Nuclear Reactions

The Nucleus

- Nuclear reactions involve transfers or transformations of neutrons or protons from the atom's nucleus
- Atomic number: # of protons
    - Never changes
- Mass number: # protons + # neutrons
    - can change
    - isotopes: atoms of same element that have different mass number
    - The atom's exact mass
- Atomic weight: weighted average of the mass # (atomic mass) for each isotope of that element

Nuclear Stability & Radioactive Decay

- At close distances, nuclear particles are attracted to each other by nuclear force
    - Neutrons also help reduce repulsive forces between protons in an atom's nucleus
- Ratio of neutron to protons directly related to nucleus stability
- Atoms beyond first 20 elements, their neutron # can exceed their proton # to a point while still maintaining stability
- The Belt of Stability
    - As # protons increase, # neutrons must increase but at a faster disproportionate rate to maintain a stable nucleus

◦ Above belt: too many neutrons relative to protons

Nuclear Reactions

- Decay (fission) reactions: ${}^{A}_{B}X \rightarrow {}^{C}_{D}Y + {}^{E}_{F}Z$
  - $A = C + E$ and $B = D + F$
  - identities of X, Y, and Z determined by their atomic # B, D, F
- Capture (fusion) reactions: ${}^{A}_{B}X + {}^{C}_{D}Y \longrightarrow {}^{E}_{F}Z$ ☆ Nuclear capture
  - $A + C = E$ and $B + D = F$
- Fission and fusion give off energy (reactants → products + energy)
  - energy released: $\Delta E = \Delta mc^2$
  - in every nuclear reaction, some mass is lost
- $\boxed{\text{EX:}}$ ${}^{131}_{53}I \longrightarrow {}^{0}_{-1}\beta + ???$ ${}^{131}_{54}Xe$
- $\boxed{\text{EX:}}$ ${}^{214}_{84}Po + 2\,{}^{4}_{2}\alpha + 2\,{}^{0}_{-1}\beta \longrightarrow ?$

  $214 + 2(4) + 2(0) = 222$

  $84 + 2(2) + 2(-1) = 86$ $\boxed{{}^{222}_{86}Rn}$

↳ Atom will emit $^{0}_{-1}\beta$ (beta particles) through beta decay to reduce neutron : proton ratio

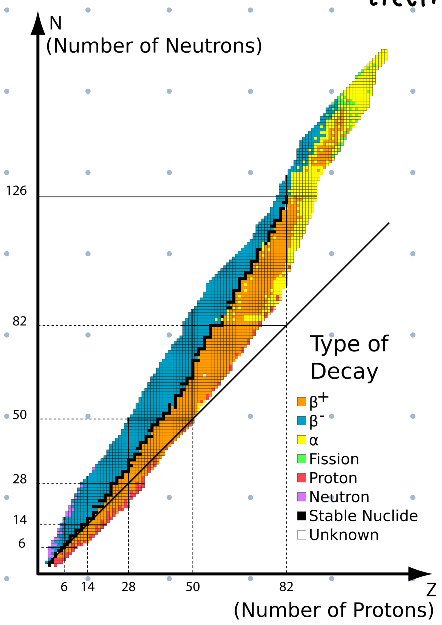
↳ Beta emission: $^{135}_{54}Xe \rightarrow ^{0}_{-1}\beta + ^{135}_{55}Cs$

• BELOW BELT: too many protons relative to neutrons

↳ emit positron ($^{0}_{+1}e$) or capture an electron ($^{0}_{-1}e$)

↳ positron emission: $^{118}_{54}Xe \rightarrow ^{0}_{+1}e \ ^{118}_{53}I$

↳ electron capture: $^{118}_{54}Xe + ^{0}_{-1}e \rightarrow ^{118}_{53}I$



Route of Decay	Nuclear particle	Result	Likely For?
α-decay	$^{4}_{2}\alpha$ product	Reduces mass #	Large nuclei
β decay (β emission)	$^{0}_{-1}\beta$ product	neutron → proton	N/Z ratio too high (too many neutrons)
β+ decay (positron emission)	$^{0}_{+1}\beta$ product	proton → neutron	N/Z ratio is too low (too many protons)
Electron capture	$^{0}_{-1}\beta$ reactant	proton → neutron	N/Z ratio is too low (too many protons)
γ decay	$^{0}_{0}\gamma$ product	no change	unpredictable

• $\boxed{\text{EX}}$ $^{17}_{8}O + ^{1}_{1}p \rightarrow ^{18}_{9}F \rightarrow ^{14}_{7}N + ^{4}_{2}He$ $\boxed{\text{Alpha-decay}}$

Kinetics of Radioactive Decay

• Radioactive decay reactions are first order reactions

◦ Half-life width stays constant and independent of concentration

◦ Half life; amount of time for sample to decay to half its mass

↳ Half life: $t_{1/2} = \frac{0.693}{k}$

▫ k = radioactive decay's rate constant

• $\boxed{\text{EX}}$ Half life = 30min, 100g of sample, 2 hour passes, how much left?

4 half lifes $100 \to 50 \to 25 \to 12.5 \to \boxed{6.25\,g}$
1 2 3

EX: $t_{1/2} = 15$ min m= 87.5g decayed starting w/ 100 g how long?

$$\begin{array}{r} 100.0 \\ -\ 87.5 \\ \hline 12.5 \end{array}$$

$100 \to 50 \to 25 \to 12.5$

12.5 g left $\to$ 3 half lifes

$15 \times 3 = \boxed{45\,min}$

FISSION, FUSION, NUCLEAR BINDING ENERGY

- protons and neutrons weigh a bit less when they are combined together than if they were seperate
  - B/C certain amount of energy needed to keep them together (nuclear binding energy)
- mass defect: difference between a nucleus' calculated mass and actual mass
  - small amount of mass converted into energy (ΔE)
  - SI unit = kg
- $\Delta E = \Delta m c^2$

nuclear binding energy

mass defect

speed of light

EX: A proton's mass is 1.00728 amu, neutron mass is 1.00867 amu

a) mass defect of ^{178}Au nucleus if a ^{178}Au nucleus weighs 177.9760 amu

$^{178}_{79}Au$ 99 neutron 79 protons

$(1.00728)(79) + (1.00867)(99) = 179.43345$

$179.43345 - 177.9760$ amu $= 1.45754$ amu

$\boxed{\Delta m = 1.45754\ amu}$

b) nuclear binding energy = ?

$\Delta E = (3\times10^8\ m/s)\left(1.45745\ amu \cdot \frac{1\ g}{6.022\times10^{23} amu} \cdot \frac{1 kg}{1000 g}\right)$

$= \boxed{2.18\times10^{-10}\ J}$

QB

(5) $^{210}Pb \rightarrow \ ^{210}Bi + \ ^{0}_{-1}\beta$

$t_{1/2} = 22$ hour

t = ? 2g of ^{210}Pb decay to 0.25 g

$2 \rightarrow 1 \rightarrow 0.5 \rightarrow 0.25$

1 2 3

3 half life

$\begin{array}{r} 22 \\ \times\ 3 \\ \hline 66 \end{array}$

(6) $1 \rightarrow 0.5 \rightarrow .25 \rightarrow .125$

.05

$^{145}_{61}Pm \rightarrow \ ^{0}_{-1}\beta + \ ^{145}_{62}Sm$

$^{137}Ba + \rightarrow \ ^{137}Cs + \ ^{0}_{1}$

$^{210}_{82}Pb \rightarrow {}^{0}_{-1}\beta + {}^{210}_{83}Bi$

$2 \rightarrow 1 \rightarrow 0.5 \rightarrow 2.5$

1 1 1

$1 \rightarrow 0.5 \rightarrow 0.25 \rightarrow 0.125$

1 1 1

$^{33}_{15}P \rightarrow {}^{4}_{2}\alpha + {}^{0}_{2}\beta$ $^{29}_{11}$

X $^{4}_{2}\alpha$ $^{5}_{6}X \rightarrow {}^{4}_{2}\alpha$ $^{1}_{4}$

$^{0}_{-1}\beta$

$^{0}_{1}\beta$

$E = mc^2$

$+ {}^{0}_{-1}e$

.03

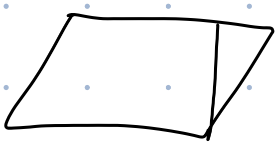
.05

33 D

34 B

35 E ✱

36 E



$$2l + 2s = 140$$
$$2(s+30) + 2s = 140$$

37 E

38 E

$$(0.7x)\,1.2 = 800$$

$$(800)$$

$\boxed{\text{Nuclear Particles}}$

INCREASING MASS ↑

Particle	Symbol
Alpha	^4_2He or $^4_2\alpha$
Neutron	$^1_0 n$
Proton	$^1_1 H$ or $^1_1 p$
Beta	$^0_{-1} e$ or $^0_{-1}\beta$
[illegible]	[illegible]

INCREASING PENETRATION

Positron	${}^{0}_{+1}e$
Gamma	${}^{0}_{0}\gamma$