Big Ideas From Quantum Mechanics:

- Everything is both a wave and a particle. These are dual descriptions of matter and forces.

$$E = hf = \frac{hc}{\lambda} = \frac{h}{2\pi}(2\pi f) = \hbar\omega$$

"h-bar"

Plank's Constant

$h = 6.626 \times 10^{-34}\ J\cdot s = 4.136 \times 10^{-15}\ eV\cdot s$ "electron volts"

- Einstein's analysis of the <u>photo-electric effect</u> used this relation for light. He predicted the outcome some 10 yrs. before R.A. Millikan verified it experimentally.

- Max Plank invented "h" as a constant to fix a troubling calculation with what is called a "black body".

- Note: $E = \overset{\text{momentum}}{p}\,c$ ← speed of light

$$E = \frac{hc}{\lambda} \longrightarrow \underbrace{p = \frac{h}{\lambda}}$$

also true for <u>matter waves</u>
DE BROGLIE RELATION.

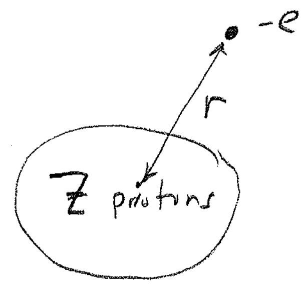
- Particles described by wave function ψ which is complex-valued and is a sort of square-root of a probability density

$$\int_{-\infty}^{\infty} \psi^*(x)\,\psi(x)\,dx = 1 \quad \left(\text{for one-dim'l motion}\right)$$

$$\frac{-\hbar^2}{2m}\frac{d^2\psi}{dx^2} + U(x)\psi(x) = E\,\psi(x)$$

TIME - INDEPENDENT SCHRÖDINGER EQⁿ.

$U(x)$ = potential energy.



Example: $\underbrace{U(r) = -\frac{kZe^2}{r}}$

electronic PE for electron in a hydrogen-like atom

$$\Rightarrow \quad E_n = -Z^2\frac{E_0}{n^2} \quad , n = 1, 2, 3, \ldots$$

$\Rightarrow$ Lyman, Balmer, Paschen series as electrons change energy level there is a photon emitted

- FERMIONS : cannot occupy identical set of quantum #'s $\Rightarrow$ electrons fill up orbitals then no other electrons can also reside in said level.

- BOSONS : can occupy same quantum state as other bosons ... like laser ~~light~~ etc...

Mass / Energy Equivalence

$$E = \gamma m c^2 \quad \text{where} \quad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

This is the total energy for a particle with rest mass m and speed v

$$\gamma = (1 - v^2/c^2)^{-1/2} \cong 1 + \frac{1}{2}\left(\frac{v^2}{c^2}\right) + \cdots$$ binomial series.

Thus, $E = mc^2\left(1 + \frac{1}{2}\left(\frac{v^2}{c^2}\right) + \cdots\right)$

$$\boxed{E = mc^2 + \frac{1}{2}mv^2 + \cdots \quad \text{for } v \ll c \text{ this approximation is best.}}$$

Naturally we identify $\frac{1}{2}mv^2 = KE$, but the mc^2 term is new. This is the so-called rest-energy of the particle. This discovery of Einstein is an important part of most of modern physics.

Example: TOTAL NUCLEAR BINDING ENERGY

$$\underbrace{E_B = (ZM_H + NM_n - M_A)c^2}$$

$$\underbrace{E_B + M_A c^2}_{\substack{\text{energy of bound nucleus} \\ \text{with mass \# } A}} = \underbrace{ZM_H + NM_n}_{\substack{\text{mass of } Z \text{ free hydrogen atoms} \\ \text{which is same as } Z\,p \oplus Z\,e^- \\ \text{\& mass of } N \text{ free neutrons.}}}$$

(A = # of total "nucleons" = $N + Z$.) (happy?)

atomic #

$\boxed{\begin{array}{l}\text{Def}^{n}/\ \text{Atomic mass unit "u" is defined to} \\ \text{be } \frac{1}{12} \text{ the mass of a } {}^{12}C \text{ atom.} \\ \qquad (1u)\,c^2 = 931.5 \text{ MeV}\end{array}}$

Recall $\underbrace{eV = 1.602 \times 10^{-19}\,J}_{\text{energy to move one electron over a potential change of 1 Volt.}}$

Examples of rest energy (mass)

^4He	p n n p	$4.002603\,u$
^1H	p	$1.007825\,u$
N	n	$1.008665\,u$

Example /

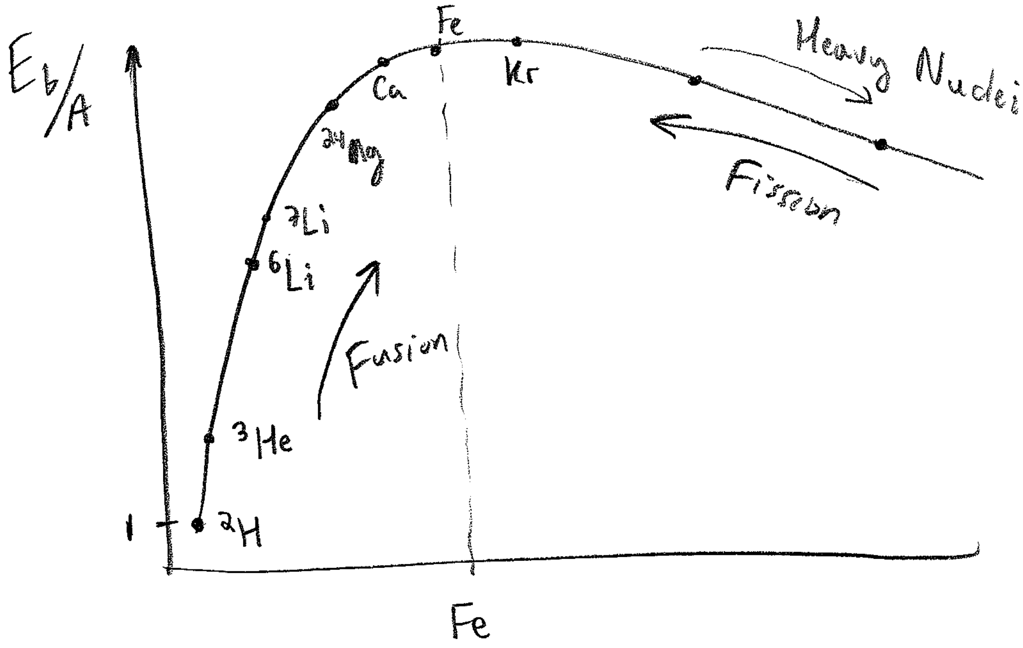
$$\underbrace{2M_{H_1}}_{\text{includes both } p \text{ and } e^- \text{ orbiting } p} + 2M_n = 4.032980\,u \neq M_{^4He}$$

$$M_{^4He} - 2M_{H_1} - 2m_n = \underbrace{0.030377\,u}_{\text{Binding Energy.}}$$

$$E_B = \left(0.030377\,uc^2\right)\left(\frac{931.5 \text{ MeV}}{1u \cdot c^2}\right)$$

$$\boxed{E_B = 28.3 \text{ MeV}}$$

(this is an example with
$A = 4,\ Z = 2,\ N = 2$
for general formula on 125



- To minimize energy of Nucleus as a whole you want Eb/A to be as large as possible since this indicates the depth of the potential well the atom as a whole is occupying in its bound state.

- Fusion combines to light nuclei to release mass-energy.
- Fission splits heavy nuclei to release mass-energy.

The shape of curve is result of battle between E&M force and the strong force which is <u>very</u> short range. Class cooperating we'll do a thought experiment about this.

Radioactive Decay: unstable states change to lower energy stable states by

$$dN = -\lambda N\,dt$$

where $N = \#$ of particles.

λ = decay constant

$$R = -\frac{dN}{dt} = \lambda N$$

$$\tau = 1/\lambda = \text{mean lifetime}\;; \quad \left(\ln(2)\tau = 10.8\text{ min for free nuetron}\right)$$

1 count per second = 1 Bq = 1 "becquerel"

$$1\,Ci = 3.7\times10^{10}\ \frac{\text{decays}}{\text{second}}$$

a Curie is huge

TYPES OF RADIATION

α : $^{232}Th \longrightarrow {}^{228}Ra + \alpha = {}^{228}Ra + {}^{4}He$ (4.08 MeV)

α ← actually ^4He split off the parent atom.

gives chains $4n,\ 4n+1,\ 4n+2,\ 4n+3$.

(half lives vary $10^{-5}s \rightarrow 10^{10}y$.)

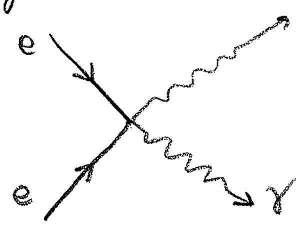
β : too many nuetrons /or to few. We have A constant but Z changes. (0.782 MeV)
by either β^+ or β^- decay. ($N \rightleftharpoons P$)

$$n \longrightarrow p + e^- + \bar{\nu}_e$$

$\bar{\nu}_e$ ← electron nuetrino.

γ : $e^+ + e^- \longrightarrow \gamma + \gamma$

electron, positron annihilation



γ ← high energy photons.