Week 4 Lecture 1 – Basics of Nuclear Structure

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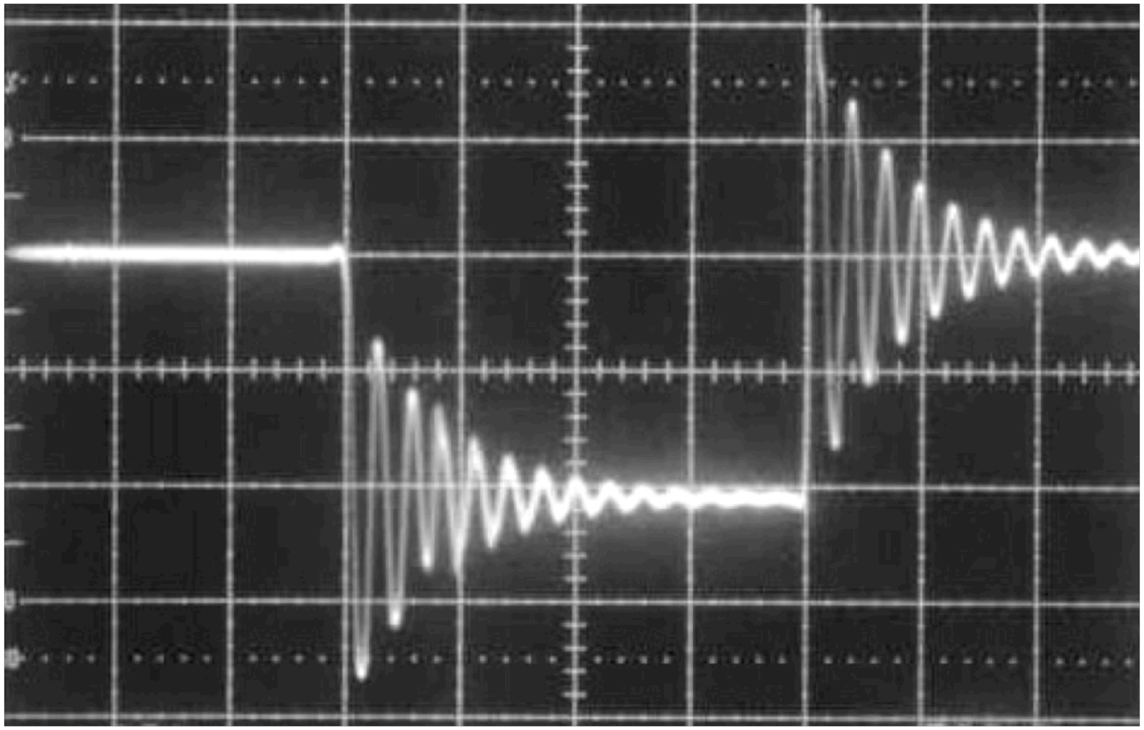
Basics of Nuclear Structure

-- Nucleon potential viz. Coulomb potential
-- Nuclear sizes & shape
-- Nuclear potential well
-- Schematic shell model of nuclei

2nd Homework due Today



Aside: Forces and Potential Energy

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The potential energy (in mathematical form) is key to understanding the behavior of physical systems. For example, the Coulomb *force* in vacuum is given by the expression:

$$F_{Coulomb}(q_1,q_2,r) = -q_1 q_2 / 4\pi\varepsilon_0 r^2$$

The potential energy is always the negative derivative of the potential energy function:

$$F(x) = -\frac{d}{dx}V(x)$$

Coulomb Force … Nuclear Force

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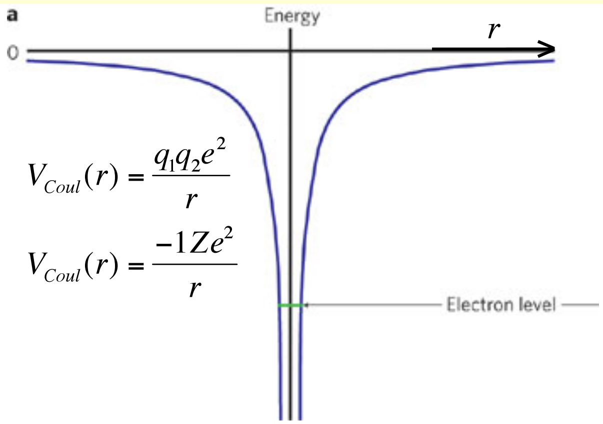
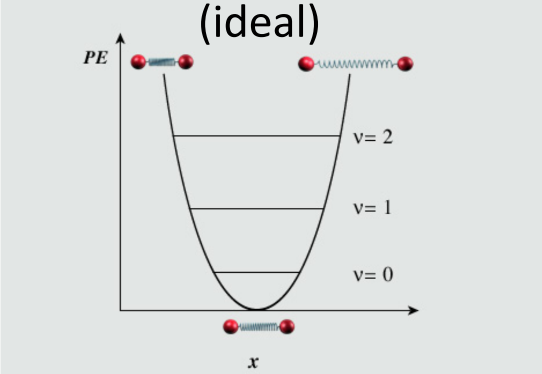


Hydrogen atom: 1 proton & 1 electron (heavy & light)
Binding Energy of electron: 13.4 eV, PE=KE = ½ $m_e v^2$
deBroglie Wavelength: λ = h/mv = 3.3×10^{-10} m
Covalent radius Hydrogen atom = 0.3×10^{-10} m

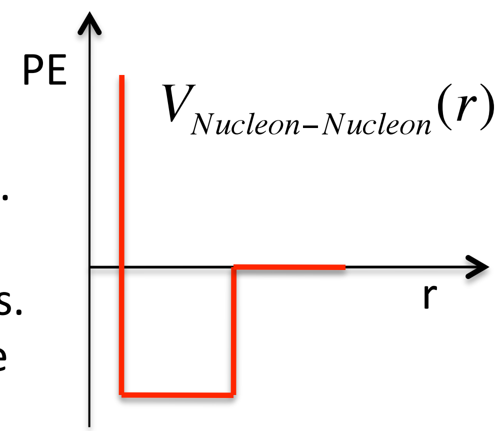
Size of system is smaller than wavelength
it should be treated Quantum Mechanically

Deuterium nucleus: 1 proton & 1 neutron (nearly equal masses)
Binding Energy per nucleon: 1.11 MeV
deBroglie Wavelength of nucleon:
Radius of deuterium nucleus: ~ 4 fm

Harmonic Potential
(ideal)



Corrections to H.O. picture:
1) The nucleons cannot interpenetrate.
2) The "bond" saturates.
3) The "bond" breaks at large distances.
a "Square Well" for Nuclear Force



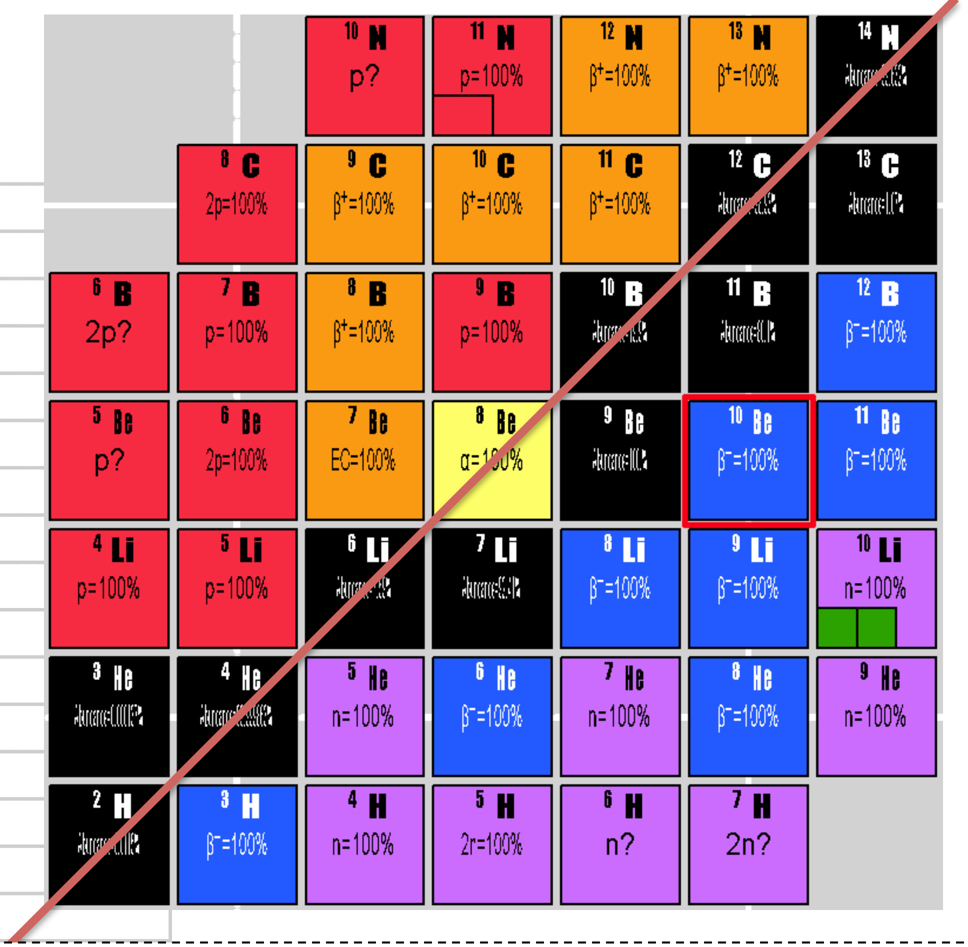
(The limit of a force only on contact is a useful approximation.)

Nuclear Force … Mirror Nuclei

Q: How does the binding energy change when neutrons and protons are interchanged?

	Z	N	BE (MeV)	V_Coul = (3/5) Z^2 / r_0 A^1/3			
3-H	1	2	8.481	0.49	r_0	1.225	fm
3-He	2	1	7.719	1.96			
	Δ BE		-0.76	-1.47			
11-B	5	6	76.208	7.93			
11-C	6	5	73.436	11.42			
	Δ BE		-2.77	-3.49			
17-O	8	9	131.767	17.56			
17-F	9	8	128.214	22.22			
	Δ BE		-3.55	-4.66			
25-Mg	12	13	205.6	34.73			
25-Al	13	12	200.525	40.76			
	Δ BE		-5.07	-6.03			

Note: Measured Binding Energies (not Calc.)



Nuclear size and shape

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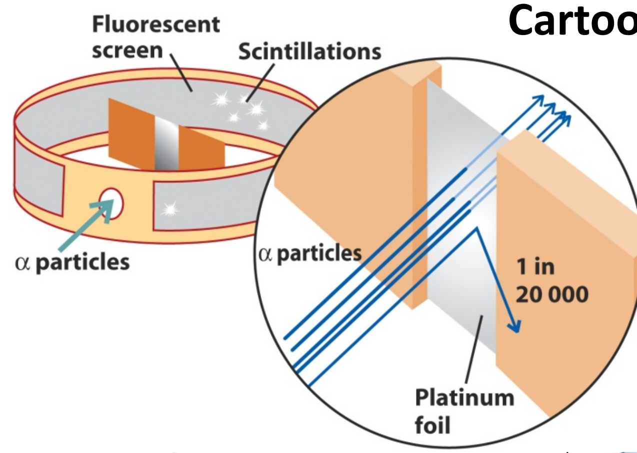
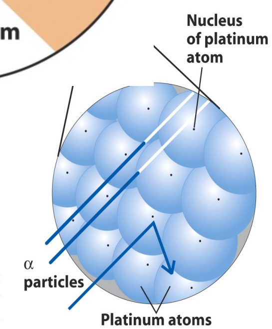
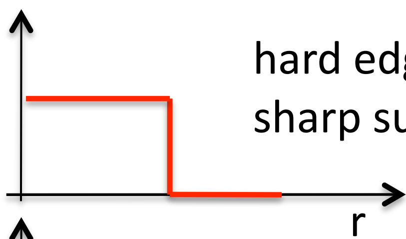
Rutherford's experiment: Irradiate thin gold foil with alpha particles, measure deflection of each particle.
Results: The vast majority of energetic helium nuclei passed through thin metal foils unscathed. Rarely, one particle will be scattered to a large angle. (Geiger & Marsden 1911-13)
Conclusion: the mass and positive charge is concentrated in a very small volume.

Cartoon !

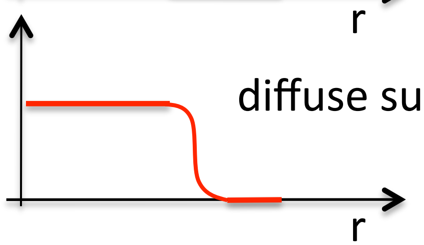




Modern results (using electrons) indicate a nearly constant nuclear density with a thin surface layer for large nuclei (A>40), lighter nuclei are mostly surface.



hard edge or sharp surface, R_{SA}



diffuse surface, R_{SA}, a

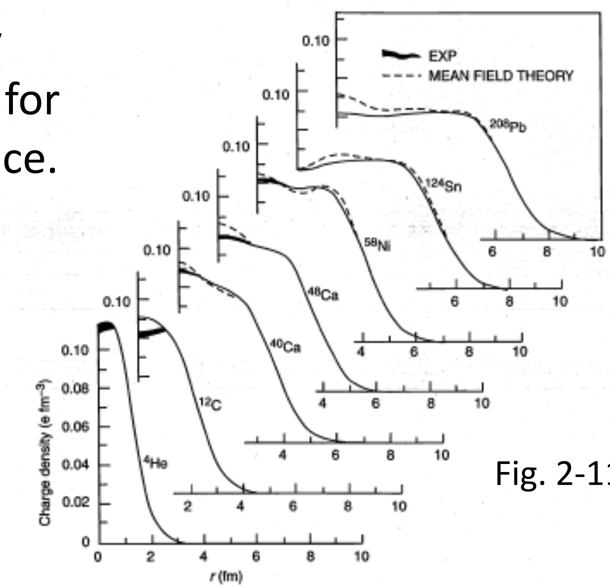


Fig. 2-11 in the text

Q: What is the value of the nuclear density in nucleons/fm^3 ?

Nuclear Force … Nucleus

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What force do we expect when a nucleon approaches a nucleus?

$$V(r) = \frac{Zke^2}{R_c}\left(1 + \frac{1}{2}\left[1 - \left(\frac{r}{R_c}\right)^2\right]\right) \qquad r < R_c$$

$$V(r) = \frac{Zke^2}{r} \qquad r > R_c$$

R_c = *charge radius, distinct from* R, *the model radius for the nuclear potential.*