8.701

Introduction to Nuclear and Particle Physics

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9. Nuclear Physics

9.5 Shell Model

Shell Model

Successful in describing hydrogen

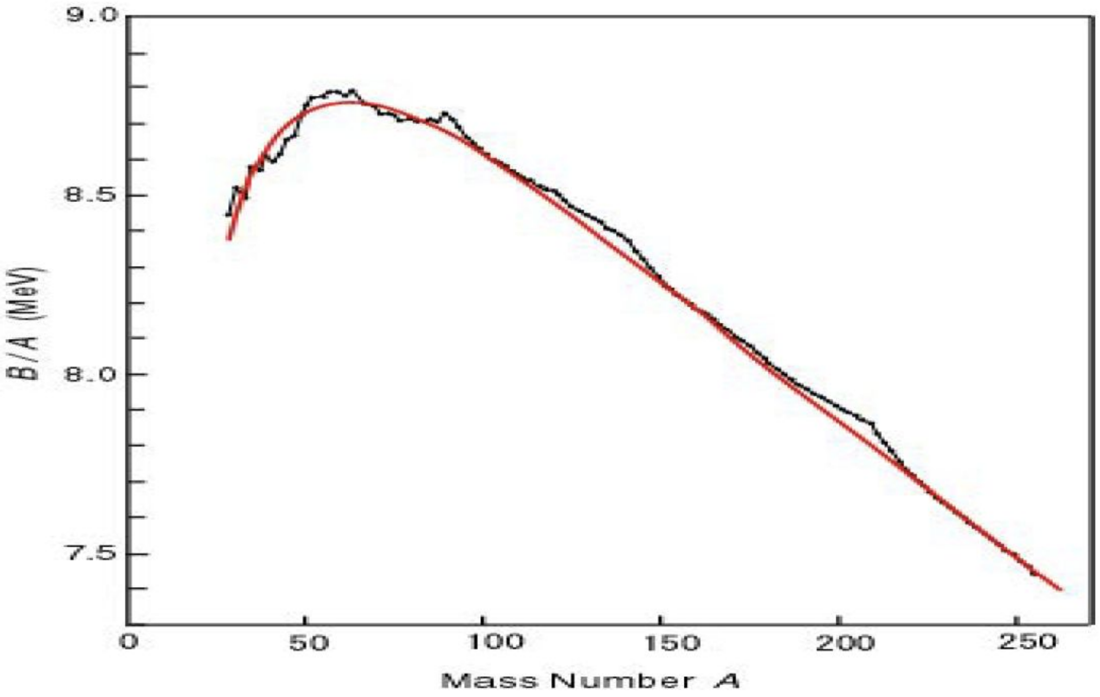
Can this work for a nucleus?

Many-body systems; no analytic solutions; no dominant center of a long-range force; short range force with many pairs of interacting nucleons, …

Interactions average out and results in a potential which depends on position but not on time “nuclear mean field”. Nuclear potential emerges from large number of nucleon-nucleon interactions.

Experimental evidence of closed nuclear shells

Binding energies deviate from liquid drop model with increased binding at N or Z at “magic” numbers of 2, 8, 20, 28, 50 and 126



Experimental evidence for closed nuclear shells

Number of stable isotopes/isotones is significantly higher for nuclei with the proton/neutron number equal to the magic number.

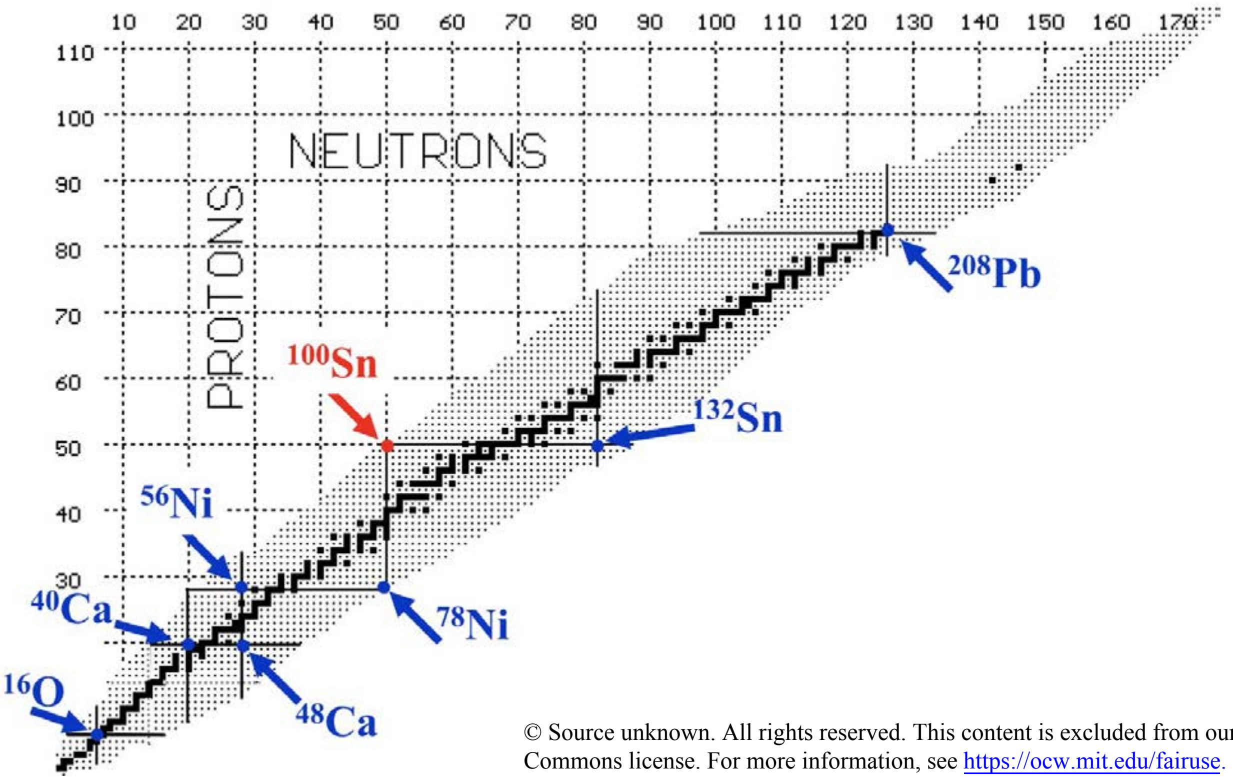
Nucleon capture cross sections are high for nuclei with one nucleon shy from the magic number (single vacancy in a closed shell), but significantly lower for nuclei with number of nucleons equal to the magic number (at the closed shell).

Energy of the first excited state for nuclei with the proton or the neutron number equal to the magic number are significantly higher than for other nuclei.

Excitation probabilities of the first excited state are low for nuclei with the proton or neutron number equal to the magic number.

Quadrupole moments vanish for nuclei with proton or neutron number equal to the magic number.

Double magic nuclei



Historic Confusion

A serious confusion arose in early comparisons of nuclear shell model predictions with data.

The data clearly pointed out to nuclear magic numbers at 2, 8, 20, 28, 50, 126.

But nuclear shell model with a flat bottom potential gave the shell gaps which explain the magic numbers at 2, 8, 20, 40, 70, 112.

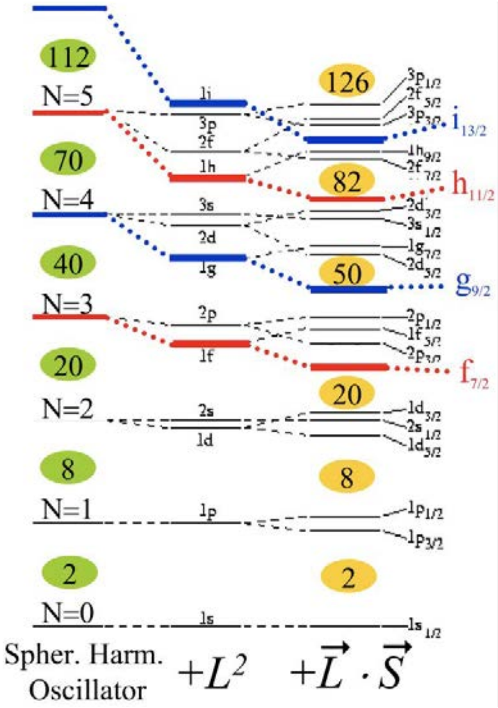
Therefore, while the first three magic numbers were in agreement with the data the consecutive higher ones were not.

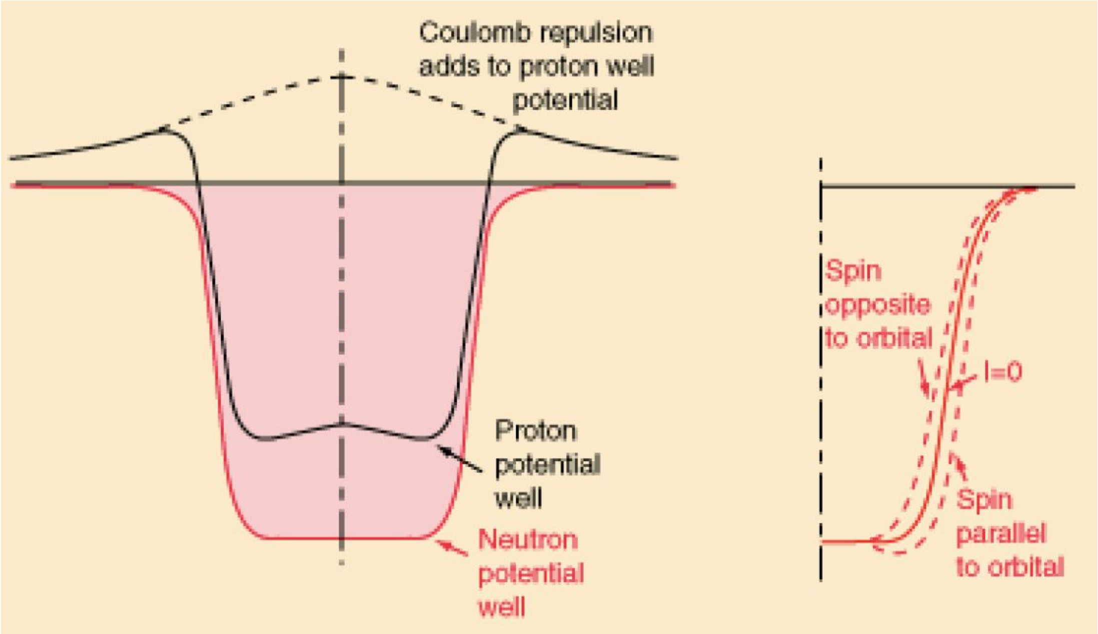
The models was wrong, but not completely wrong.

An important piece was missing!

Spin-orbit splitting

$$H_{SM} = V(r) + V_{LS}(r)\,\vec{L}\cdot\vec{S}$$





Nuclear vs Atomic shell model