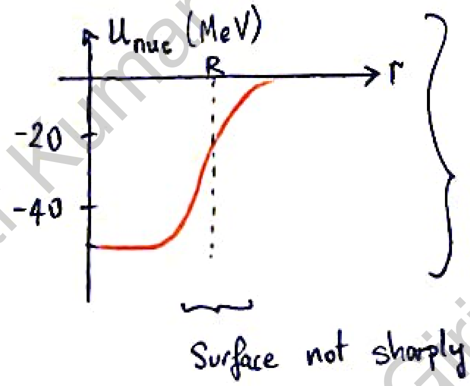
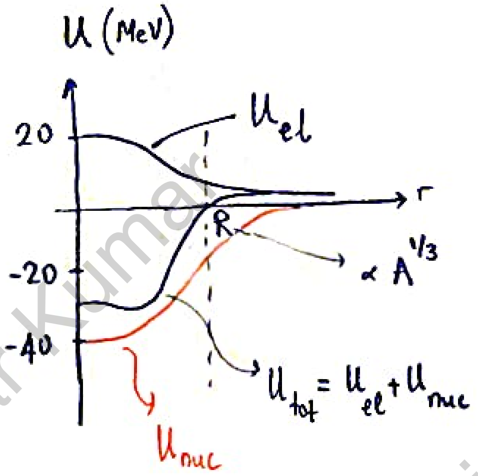
Shell Model

* Analogous to the central-field approximation in atomic physics.
As if, each nucleon is moving in a potential that represents averaged-out effect of all other nucleons.

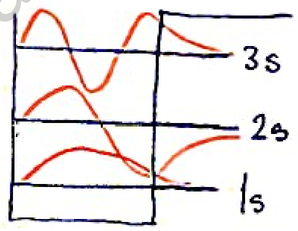


Potential energy profile for neutrons (no Coulombic force contribution in this case)
It is a rounded square-well potential

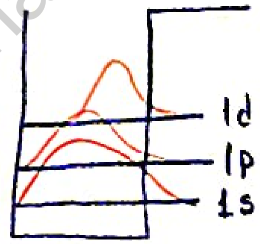


Potential energy profile for protons
In this case, we add the repulsive Coulomb energy among protons.

For any spherically symmetric potential energy (note that this only an approximation for the nuclear matter), the angular momentum states $Y_{lm}(\theta, \phi)$ are the same as for the $\bar{e}$'s in the central-field approximation in atomic physics. However, radial force in nuclear matter is different from the Coulomb potential; there is even a notational subtlety. To illustrate this, consider a square-well



Atomic Phys.



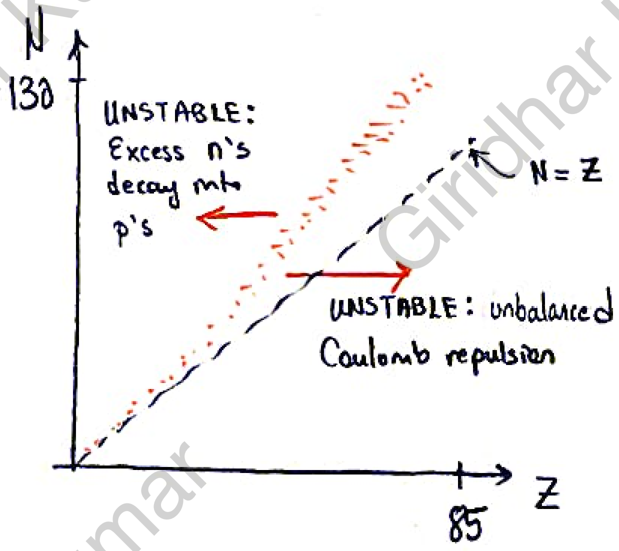
Nuclear Phys.

It should be noted that when using the radial node quantum number n of nuclear physics there is no restriction on the largest possible value of l for a given n. There is such a restriction in atomic physics because the quantum number n used there, called the principal q.#, is defined as:

$$n_{principal} = n_{radial} + l$$

Since the minimum of n_{radial} is 1, the largest value of l for a given $n_{principal}$ is $(n_{principal} - 1)$. So, then why $n_{principal}$ is used atomic physics? This is because $V(r)$ is an attractive Coulomb pot. $-1/r$, the way the energy of a level increases with increasing n_{radial} happens to be precisely the same way it increases with increasing l. Thus the energy of the levels of a Coulomb potential does not depend on both n_{radial} & l, but only on their sum $n_{principal}$. This gives yet another insight into the origin of the degeneracy of the H atom.

In nuclear physics n refers to n_{radial}. If you observe the plot on the right (top of page), the states with $n=1$ and $l=0, 1$ and 2 we observe the centrifugal effect that tends to prevent a nucleon from approaching $r=0$ as the orbital angular momentum l increases. Solving the Schrödinger eqn. with $\psi(r,\theta,\phi) = R_n(r) Y_{lm}(\theta,\phi)$ yields the same filled shells and subshells as in atomic physics, from which we can infer the stability of the nuclei.



General Trends:
- For low mass numbers, $N \approx Z$.
- N/Z gradually increases with A up to 1.6 at large mass
  (This is to compensate the increasing EM repulsion among p's)
- No nuclide with $A > 209$ or $Z > 83$ is stable

In Particular:
- Only 4 stable $N=$odd, $Z=$odd nuclides exist:

  ${}^{2}_{1}H$, ${}^{6}_{3}Li$, ${}^{10}_{5}B$, ${}^{14}_{7}N$

  This shows the power of pairing!
- Unusual stability of doubly magic ${}^{4}_{2}He$ nucleus,
  renders $A=5$ and $A=8$ unstable

  eg. ${}^{8}_{4}Be$ immediately splits into $\alpha + \alpha$
- There is no stable nuclide with $A = 43$ or 61

  technetium promethium

About 90% of the known nuclides are radioactive; they decay into other nuclides by emitting α or β particles.

${}^{4}He$ e^{-}