^{10}_{5}\mathrm{B}$ from the IAEA Live Chart of Nuclides:
   `https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html`

SEMF

5. Sketch and explain the key features of the binding energy per nucleon as a function of A.
6. Describe the physical meaning of each term in the semi-empirical mass formula (SEMF):
   a) **Volume term**
   b) **Surface term**
   c) **Coulomb term**
   d) **Asymmetry term**
   e) **Pairing term**
7. How do the different terms in the semi-empirical mass formula (SEMF) explain the overall shape of the binding-energy-per-nucleon curve?
   In your answer, discuss:
   a) why the binding energy per nucleon initially increases with mass number A;
   b) why it reaches a maximum for medium-mass nuclei; and
   c) why it gradually decreases for heavy nuclei.

Mass Chains

8. What is a **mass chain**?

9. Show that the value of Z that minimises the mass (or maximises the binding energy) for a given mass number A is given by

$$Z_{\text{min}} = \frac{m(n) - M(^1_1\text{H}) + a_{\text{coulomb}}\, A^{-1/3} + 4a_{\text{symmetry}}}{2a_{\text{coulomb}}\, A^{-1/3} + 8a_{\text{symmetry}}\, A^{-1}}.$$

Q-value

The Q-value for a reaction is defined by

$$Q = (\text{initial mass}) - (\text{final mass}) = (M_i - M_f)c^2.$$

10. Show that

$$Q = T_f - T_i,$$

where T_i and T_f are the total initial and final kinetic energies, respectively.
Is this relationship always true?

11. Consider the reaction

$$^{10}\text{B} + n \rightarrow ^{11}\text{B}^* \rightarrow \alpha + ^7\text{Li} + \gamma.$$

a) How is the Q-value related to the binding energies of the nuclei in the initial and final states?

b) Calculate the Q-value of this reaction using data from the IAEA Live Chart of Nuclides:
`https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html`

c) Confirm your result using `QCal`.
`https://www.nndc.bnl.gov/qcalc/`

d) What does the sign of the Q-value tell you about the reaction?

e) Using the JANIS nuclear data system,
`https://www.oecd-nea.org/janis/`
determine the resonance energy for this reaction.