NUCLEAR PHYSICS FUNDAMENTALS

INTRODUCTION

$$\boldsymbol{m_{nucleus}} < \sum \boldsymbol{m_p} + \sum \boldsymbol{m_n}$$

FUNDAMENTAL TERMS

Z : proton number

N : neutron number

(Z and N: nucleons)

A = Z + N : mass number

Isotopes : different A, same Z

Isobars : same A, different Z

Radius nucleons : $r_0 = 1.25 fm$

Radius nucleus : $R = r_0 * A^{\frac{1}{3}}$

BINDING ENERGY

$$B = \Delta E = E_{constituents} - E_{nucleus}$$

$$(Z * m_p + N * m_n) * c^2$$

$$m_{nucleus} * c^2$$

Average binding energy: $\frac{B}{A}$

LIQUID DROP MODEL

Short ranged strong force

→ Interaction just with neighboured nucleons

→ constant density

Bethe-Weizsäcker-formula:

$$B = B_{volume} + B_{surface} + B_{coulomb} + B_{asymmetry} + \delta(A, Z)$$

VOLUME-TERM

$$B = \boldsymbol{B_{volume}} + B_{surface} + B_{coulomb} + B_{asymmetry} + \delta(A, Z)$$

Explanation

- Attracting strong force

Influence

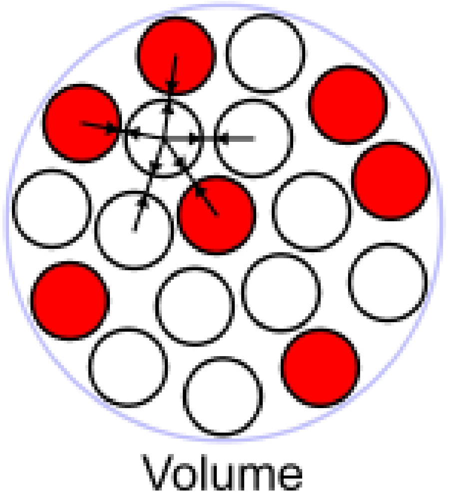
- Independent of A

$$B_{volume} = a_v * A$$

$$V \sim R^3$$

$$\mathrm{R} = r_0 * A^{\frac{1}{3}}$$

$$V \sim A$$



$a_v = 15.85\ MeV$

https://upload.wikimedia.org/wikipedia/commons/5/5b/Liquid_drop_model.svg

SURFACE-TERM

$$B = B_{volume} + \boldsymbol{B_{surface}} + B_{coulomb} + B_{asymmetry} + \delta(A, Z)$$

Explanation

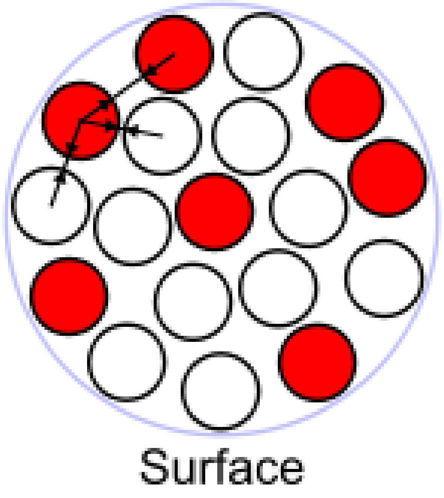
- surface nucleons have less neighbours

influence

- Most for small nuclei

$$B_{surface} = -a_s * A^{\frac{2}{3}}$$

$S = 2\pi R^2$ $\quad$ $R = r_0 * A^{\frac{1}{3}}$



$a_s = 18.85\ MeV$

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COULOMB-TERM

$$B = B_{volume} + B_{surface} + \boldsymbol{B_{coulomb}} + B_{asymmetry} + \delta(A,Z)$$

Explanation

- coulomb repulsion between protons

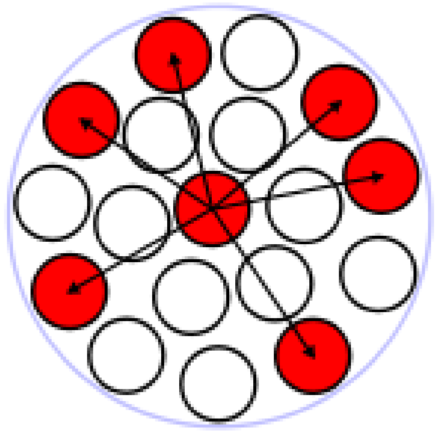
Biggest influence

- Heavy nuclei, great Z

$$B_{coulomb} = -a_c * Z^2 * A^{-\frac{1}{3}}$$

$$E_c = \frac{5}{3} * \frac{q^2}{R}$$

$$R = r_0 * A^{\frac{1}{3}}$$



$$a_c = 0.71\ MeV$$

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ASYMMETRY TERM

$$B = B_{volume} + B_{surface} + B_{coulomb} + \boldsymbol{B_{asymmetry}} + \delta(A, Z)$$

<u>Explanation</u>

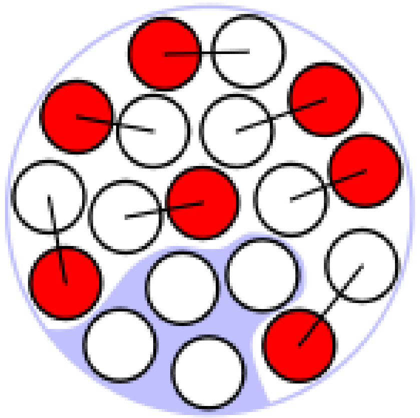
- Quantum mechanics
- Prefer equal number of neutron and protons

<u>influence</u>

- Increase for big nuclei

$a_a = 92.85\ MeV$

$$B_{asymmetry} = -a_a * \frac{(\overbrace{A - 2Z}^{N-Z})^2}{A}$$



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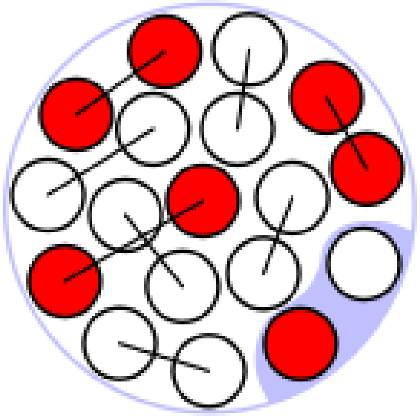
PAIRING-TERM

$$B = B_{volume} + B_{surface} + B_{coulomb} + B_{asymmetry} + \boldsymbol{\delta(A,Z)}$$

<u>Explanation</u>

- Quantum mechanics
- Prefer paired nucleons of the same kind

$$\delta(A,Z) = \begin{cases} +a_p * A^{-\frac{1}{2}} & ;\, even\ Z, even\ N \\ 0 & ;\, odd\ A \\ -a_p * A^{-\frac{1}{2}} & ;\, odd\ Z, odd\ N \end{cases}$$



$a_p = 11.46\ MeV$

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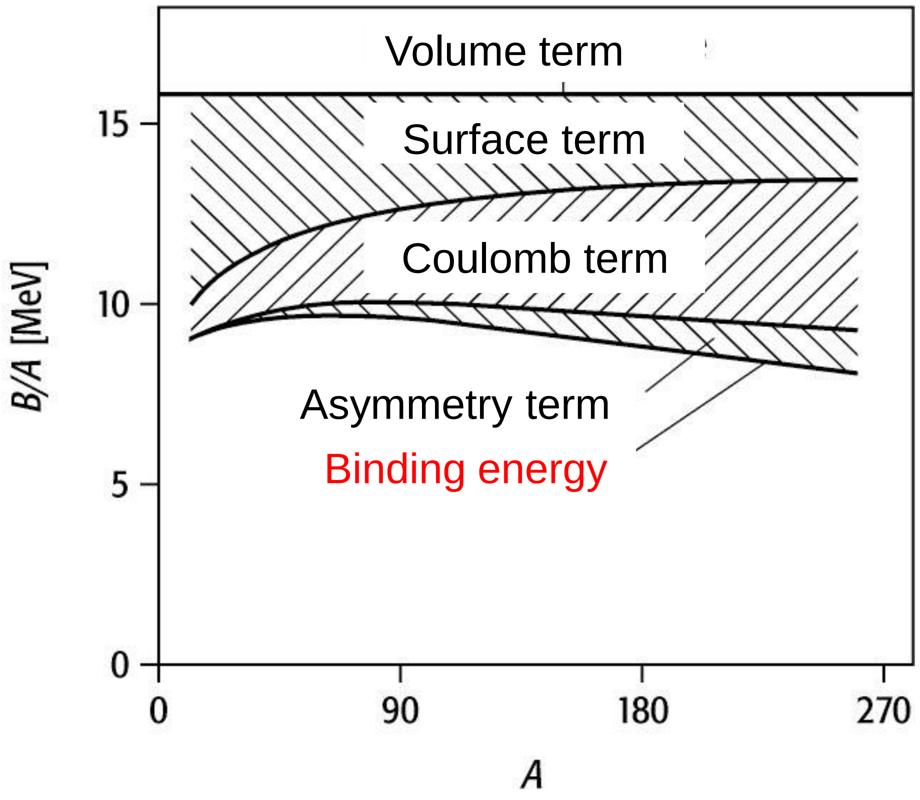
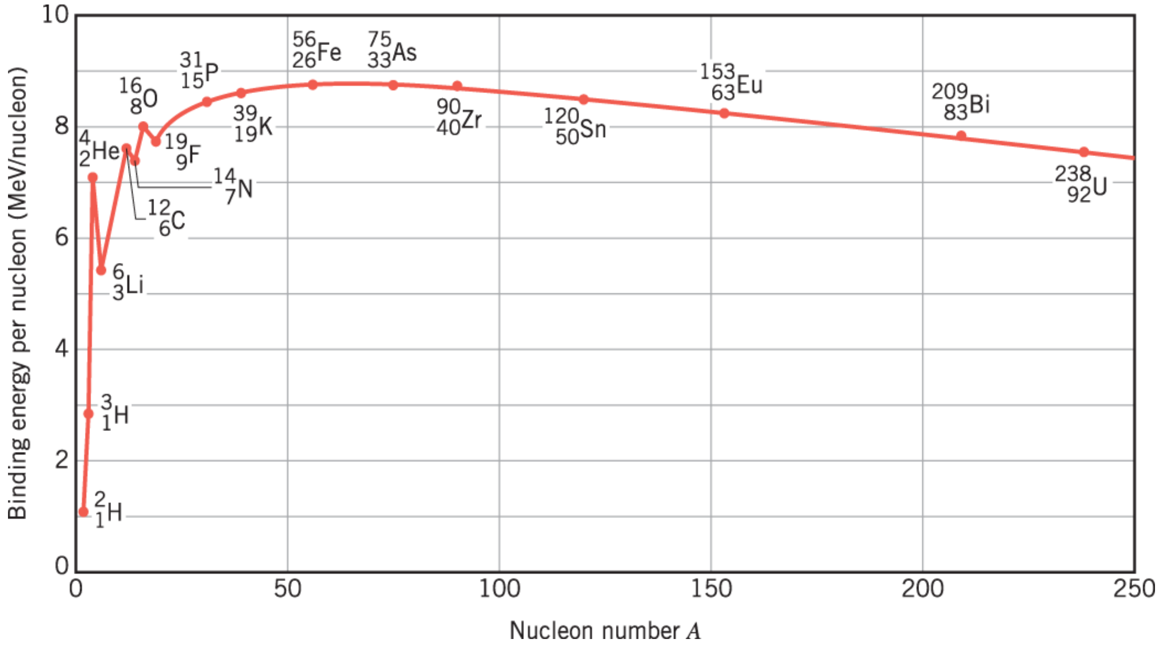
BINDING ENERGY



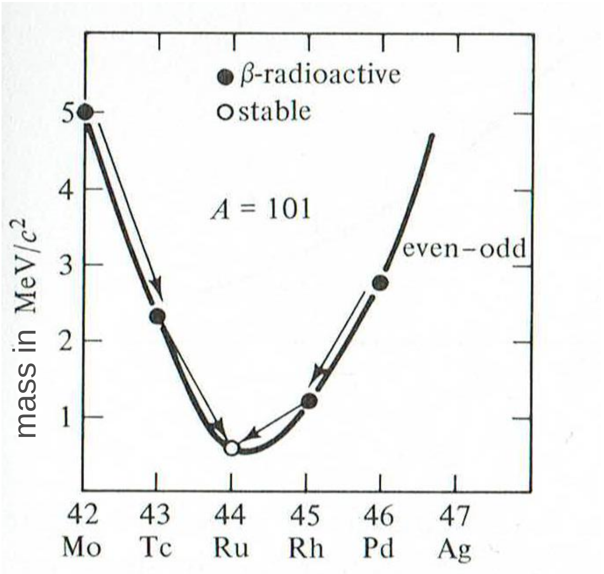


http://www.spektrum.de/lexika/images/physik/fff1089.jpg

http://staff.orecity.k12.or.us/les.sitton/Nuclear/313_files/nfg005.gif

BETA-DECAY

<u>Odd A</u>

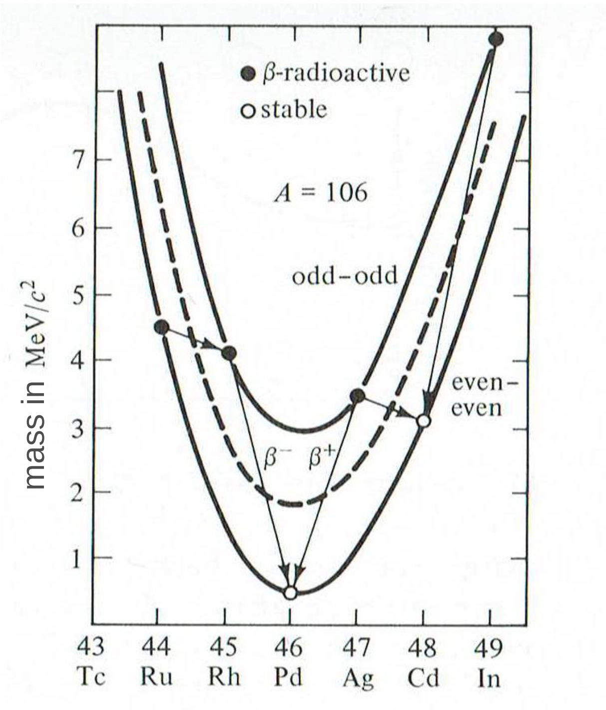


Z

$$m(Z, A) = Zm_p + (A - Z)m_n - \frac{1}{c^2}B$$

$$\mathbf{B \sim Z^2}$$

<u>Even A</u>

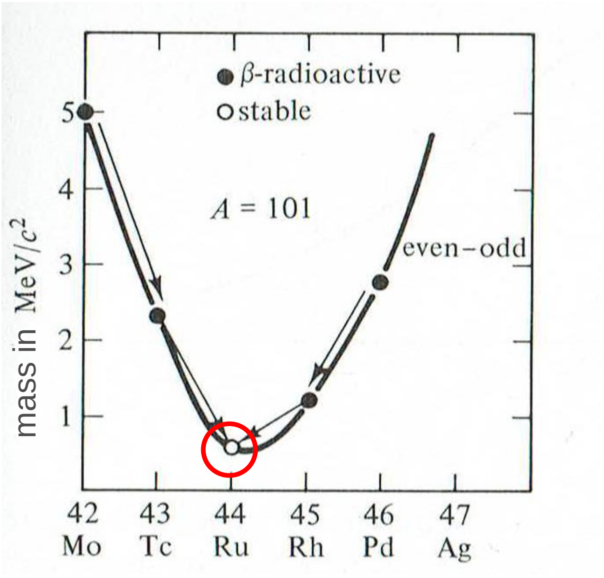


Z

N. A. Jelley, Fundamentals of nuclear physics

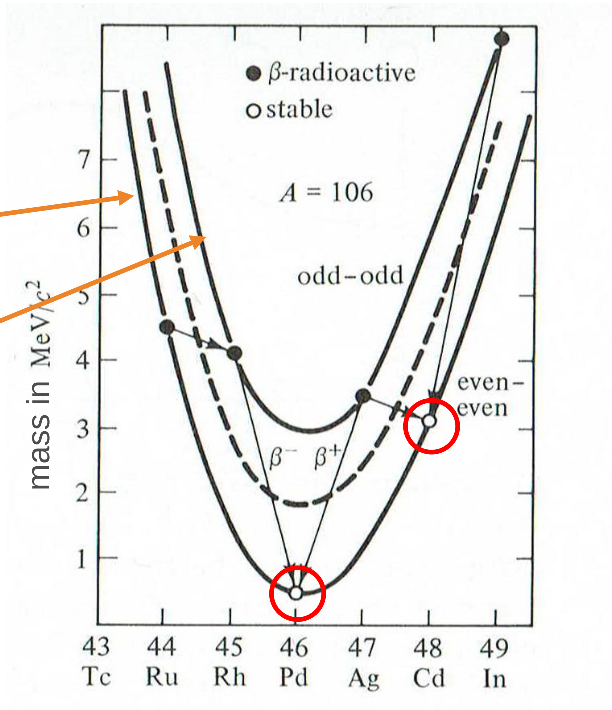
BETA-DECAY

Odd A



$$\delta(A,Z) = \begin{cases} +a_p * A^{-\frac{1}{2}} & ;\, even\ Z, even\ N \\ 0 & ;\, odd\ A \\ -a_p * A^{-\frac{1}{2}} & ;\, odd\ Z, odd\ N \end{cases}$$

Even A



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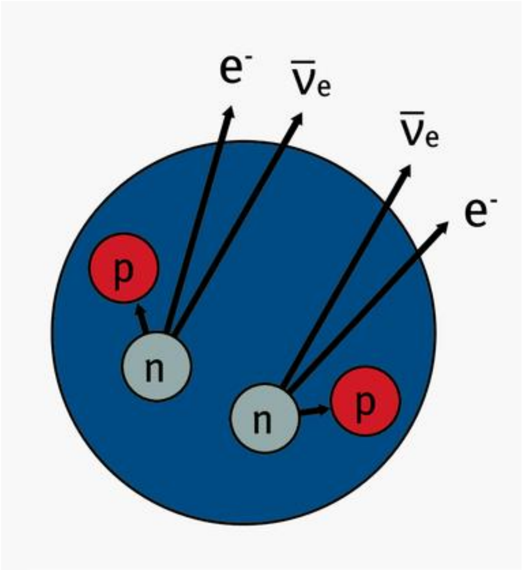
DOUBLE BETA DECAY

<u>Ordinary double beta decay</u>



$n \to p + e^- + \bar{\nu}$

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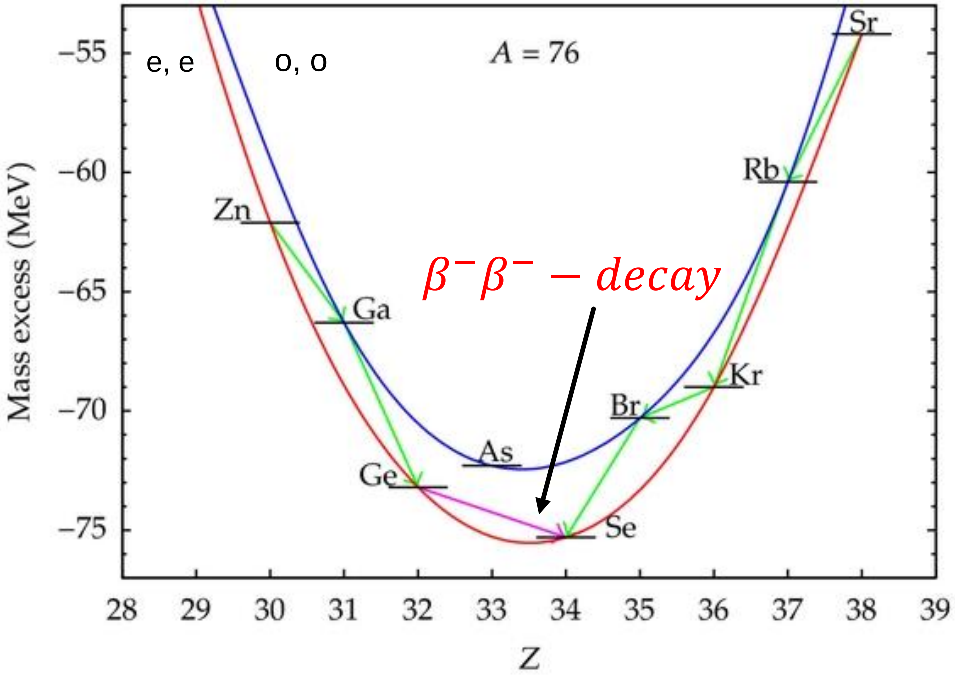
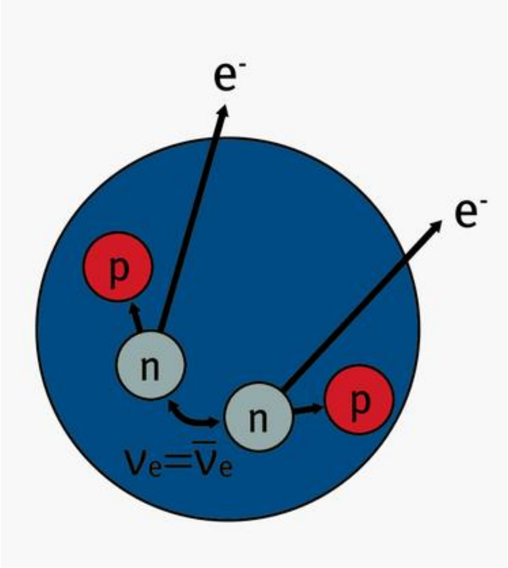


<u>Neutrinoless double beta decay</u>



$n \to p + e^- + \cancel{\bar{\nu}}$

$n \to p + e^- + \cancel{\bar{\nu}}$

https://www.hindawi.com/journals/ahep/2012/857016/

https://www.mpp.mpg.de/forschung/astroteilchenphysik-und-kosmologie/gerda-detektor-neutrinophysik/neutrinoloser-doppelter-beta-zerfall/

SUMMARY

Liquid drop model ; Bethe-Weizsäcker-formula

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Binding Energy

↙ ↘

Mass defect: $m_{nucleus} < \sum m_p + \sum m_n$

Beta-decay