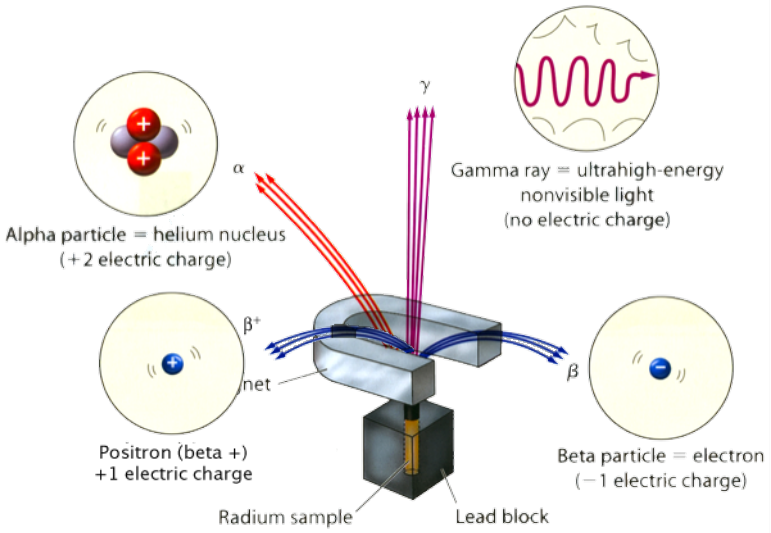
Notes 5-1: Nuclear Chemistry: Geiger Counter & α, β, γ Radiation; Nuclear Decay Equations

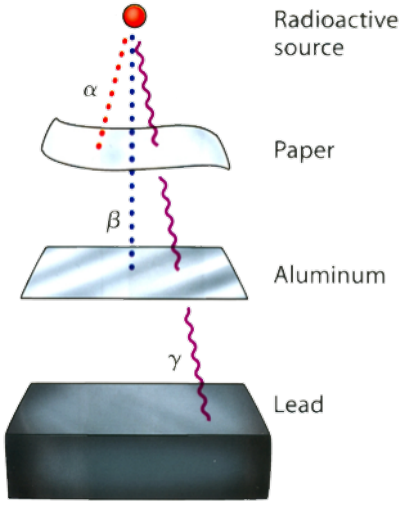
- Radioactivity: Unstable nucleus spontaneously emits ***nuclear radiation*** (comes out of nucleus)
  - Any isotope that emits nuclear radiation is **radioactive nuclide**.
  - Resulting nucleus is different, more stable element (transmutation)
  - Nuclei continue emitting radiation until stable nucleus is reached
- Types of Radioactive Decay

Radiation	Composition	Symbols	Charge	Mass	Penetrating Strength
Alpha particle	He-4 nucleus	α, $^{4}_{2}\mathrm{He}$	2+	4.003 amu	Stopped by paper
Beta particle	High-E electron	β^-, $^{0}_{-1}\mathrm{e}$	1–	$\frac{1}{1823}$ amu	Stopped by metal sheet
Positron	anti-electron	β^+, $^{0}_{+1}\mathrm{e}$	1+	$\frac{1}{1823}$ amu	Stopped by metal sheet
Gamma ray	High-E EM rad.	γ, $^{0}_{0}\gamma$	0	0	Penetrates thick Pb

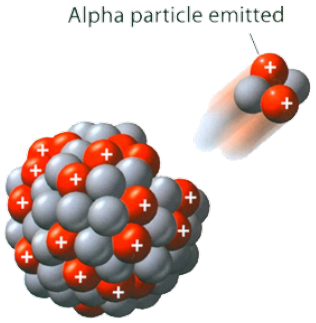
Deflection by electric or magnetic fields



Penetrating Strength



- Decay Equations (Spontaneous Transmutation)
  a) Alpha decay/emission: Too-large nucleus *emits* 2 p^+ and 2 n^0 $\left(^{4}_{2}\alpha \text{ or } ^{4}_{2}\mathrm{He}\right)$
  - $^{227}_{88}\mathrm{Ra} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{A}_{Z}\mathrm{X}$ $\begin{cases} A=227-4=223 \\ Z=98-2=86 \end{cases} \Rightarrow {}^{223}_{86}\mathrm{Rn}$
    - Total mass # (A) and atomic # (Z) both need to balance
      - atomic # ↓2 and mass # ↓4
    - New Z gives identity of unknown element



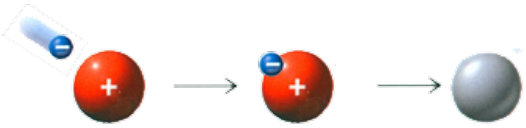
  b) Beta decay/emission: neutron emits high energy electron $\left(^{0}_{-1}\mathrm{e}\right)$ and becomes proton
  - $^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e}$
  - $^{18}_{8}\mathrm{O} \rightarrow {}^{0}_{-1}\beta + \underline{{}^{18}_{9}\mathrm{F}}$ $\begin{cases} 18=0+A;\ A=18-0=18 \\ 8=-1+Z;\ Z=8-(-1)=9 \Rightarrow \mathrm{F} \end{cases}$
    - atomic # ↑1 and mass # unchanged
    - Note: we ignore the antineutrino that is also emitted

c) Positron decay: proton emits *positive electron* $\left({}^{0}_{+1}\mathrm{e}\right)$ and becomes neutron

- ${}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + {}^{0}_{+1}e$
- ${}^{11}_{6}\mathrm{C} \rightarrow {}^{0}_{+1}\beta + \underline{{}^{11}_{5}\mathrm{B}}$ $\begin{cases} 11=0+A;\ A=11-0=11 \\ 6=1+Z;\ Z=6-1=5 \Rightarrow \mathrm{B} \end{cases}$
  - atomic # ↓1 and mass # unchanged
  - neutrino is ignored
- Sometimes called "β-plus"

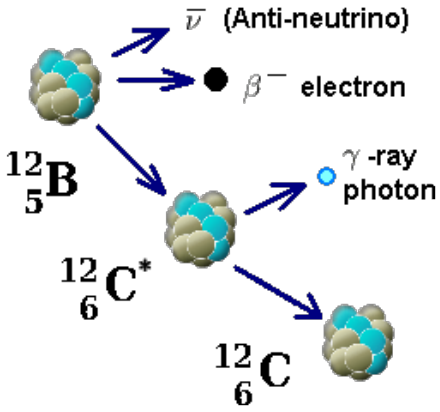
d) Electron capture: Unstable electron, ${}^{0}_{-1}\mathrm{e}$ (a *<u>reactant</u>*) captured by proton and becomes a neutron

- ${}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{1}_{0}\mathrm{n}$
- ${}^{38}_{18}\mathrm{Ar} + {}^{0}_{-1}\mathrm{e} \rightarrow \underline{{}^{38}_{17}\mathrm{Cl}}$ $\begin{cases} A=38+0=38 \\ Z=18+(-1)=17 \Rightarrow \mathrm{Cl} \end{cases}$
  - result looks the same as positron decay



e) Gamma radiation: γ, ${}^{0}_{0}\gamma$: high energy nucleus emits energy

- ${}^{12}_{5}\mathrm{B} \rightarrow {}^{0}_{-1}\beta + {}^{12}_{6}\mathrm{C}^{*} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{0}_{0}\gamma$
  - * Indicates excited state (excess energy)
- No particles emitted, no change in nucleus



- Can identify decay type (particle) if given starting and ending nuclei:
  - ${}^{231}_{90}\mathrm{Th} \longrightarrow {}^{231}_{91}\mathrm{Pa} + \underline{{}^{0}_{-1}\beta}$ $\begin{cases} 231=231+A;\ A=231-231=0 \\ 90=91+Z;\ Z=90-91=-1 \end{cases} \Rightarrow {}^{0}_{-1}\beta\ \left(\beta^{-}\right)$