Radioactive Decay

IB PHYSICS | ATOMIC PHYSICS

Standard Notation

What do you notice about the notation written below?
Can you determine what each color represents?

Mass Number

$^{27}_{13}\mathrm{Al}$

Atomic Number

13
Al
Aluminum
26.98
+3

$^{A}_{Z}X$

Try This

$^{23}_{11}Na$

$^{25}_{12}Mg$

Mass Number	23
Atomic Number	11
# of Protons	11
# of Neutrons	12

Mass Number	25
Atomic Number	12
# of Protons	12
# of Neutrons	13

Sample IB Question

A nucleus of Californium (Cf) contains 98 protons and 154 neutrons. Which of the following correctly identifies this nucleus of Californium?

$^{98}_{254}\mathrm{Cf}$

$^{252}_{98}\mathrm{Cf}$

$^{154}_{98}\mathrm{Cf}$

$^{350}_{154}\mathrm{Cf}$

Isotopes & Nuclides

$^{12}_{6}C$ $^{14}_{6}C$

Isotopes of Carbon

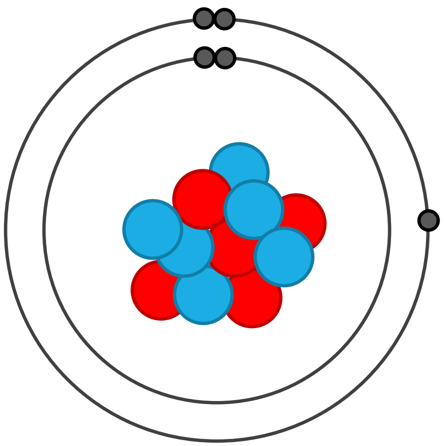
Same # of protons

Different # of neutrons

Nuclide

Single atom configuration

Fundamental Forces



$^{11}_{5}\mathrm{B}$

Remember Coulomb's Law?

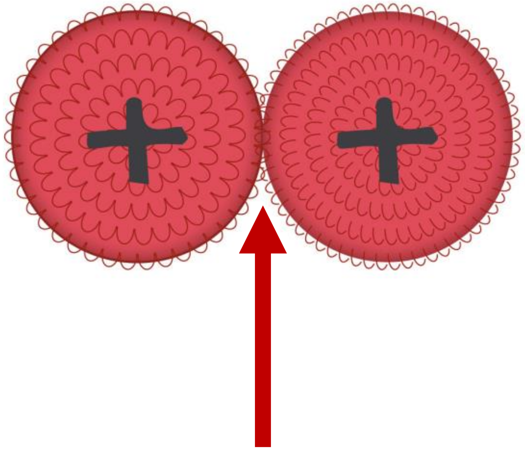
$$F = k\frac{q_1 q_2}{r^2}$$

Opposite charges attract
Like charges repel

Fundamental Forces

Strong Nuclear Force

- Very short range
- Very <u>strong</u>



Like Velcro

Electromagnetic Force

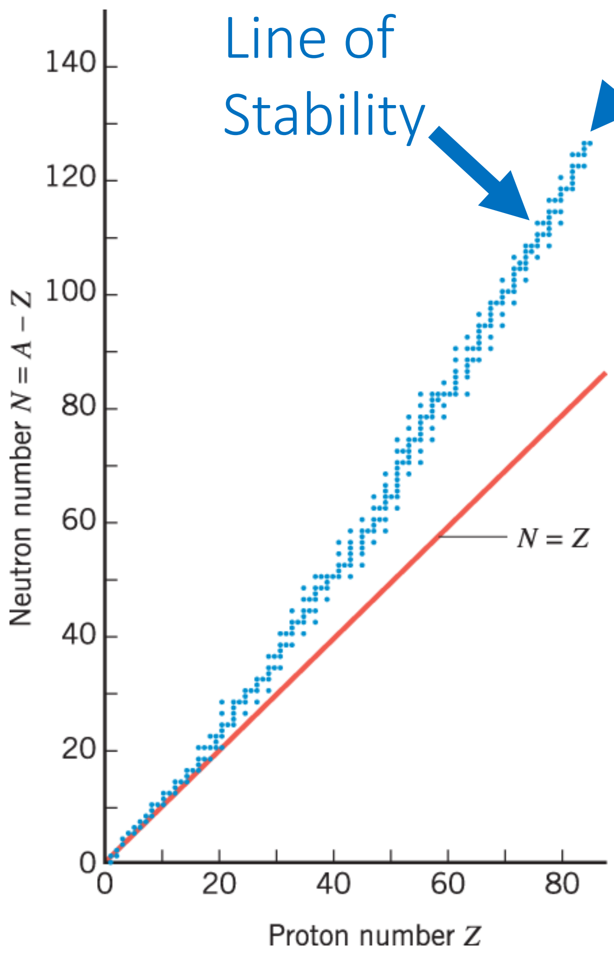
Gravitational Force

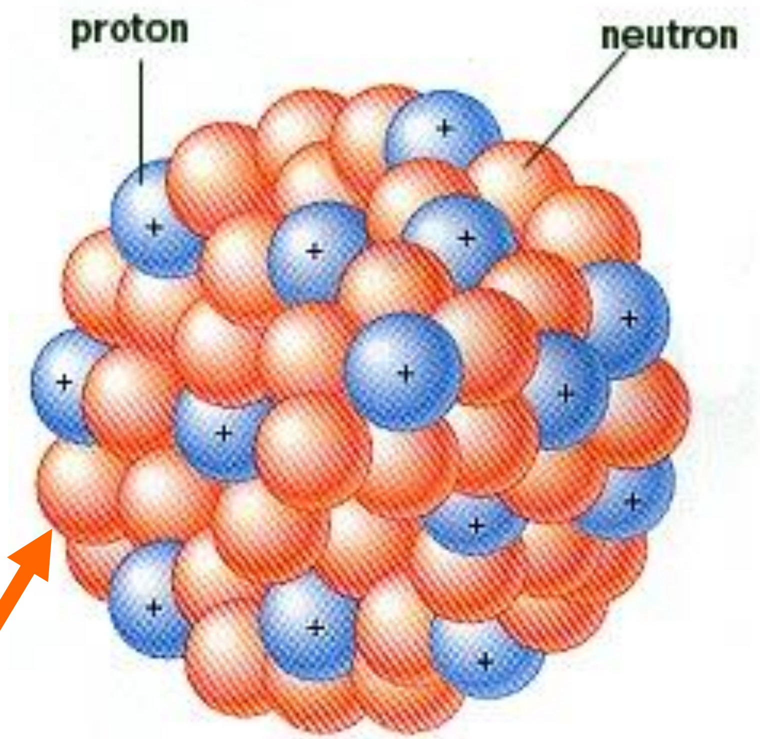
Weak Nuclear Force

Unstable Nuclei

Line of Stability

More neutrons than protons

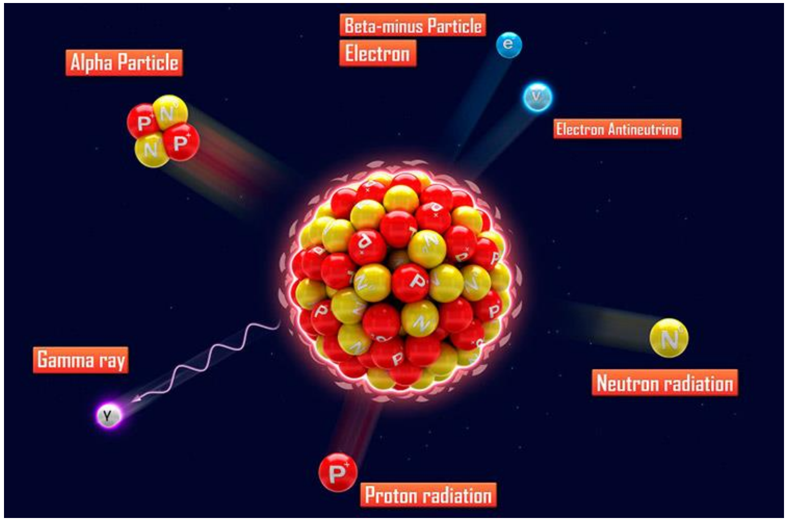




Neutrons serve as a buffer between repelling protons

Radioactivity

Radioactivity is a process where unstable elements decay into new elements and release energy as particles and/or waves



Alpha Decay

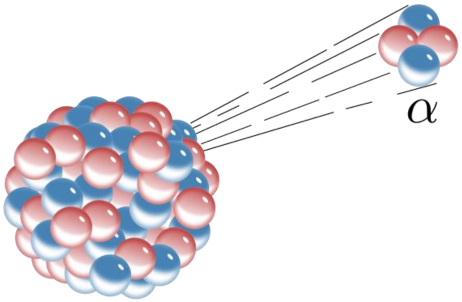
An unstable nucleus sheds alpha particle (helium nucleus) made from **2 protons** and **2 neutrons**

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

Parent Nuclide

Daughter Nuclide

Alpha Particle



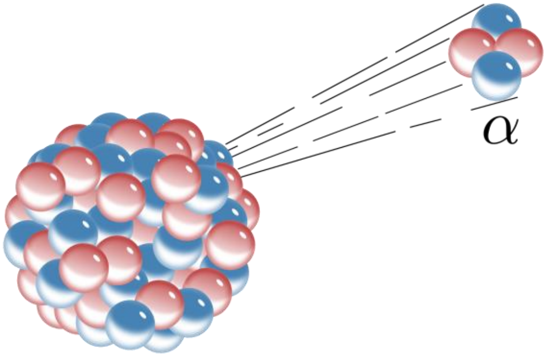
Complete the missing notation:

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

Alpha Decay - Predict

$$^{222}_{88}Ra \rightarrow {}^{218}_{86}Rn + \underline{{}^{4}_{2}He}$$

$$^{208}_{84}Po \rightarrow {}^{204}_{82}Pb + {}^{4}_{2}\alpha$$

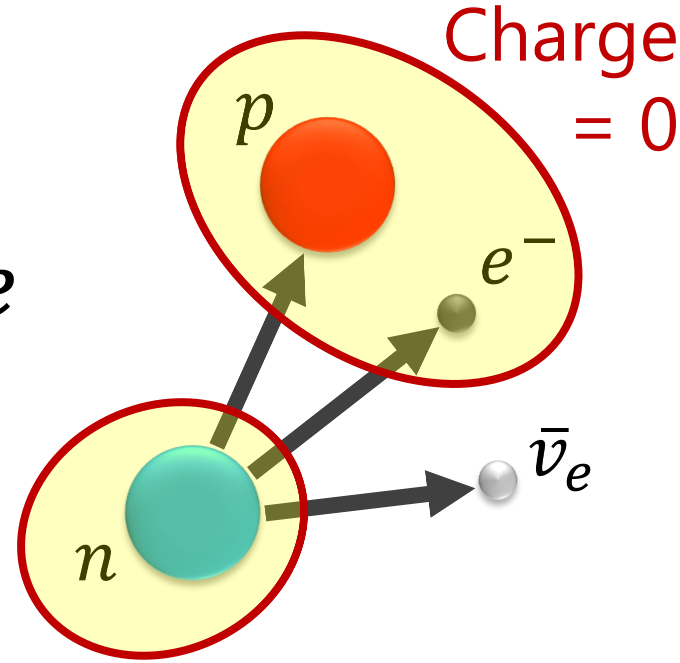


Beta-Negative Decay

In an unstable nucleus, sometimes a neutral neutron is converted into a positive proton and negative electron. When this happens, another particle called an antineutrino ($\bar{v}_e$) is also formed

"anti-"

$$ {}^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e} + \bar{v}_e $$



Beta-Negative Decay

BETA-DECAY SET WITH MINI PARTICLES

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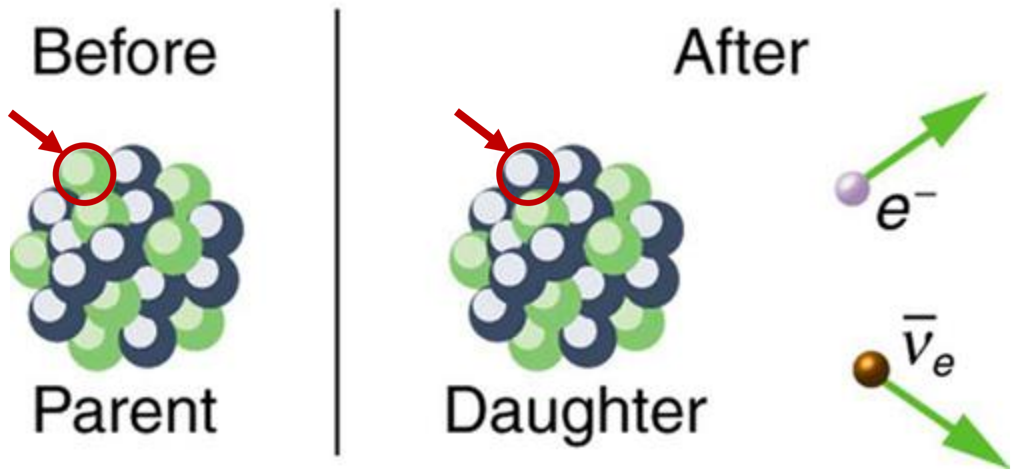
Beta-Negative Decay

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}X + {}^{0}_{-1}e + \bar{\nu}_e$$

Parent Nuclide | Daughter Nuclide | Electron | Antineutrino

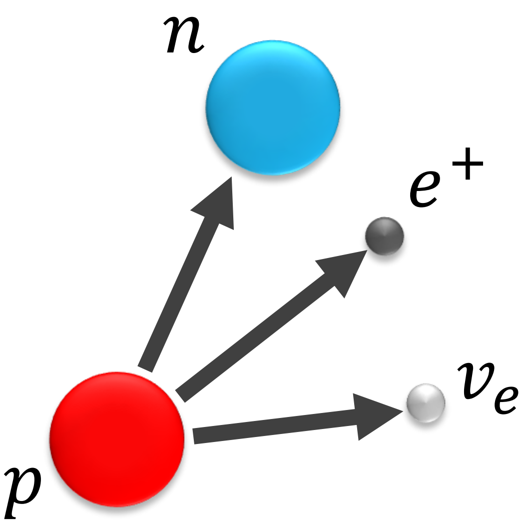
**The proton stays and the electron and antineutrino flies away as “radiation”



Beta-Positive Decay

In an opposite process, a positive proton can be converted into a neutral neutron and positively charged electron (known as a **positron**). When this happens, another particle called a neutrino (v_e) is also formed

$$ {}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + {}^{0}_{+1}\mathrm{e} + v_e $$



Beta-Positive Decay

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}X + {}^{0}_{+1}e + v_e $$

Parent Nuclide

Daughter Nuclide

Positron

Neutrino

Beta Decay - Predict

$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\mathrm{e} + \bar{\nu}_e$$

$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + \underline{{}^{0}_{-1}\mathrm{e}\quad} + \bar{\nu}_e$$

$$^{14}_{6}\mathrm{C} \rightarrow \underline{{}^{14}_{\ 7}}\mathrm{N} + {}^{0}_{-1}\mathrm{e} + \bar{\nu}_e$$

$$^{23}_{12}\mathrm{Mg} \rightarrow \underline{{}^{23}_{11}}\mathrm{Na} + {}^{0}_{+1}\mathrm{e} + \nu_e$$

Gamma Decay

After an unstable nucleus has emitted an alpha or beta particle, it can contain excess energy that is released as gamma radiation

$$^{234}_{90}\mathrm{Th}^{*} \rightarrow\ ^{234}_{90}\mathrm{Th} + \ ^{0}_{0}\gamma$$

The Math Always Adds Up

$$^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

$$^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e} + \bar{\nu}_e$$

$$^{23}_{12}\text{Mg} \rightarrow {}^{23}_{11}\text{Na} + {}^{0}_{+1}\text{e} + \nu_e$$

$$^{234}_{90}\text{Th}^{*} \rightarrow {}^{234}_{90}\text{Th} + {}^{0}_{0}\gamma$$

Particle Review

	Particle	Name
	${}^{1}_{1}\mathrm{p}$	Proton
	${}^{1}_{0}\mathrm{n}$	Neutron
	${}^{0}_{-1}\mathrm{e}$	Electron
	${}^{0}_{+1}\mathrm{e}$	Positron
	$\bar{v}_e$	Antineutrino
	v_e	Neutrino
	${}^{4}_{2}\mathrm{He}$	Alpha Particle

Sample IB Question

24. Which of the following correctly identifies the three particles emitted in the decay of the nucleus $^{45}_{20}Ca$ into a nucleus of $^{45}_{21}Sc$?

A. α, β^-, γ

B. $\beta^-, \gamma, \bar{\nu}$

C. $\alpha, \gamma, \bar{\nu}$

D. $\alpha, \beta^-, \bar{\nu}$

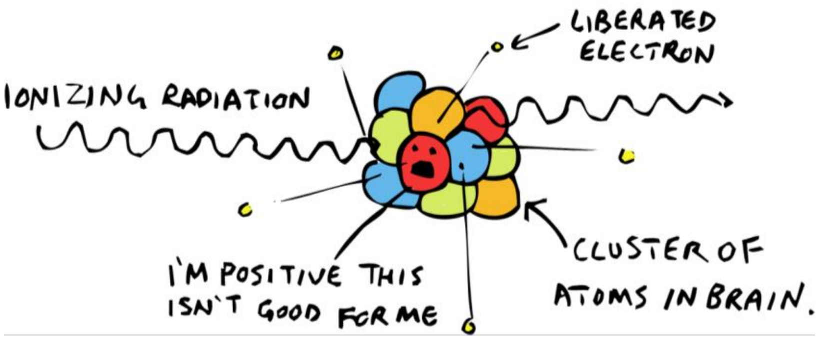
Ionizing Radiation

α

β

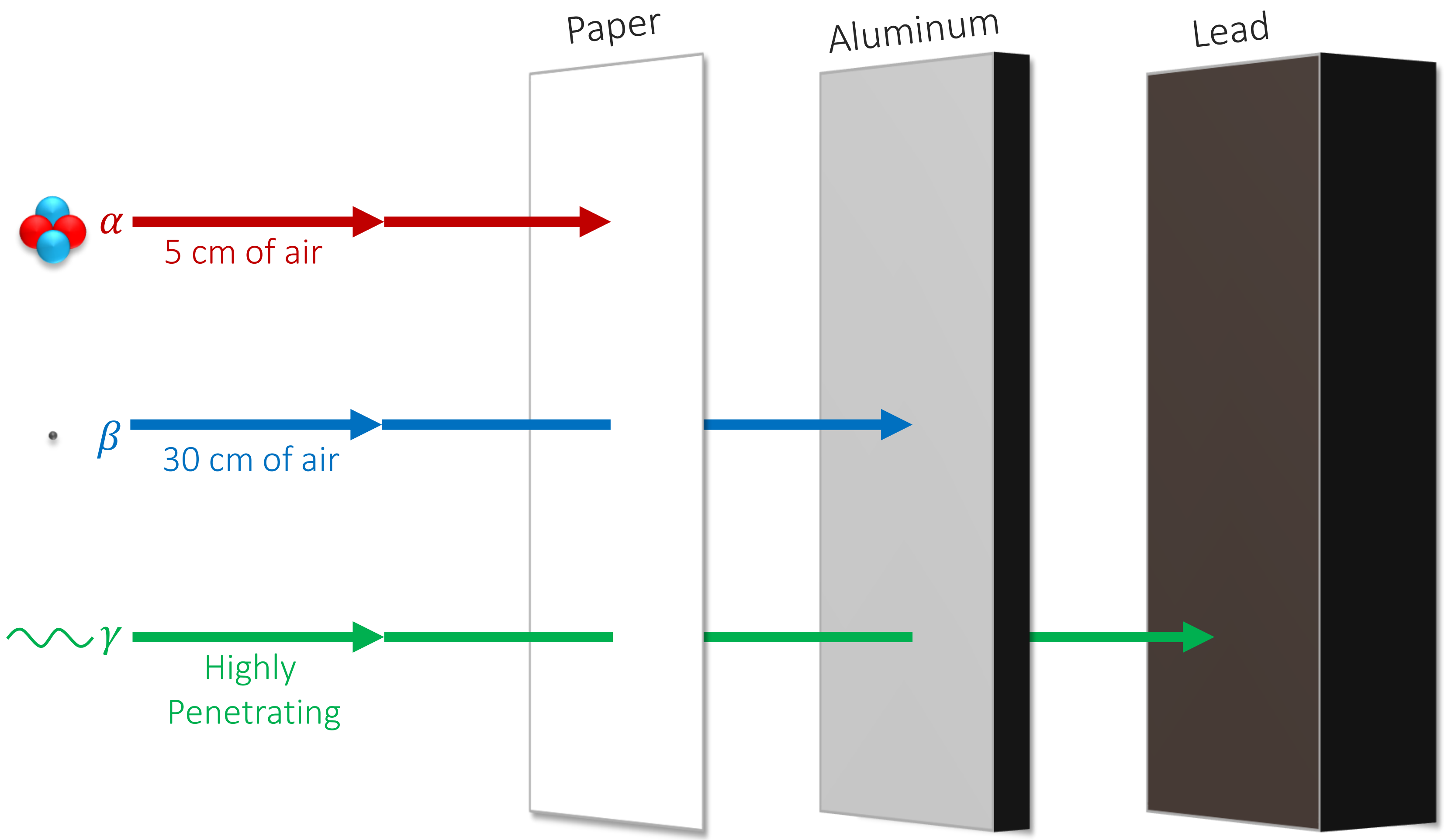
γ

Most mass
Most ionizing

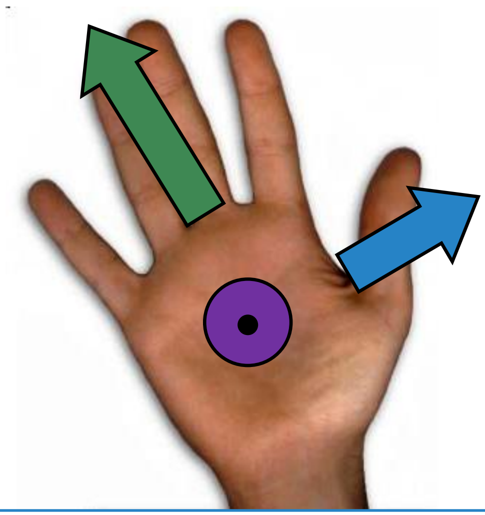


More mass allows particles to more efficiently transfer energy and ionize an atom

Radiation Penetration



Remember the Right Hand Rule?



Thumb points in direction of the current

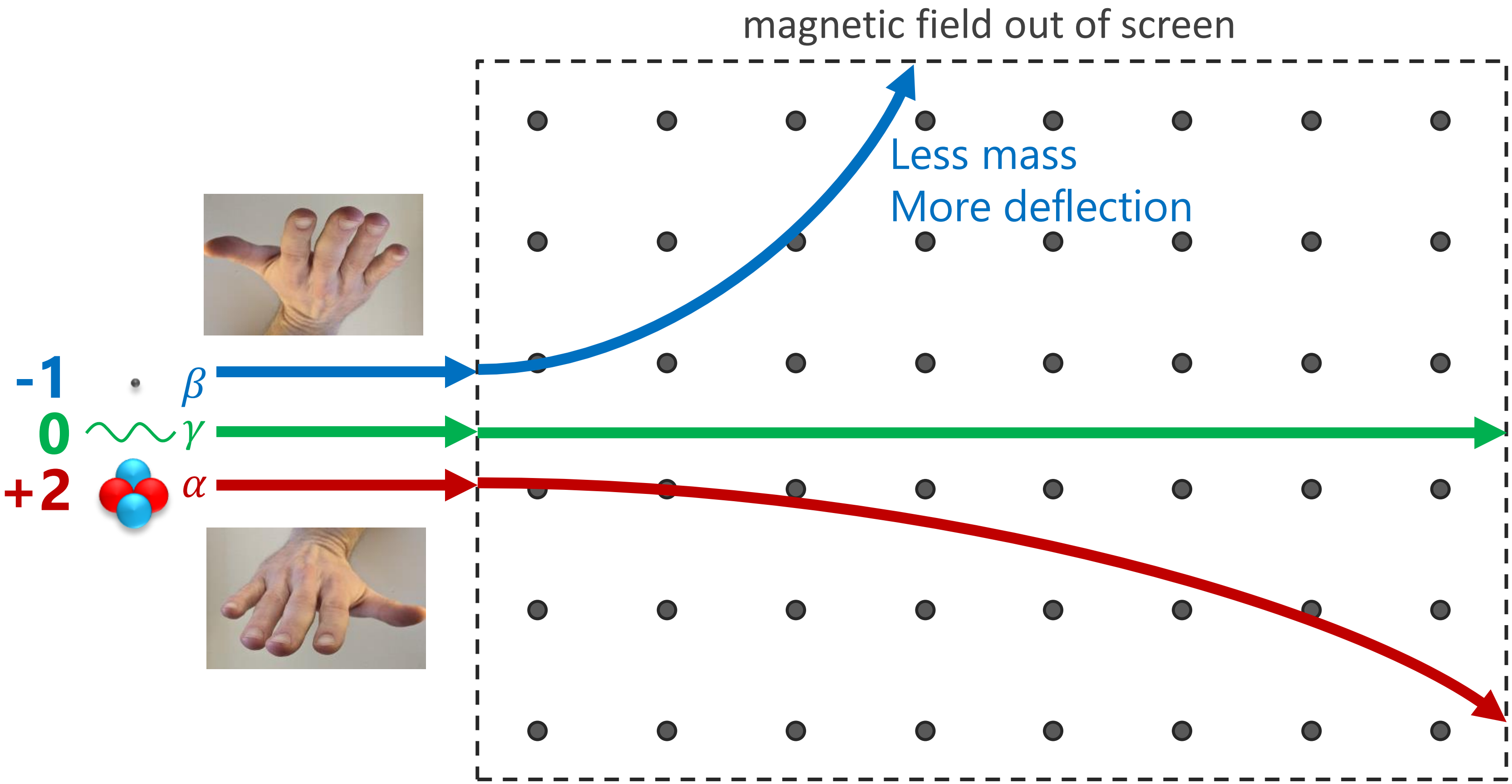
Fingers point in direction of the field lines

Palm points in direction of the force

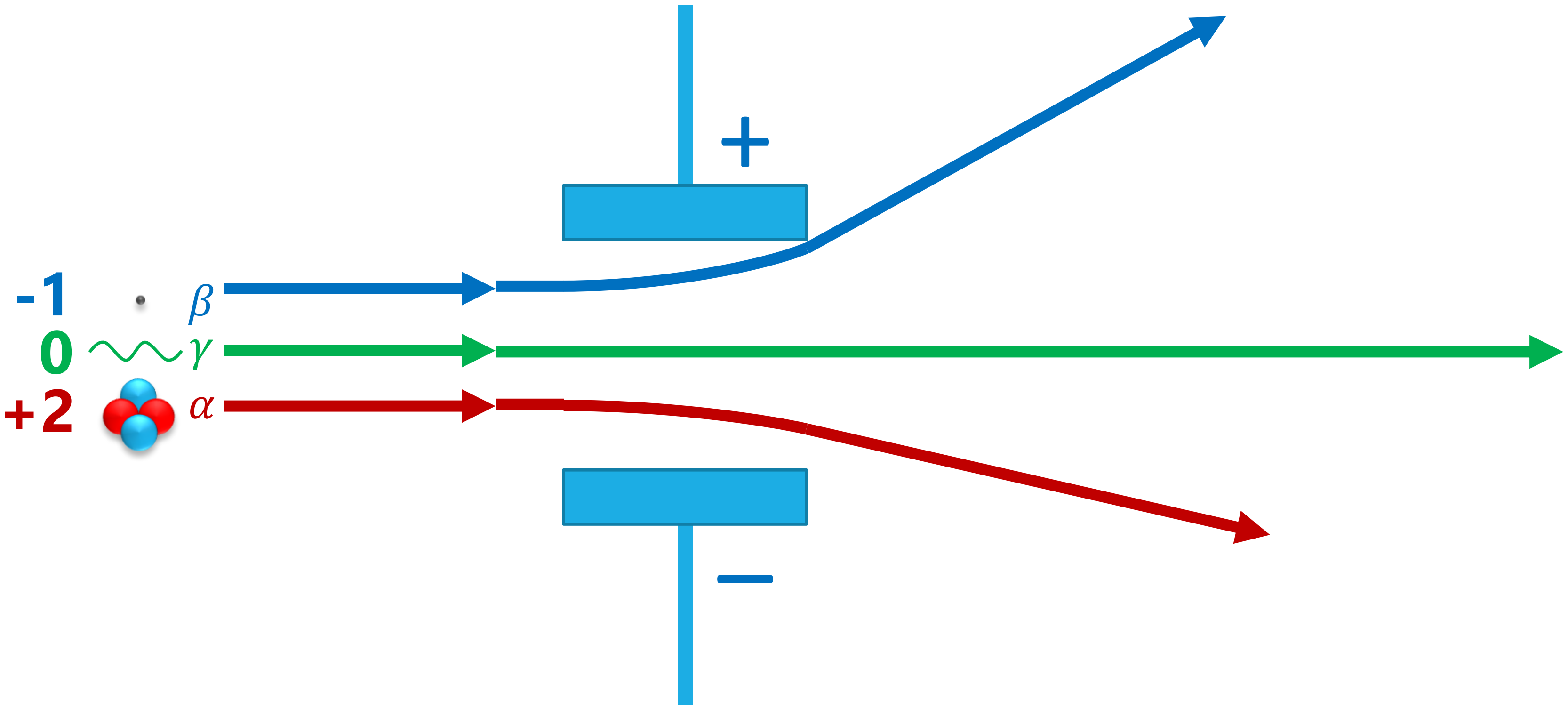
How do you represent a direction that's perpendicular to the paper?

Into the paper	✖
Out of the paper	●

Radiation Deflection



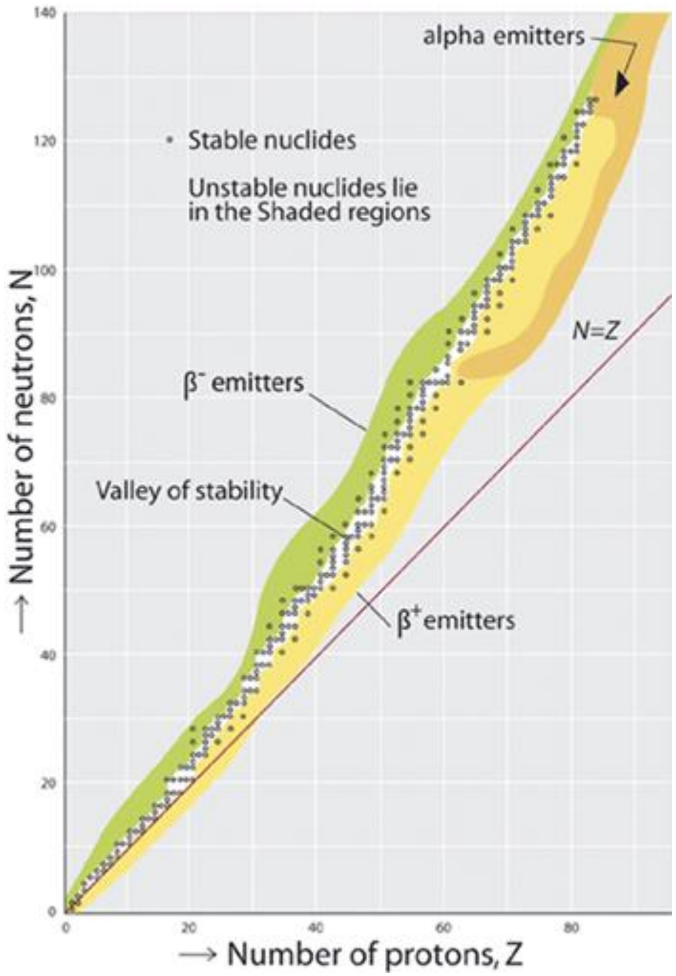
Radiation Deflection



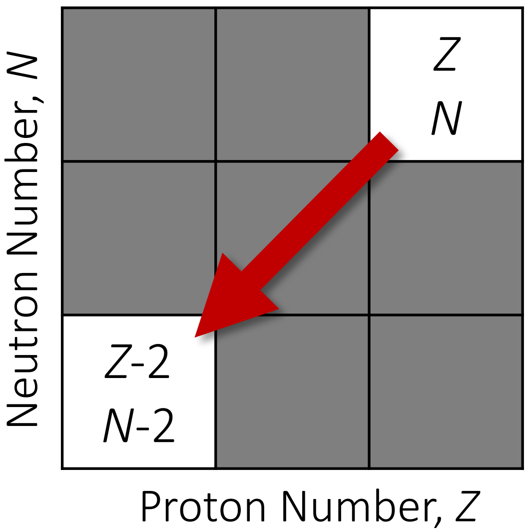
Summary of α, β, and γ

Property	Alpha (α)	Beta (β^+ or β^-)	Gamma (γ)
Relative Charge	+2	+1 or -1	0
Relative Mass	4	0.0005	0
Typical Penetration	5 cm of air	30 cm of air	Highly penetrating
Nature	Helium nucleus	Positron or Electron	Electromagnetic wave
Typical Speed	10^7 m s^{-1}	2.5×10^8 m s^{-1}	3.00×10^8 m s^{-1}
Notation	${}^4_2\mathrm{He}$ or ${}^4_2\alpha$	${}^{0}_{-1}\mathrm{e}$ or ${}^{0}_{-1}\beta$	γ or ${}^0_0\gamma$
Ionizing Effect	Strong	Weak	Very Weak
Abosorbed by	Paper or skin	3 mm of Aluminum	Intensity halved by 2 cm of Lead

Valley of Stability



Graphing Decay

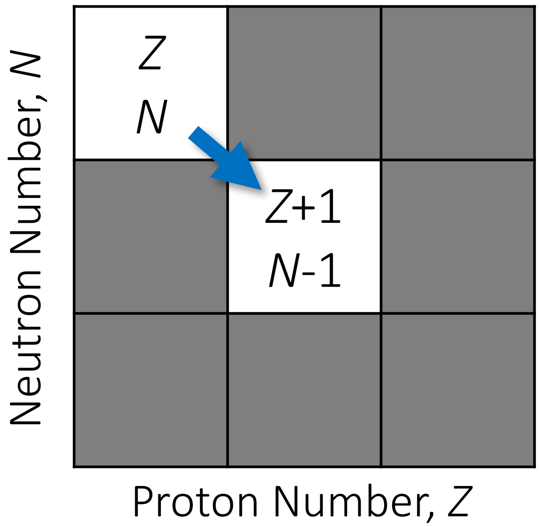


α Decay

Mass #

-4

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$



β⁻ Decay

Mass #

same

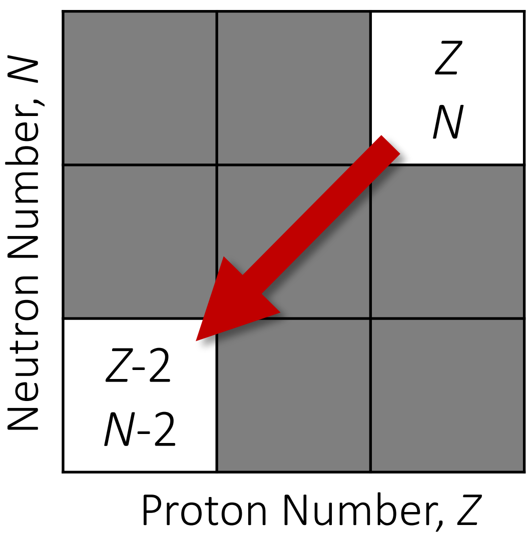
$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\mathrm{e} + \bar{\nu}_e$$

Alpha Decay

82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon	87 Fr Francium	88 Ra Radium	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium

α Decay of Radium-226

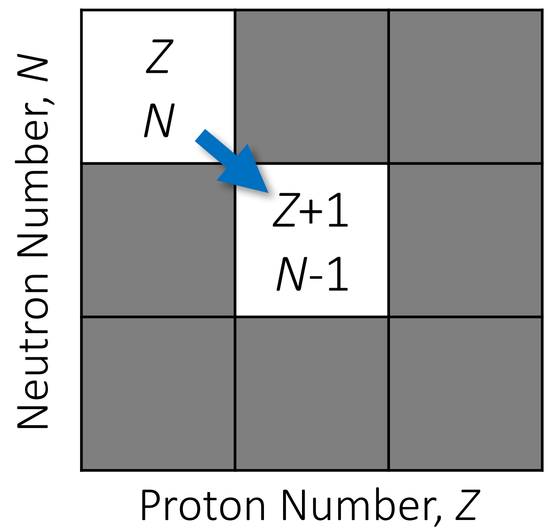
$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$



α Decay

Mass #

- 4



β^- Decay

Mass #

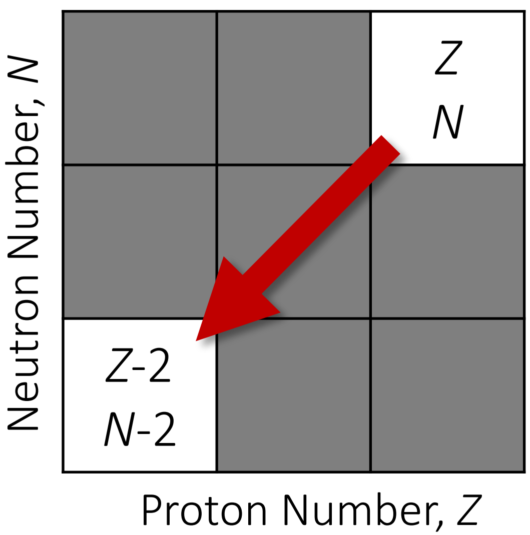
Same

Beta Decay

82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Pb	Bi	Po	At	Rn	Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf
Lead	Bismuth	Polonium	Astatine	Radon	Francium	Radium	Actinium	Thorium	Protactinium	Uranium	Neptunium	Plutonium	Americium	Curium	Berkelium	Californium

β^- Decay of Protactinium-234

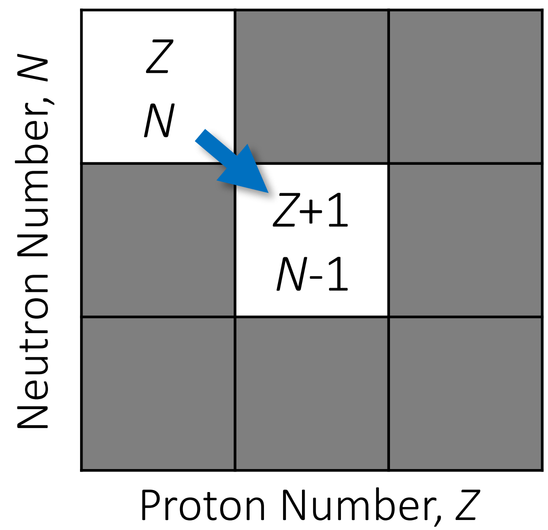
$$^{234}_{91}\mathrm{Pa} \rightarrow {}^{234}_{92}\mathrm{U} + {}^{0}_{-1}\mathrm{e} + \bar{\nu}_e$$



α Decay

Mass #

- 4



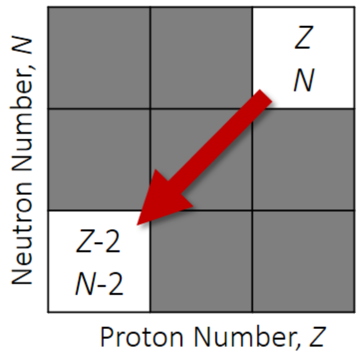
β^- Decay

Mass #

Same

Keeps right on going...

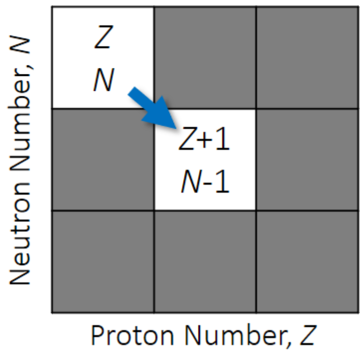
82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon	87 Fr Francium	88 Ra Radium	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium



α Decay

Mass #

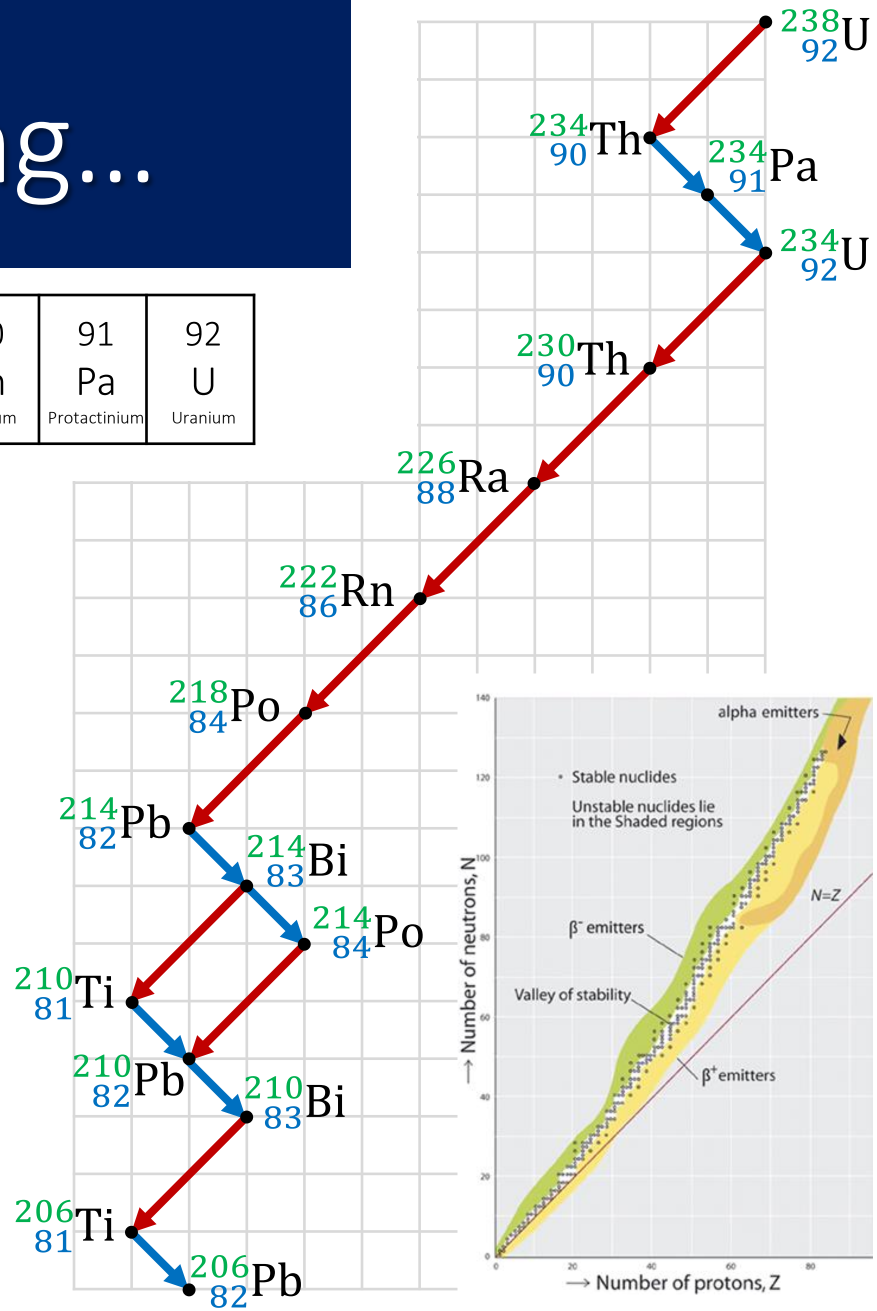
- 4



β^- Decay

Mass #

Same

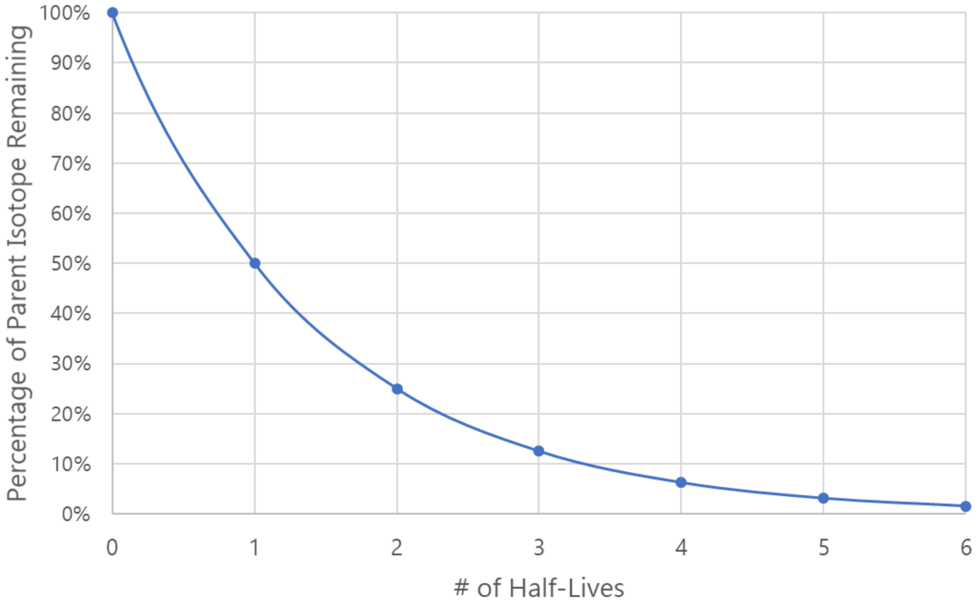


Half-Life

The amount of time it takes for one half of the original sample to **decay**

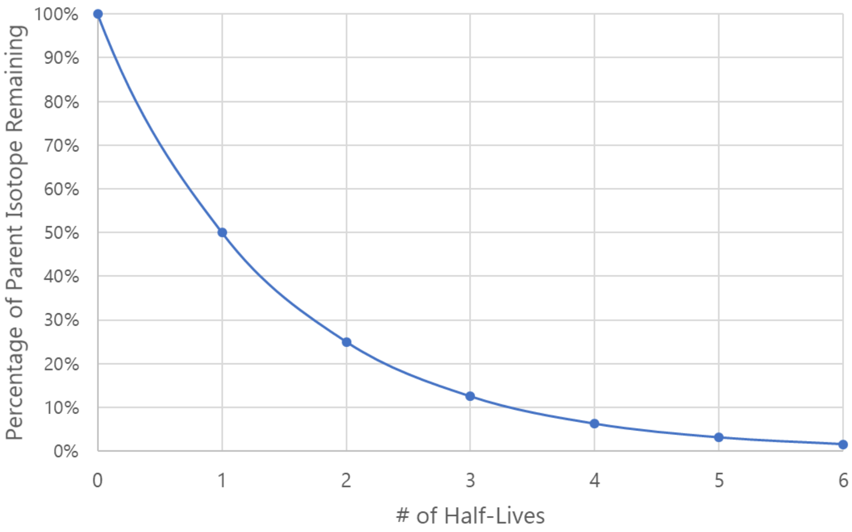
Radioactive Nuclide	Half-life
Uranium-238	4.5×10^9 years
Radium-226	1,600 years
Radon-222	3.8 days
Francium-221	4.8 minutes
Astatine-217	0.03 seconds

This can be in the scale of seconds, minutes, days or even years!



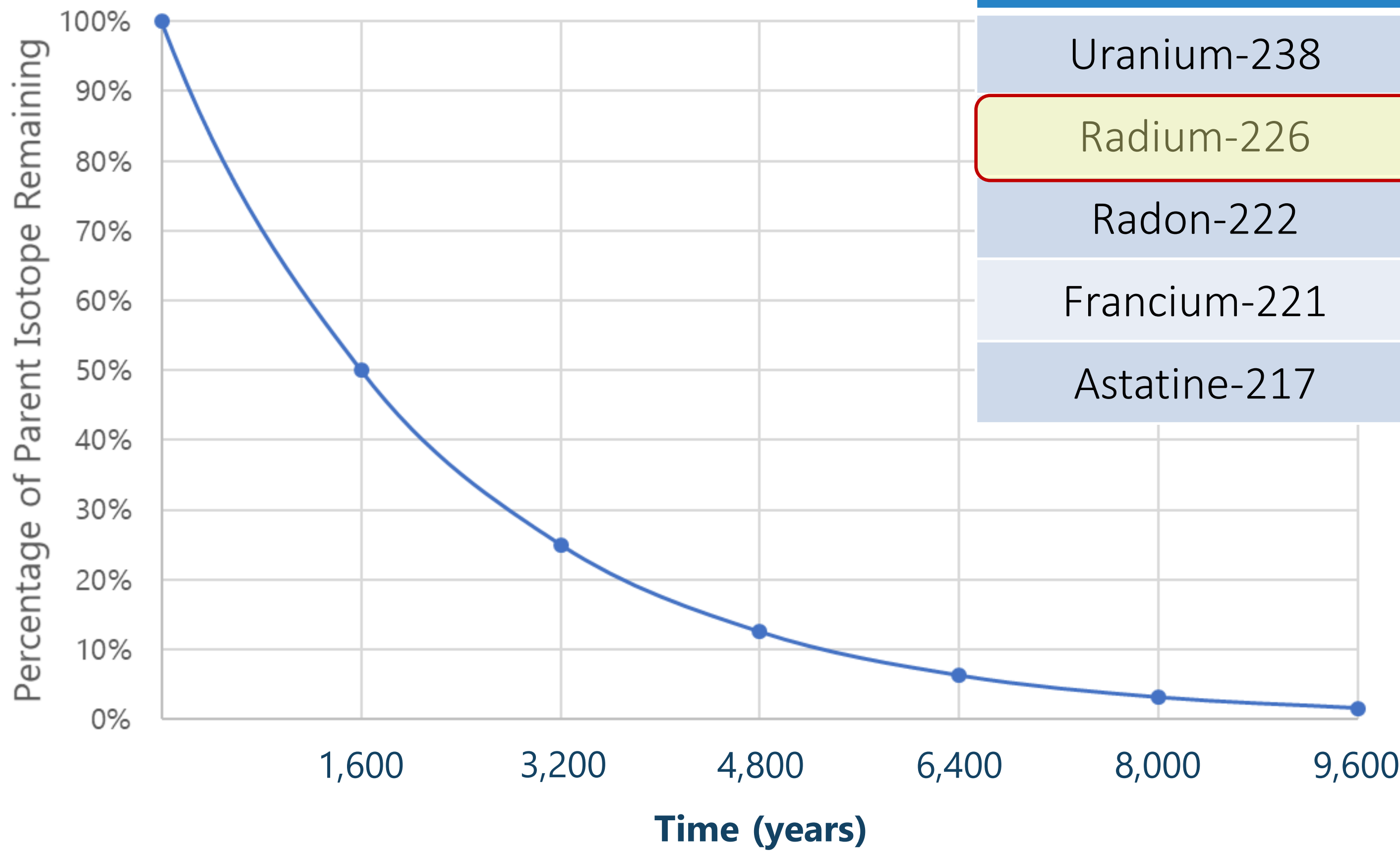
Half-Life Example

How many half-lives does it take for there to only be ___% of the original sample remaining?



100% / 2 = 50%	remains after 1 half-life
50% /2 = 25%	remains after 2 half-lives
25% /2 = 12.5%	remains after 3 half-lives
12.5% /2 = 6.25%	remains after 4 half-lives
6.25% /2 = 3.125%	remains after 5 half-lives

The length of a half life depends…



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Half Life Problem:

How many half-lives does it take for 100 g of a radioactive sample to decay to 12.5 g?

$$100\text{ g} \xrightarrow{1} 50\text{ g} \xrightarrow{2} 25\text{ g} \xrightarrow{3} 12.5\text{ g}$$

3 Half-Lives

If the half-life of the sample is 7 years, how long will this take?

$$(3\text{ half-lives}) \times (7\text{ years}) = 21\text{ years}$$

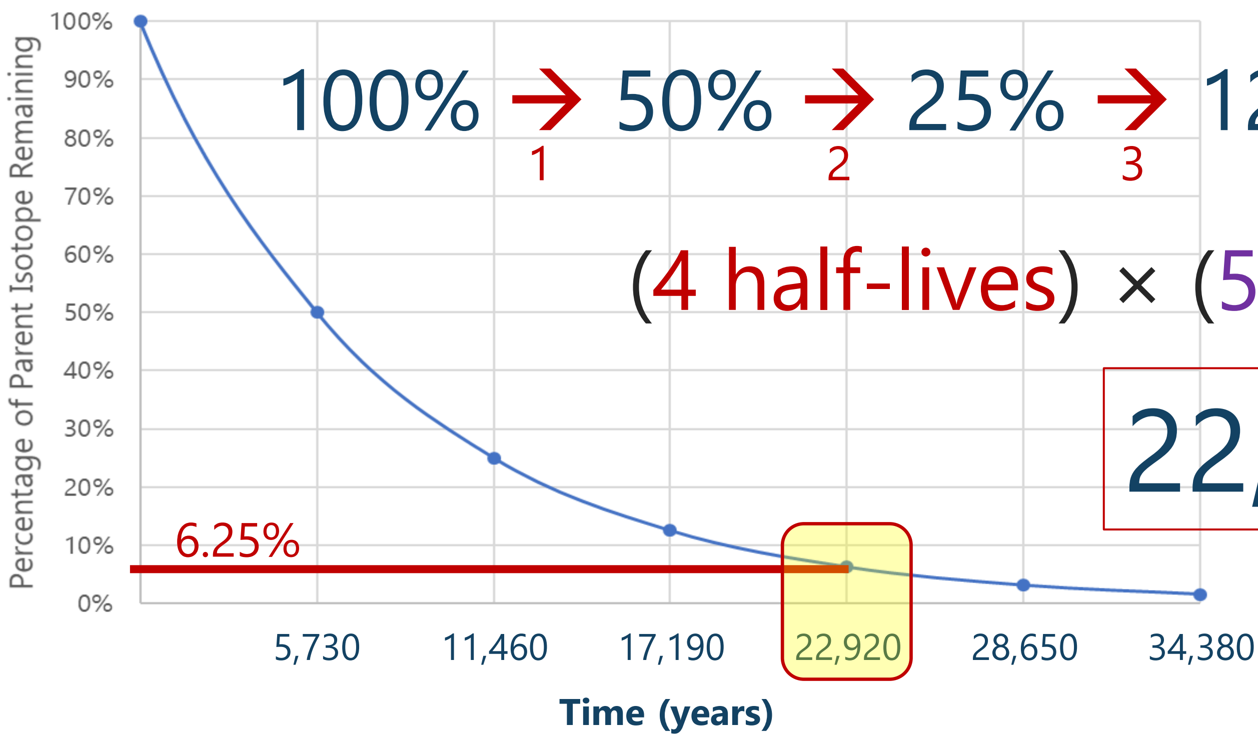
The half-life of radium-226 is 1600 years. What percentage remains undecayed after 3200 years?

$$(3200\text{ years}) \div (1600\text{ years}) = 2\text{ Half-Lives}$$

$$100\% \xrightarrow[1]{} 50\% \xrightarrow[2]{} \mathbf{25\%}$$

Radiocarbon Dating

How old is a sample of rock that has 6.25% of its original C-14. The half-life of C-14 is 5,730 years.



100% → 50% → 25% → 12.5% → **6.25%**

1, 2, 3, 4

(4 half-lives) × (5730 years) =

22,920 years