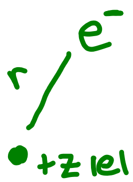
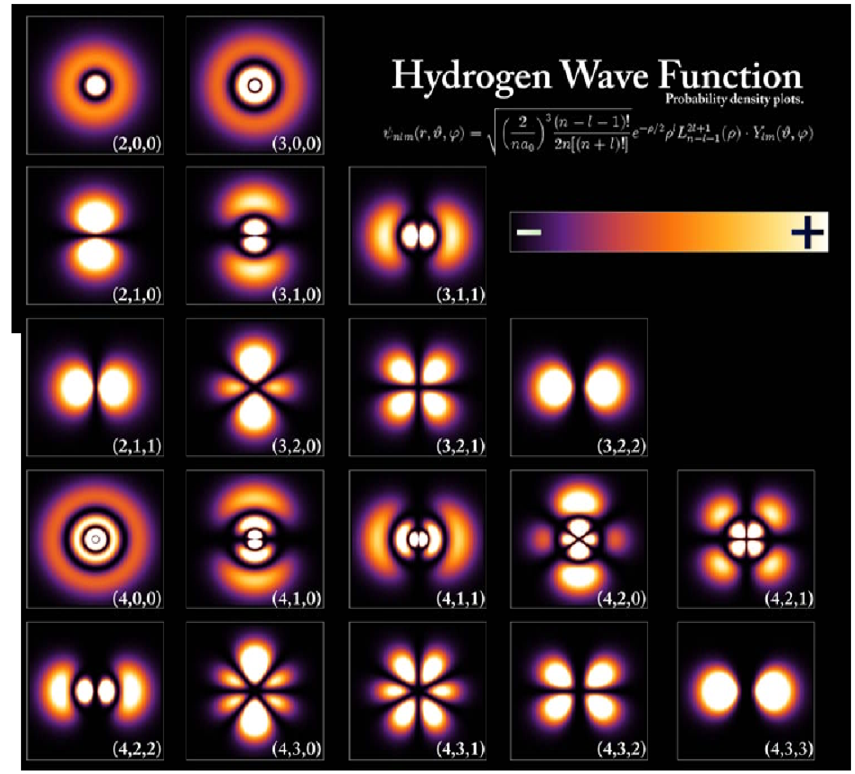
Physics 123 - April 24, 2013

- 2 more lectures (After today's lecture) ... yes, we have class next wednesday
- Today - Finishing up w/ Multi-electron atoms Giancoli, chapt 39
  - chemical properties
  - X-rays
  - Zeeman splitting
  - Starting nuclear physics Giancoli, chapts 41 and 42
- Skipping molecules + solids — chapter 40 important ... but can't do everything



$$-\frac{\hbar^2}{2m}\nabla^2\psi + V\psi = E\psi$$

$$V = k\frac{Ze^2}{r^2}$$



$$\Psi_{n,l,m_l}(\mathbf{r}) = R_{n,l}(r)Y_{l,m_l}(\theta,\phi)$$

$n=1$ $l=0$ $m_l=0$ $\psi_{100} = \frac{2}{\sqrt{r_0^3}}e^{-r/r_0}\sqrt{\frac{1}{4\pi}}$

$n=2$ $l=0$ $m_l=0$ $\psi_{200} = \frac{1}{\sqrt{2r_0^3}}\left(1-\frac{r}{2r_0}\right)e^{-r/2r_0}\sqrt{\frac{1}{4\pi}}$

$n=2$ $l=1$ $m_l=+1$ $\psi_{211} = \frac{1}{2\sqrt{6r_0^3}}\left(\frac{r}{r_0}\right)e^{-r/2r_0}\sqrt{\frac{3}{8\pi}}\sin\theta\, e^{i\varphi}$

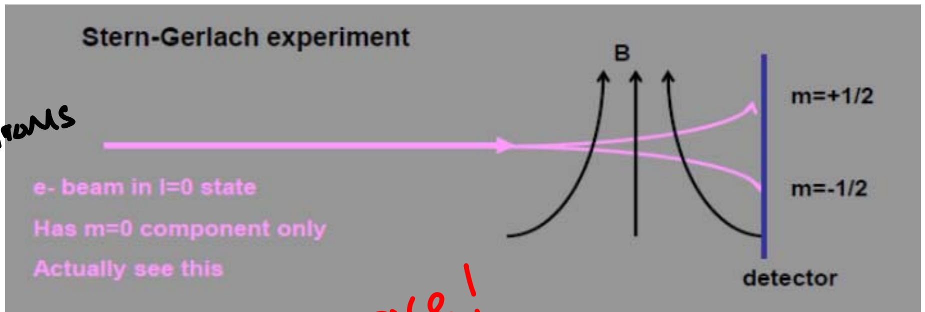
$n=2$ $l=1$ $m_l=0$ $\psi_{210} = \frac{1}{2\sqrt{6r_0^3}}\left(\frac{r}{r_0}\right)e^{-r/2r_0}\sqrt{\frac{3}{4\pi}}\cos\theta$

$n=2$ $l=1$ $m_l=-1$ $\psi_{21-1} = \frac{1}{2\sqrt{6r_0^3}}\left(\frac{r}{r_0}\right)e^{-r/2r_0}\sqrt{\frac{3}{8\pi}}\sin\theta\, e^{-i\varphi}$

⋮

Particle Spin dictates Particle Promiscuity

ATOMS



Surprise!

intrinsic spin

$e, \mu, p, n, q \cdots$	
$\frac{1}{2}, \frac{3}{2}, \frac{5}{2} \cdots$	Fermions
$0, 1, 2, \cdots$	Bosons
$\gamma, \pi, W, Z \cdots$	

ATOMIC e^- Quantum #'s

$n \equiv$ principal $\quad 1, 2, 3 \cdots$

$\ell \equiv$ orbital $\quad 0, 1, \cdots n-1$

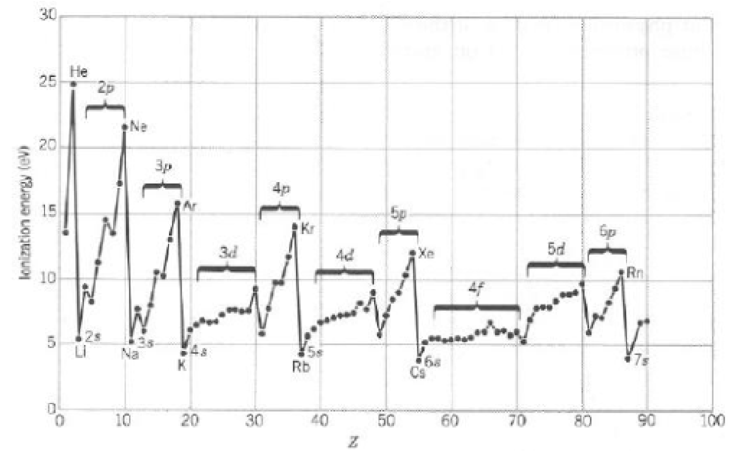
$m_\ell \equiv$ magnetic $\quad -|\ell|, -|\ell-1|, \cdots 0, \cdots, |\ell-1|, |\ell|$

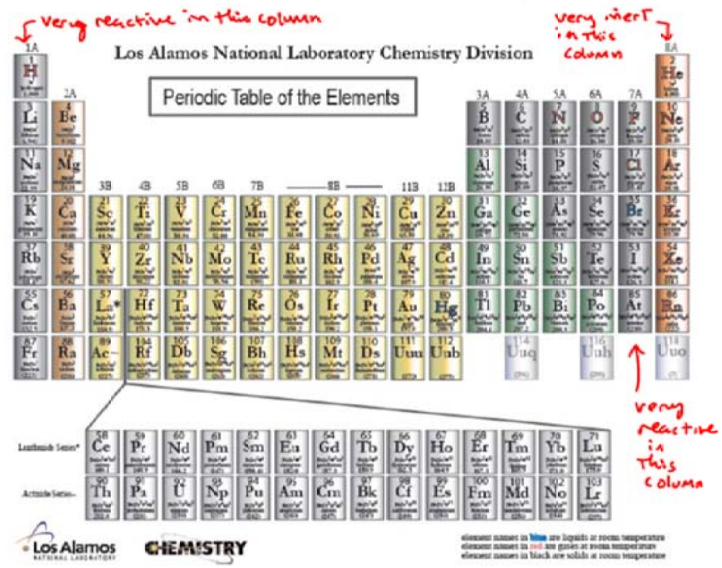
$m_s \equiv$ spin $\quad +\frac{1}{2}$ or $-\frac{1}{2}$

No two e^- in same quantum state

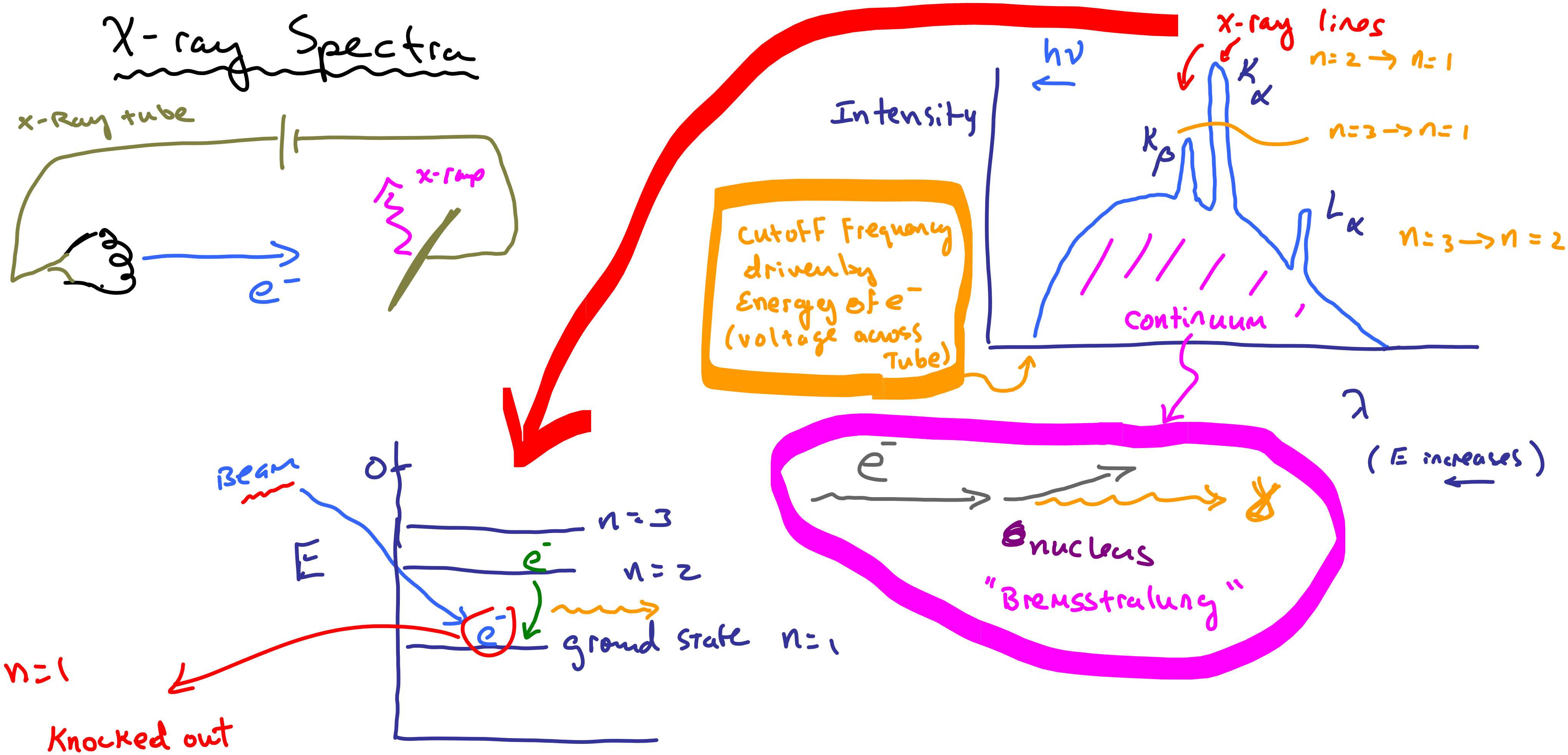
Thus Follows chemistry

		K shell	L shell				M shell				4f 5f
Energy level (n)		1	2				3				. . .
Sublevel (ℓ)		s	s	p			s	p			. . .
$Z = \# e^-$				$m_\ell=-1$	$m_\ell=0$	$m_\ell=1$					
1	H	↑	—	—	—	—	—	—	—	—	$1s^1$
2	He	↑↓	—	—	—	—	—	—	—	—	$1s^2$
3	Li	↑↓	↑	—	—	—	—	—	—	—	$1s^2 2s^1$
4	Be	↑↓	↑↓	—	—	—	—	—	—	—	$1s^2 2s^2$
5	B	↑↓	↑↓	↑	—	—	—	—	—	—	$1s^2 2s^2 2p^1$
6	C	↑↓	↑↓	↑	↑	—	—	—	—	—	
7	N	↑↓	↑↓	↑	↑	↑	—	—	—	—	
8	O	↑↓	↑↓	↑↓	↑	↑	—	—	—	—	$1s^2 2s^2 2p^4$
9	F	↑↓	↑↓	↑↓	↑↓	↑	—	—	—	—	
10	Ne	↑↓	↑↓	↑↓	↑↓	↑↓	—	—	—	—	
11	Na	↑↓	↑↓	↑↓	↑↓	↑↓	↑	—	—	—	$1s^2 2s^2 2p^6 3s^1$
⋮				⋮							⋮





X-ray Spectra



recall from Bohr $E_n = -\dfrac{m_e e^4 Z^2}{8\epsilon_0^2 h^3 n^2}$

for $n=2 \rightarrow n=1$ in atom w/ $n=1$ e^- knocked out

"sees" $Z-1$ due to remaining $n=1$ e^-

charge screening of Z

$n \rightarrow n'$

X-ray wavelength

$$\frac{1}{\lambda} = \left(\frac{e^4 m_e}{8\epsilon_0^2 h^3 c}\right)(Z-1)^2\left[\frac{1}{(n')^2} - \frac{1}{n^2}\right]$$

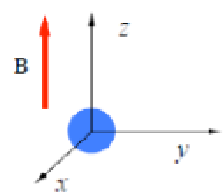
Magnetic Spectroscopy

$\vec{B}$ ↑

e^- ↑ or ↓

An atom placed in a magnetic field will have its energy levels shifted depending on the value of m_l .

This is called the Zeeman effect:

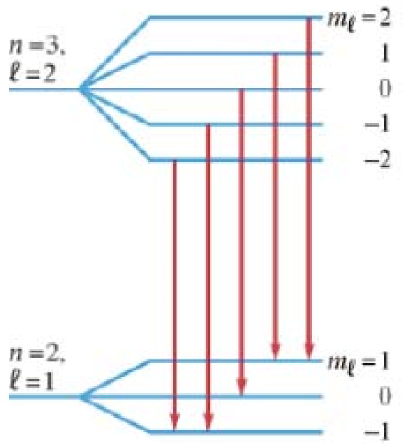


$$U = -\vec{\mu} \cdot \vec{B} = \mu_B B \, m_l$$

CONSTANT – "Bohr Magneton"

$$\frac{e\hbar}{2m_e}$$

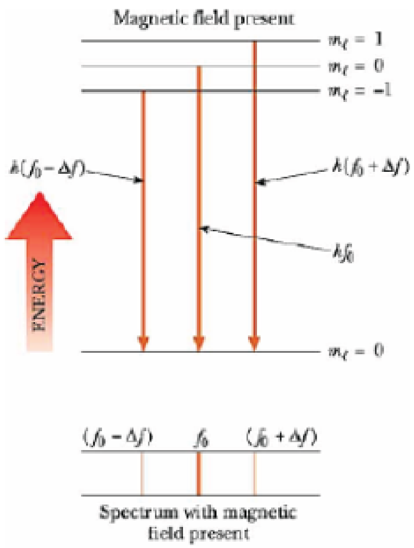
In a magnetic field, the energy levels of an atom split depending on m_l (*Zeeman effect*).



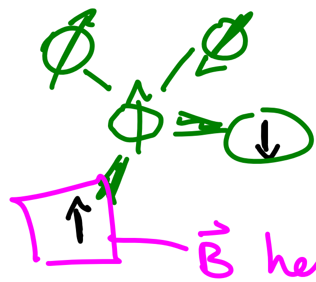
Zeeman Effect

The Zeeman effect appears as the splitting of spectral lines in a strong magnetic field.

In this case the upper level, with $l = 1$, splits into three different levels

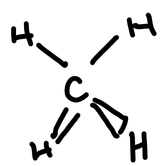


Protons in Matter are in a local B field

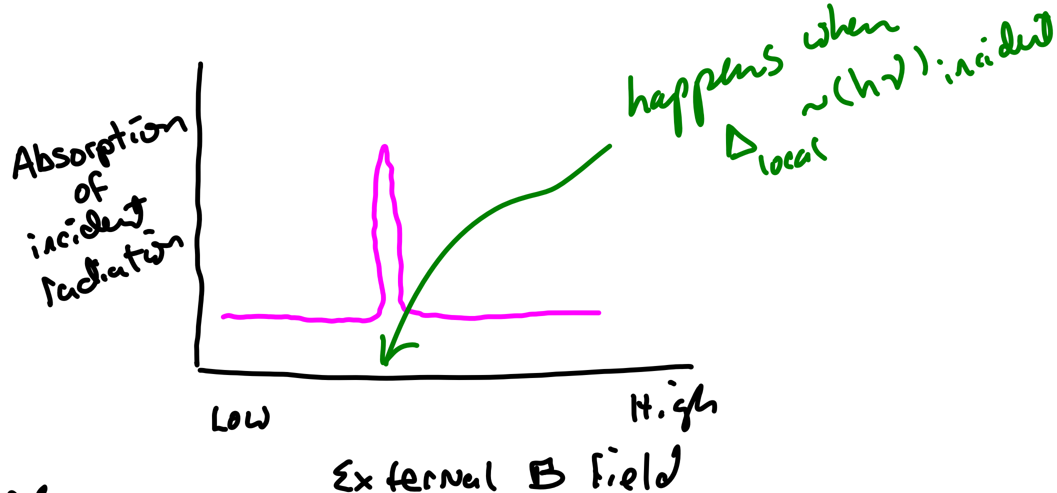


$\vec{B}$ here depends on other atoms nearby

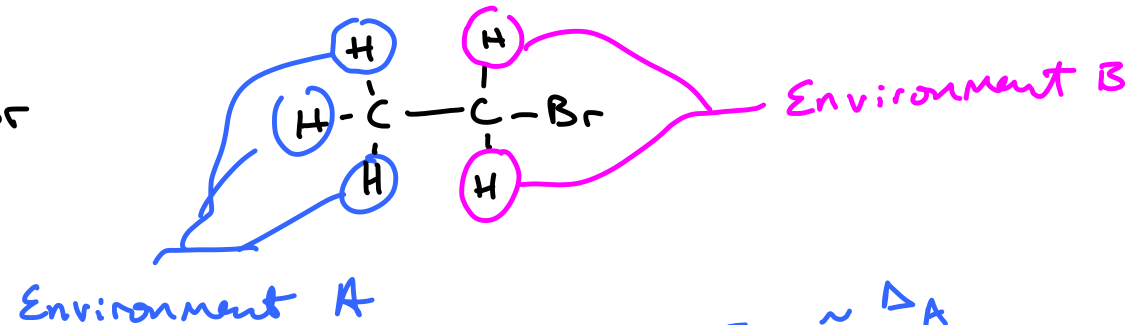
Methane CH_4



All protons in "similar" magnetic environment on average



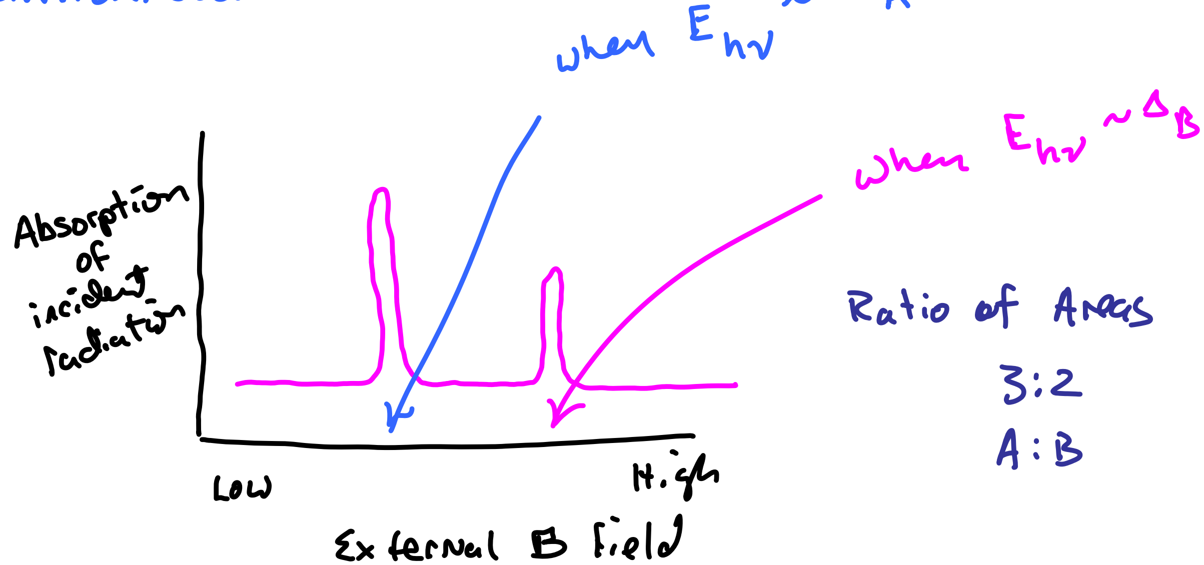
CH_3CH_2Br



Magnetic Resonance is a very powerful tool to prob chemical structure

Can be done in real time with spatial information

Powerful medical diagnostic



The Journey into Inner Space

Nuclear physics

By the way, the word
'nuclear' is pronounced

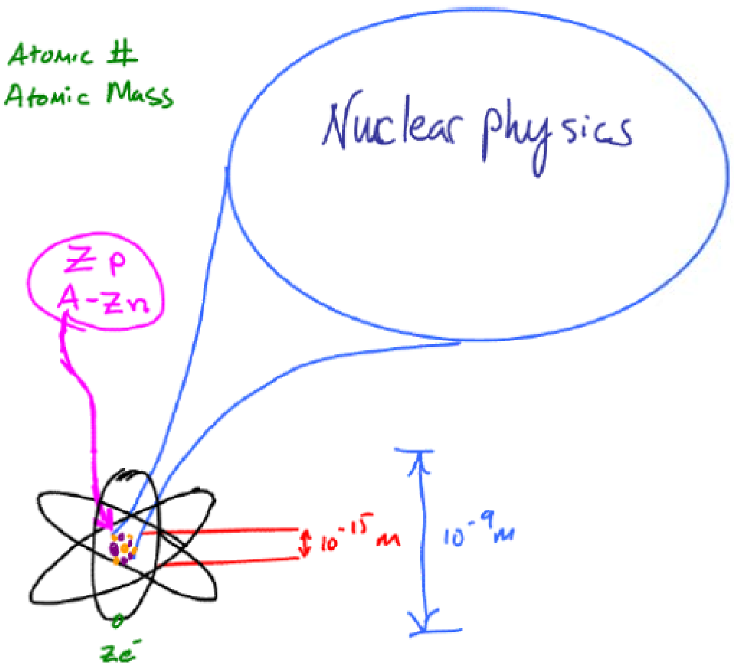
nūk-lē-ər

and *not*

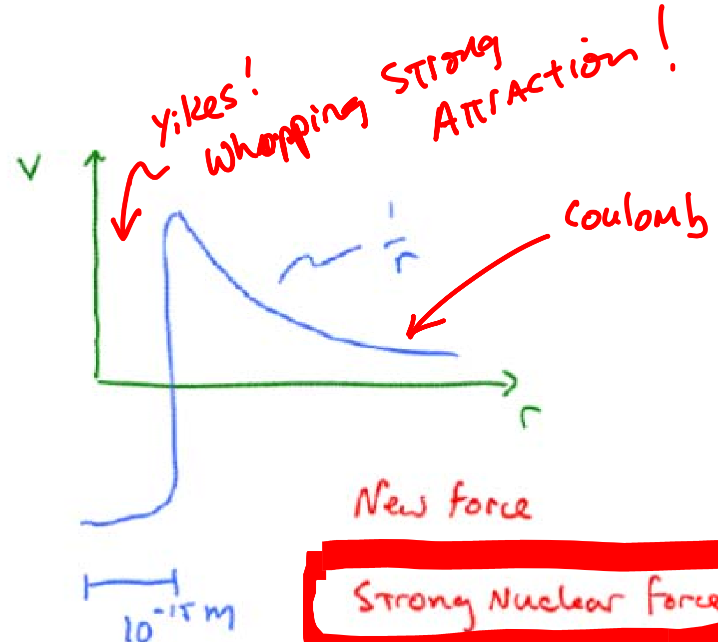
nūk-ū-lər.

Got that Mr.
President!?

$Z \equiv$ Atomic #
$A \equiv$ Atomic Mass



Particle	chg	Mass (MeV/c^2)	Spin
Proton, p	+e	938.28	½
neutron, n	0	939.37	½
electron, e	-e	0.511	½



New force

Strong Nuclear Force

Nuclear radius ~ 1-10 Fermi (10^{-15} m)

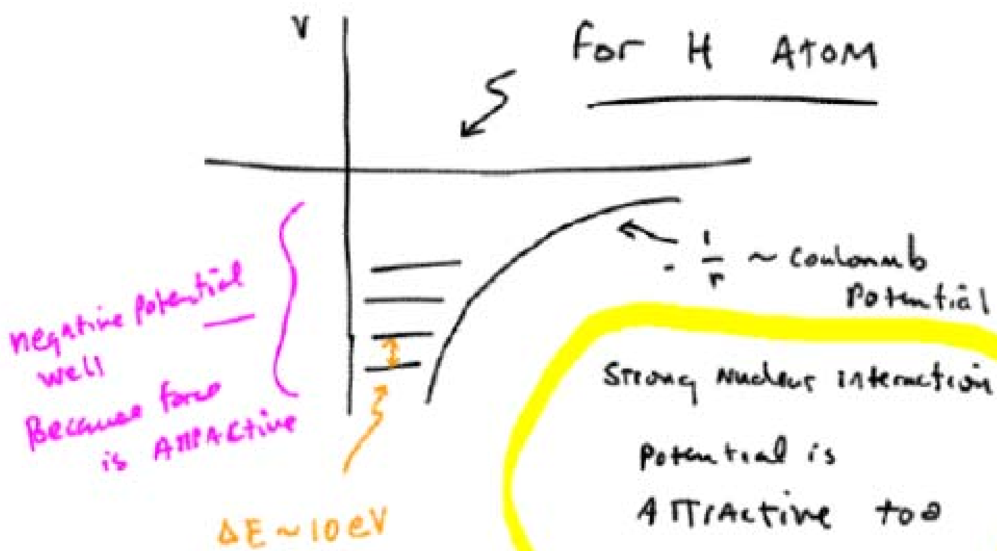
Nuclear density is constant

$$\frac{A}{\frac{4}{3}\pi R^3} \sim \text{const.} \qquad A \sim R^3 \qquad R \sim A^{1/3}$$

$\rho \sim 10^{17}\ \text{kg}/\text{m}^3$

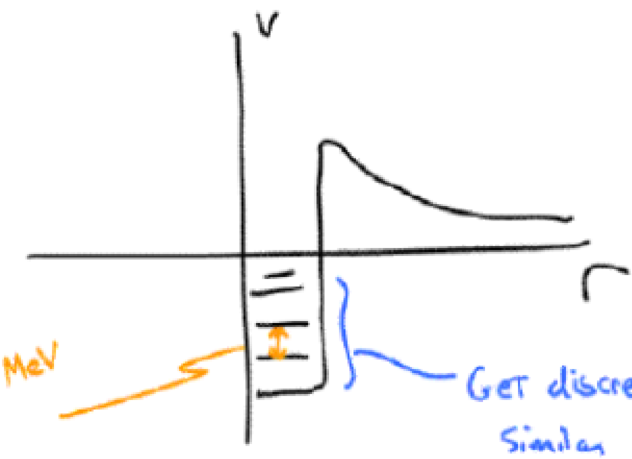
At this density

$M_{earth} \rightarrow$ ball 140 m in radius



Strong nuclear interaction

Potential is ATTRACTIVE too



Get discrete energy levels

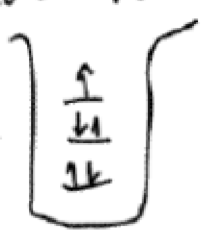
Similar to Atom

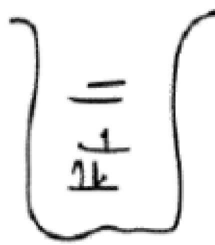
But separation O(MeV) instead of O(10 eV)

Why do you care?

p, n spin 1/2

fill shells w/ protons + neutrons in much the same way we fill atomic shells





$${}^{A}_{Z}X$$

x, Z same info

Symbol for a nucleus

$X \equiv$ Atomic Symbol

$Z \equiv$ # protons — Atomic #

$A \equiv$ Atomic Mass

$N \equiv A - Z \equiv$ # neutrons

Isotope → same Z, different A

protons + neutrons collectively called "Nucleons"

Transitions between States very energetic

$${}^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + \gamma$$

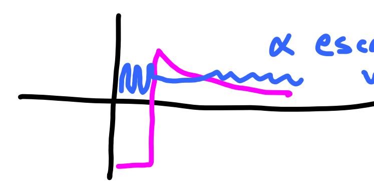
GAMMA radiation γ

$${}^{A}_{Z}X' \longrightarrow {}^{A}_{Z+1}X + e^{-} + \bar{\nu}_e$$

$${}^{A}_{Z}X' \longrightarrow {}^{A}_{Z-1}X + e^{+} + \nu_e$$

β

β radiation



α escapes via quantum Tunneling

$${}^{A}_{Z}X' \longrightarrow {}^{A-4}_{Z-2}X + \alpha$$

Alpha radiation

α = ${}^{4}_{2}He$