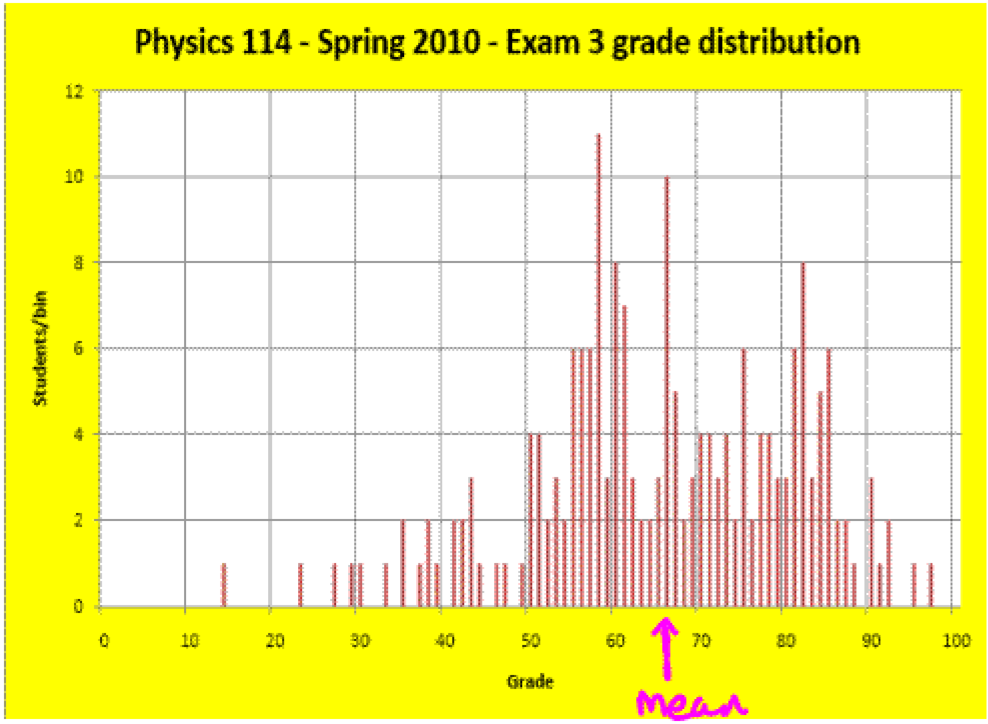
Physics 114 – April 22, 2010

- Exam 3 graded

  Mean = 65



- Email coming with details about endgame

  Deal on Final Exam

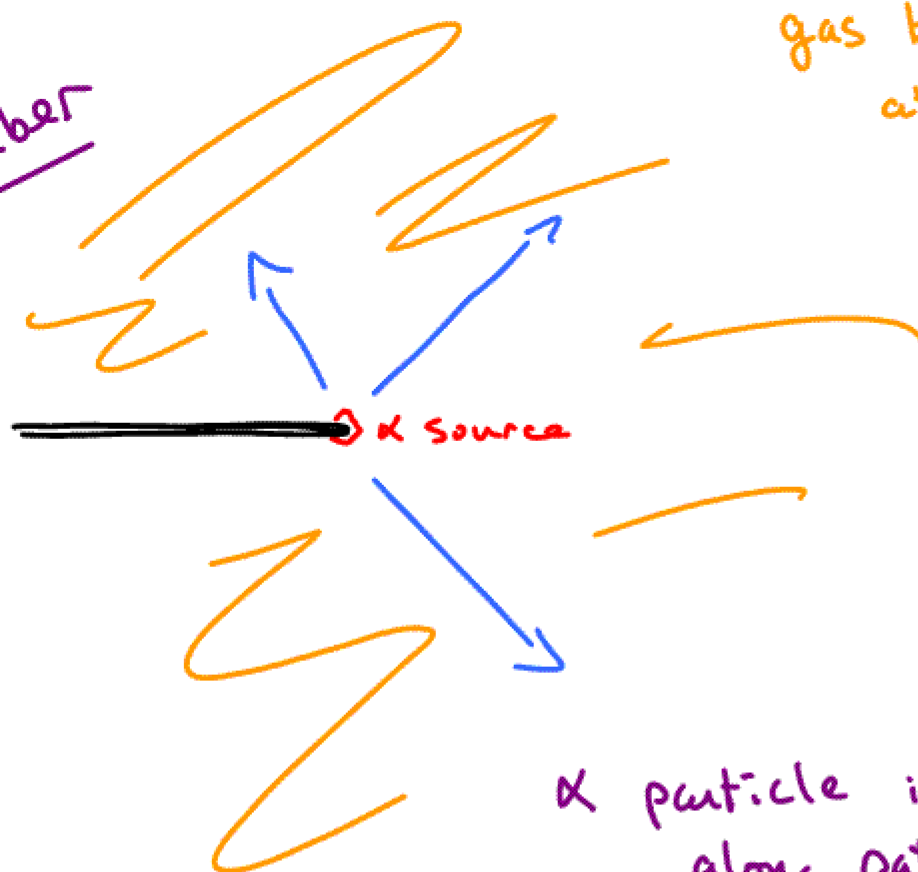
  expectations

  Material

  Q+A Session

Cloud chamber

gas kept just at point of condensation



α particle ionizes gas along path

gas condenses at points of energy deposition

"See" track

Max Born German (1882 - 1970)

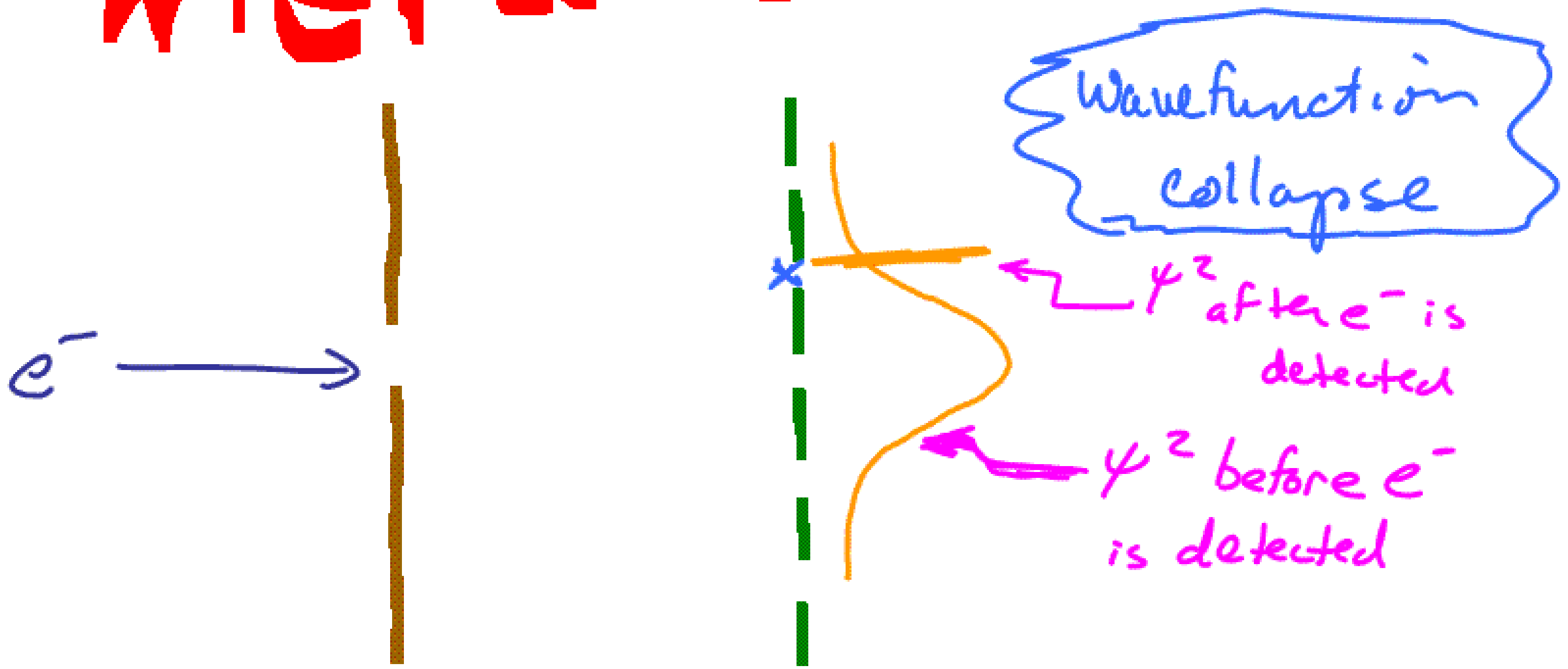
1954 Nobel Prize in physics

"For his fundamental research in quantum mechanics, especially for his statistical interpretation of the wavefunction"

$\psi(x)$ wave function

$\psi^2(x) \sim$ probability of finding particle in region of space

Quantum Wierdness!

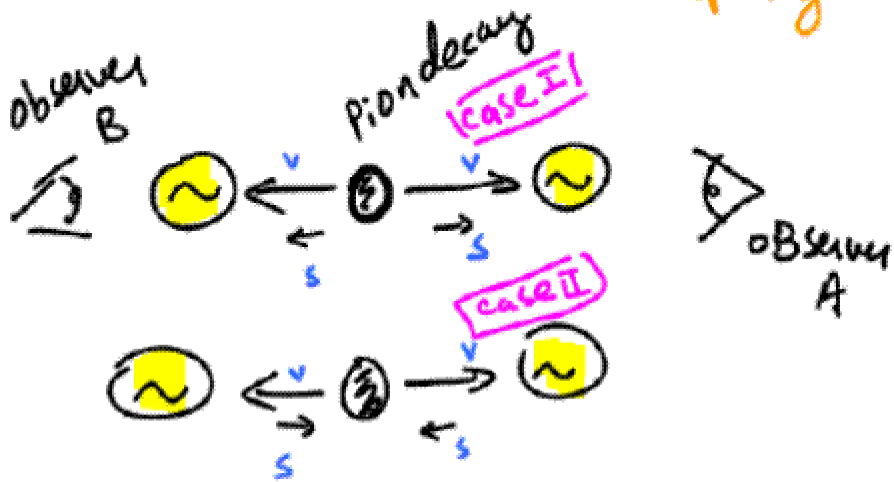


Once electron hits the film/Detector we know with 100% certainty where the electron hits
- so wavefunction has to "collapse"

EPR Paradox — Einstein, Podolski, Rosen
1935

"Spooky Action at a distance"

photon spin = 1



Two photons are produced at once — They are correlated.

If one has spin one way the other has spin the other way.

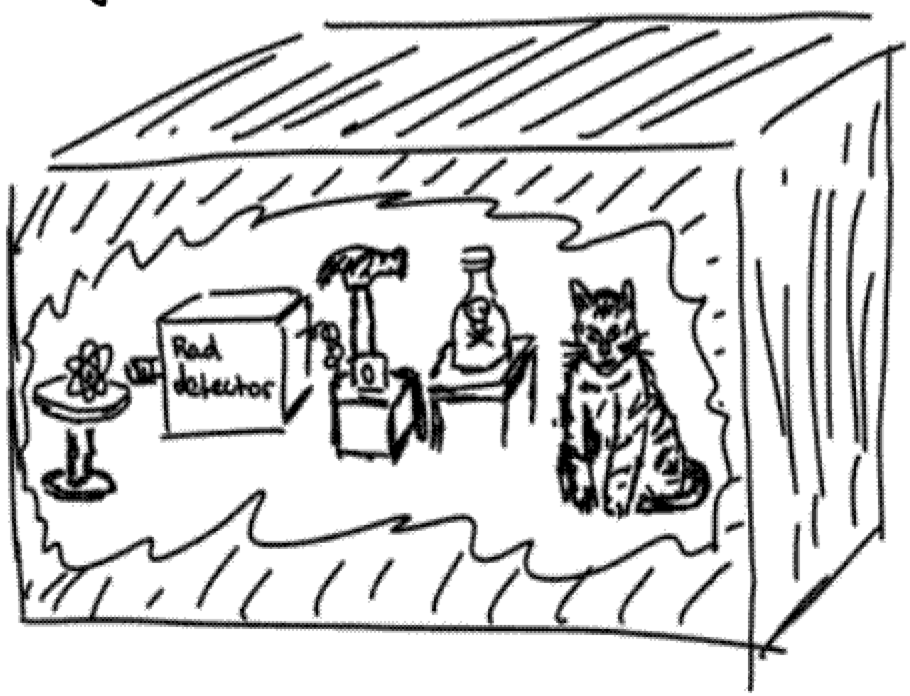
They are in an "entangled quantum STATE"

When observer A observes the spin of photon — The wavefunction collapses and the spin of the photon observer B will observe is determined.

But collapse instantaneous and observers A + B far apart

Does this mean information conveys faster than speed of light?

Schrödinger's Cat

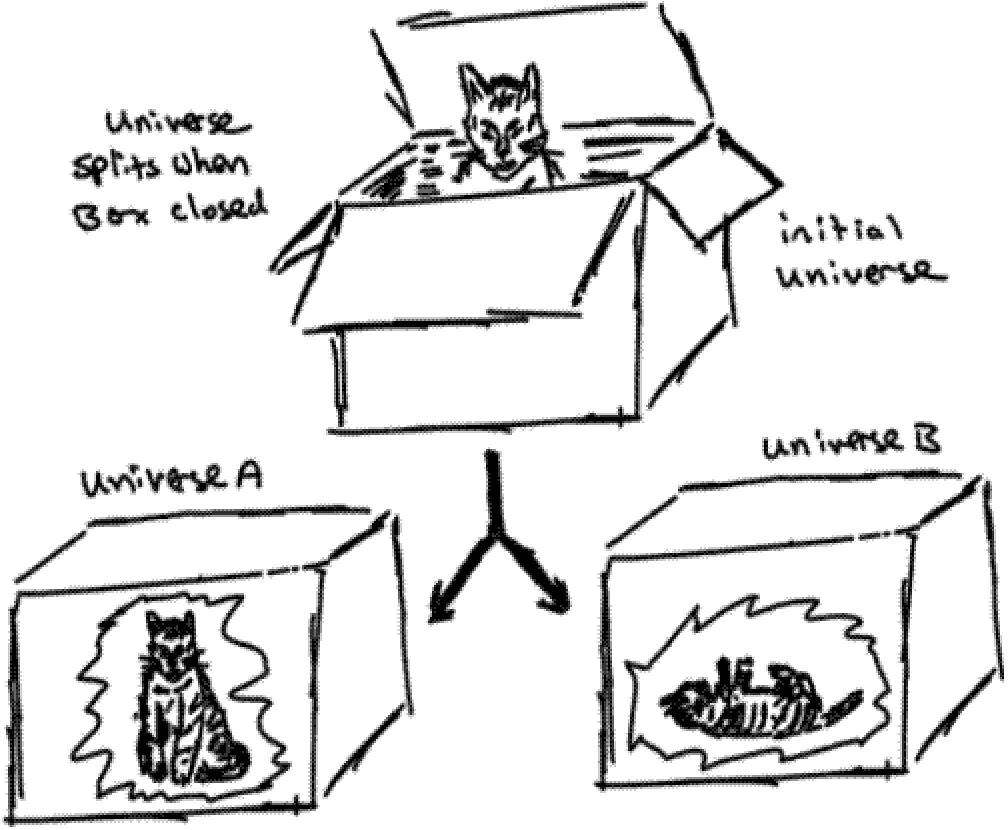


thought experiment
nucleus has 50:50 chance of decaying + killing the cat.
What is the "state" of the cat before box opened?

Copenhagen Interpretation

$$\text{nucleus quantum state} = \frac{1}{2}(\text{decayed}) + \frac{1}{2}(\text{not decayed})$$

$$\text{cat state} = \frac{1}{2}(\text{dead}) + \frac{1}{2}(\text{alive})$$



Hugh Everett (1957)

Bryce DeWitt 1960's + 70's → Many Worlds interpretation

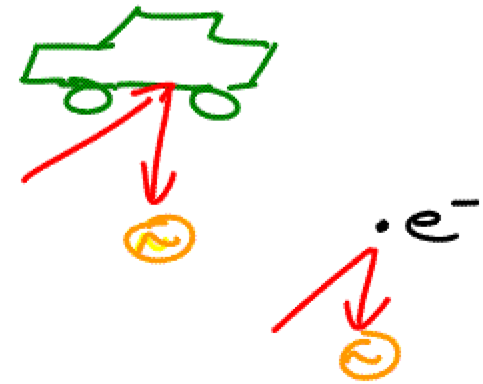
Overall wavefunction does not collapse. It evolves in time. "Decoherence" forces wavefunction to evolve into different streams that do not interact.

Heisenberg's Uncertainty Principle

~1927

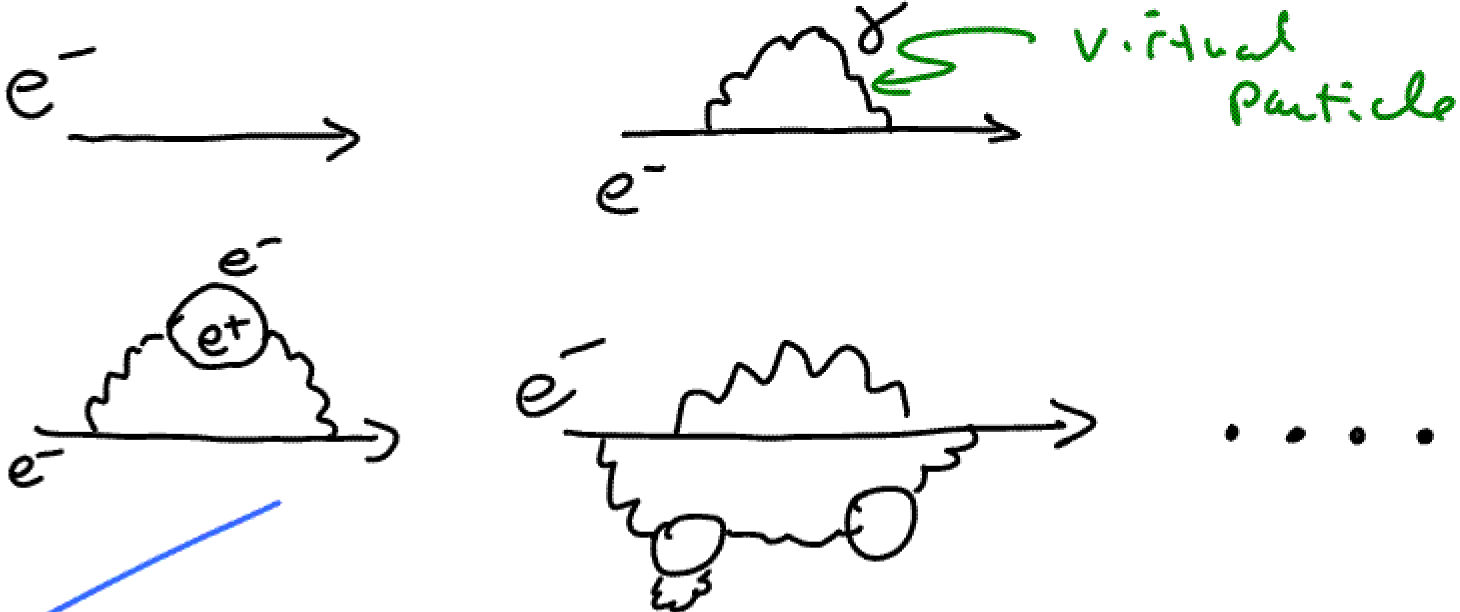
$$\Delta x \, \Delta p \geq \frac{h}{2\pi}$$

- Δx: uncertainty in position
- Δp: uncertainty in Momentum (mv)

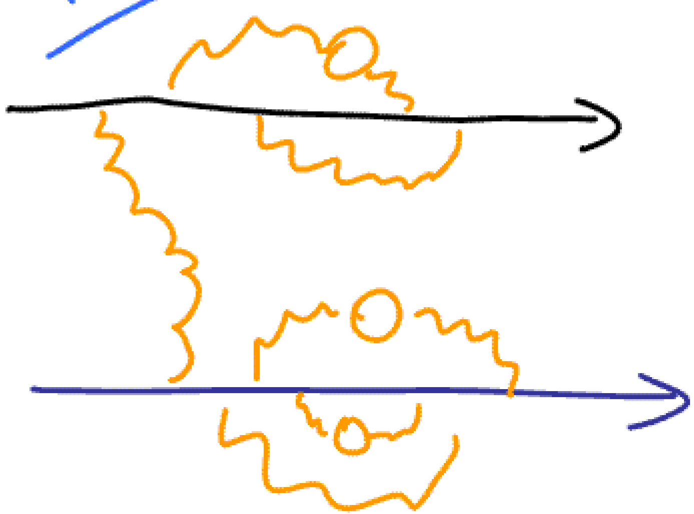


$$\Delta E \, \Delta t > \frac{h}{2\pi}$$

- ΔE: uncertainty in energy
- Δt: Time over which system exists



Quantum Field theory

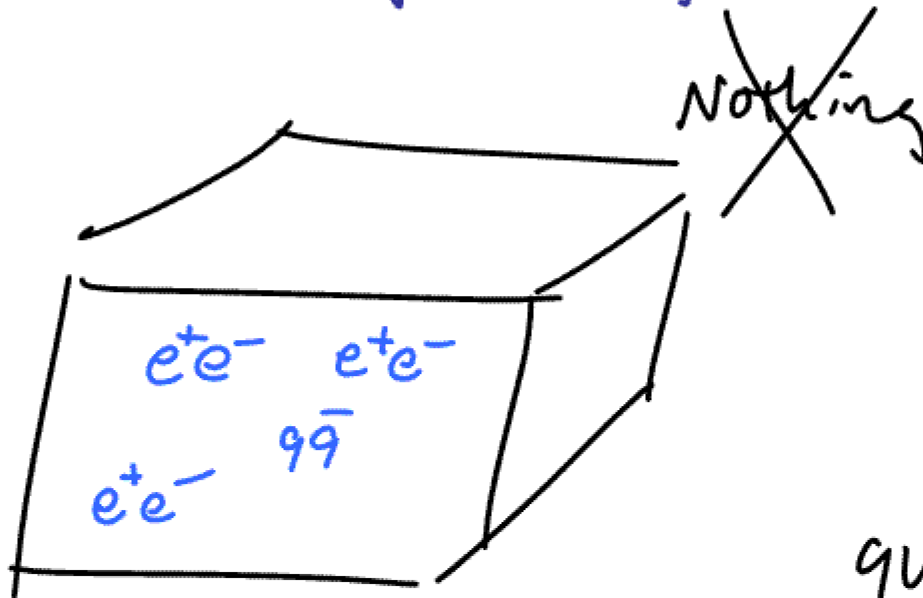


Quantum Electrodynamics

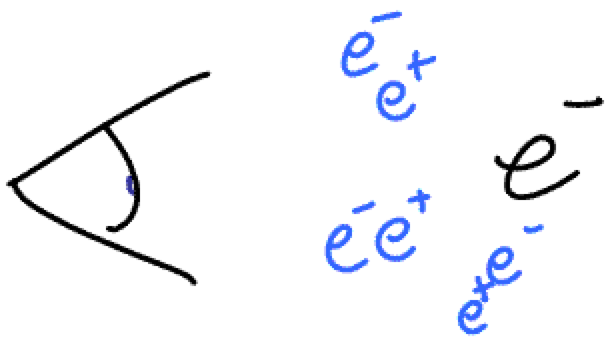
Richard Feynman
+ others

essence of force in quantum field theory is exchange of virtual particles

Vacuum is NOT empty - fleeting Particle - Antiparticle pairs Appear consistent w/ Heis. Unc. Principle



Quantum Vacuum

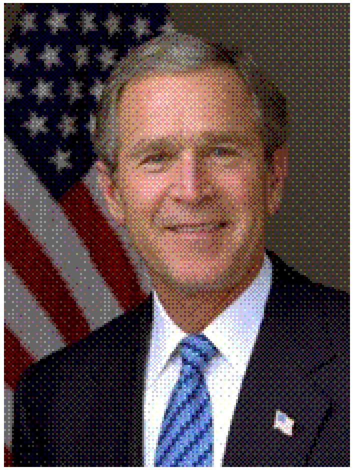


Vacuum polarization -

can actually see an effect on Atomic spectra (Lamb shift)

The Journey into Inner Space

Nuclear physics



By the way, the word 'nuclear' is pronounced

nūk-lē-ər

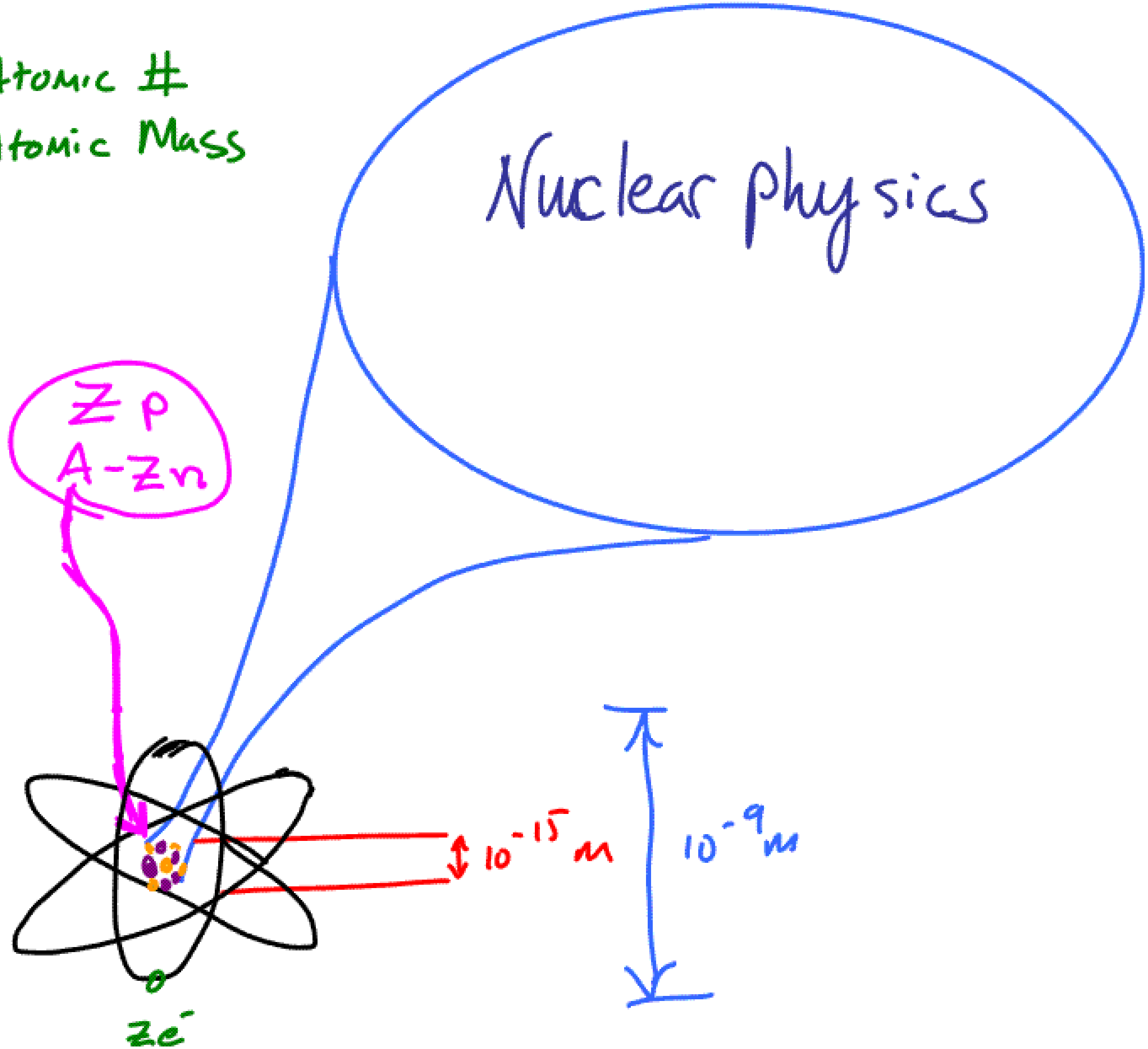
and *not*

nūk-ū-lər.

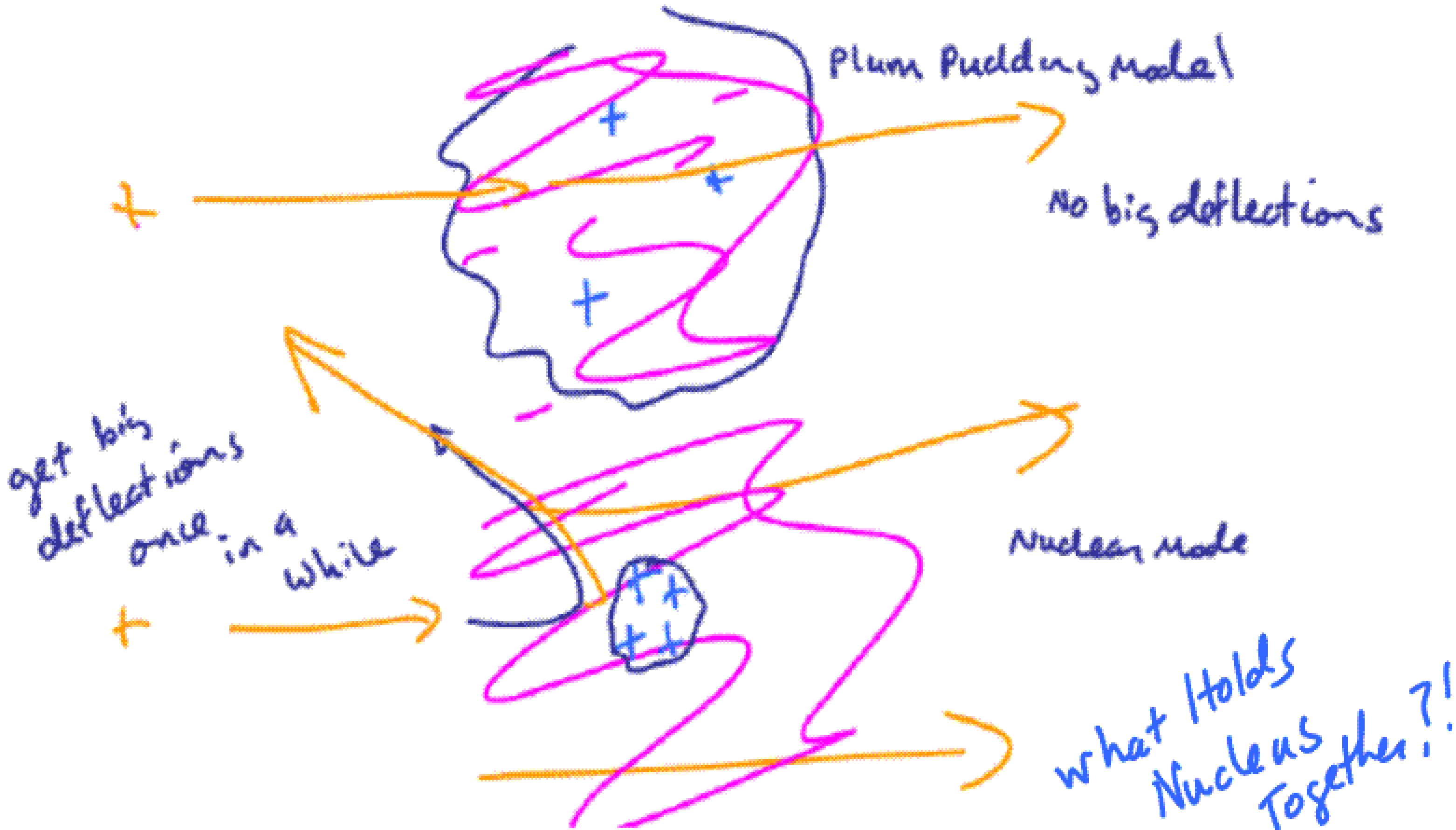
Got that Mr. President!?

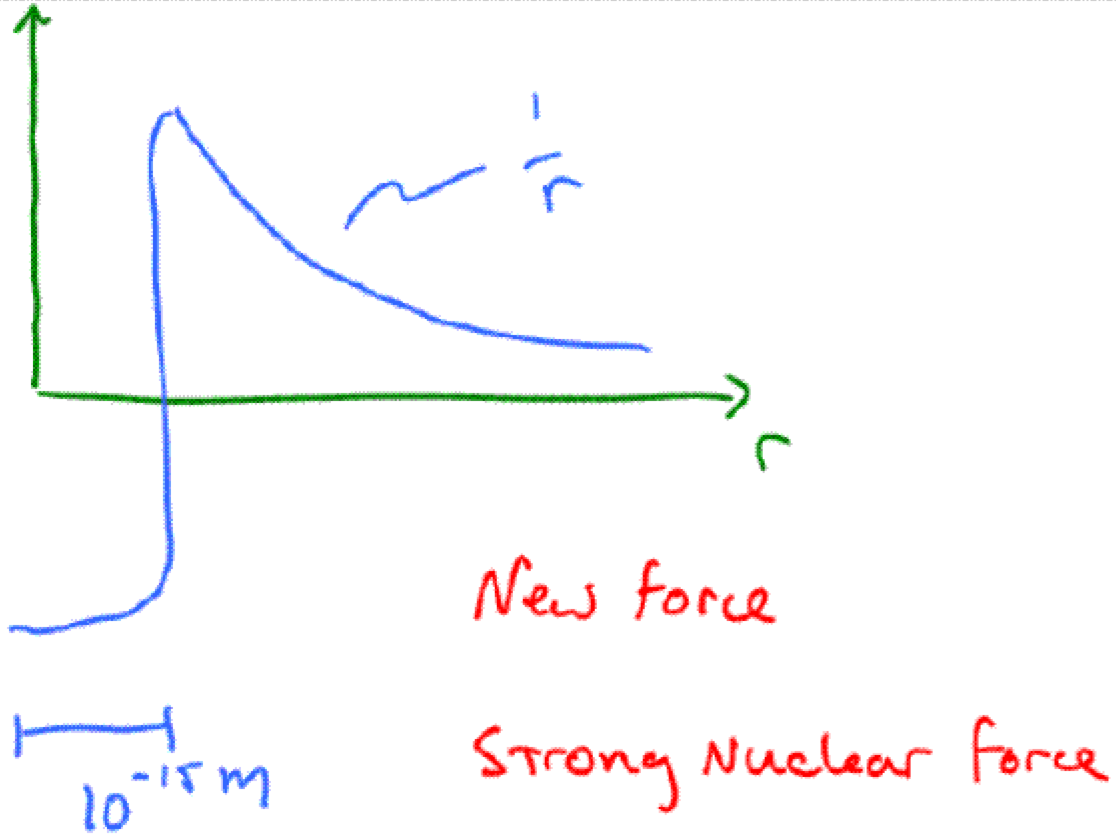
$Z \equiv$ Atomic #

$A \equiv$ Atomic Mass



Nuclear Model of Atom from Rutherford





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

Nuclear density is constant

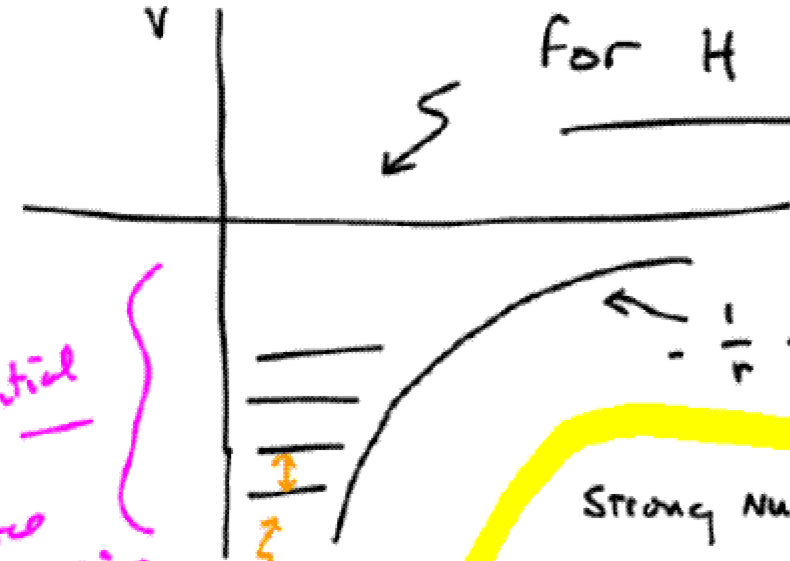
$$\frac{A}{\frac{4}{3}\pi R^3} \sim \text{const.} \qquad A \sim R^3 \qquad R \sim A^{1/3}$$

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

At this density

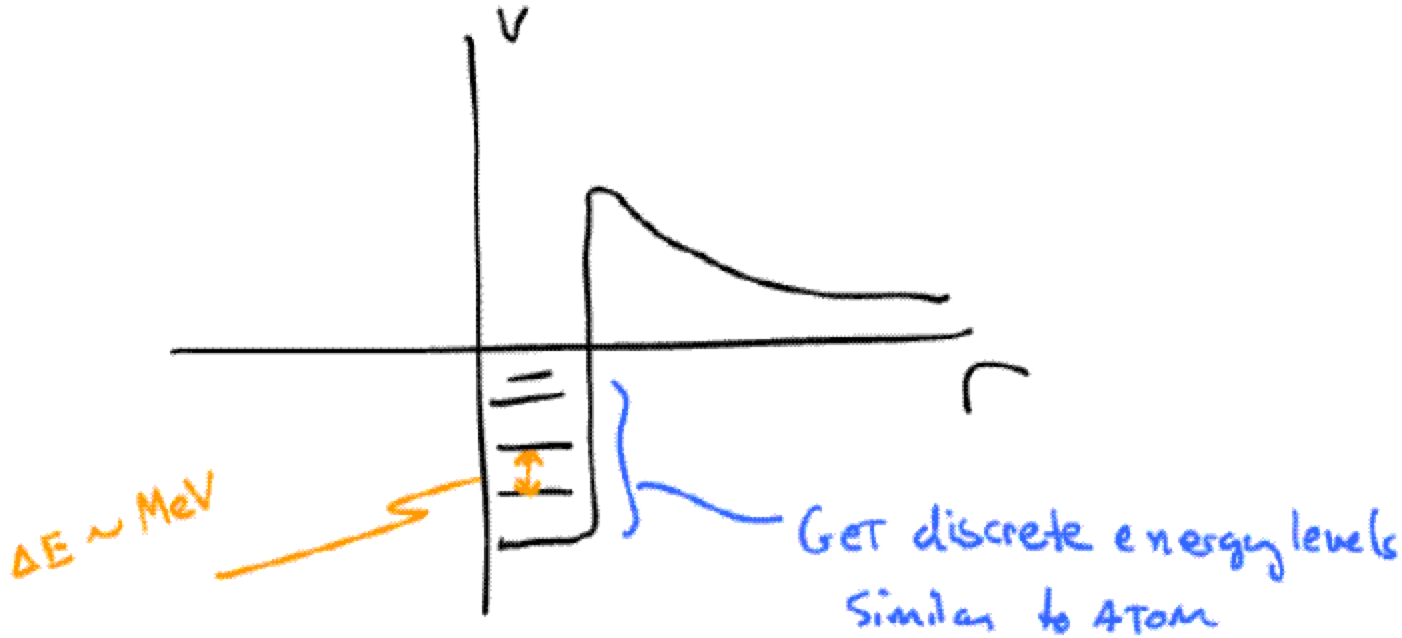
$M_{earth} \rightarrow$ ball 140 m in radius

For H ATOM



Strong Nuclear interaction

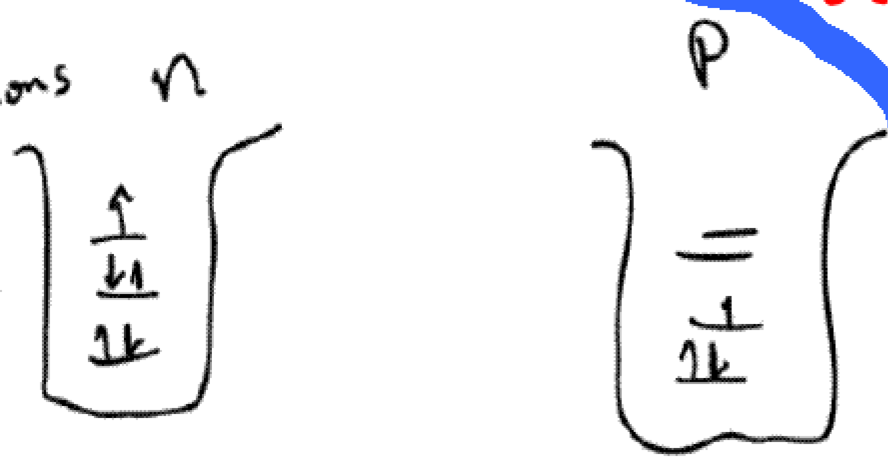
potential is ATTRACTIVE too



p, n Spin 1/2

BUT separation $O(\text{MeV})$ instead of $O(10\text{ eV})$

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



Nuclear physics units

$E = mc^2$ from Special theory of relativity [Not covered yet]

recall the electron-Volt $\equiv$ eV

Chemistry typical energy scale $O(10\ eV)$

Nuclear physics typical energy scal $O(10^6\ eV)$

$E \sim MeV$

Mass units MeV/c^2 (or MeV ... loose + incorrect)

$M_e = 0.511\ MeV/c^2$

$M_p = 938\ MeV/c^2$

1 GeV = 1000 MeV or (1 billion eV)

LHC Now $\approx$ 5 TeV = 5000 GeV = 5×10^{12} eV

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

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

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

GAMMA radiation γ

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

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

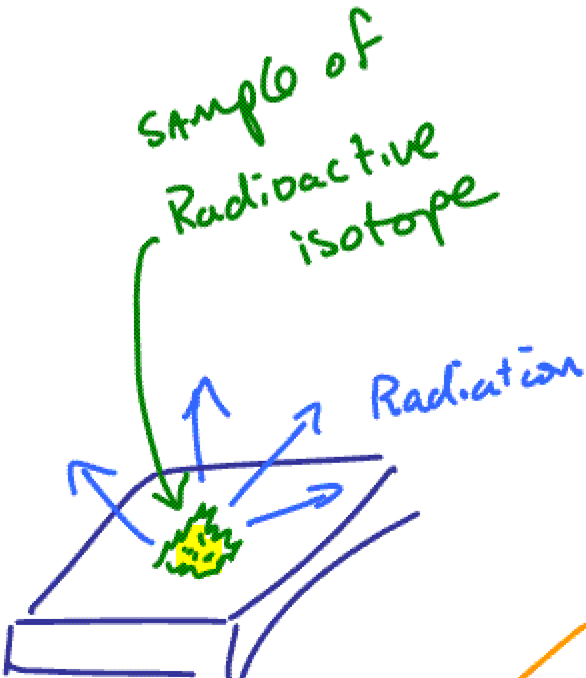
β

β radiation

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

Alpha radiation

α = ${}^{4}_{z}He$



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

λ: decay constant

$N \equiv$ # radioactive nuclei in sample

$\frac{dN}{dt}$: Activity $\equiv$ # nuclei decaying per second

measured in Curies

$1\,ci = 3.7 \times 10^{10}\ \frac{dec.}{s}$

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

$$\int_{N_0}^{N} \frac{dN}{N} = -\int_{0}^{t} \lambda\, dt$$

$$\ln \frac{N}{N_0} = -\lambda t$$

$$\frac{N}{N_0} = e^{-\lambda t} \rightarrow N = N_0 e^{-\lambda t}$$

$\lambda \equiv$ decay constant

nuclei drop by $\frac{1}{e}$ when $t = \frac{1}{\lambda}$

"fast decay" $\rightarrow$ large λ

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda} \equiv \text{half-life} \equiv \text{time for } \tfrac{1}{2} \text{ the nuclei to decay}$$

N atoms in sample at time = 0

$$\text{Activity} \equiv \frac{\#\text{decays}}{\text{second}} = \frac{\Delta N}{\Delta t} = \lambda N$$

↑ decay constant

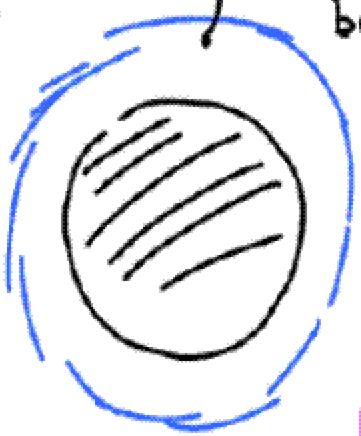
halflife $\equiv t_{1/2}$ = time for ½ sample to decay

$$t_{1/2} = \frac{0.693}{\lambda}$$

Radioactive Dating

"Normal" carbon $^{12}_{6}C$

$^{14}_{6}C$ produced by cosmic rays hitting atmosphere



^{14}C is naturally radioactive β-emitter

$t_{1/2}$ = 5730 years

- ^{14}C incorporated into living tissue
- stops at death
- $^{14}C/^{12}C$ ratio gives estimate of time since death
- ^{14}C concentration in atmosphere varies, calibrate w/ tree rings

A sample of bone

^{14}C activity to be 25 % of that in living material. How old is the bone?

$$^{14}C \quad t_{\frac{1}{2}} = 5730$$

after 1 half life Activity = 50 % of original

after 2 " " = 25 % of original

Age ~ (2) 5730 years ~ 11,400 years

Nuclear Binding Energy

Consider atomic binding energy (ionization energy)

$$m_e c^2 + m_p c^2 - M_H c^2 = 13.6\,eV$$

Energy of separate parts — energy of Bound beast

Binding energy

For Atoms ... ionization energy is what we call it.

For a nucleus "x" with A, Z:

$$(A-Z) M_n c^2 + Z M_p c^2 - M_x c^2 = \text{Total Nuclear Binding Energy}$$

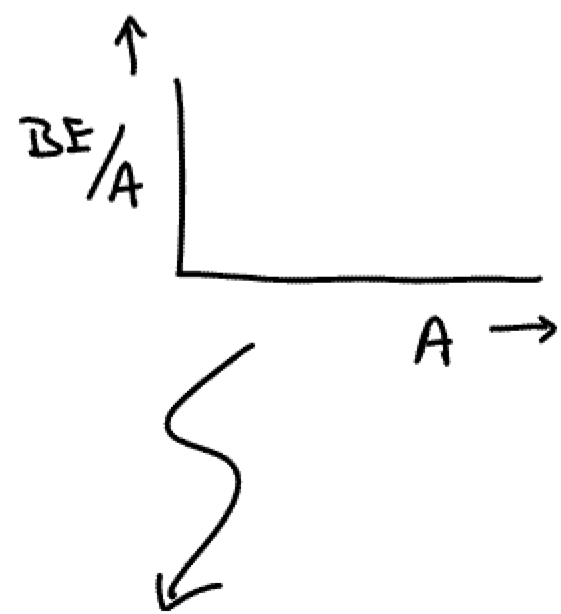
Binding Energy Per Nucleon = Total BE/A

≡ Amount of E to remove a nucleon if you will "ionization energy for a nucleon" sort of

High BE/A → Very Stable nucleus

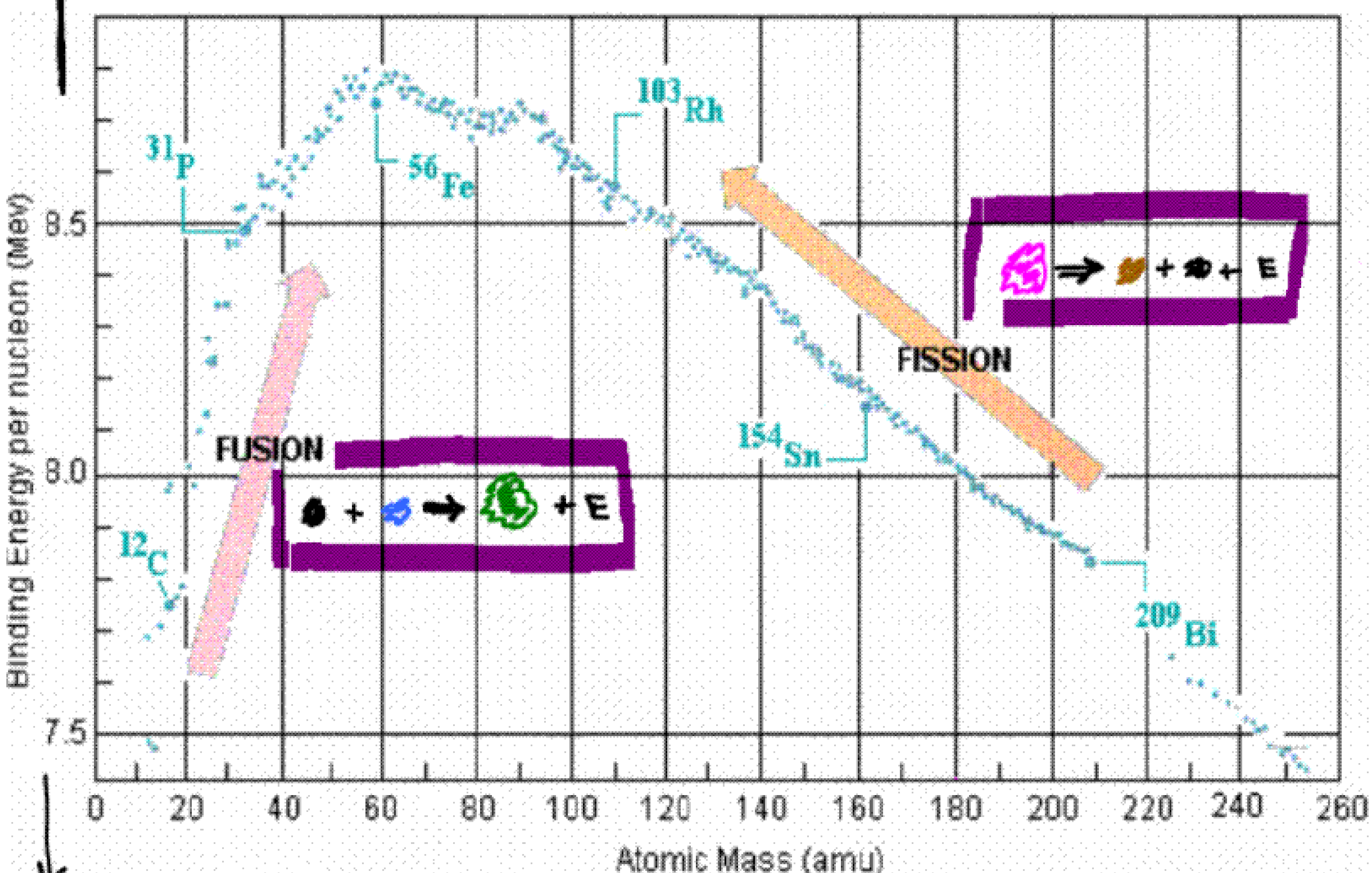
Low BE/A → less Stable nucleus

let's look at



Inherent Nuclear stability as function of nuclear size

nucleons held more tightly



nucleons held less tightly

A very important nuclear process ...

$$^{235}_{92}U + n \longrightarrow {}^{93}_{37}Rb + {}^{141}_{58}Cs + 2n$$

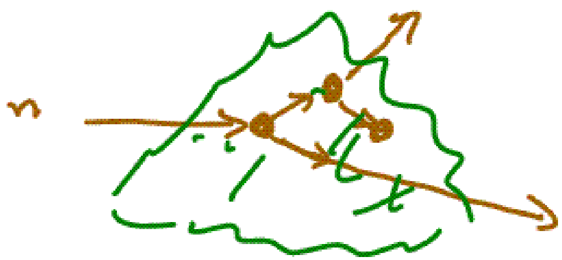
$\sum mass = M_{initial}$

$Rb \rightarrow \gamma\ \gamma \qquad Cs \rightarrow \gamma\ \gamma$

cascade of decays

$\sum mass = M_{final}$

$M_{initial} - M_{final} > 0$

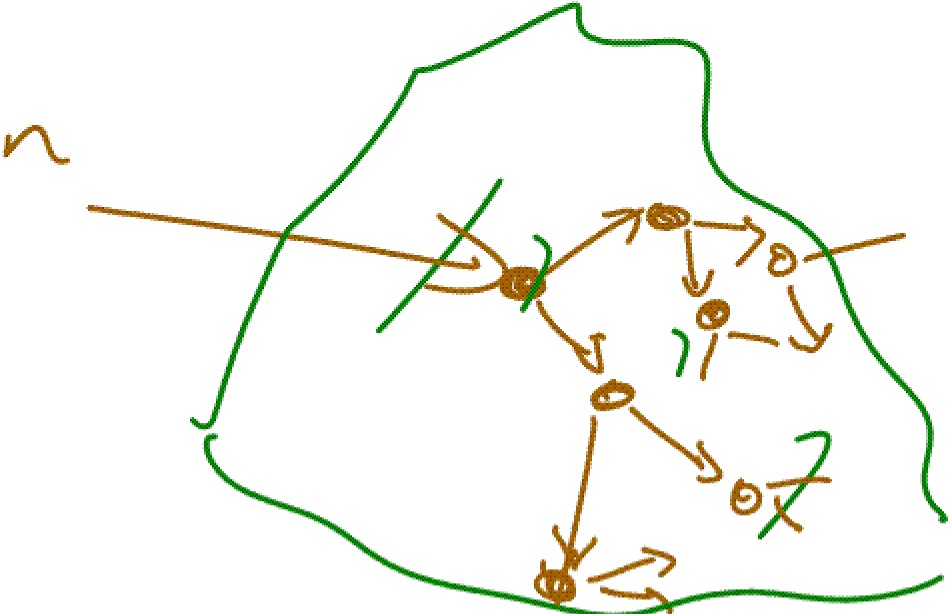


Critical

1 Split per Split

Subcritical

<1 Split per Split



Supercritical

> 1 split per split

Watch out!

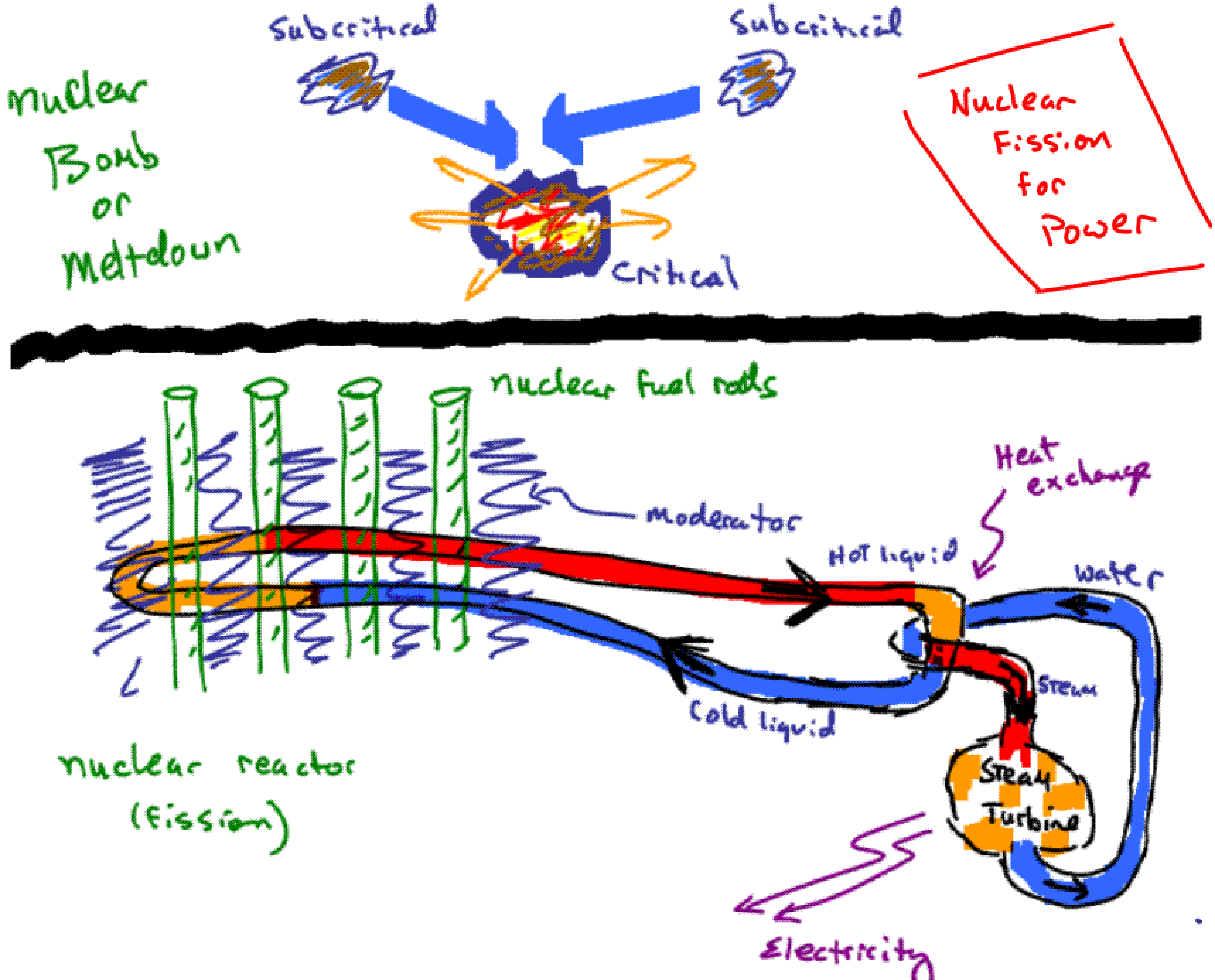
kablooey!

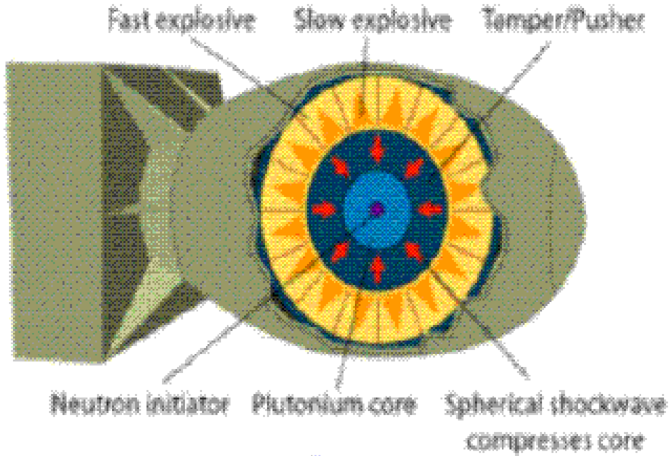
or

meltdown

+

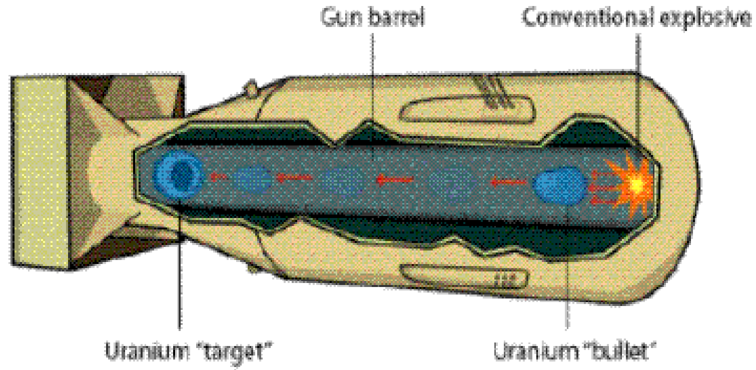
Fire


Nuclear Bomb or Meltdown
Subcritical
Subcritical
Critical
Nuclear Fission for Power
nuclear fuel rods
moderator
Heat exchange
Hot liquid
water
Cold liquid
Steam
Steam Turbine
nuclear reactor (fission)
Electricity



Similar to Fat Man
used on Nagasaki
Aug. 9, 1945

Similar to "little Boy"
used on Hiroshima
August 6, 1945



Diagrams
from
Wikipedia

Natural U
~99% ^{238}U
Must enrich
in ^{235}U to
use as
nuclear fuel
or bomb