University of Pittsburgh

ME/ENGR 2100 Fundamentals of Nuclear Engineering

Radiation and Nuclear Reactions:

Binding Energy

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Relevant Reading Assignments

- Chapter 2/3 of "Introduction to Nuclear Engineering," Lamarsh and Baratta, 3rd edition, Prentice-Hall (2001)
- Chapter 2 of "Nuclear Engineering: Theory and Technology of Commercial Nuclear Power," Knief, 2nd edition, American Nuclear Society (1992, reprint by ANS 2008)
- Chapter 2 of "Nuclear Reactor Analysis," Duderstadt and Hamilton, Van Nostrand (1976)
- Module 1 of DOE Fundamentals Handbook, "Nuclear Physics and Reactor Theory," U.S.DOE (1993)Available at:

https://www.standards.doe.gov/standards-documents/1000/1019-bhdbk-1993-v1

- Not required but useful and clear is the discussion of nuclear masses and binding energies at the beginning of Chapter 7 of "Concepts of Nuclear Physics" by Bernard L. Cohen, McGraw-Hill, 1971, available in most scientific libraries.

Learning Objectives

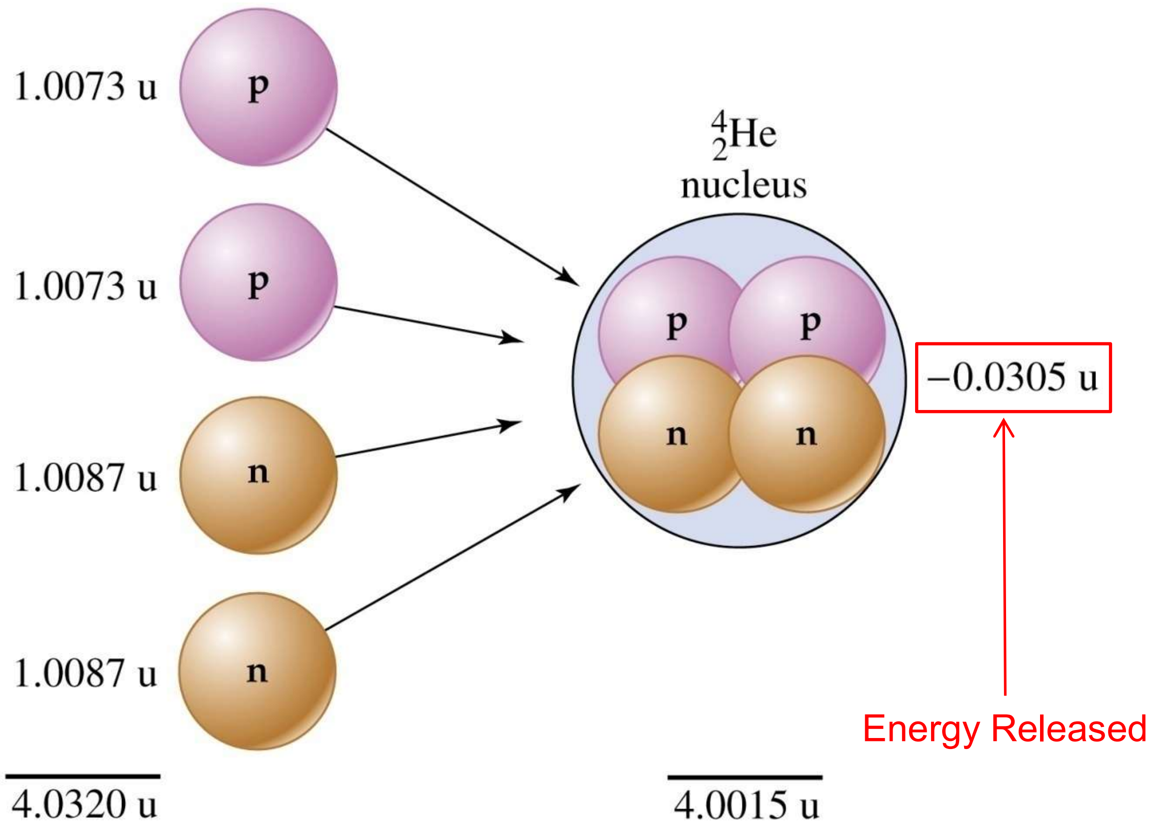
- Define binding energy and calculate for a nuclide using the principle of mass defect

Define binding energy and calculate for a nuclide using the principle of mass defect

Nuclear Binding Energy

- Due to the structure of the nucleus and the balance of forces, nucleons bound in a nucleus are more stable (have a lower energy) than free nucleons.
- When bound, each nucleon turns a small fraction of its mass into energy, which is typically radiated from the nucleus.
- This binding energy must then be added to the nucleus if we wish to remove (unbind) a nucleon.

Nuclear Binding Energy



- The binding energy can be seen as a mass defect between the weight of the nucleus and the individual (unbound) weights of its constituent nucleons.
- $E=mc^2$ – Lots of energy for a very small mass defect

u = abbreviation for amu

Nuclear Binding Energy

- Mass Defect:

$$\Delta = \text{Mass}_{\text{bound nucleus}} - \sum \text{Mass}_{\text{constituents}}$$

- Mass Energy Equivalence: $E = mc^2$
  - Watch your units!
- Binding Energy:

$$\text{Binding Energy} = \left[\text{Mass}_{\text{bound nucleus}} - \sum \text{Mass}_{\text{constituents}}\right] c^2$$

Calculating Binding Energy

- To calculate mass defect using tabulated masses of neutral atoms

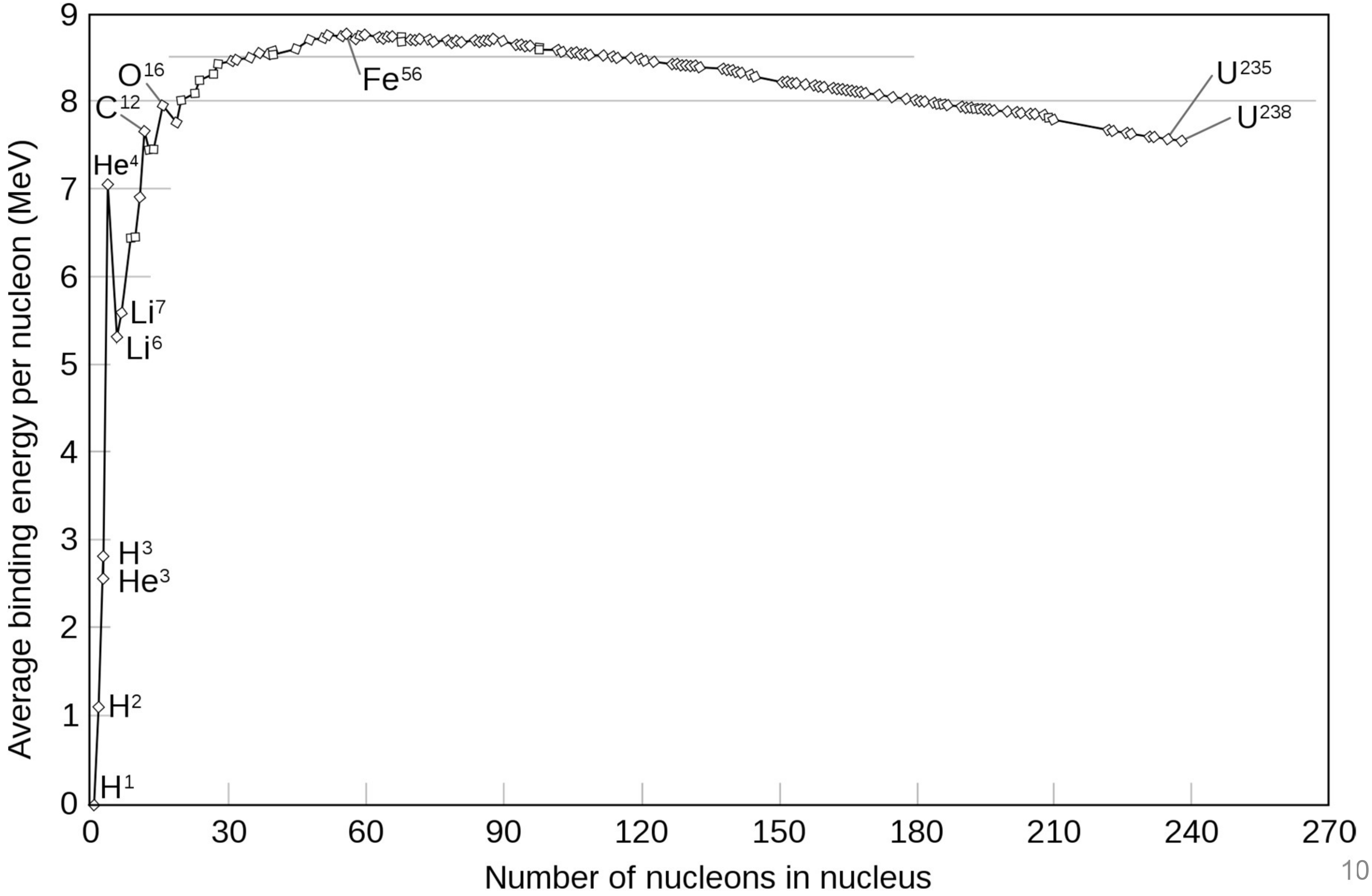
$$\Delta = ZM(^{1}H) + NM_{n} - M$$

  - Z is the atomic number
  - N is neutron number
  - M is atomic mass of the neutral atom
  - $M(^{1}H)$ is atomic mass of ^{1}H
  - M_n is neutron mass
- We need to use the formula above because binding energy represent the change in mass between the constituents of the nucleus and the bound nucleus but we commonly tabulate neutral atom masses and not just nucleus masses
- **The difference between the mass of H1 and a proton is the electron**

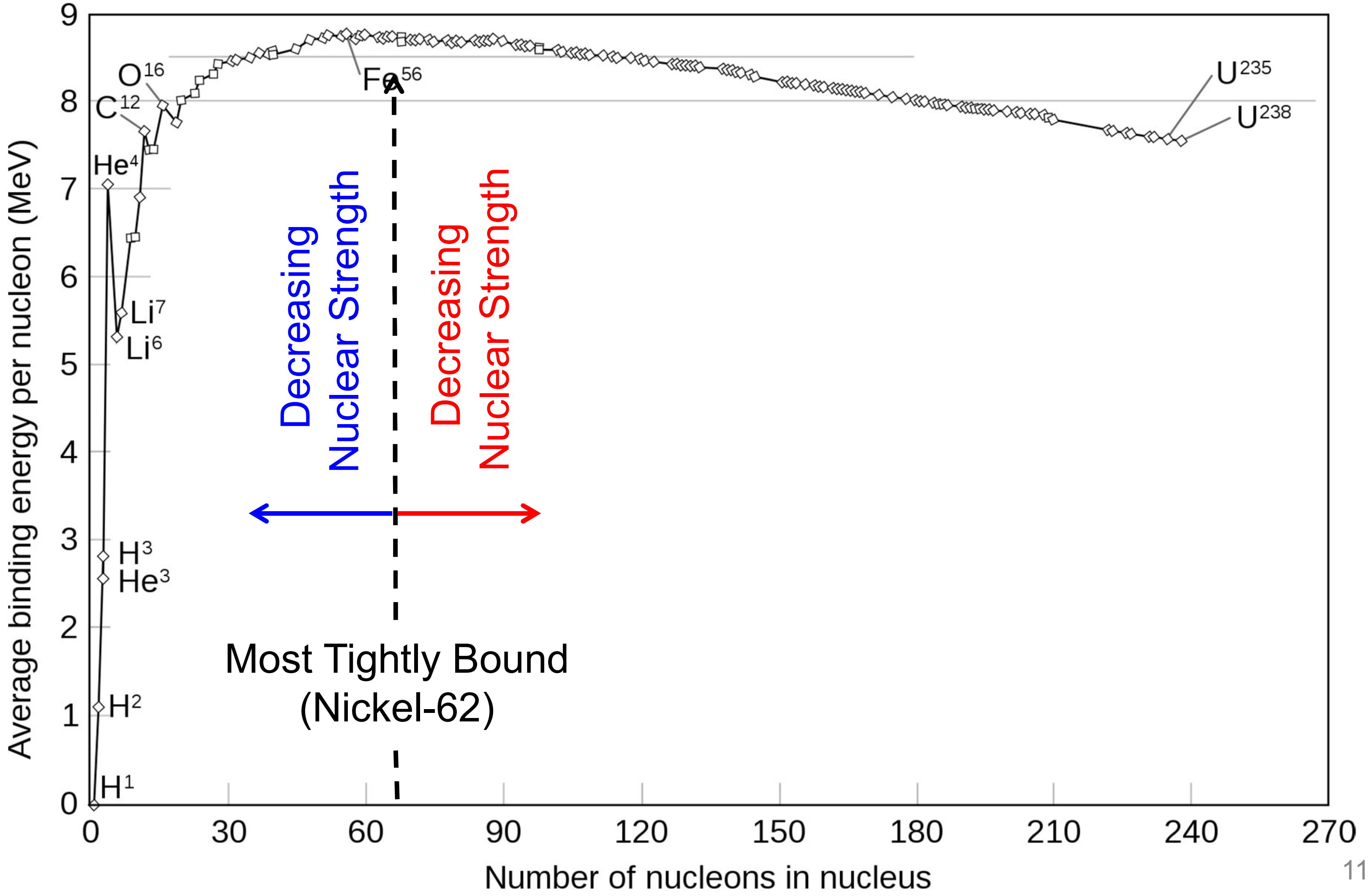
Binding Energy Tips

- Nuclei are more stable than free nucleons.
- The binding energy provides a measure of how tightly bound a nucleus is.
  - Nuclei with larger binding energies require more energy to break apart.
- Binding Energy Per Nucleon
  - Gives a measure of the forces acting on each nucleon in the nucleus.
  - Amount of energy required to rip a single nucleon out of the nucleus.

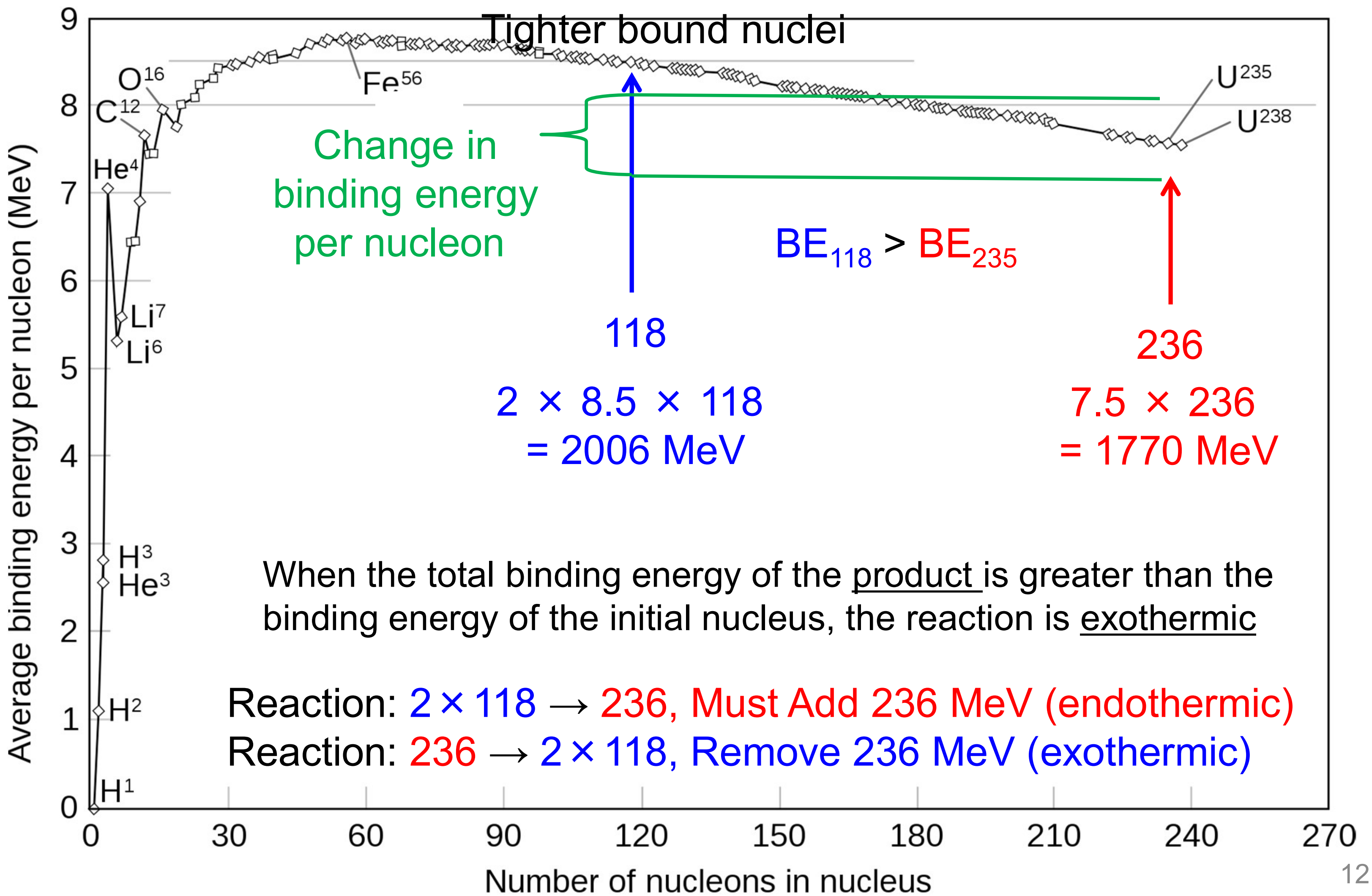
Binding Energy Per Nucleon



Binding Energy Per Nucleon



Binding Energy Example



$2 \times 8.5 \times 118$
$= 2006$ MeV

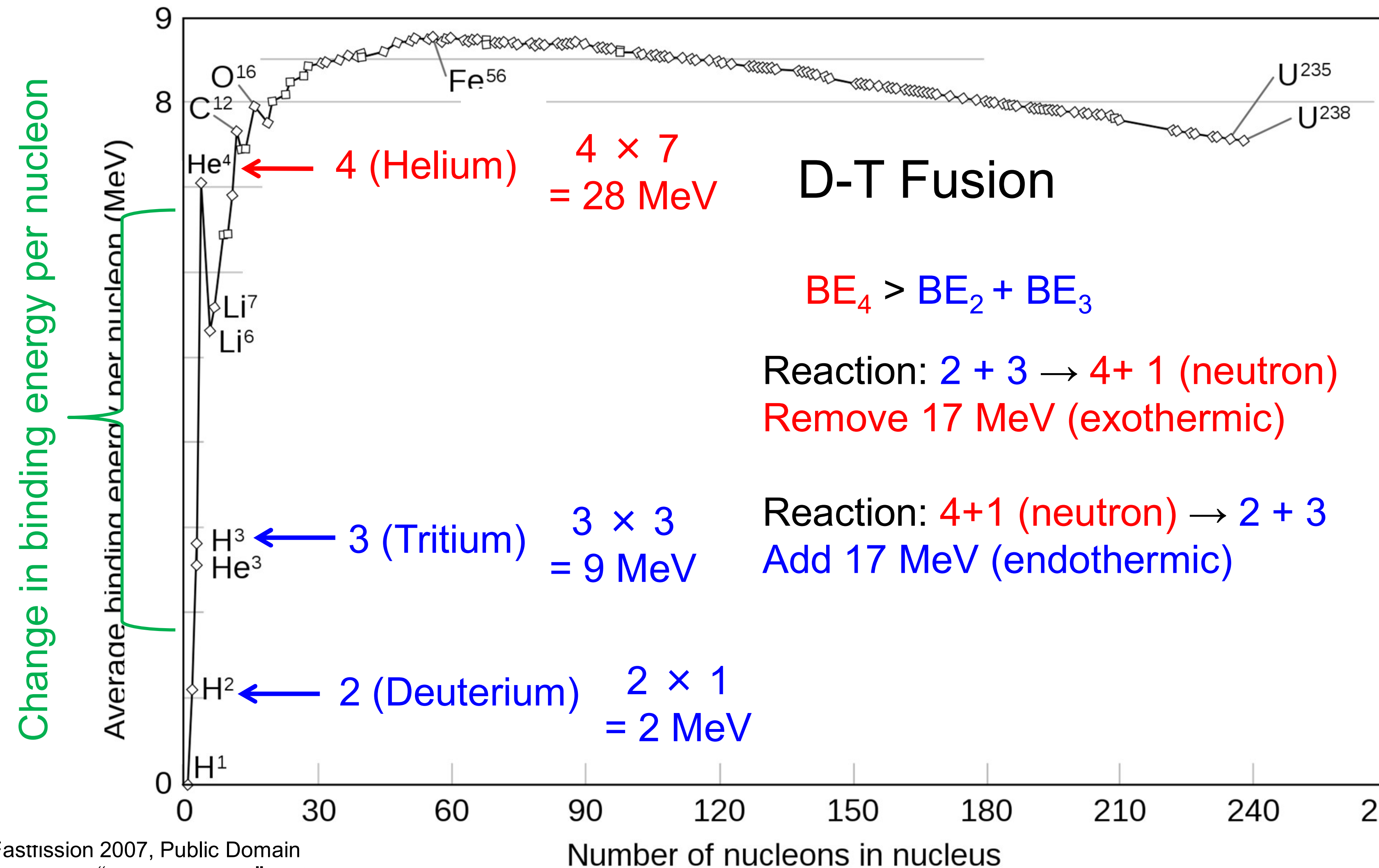
7.5×236
$= 1770$ MeV

When the total binding energy of the product is greater than the binding energy of the initial nucleus, the reaction is exothermic

Reaction: $2 \times 118 \rightarrow 236$, Must Add 236 MeV (endothermic)

Reaction: $236 \rightarrow 2 \times 118$, Remove 236 MeV (exothermic)

Binding Energy Example



Fastfission 2007, Public Domain
Wikipedia: "Binding Energy", 8-17-2007