Liquid drop concepts

- Binding energy per particle

- Note scale

- Small fraction of mass energy

- Large cancellation between kinetic and potential energy expected

- Shell effects visible --> “magic numbers”
Corrections to dominant volume term

- Surface effect

- Visualize corrections
Deformation

• Qualitative result for potential energy between two nuclei

• Fission can also be viewed as a tunneling problem --> not so likely event depending on details of barrier

• Example of barrier height
  
  \[ x = \frac{Z^2}{A} / \frac{Z^2}{A} c = \frac{Z^2}{A} / 50.13 \]
Corrections to dominant volume term

- Surface effect

- Visualize corrections
Corrections to liquid drop

- Symmetry energy

There is also a direct contribution from the interaction between nucleons that favors np pairs over pp, nn, or symmetric np pairs (T=0 over T=1)
Separation energy

- Example for Ce nuclei
- $Z=58$
- Costs more energy to remove neutron when $N$ even than odd
- Jump at $N=82$
Ionization energy

- Noble gases

- What does it mean?
Illustration of odd-even effect

- from Bohr & Mottelson Vol.1 (BM1)

\[ S_n (N, Z) = B(N, Z) - B(N-1, Z) \]
Shell closure at $N=126$

- Odd-even effect: plot only even $Z$

- Also at other values $N$ and $Z$

**Graph details:**
- Solid line: $N-Z=41$
- Dashed line: $N-Z=43$

**Axes:**
- $S_n$ (MeV) on the vertical axis
- $N$ on the horizontal axis

**Data range:**
- $S_n$ values range from 4 to 8
- $N$ values range from 110 to 140
Odd-even mass differences

- For neutrons and protons

\[ \Delta = \delta \simeq a_p A^{-1/2} \]
How does it work?

- Typical result --> magic numbers
Valley of stability

- Consider mass equation
- Solve for fixed $A$ quadratic equation in $Z$
- Find minimum where derivative vanishes

--> valley
Chart

- Distribution of nuclei
Cut for fixed $A$

- Parabolic behavior
- Odd $A$: only one stable nucleus
- Even
  - even-even
  - odd-odd
  - different parabola
- Typically more than one stable nucleus
- $A=124 \rightarrow 3$
Chart of nuclides

- Lots of nuclei and lots to be discovered

- Links to astrophysics
Two-neutron separation energies

- LDM and data
- Even-even nuclei
- Connected: same Z
- Linear behavior --> LDM
Update

• Note recent improvements

• pdf finnish group