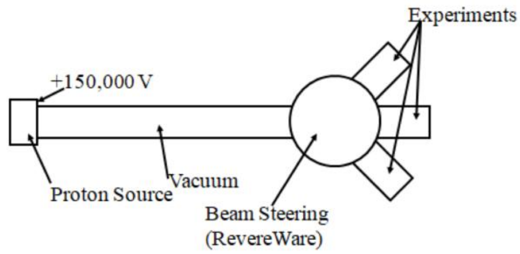
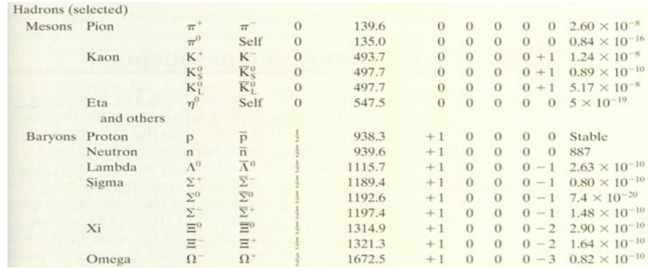
Noteguide for Particle Accelerators - Video 32A **Name**______________________________

Basic concept - $Vq = {}^{1}/_{2}mv^2$

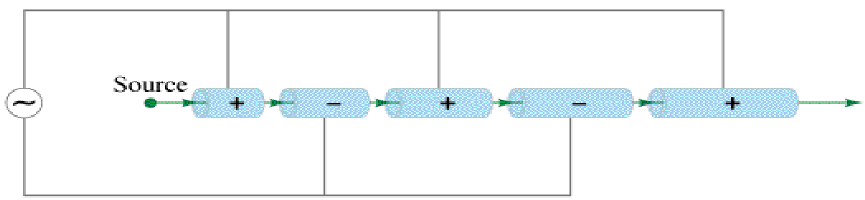




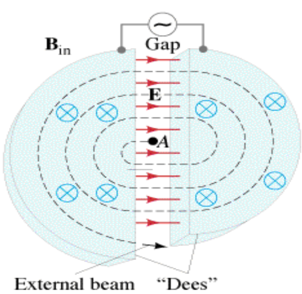
Hadrons (selected)

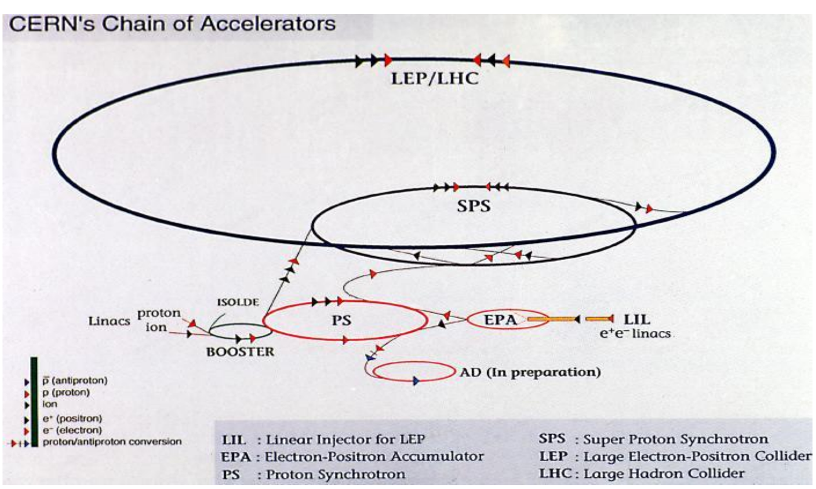
Mesons	Pion	π^+	π^-	0	139.6	0	0	0	0	0	2.60×10^{-8}
		π^0	Self	0	135.0	0	0	0	0	0	0.84×10^{-16}
	Kaon	K^+	K^-	0	493.7	0	0	0	0	+1	1.24×10^{-8}
		K^0_S	$\overline{K}^0_S$	0	497.7	0	0	0	0	+1	0.89×10^{-10}
		K^0_L	$\overline{K}^0_L$	0	497.7	0	0	0	0	+1	5.17×10^{-8}
	Eta	η^0	Self	0	547.5	0	0	0	0	0	5×10^{-19}
	and others										
Baryons	Proton	p	$\overline{p}$	$\frac{1}{2}$	938.3	+1	0	0	0	0	Stable
	Neutron	n	$\overline{n}$	$\frac{1}{2}$	939.6	+1	0	0	0	0	887
	Lambda	Λ^0	$\overline{\Lambda}^0$	$\frac{1}{2}$	1115.7	+1	0	0	0	−1	2.63×10^{-10}
	Sigma	Σ^+	$\overline{\Sigma}^-$	$\frac{1}{2}$	1189.4	+1	0	0	0	−1	0.80×10^{-10}
		Σ^0	$\overline{\Sigma}^0$	$\frac{1}{2}$	1192.6	+1	0	0	0	−1	7.4×10^{-20}
		Σ^-	$\overline{\Sigma}^+$	$\frac{1}{2}$	1197.4	+1	0	0	0	−1	1.48×10^{-10}
	Xi	Ξ^0	$\overline{\Xi}^0$	$\frac{1}{2}$	1314.9	+1	0	0	0	−2	2.90×10^{-10}
		Ξ^-	$\overline{\Xi}^+$	$\frac{1}{2}$	1321.3	+1	0	0	0	−2	1.64×10^{-10}
	Omega	Ω^-	Ω^+	$\frac{3}{2}$	1672.5	+1	0	0	0	−3	0.82×10^{-10}

Velocity of particles?



(2 miles long, 50 GeV)



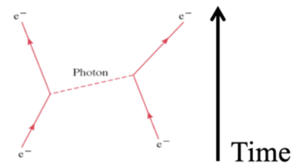


(6.5 TeV)

Noteguide for QED and Types of Particles - Video 32B **Name**______________________________

Quantum Electrodynamics (QED) – Richard Feynman

Forces are mediated by virtual particles



$$\Delta E \Delta t \geq \frac{h}{4\pi}$$

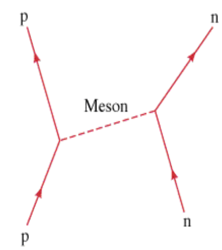
How QED Explains:

What charge actually is

Force dropping off over distance

How accelerating a charge causes it to radiate actual photons

The Yukawa Particle:



π^+ - 139.6 MeV/c^2

π^o - 135.0 MeV/c^2

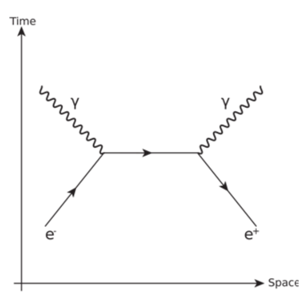
π^- - 139.6 MeV/c^2

Type	Relative Strength	Field Particle
Strong Nuclear	1	Gluons
Electromagnetic	10^{-2}	Photon (γ)
Weak Nuclear	10^{-6}	$W^{\pm}$ and Z^o
Gravitational	10^{-38}	Graviton?

	Gravitational	Weak	Electromagnetic	Strong
Particles experiencing	All	Quarks, leptons	Charged	Quarks, gluons
Particles mediating	Graviton	W^+, W^-, Z^0	γ	Gluons

Name	Particle	Antiparticle
Electron	e^-	e^+
Proton	p	$\overline{p}$
Pion	π^+	π^-

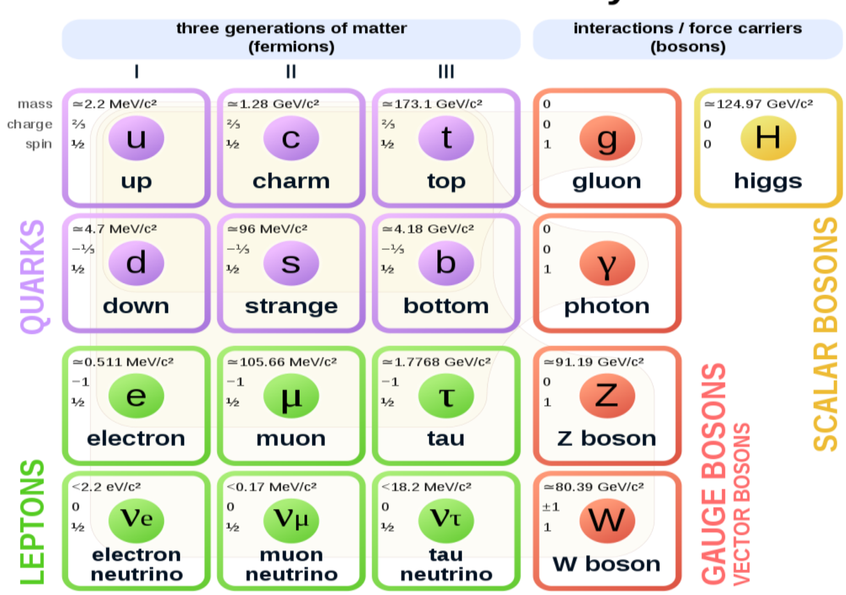
Annihilation:



(Write down what the axes mean, and why the positron is going backwards in time)

Category	Particle Name	Symbol	Anti-particle	Spin	Rest Mass (MeV/c^2)
Gauge bosons	Photon	γ	Self	1	0
	W	W^+	W^-	1	80.33×10^3
	Z	Z^0	Self	1	91.19×10^3
Leptons	Electron	e^-	e^+	$\frac{1}{2}$	0.511
	Neutrino (e)	ν_e	$\bar{\nu}_e$	$\frac{1}{2}$	$0(<7.0 \times 10^{-6})^{\ddagger}$
	Muon	μ^-	μ^+	$\frac{1}{2}$	105.7
	Neutrino (μ)	ν_μ	$\bar{\nu}_\mu$	$\frac{1}{2}$	$0(<0.17)^{\ddagger}$
	Tau	τ^-	τ^+	$\frac{1}{2}$	1777
	Neutrino (τ)	ν_τ	$\bar{\nu}_\tau$	$\frac{1}{2}$	$0(<24)^{\ddagger}$
Hadrons (selected)					
Mesons	Pion	π^+	π^-	0	139.6
		π^0	Self	0	135.0
	Kaon	K^+	K^-	0	493.7
		K^0_S	$\bar{K}^0_S$	0	497.7
		K^0_L	$\bar{K}^0_L$	0	497.7
	Eta	η^0	Self	0	547.5
	and others				
Baryons	Proton	p	$\bar{p}$	$\frac{1}{2}$	938.3
	Neutron	n	$\bar{n}$	$\frac{1}{2}$	939.6
	Lambda	Λ^0	$\bar{\Lambda}^0$	$\frac{1}{2}$	1115.7
	Sigma	Σ^+	$\bar{\Sigma}^-$	$\frac{1}{2}$	1189.4
		Σ^0	$\bar{\Sigma}^0$	$\frac{1}{2}$	1192.6
		Σ^-	$\bar{\Sigma}^+$	$\frac{1}{2}$	1197.4
	Xi	Ξ^0	$\bar{\Xi}^0$	$\frac{1}{2}$	1314.9
		Ξ^-	Ξ^+	$\frac{1}{2}$	1321.3
	Omega	Ω^-	Ω^+	$\frac{3}{2}$	1672.5
	and others				

Standard Model of Elementary Particles



Bosons (Integer spin)

Gauge Bosons (Spin 1)

Scalar Boson (Spin 0)

Mesons (Even # of Spin ½)

Fermions **(Non integer Spin or Spin 1/2)**

Leptons

Bosons

Quarks

Noteguide for Conservation Laws- Videos 32C **Name______________________________**

Conservation Laws:

Charge Mass/Energy Nucleon #

Conservation of Baryon number: (All Baryons are B = +1, anti-Baryons are B = -1)

TABLE 32–2 Particles (stable under strong decay)†

Category	Particle Name	Symbol	Anti-particle	Spin	Rest Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Lifetime (s)	Principal Decay Modes
Baryons	Proton	p	$\bar{p}$	$\frac{1}{2}$	938.3	+1	0	0	0	0	Stable	
	Neutron	n	$\bar{n}$	$\frac{1}{2}$	939.6	+1	0	0	0	0	887	$pe^-\bar{\nu}_e$
	Lambda	Λ^0	$\bar{\Lambda}^0$	$\frac{1}{2}$	1115.7	+1	0	0	0	−1	2.63×10^{-10}	$p\pi^-, n\pi^0$
	Sigma	Σ^+	$\bar{\Sigma}^-$	$\frac{1}{2}$	1189.4	+1	0	0	0	−1	0.80×10^{-10}	$p\pi^0, n\pi^+$
		Σ^0	$\bar{\Sigma}^0$	$\frac{1}{2}$	1192.6	+1	0	0	0	−1	7.4×10^{-20}	$\Lambda^0\gamma$
		Σ^-	$\bar{\Sigma}^+$	$\frac{1}{2}$	1197.4	+1	0	0	0	−1	1.48×10^{-10}	$n\pi^-$
	Xi	Ξ^0	$\bar{\Xi}^0$	$\frac{1}{2}$	1314.9	+1	0	0	0	−2	2.90×10^{-10}	$\Lambda^0\pi^0$
		Ξ^-	Ξ^+	$\frac{1}{2}$	1321.3	+1	0	0	0	−2	1.64×10^{-10}	$\Lambda^0\pi^-$
	Omega	Ω^-	Ω^+	$\frac{3}{2}$	1672.5	+1	0	0	0	−3	0.82×10^{-10}	$\Xi^0\pi^-, \Lambda^0K^-, \Xi^-\pi^0$
	and others											

†See also Table 32–4 for particles with charm and bottomness.

‡Experimental upper limits on neutrino masses are given in parentheses.

Example: Can the following reaction occur?

$$p + n \rightarrow p + p + \bar{p}$$

Charge:

Mass/Energy

Baryon #

Watch all these videos, so you know you got it right:

What is the total Baryon number of $p + n + \bar{n} + \Omega^+$ (0)	What is the total Baryon number of $\Xi^+ + \bar{\Sigma}^+ + \Lambda^o + \pi^+$ (-1)
Can this reaction occur? $p + \bar{p}$ ---> $\Omega^- + \Xi^+ + K_s^o$ Q E B (y)	Can this reaction occur? $p + \bar{n}$ ---> $\bar{\Sigma}^o + \bar{\Sigma}^+$ Q E B (n)
Can this reaction occur? $\Lambda^o + \bar{n}$ ---> $\Sigma^o + \bar{\Sigma}^+$ Q E B (n)	Example This reaction occurs with high probability: $\pi^- + p \rightarrow K_L^o + \Lambda^o$ This reaction is never observed: $\pi^- + p \rightarrow K_L^o + n$

Example:

Does this reaction conserve strangeness?

$p + \bar{p}$ ---> $\Omega^- + \Xi^+ + K_s^o$

Noteguide for Lepton Number- Videos 32D **Name______________________________**

Conservation of Lepton number: (Conserved by type L_e, L_m, L_τ)

TABLE 32–2 Particles (stable under strong decay)†

Category	Particle Name	Symbol	Anti-particle	Spin	Rest Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Lifetime (s)
Leptons	Electron	e^-	e^+	$\frac{1}{2}$	0.511	0	+1	0	0	0	Stable
	Neutrino (e)	ν_e	$\bar{\nu}_e$	$\frac{1}{2}$	$0(<7.0 \times 10^{-6})$‡	0	+1	0	0	0	Stable
	Muon	μ^-	μ^+	$\frac{1}{2}$	105.7	0	0	+1	0	0	2.20×10^{-6}
	Neutrino (μ)	ν_μ	$\bar{\nu}_\mu$	$\frac{1}{2}$	$0(<0.17)$‡	0	0	+1	0	0	Stable
	Tau	τ^-	τ^+	$\frac{1}{2}$	1777	0	0	0	+1	0	2.91×10^{-13}
	Neutrino (τ)	ν_τ	$\bar{\nu}_\tau$	$\frac{1}{2}$	$0(<24)$‡	0	0	0	+1	0	Stable

Charge	Leptons		
−1	e	μ	τ
0	υ_e	υ_μ	υ_τ

All leptons have a lepton number of 1 and antileptons have a lepton number of −1

Can this decay occur?

$$\tau^- \rightarrow \pi^- + \pi^o + \upsilon_\tau$$

Find the missing decay product:

$$\tau^- \rightarrow \upsilon_\tau + e- + ??$$

Whiteboards

Does this decay occur?

	μ^- ---> e^- + $\bar{\nu}_e$
q	
L_e	
L_μ	
L_τ	
M/E	

(no)

Why not:

Does this decay occur?

	μ^- ---> e^- + $\bar{\nu}_e$ + ν_μ
q	
L_e	
L_μ	
L_τ	
M/E	

(yes)

Does this decay occur?

	τ^- ---> π^- + π^- + π^+ + ν_τ
q	
L_e	
L_μ	
L_τ	
M/E	

(yes)

Does this decay occur?

	μ^- ---> ν_e + $\bar{\nu}_e$ + ν_μ
q	
L_e	
L_μ	
L_τ	
M/E	

(no)

Why not:

Does this decay occur?

	μ^- ---> τ^- + $\bar{\nu}_\tau$ + ν_μ
q	
L_e	
L_μ	
L_τ	
M/E	

(no)

Why not:

In this space draw a picture of a pretty pony:

Whiteboards:

What is the missing decay product?

	τ^- --->	μ^- +	$\overline{\nu}_\mu$ +	???
q				
L_e				
L_μ				
L_τ				

ν_τ

What is the missing decay product?

	μ^+ --->	?? +	$\overline{\nu}_\mu$ +	ν_e
q				
L_e				
L_μ				
L_τ				

e^+

What is the missing decay product?

	τ^+ --->	μ^+ +	?? +	$\overline{\nu}_\tau$
q				
L_e				
L_μ				
L_τ				

ν_μ

What is the missing particle?

	?? --->	e- +	$\overline{\nu}_e$ +	ν_μ
q				
L_e				
L_μ				
L_τ				

μ^-

Noteguide for Quark Theory - Videos 32E   Name______________________________

Quark Theory:

TABLE 32–3 Properties of Quarks and Antiquarks

Quarks								
Name	Symbol	Spin	Charge	Baryon Number	Strangeness	Charm	Bottomness	Topness
Up	u	$\frac{1}{2}$	$+\frac{2}{3}e$	$\frac{1}{3}$	0	0	0	0
Down	d	$\frac{1}{2}$	$-\frac{1}{3}e$	$\frac{1}{3}$	0	0	0	0
Strange	s	$\frac{1}{2}$	$-\frac{1}{3}e$	$\frac{1}{3}$	−1	0	0	0
Charmed	c	$\frac{1}{2}$	$+\frac{2}{3}e$	$\frac{1}{3}$	0	+1	0	0
Bottom	b	$\frac{1}{2}$	$-\frac{1}{3}e$	$\frac{1}{3}$	0	0	−1	0
Top	t	$\frac{1}{2}$	$+\frac{2}{3}e$	$\frac{1}{3}$	0	0	0	+1
Antiquarks								
Name	Symbol	Spin	Charge	Baryon Number	Strangeness	Charm	Bottomness	Topness
Up	$\bar{u}$	$\frac{1}{2}$	$-\frac{2}{3}e$	$-\frac{1}{3}$	0	0	0	0
Down	$\bar{d}$	$\frac{1}{2}$	$+\frac{1}{3}e$	$-\frac{1}{3}$	0	0	0	0
Strange	$\bar{s}$	$\frac{1}{2}$	$+\frac{1}{3}e$	$-\frac{1}{3}$	+1	0	0	0
Charmed	$\bar{c}$	$\frac{1}{2}$	$-\frac{2}{3}e$	$-\frac{1}{3}$	0	−1	0	0
Bottom	$\bar{b}$	$\frac{1}{2}$	$+\frac{1}{3}e$	$-\frac{1}{3}$	0	0	+1	0
Top	$\bar{t}$	$\frac{1}{2}$	$-\frac{2}{3}e$	$-\frac{1}{3}$	0	0	0	−1

Baryons are (qqq)

Particle name	Symbol	Quark content	Rest mass (MeV/c^2)	I	J^P	Q (e)	S	C	B′
nucleon/proton[7]	p / p$^+$ / N$^+$	uud	938.272 046(21)[a]	½	½$^+$	+1	0	0	0
nucleon/neutron[8]	n / n^0 / N^0	udd	939.565 379(21)[a]	½	½$^+$	0	0	0	0
Lambda[9]	Λ^0	uds	1 115.683 ± 0.006	0	½$^+$	0	−1	0	0
charmed Lambda[10]	Λ_c^+	udc	2 286.46 ± 0.14	0	½$^+$	+1	0	+1	0
bottom Lambda[11]	Λ_b^0	udb	5 619.4 ± 0.6	0	½$^+$	0	0	0	−1

B   S   q

p =

n =

Λ^o =

Mesons are ($q\bar{q}$)

Particle name	Particle symbol	Antiparticle symbol	Quark content	Rest mass (MeV/c^2)	I^G	J^{PC}	S	C	B′
Pion[6]	π^+	π^-	$u\bar{d}$	139.570 18 ± 0.000 35	1$^-$	0$^-$	0	0	0
Pion[7]	π^0	Self	$\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$ [a]	134.9766 ± 0.0006	1$^-$	0^{-+}	0	0	0
Eta meson[8]	η	Self	$\frac{u\bar{u}+d\bar{d}-2s\bar{s}}{\sqrt{6}}$ [a]	547.862 ± 0.018	0$^+$	0^{-+}	0	0	0
Eta prime meson[9]	η′(958)	Self	$\frac{u\bar{u}+d\bar{d}+s\bar{s}}{\sqrt{3}}$ [a]	957.78 ± 0.06	0$^+$	0^{-+}	0	0	0
Charmed eta meson[10]	η_c(1S)	Self	$c\bar{c}$	2 983.6 ± 0.7	0$^+$	0^{-+}	0	0	0

B   S   q

π^+ =

π^o ($u\bar{u}$) =

η_c =

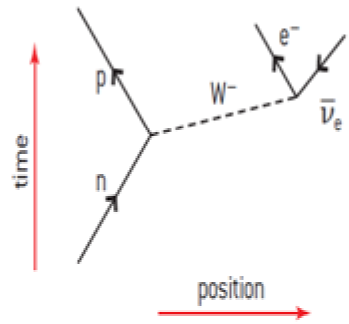
Whiteboards:

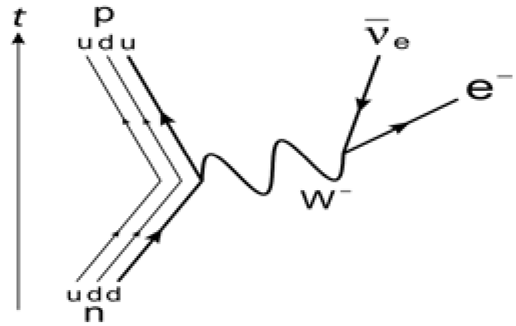
		Baryon or Meson?	B = ?	S = ?	q = ?
1	usc				
2	$u\bar{s}$				
3	ddc				
4	$d\bar{s}$				

Charge	Quarks			Baryon number
$\frac{2}{3}e$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}e$	d	s	b	$\frac{1}{3}$

All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of −1

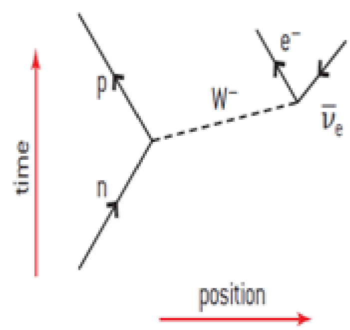
Noteguide for Feynman Diagrams - Videos 32F **Name**______________________________

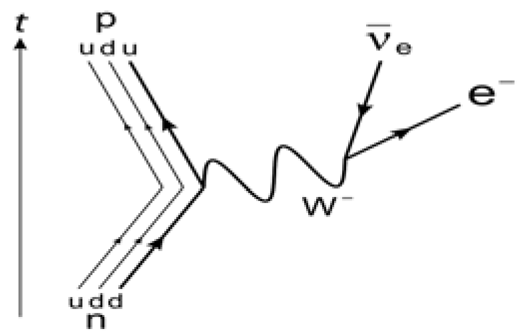




Rules

- Time is up, position is to the right. (Sometimes reversed btw)
- Exchange particles (Z^o, W^+, W^-, γ, π^o, π^+, π^-) are a dotted line, or wavy line.
- Matter particles are shown with an arrow forward in time, anti matter, backward.
- Vertices obey conservation laws.





Examples:

B^- decay: $n \rightarrow p + e^- + \bar{\upsilon}_e$

B+ decay: $p \rightarrow n + e^+ + \upsilon_e$

μ^- decay: $\mu^- \rightarrow \upsilon_\mu + e^- + \overline{\upsilon}_e$

μ^+ decay: $\mu^+ \rightarrow \overline{\upsilon}_\mu + e^+ + \upsilon_e$

τ^- decay: $\tau^- \rightarrow \upsilon_\tau + \mu^- + \overline{\upsilon}_\mu$

τ^+ decay: $\tau^+ \rightarrow \overline{\upsilon}_\tau + \mu^+ + \upsilon_\mu$

Neutron proton Collision: (Label the exchange particle)

Proton electron collision: $p + e- \rightarrow n + \upsilon_e$.

$n + \upsilon_e \rightarrow \upsilon_e + n$ $n + \upsilon_e \rightarrow p + e^-$

Noteguide for Atomic Notation and Isotopes - Videos 30A **Name**______________________

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

X = Symbol (C, Au)
A = Atomic Mass Number = #nucleons
(Protons + Neutrons)
Z = Atomic Number = #protons

$${}^{12}_{6}C$$

Carbon A = 12, Z = 6. #neutrons?

(C-12 is another notation, so the number 12 is the mass number, everyone knows Carbon is element 6)

$${}^{12}_{6}C$$

Carbon 12 has 6 Neutrons

$${}^{14}_{6}C$$

Carbon 14 has <u>8</u> Neutrons
Carbon 14 is an <u>isotope</u> of Carbon
Chemically the same
Nuclear-lly different (it's unstable)
C-14, C-12

Whiteboards:

What is the Atomic notation for tritium? (tritium is an isotope of Hydrogen with 2 neutrons) (3/1 H)	10 protons, 12 neutrons. What is its atomic notation? (22/10 Ne)
How many neutrons in U 235? (235 = A) (143)	How many neutrons in Pb 208? (208 = A) (126)
How many neutrons in Kr 78? (42)	Draw a picture of a bunny here:

Noteguide for Binding Energy - Videos 30B **Name______________________**

Binding energy - the energy to take an atom apart

Unified Mass Units: (u)
C 12 (neutral atom) = 12.0000000 u (defined)
1 u = 1.6605 x 10^{-27} kg = 931.5 MeV (show c = 2.998x10^8 m/s)
Electron = .00054858 u (not useful)
Proton = 1.007276 u (not useful)
H (neutral atom) = 1.007825 u (very useful)
Neutron = 1.008665 u (very useful)

(The bigger the binding energy per nucleon, the more stable the nucleus)

Binding energy Example – Binding Energy of C-14

H (neutral atom) = 1.007825 u, Neutron = 1.008665 u
1 u = 931.5 MeV
C 14 has a mass of 14.003242 u (Appendix B)

H (neutral atom) = 1.007825 u (very useful)
Neutron = 1.008665 u (very useful)
1 u = 931.5 MeV

Binding energy in general

1. Look neutral atom mass
2. Break atom into H and n
3. Subtract neutral atom mass from taken apart mass
4. Multiply mass difference by 931.5 Mev/u

What is the binding energy for Nitrogen 13? (Z = 7) N 13 mass = 13.005739 u H = 1.007825 u Neutron = 1.008665 u 1 u = 931.5 MeV (94.11 MeV)	What is the binding energy for Carbon 12? (Z = 6) C 12 mass = 12.000000 u (duh?) H = 1.007825 u Neutron = 1.008665 u 1 u = 931.5 MeV (92.16 MeV)

Noteguide for Balancing Nuclear Reactions- Videos 30M **Name______________________**

$${}^{4}_{2}He + {}^{14}_{7}N \text{ ---> } {}^{17}_{8}O + {}^{1}_{1}H$$

- Charge and nucleon number are conserved
- Can be written as follows:

$${}^{14}_{7}N(\alpha, p){}^{17}_{8}O$$

Initial Nucleus(bombarding particle, emitted particle)Final Nucleus

Common Particles you should know:

$\alpha = {}^{4}_{2}He$, $p = {}^{1}_{1}H$, d(deuterium) = ${}^{2}_{1}H$, t(tritium) = ${}^{3}_{1}H$, ${}^{1}_{0}n$ = neutron, ${}^{0}_{0}\gamma$ = gamma

Exoergic means:

Endoergic means:

Example:
What is the initial nucleus:

$$??? \quad + \quad n \quad \text{--->} \quad p \quad + \quad {}^{14}_{6}C$$

Whiteboards: - Find the missing nucleus

${}^{137}_{56}Ba$	(n	, γ)	???
$({}^{138}_{56}Ba)$			
${}^{137}_{56}Ba$	(n	, ???)	${}^{137}_{55}Cs$
$(p = {}^{1}_{1}H)$			
${}^{2}_{1}H$	(d	, ?)	${}^{4}_{2}He$
(γ)			
${}^{197}_{79}Au$	(α	, d)	???
$({}^{199}_{80}Hg)$			
${}^{9}_{4}Be$	(???	, t)	${}^{8}_{4}Be$
$({}^{2}_{1}d)$			

Noteguide for Q Value - Videos 30N **Name**_______________________

Example:

Is this reaction exoergic or endoergic? What energy does it require or give off? (Known as the Q value)

$$^{197}_{79}\mathbf{Au}(\alpha, \mathbf{d})\ ^{199}_{80}\mathbf{Hg}$$

$^{197}_{79}\mathbf{Au}$ = 196.966552 $^{199}_{80}\mathbf{Hg}$ = 198.968262

α = He = 4.002603 d = $^{2}\mathbf{H}$ = 2.014102

Whiteboards:

Try this reaction - is it endo or exo, and how much?

$$^{40}_{19}\mathbf{K}(\mathbf{p}, \mathbf{n})\ ^{40}_{20}\mathbf{Ca}$$

$^{40}_{19}\mathbf{K}$ = 39.9639987 $^{40}_{20}\mathbf{Ca}$ = 39.9625912

p = H = 1.007825 n = 1.008665

(Q = +0.529 MeV (Exo))

Try this reaction - is it endo or exo, and how much?

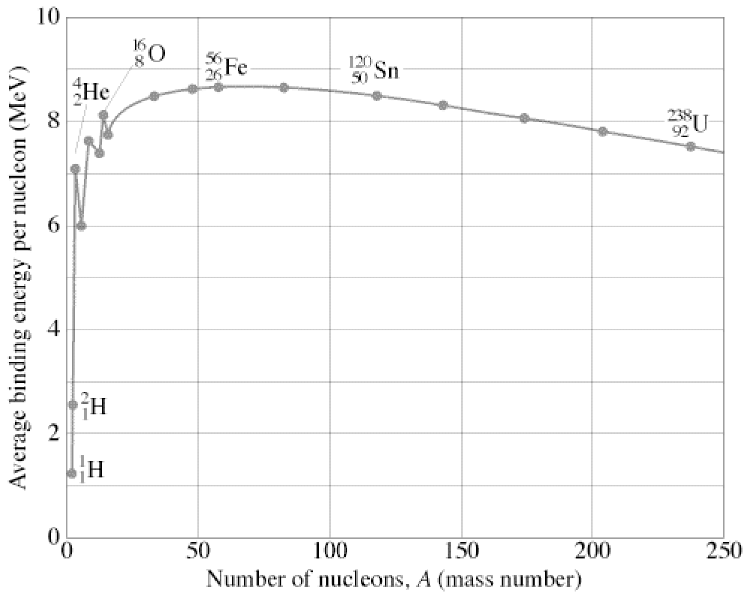
$$^{137}_{56}\mathbf{Ba}(\mathbf{n}, \gamma)\ ^{138}_{56}\mathbf{Ba}$$

$^{137}_{56}\mathbf{Ba}$ = 136.905821 $^{138}_{56}\mathbf{Ba}$ = 137.9052413

n = 1.008665 γ = ??

(Q = +8.611MeV (Exo))

Noteguide for The Curve of Binding Energy- Videos 30O **Name_______________________**



The curve of binding energy:
Define:
Binding energy per nucleon -

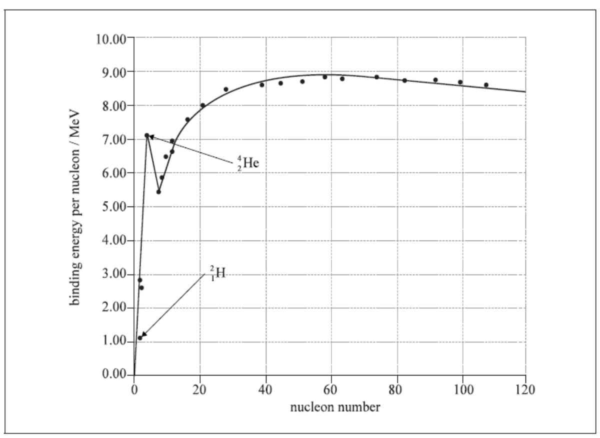
What's more and less stable –

Mark where fusion (joining) and fission (splitting) can release energy. Where are the most stable nuclei?

Fusion powers the sun:	Helium can also fuse:
Energy comes primarily from the Proton-Proton cycle: $^{1}H + ^{1}H = ^{2}H + e^{+} + \nu$ $^{1}H + ^{2}H = ^{3}He + \gamma$ $^{3}He + ^{3}He = ^{4}He + ^{1}H + ^{1}H$	$^{4}He + ^{4}He = ^{8}Be + \gamma$ $^{4}He + ^{8}Be = ^{12}C + \gamma$ Carbon can fuse as well: $^{12}C + ^{12}C = ^{24}Mg + \gamma$ $^{16}O + ^{16}O = ^{28}Si + ^{4}He$

Part 2 Nuclear fusion

The diagram shows the variation of nuclear binding energy per nucleon with nucleon number for some of the lighter nuclides.



(iii) Show that the energy released when two $^{2}_{1}$H nuclei fuse to make a $^{4}_{2}$He nucleus is approximately 4 pJ. *[4]*

. . . .

. . . .

. . . .

Finding Q-Value from Binding Energy per nucleon: (We did these before using mass)

$$^{40}_{19}\mathrm{K}(p, n)\ ^{40}_{20}\mathrm{Ca}$$

K-40 has a BE of 8.538080 MeV per nucleon
Ca-40 has a BE of 8.551299 MeV per nucleon (Q = +0.529 MeV (Exo))

Is this reaction exoergic or endoergic? What energy does it require or give off? (Known as the Q value)

$$^{197}_{79}\mathrm{Au}(\alpha, d)\ ^{199}_{80}\mathrm{Hg}$$

7.915744	Au-197
7.073918	He-4
1.112287	H-2
7.905368	Hg-199

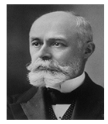
(-12.30 MeV)

Noteguide for Radioactivity and Decay Series- Videos 30CD **Name________________________**

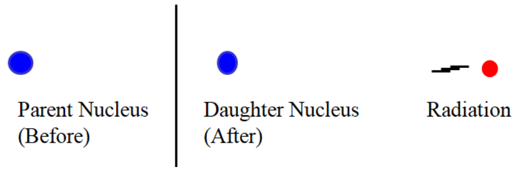
Videos C:

Discovery of Radioactivity

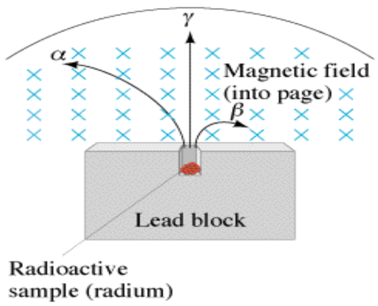
U salts cloud film on protected plates
Ionized air
Could be deflected by B field (unlike X rays)
Discovered radioactive decay



Antoine Henri Becquerel
1852-1908



α (Alpha)	2p2n (He nuc) (4 cm air)	A - 4, Z - 2
β- (Beta-)	e- (electron) (Thin Al foil, 1-3 m air)	A - 0, Z + 1 (Conservation of charge) (neutron to proton)
β+ (Beta+)	e+ (positron)	A - 0, Z - 1 (proton to neutron)
γ (Gamma)	High energy Photon (5 - .05 nm) (some thickness of lead)	A - 0, Z - 0 Parent loses mass

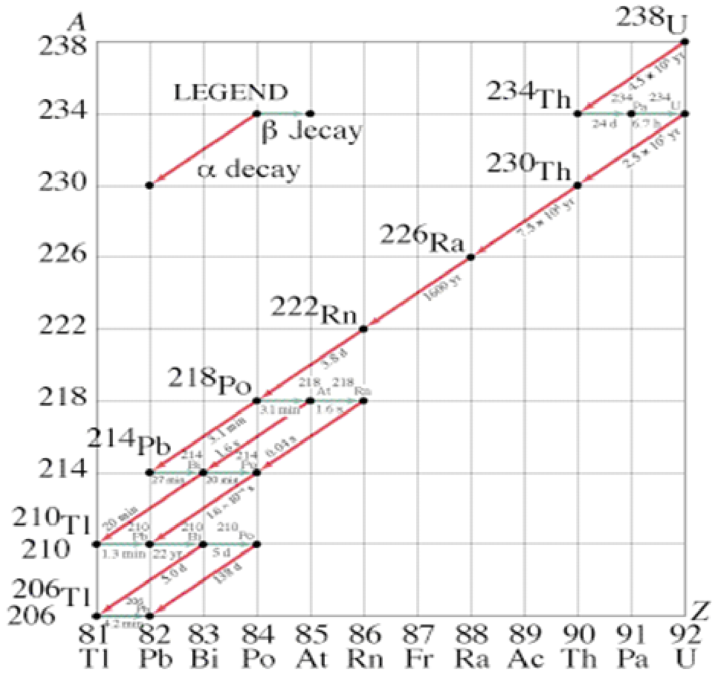


Whiteboards:

1. $^{145}_{61}\mathbf{Pm} \rightarrow$ ______ $+ \alpha$ (141/59 Praseodymium)	2. $^{60}_{27}\mathbf{Co} \rightarrow$ ______ $+ \beta-$ (60/28 Ni)
3. $^{40}_{19}\mathbf{K} \rightarrow$ ______ $+ \beta+$ (40/18 Ar)	4. $^{222}_{86}\mathbf{Rn} \rightarrow$ ______ $+ \gamma$ (222/86 Rn)
5. ?? $\rightarrow$ $^{40}_{20}\mathbf{C} + \beta-$ ($^{40}_{19}\mathbf{K}$)	6. $^{210}_{82}\mathbf{Pb} \rightarrow$ $^{206}_{80}\mathbf{Hg}$ + ?? (α)
7. ?? $\rightarrow$ $^{15}_{7}\mathbf{N} + \beta+$ ($^{15}_{8}\mathbf{O}$)	8. $^{14}_{6}\mathbf{C} \rightarrow$ $^{14}_{6}\mathbf{C}$ + ?? (γ)

Videos D:

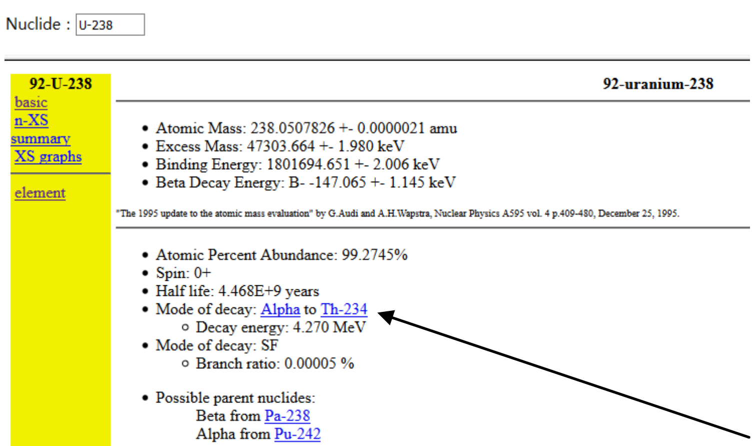
Decay series:
U238>Th234+α
Th234>Pa234+β
Pa234>U234+β
U234>Th230+α
Th230>Ra226+α
Ra226>Rn222+α
Rn222>Po218+α
•Uh - then it gets a little complicated
•Eventually the product is stable
•Online Nuclides



OK - So try this yourself - go to

http://atom.kaeri.re.kr:8080/ton/nuc8.html

and type U-238 into the box in the upper left corner that says Nuclide :


Nuclide : U-238

92-U-238
basic
n-XS
summary
XS graphs
element

92-uranium-238

- Atomic Mass: 238.0507826 +- 0.0000021 amu
- Excess Mass: 47303.664 +- 1.980 keV
- Binding Energy: 1801694.651 +- 2.006 keV
- Beta Decay Energy: B- -147.065 +- 1.145 keV

"The 1995 update to the atomic mass evaluation" by G.Audi and A.H.Wapstra, Nuclear Physics A595 vol. 4 p.409-480, December 25, 1995.

- Atomic Percent Abundance: 99.2745%
- Spin: 0+
- Half life: 4.468E+9 years
- Mode of decay: Alpha to Th-234
  - Decay energy: 4.270 MeV
- Mode of decay: SF
  - Branch ratio: 0.00005 %
- Possible parent nuclides:
  Beta from Pa-238
  Alpha from Pu-242

Then click on the link for Th-234.

Off you go. Keep following links after "mode of decay". Sometimes there are more than one...

Eventually, as long as you are clicking on the <u>products of the decay,</u> you will always end up at Pb-206
Try **Bk-247**
Look around up there near the top of the Chart of the Nuclides, and find other exciting decay series..

Noteguide for Alpha Decay and Tunneling- Videos 30EF **Name________________________**

Videos 30E:

Alpha Decay - Energy of alpha particle

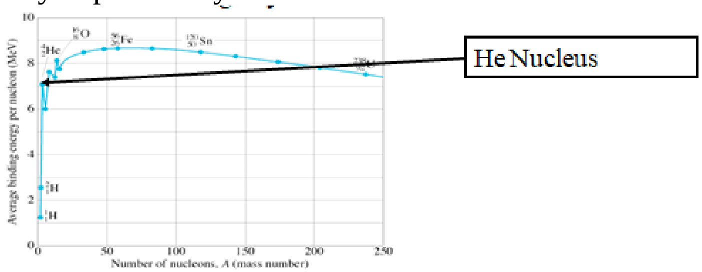
1 u = 931.5 MeV

He (neutral atom) = 4.002603 u

Calculating mass defect of alpha decay (5.414 MeV)

92-U-232	-->	90-Th-228	+	Alpha
232.037131	-->	228.028716	+	4.002603

Why Alpha Decay:



Whiteboards:

Find the energy of this Alpha Decay in MeV:

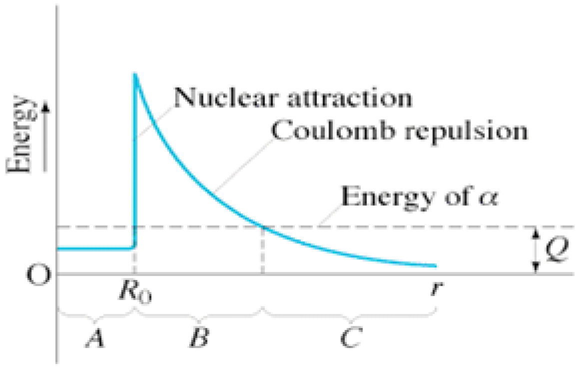
$^{247}_{97}Bk$	-->	$^{243}_{95}Am$	+	α
247.070300	-->	243.061373	+	4.002603

Find the energy of this Alpha decay in MeV, Joules, and calculate the velocity of the particle given the mass of an alpha particle is 6.64×10^{-27} kg

$^{243}_{95}Am$	-->	$^{239}_{93}Np$	+	α
243.061373	-->	239.052932	+	4.002603

Videos 30F:

Tunneling - Energy is not conserved!



E_k of alpha - observed

Shape of curve

Capture of Alpha:

- Repulsion - Coulombic
- Attraction - Strong Nuc.

$E_{k(Alpha)} < E_{k(Capture)}$

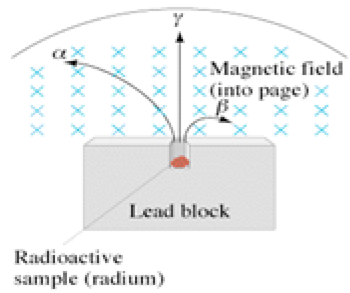
Alpha shouldn't escape (energy)

$\Delta E \Delta t \geq h/2\pi$

Violates COE (briefly)

"Tunneling"

Pure quantum randomness



Noteguide for Beta and Gamma Decay- Videos 30GH **Name______________________**

Video 30G:

$$^{60}_{27}Co \longrightarrow {}^{60}_{28}Ni + \beta- + \bar{\nu}_e$$

$$^{13}_{7}N \longrightarrow {}^{13}_{6}C + \beta+ + \nu_e$$

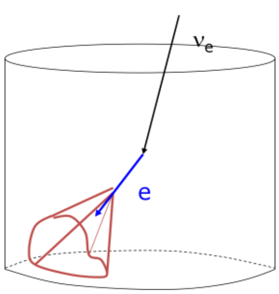
Conservation of charge
Beta minus - electron
 "As if" neutron -> proton + electron
Beta plus - positron
 "As if" proton -> neutron + positron
Particles are "of the nucleus" (not orbital)
 ν - Neutrino, (anti neutrino) – fudge
Energy is continuous (i.e. neutrino gets random share)

Pauli, Fermi, and the little neutral one

Wolfgang Pauli
1900-1958

Enrico Fermi
1901-1954

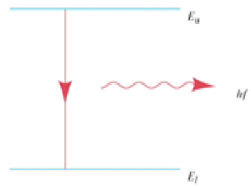
Beta decay products were missing energy
Pauli proposes a particle is carrying away energy
Fermi names it Neutrino - "Little neutral one" - It.
Neutrinos confirmed in 1956, no surprise



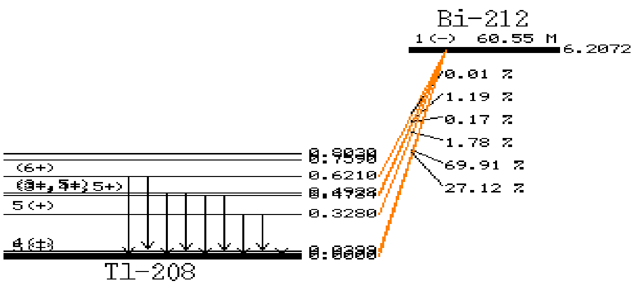
Videos 30H:

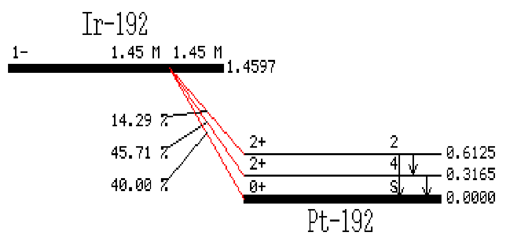
Gamma Decay:

$^{239}_{94}Pu \longrightarrow\ ^{239}_{94}Pu + \gamma$



Nucleus has energy levels
Energy of transition emitted as a high energy photon (λ ≈ 5 - .05 nm)
Usually after a beta or alpha decay
Many energies possible
Stopped by meters of lead
Used for food irradiation





Gamma ray energies associated with alpha and beta decays – so Alpha and Gamma energies are discrete. (Like spectral lines we saw)

$^{239}_{94}Pu$ --> $^{239}_{94}Pu$ + γ
239.052464 --> 239.052157
What is the energy of the gamma emitted?

Whiteboards:
Tl-208 emits a 0.6210 MeV gamma and the neutral atom in the unexcited state has a mass of 207.9820047 u. What was the mass of the excited state before the gamma was emitted? (207.9826714 u)

$^{245}_{96}Cm$ --> $^{245}_{96}Cm$ + γ
245.0658034 u --> ???????
What is the mass of the daughter nucleus, if a 0.2957 MeV gamma photon is emitted?

(245.065486 u)

Noteguide for Activity and Half Life - Videos 30IJK **Name______________________**

Videos 30I:

Probability and activity

N - Number of un-decayed nuclei (number)
λ - Per second probability of a nuclei decaying (s^{-1})
A - Activity - decays/sec (Becquerels (Bq) = s^{-1})

$$A = -\frac{\Delta N}{\Delta t} \qquad A = \lambda N = \lambda N_o e^{-\lambda t}$$

Example - Radon 222 has an atomic mass of 222.02. How many grams of it do you have if your activity is 8.249×10^{16} decays/sec, and your decay probability is 2.098×10^{-6} s^{-1}? $N_A = 6.02 \times 10^{23}$ atoms/mol

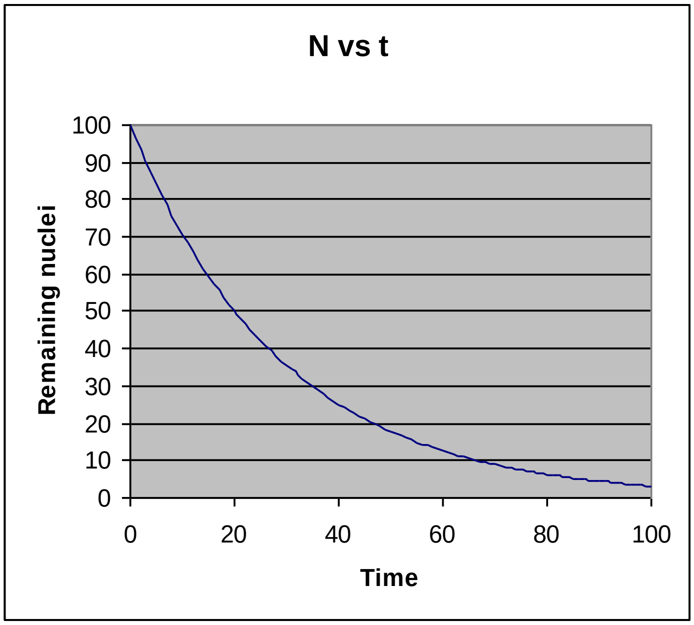
Whiteboards:

What is the activity if you have a λ of 3.19×10^{-10} s^{-1}, and you have 5.12×10^{23} un-decayed nuclei? (1.63×10^{14} decays/sec)	What is the λ if 1.27×10^{20} un-decayed nuclei generate 1420 decays per second? (1.12×10^{-17} s^{-1})

Videos 30J:

λ - Per second probability of a nuclei decaying (s^{-1})
N - Number of un-decayed nuclei (number)
A = Activity - decays/sec (s^{-1})
A = $^{-\Delta N}/_{\Delta t}$
$N = N_o e^{-\lambda t}$ - Exponential decay
N_o - Original value
N - Value at time t
t - Elapsed time
DiffEQ…

$A = \lambda N = \lambda N_o e^{-\lambda t}$



Half life

$T_{1/2}$ - Half life - time for half nuclei to decay

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Example:
$A = \lambda N = \lambda N_o e^{-\lambda t}$
$A = {}^{-\Delta N}/_{\Delta t}$
$N = N_o e^{-\lambda t}$
$T_{1/2} = {}^{\ln(2)}/_{\lambda}$

Bi 211 has a half life of 128.4 s. What is the per-second probability of a nuclei decaying? If you start out with 32 grams of Bi 211, how much is left after 385.2 s? After what time is there 23 grams left? What is the activity when there is 23 grams left? (m = 210.987 u) (4.0 g, 61 s, 3.54E+20 Bq)

Whiteboards:

1. Oregonium has a decay probability of 8.91×10^{-8} s^{-1}. What is its half life in days? (90 days)	2. What is the nuclear decay probability of a substance that has a half life of 96.23 minutes? (0.0001201 s^{-1})
3. Oregonium has a decay probability of 8.91×10^{-8} s^{-1}. If you have 1250 grams of Oregonium initially, how many grams do you have after 30.00 days? (x24x3600) (992 g)	4. Tualatonium has a half life of 12 seconds. If you start with 64 grams of it, how much remains after a minute? (Cheat) (2.0 g)
5. Tigardium has a half life of 8.34 seconds. The initial activity is 1350 counts/second, after what time is the activity 125 counts/sec? (28.6 s)	6. A certain substance has an activity of 1245 counts/sec initially, and an activity of 938 counts/second after exactly 3.00 minutes. What is the half life of the substance? (441 s)

Video 30K: Radiometric Dating

So - go read the account of Clair Patterson: https://en.wikipedia.org/wiki/Clair_Cameron_Patterson (You won't believe it)

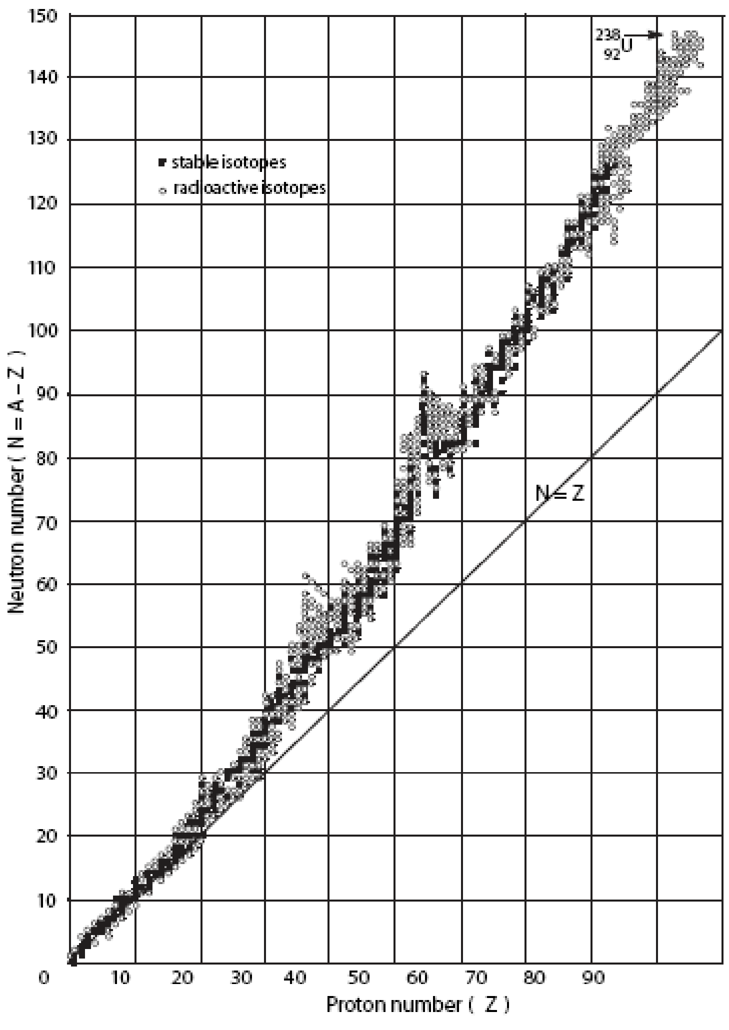
Noteguide for Nuclear Stability- Videos 30L **Name_______________________**

A nucleus is bound by the strong nuclear force. Since this force is extremely short range ($1x10^{-15}$ m) as the nucleus gets bigger, nuclei become in general less stable because the Coulombic repulsion of the protons gets stronger, and the strong nuclear gets weaker. Ultimately there is an upper limit to the size of a stable nucleus.

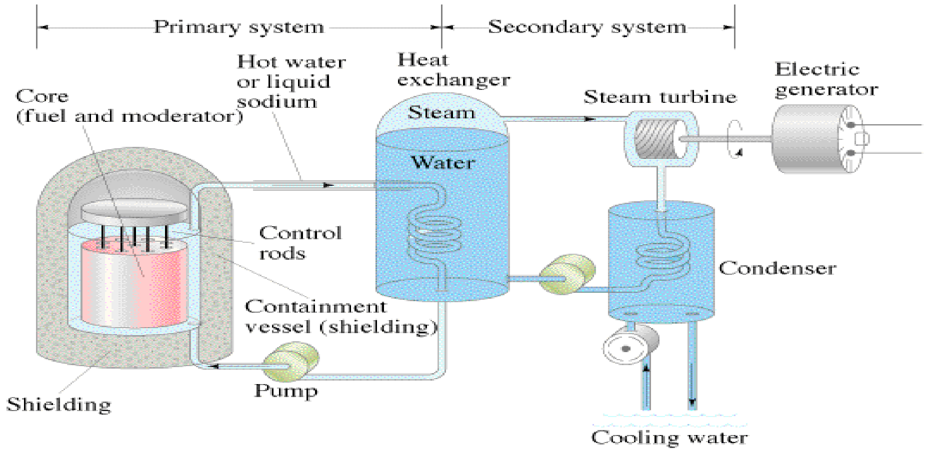
Forces in a nucleus:

Coulombic force: Strong Nuclear Force:

A graph of neutrons vs. protons for stable nuclei:



Noteguide for Nuclear Power- Videos 30Q **Name______________________**



Pros: Cons:

Example Question: An 820 MW power plant is 30.% efficient. How much Uranium 235 will it use in a year? Assume that a single atom will yield 200. MeV of energy. Uranium 235 has a mass of 235.0439231u, N_A is 6.02 x 10^{23}.

Chernobyl: