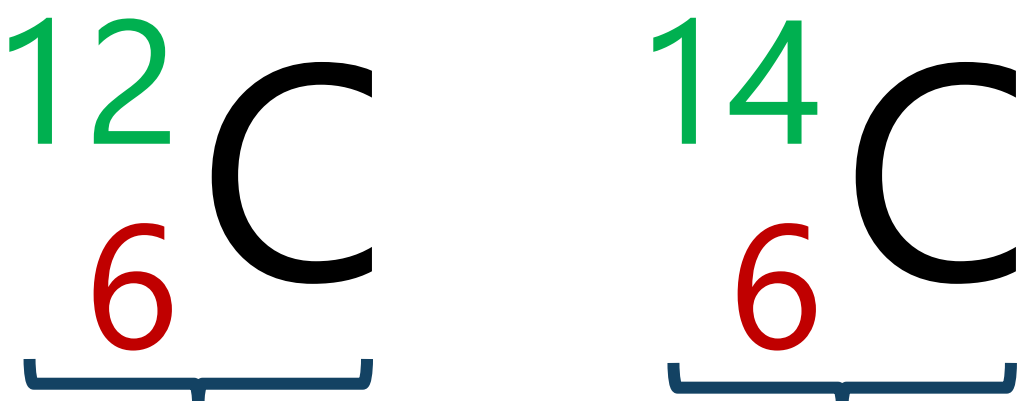
E.2

Radioactive Decay

IB PHYSICS | ATOMIC PHYSICS

Isotopes & Nuclides



Isotopes of Carbon

Same # of protons

Different # of neutrons

Nuclide

Single atom configuration

Fundamental Forces

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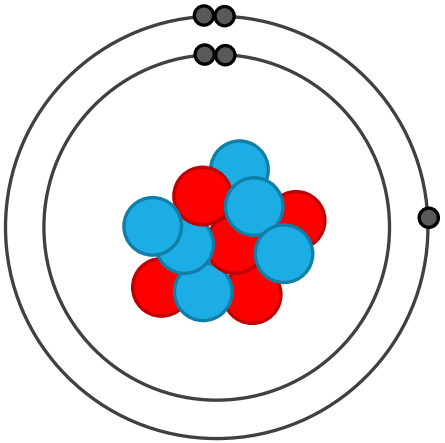


$^{11}_{5}B$

Remember Coulomb's Law?

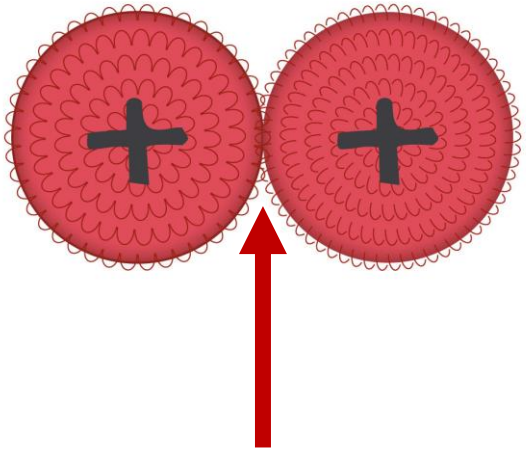
$$F = k\frac{q_1 q_2}{r^2}$$

Opposite charges attract
Like charges repel

Fundamental Forces

Strong Nuclear Force

- Very short range
- Very strong

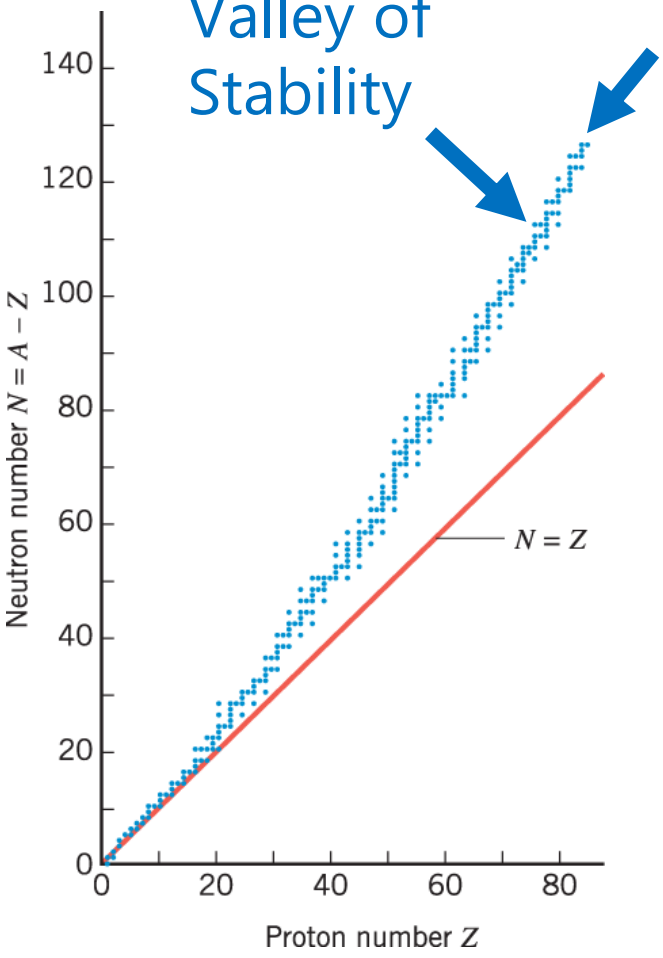


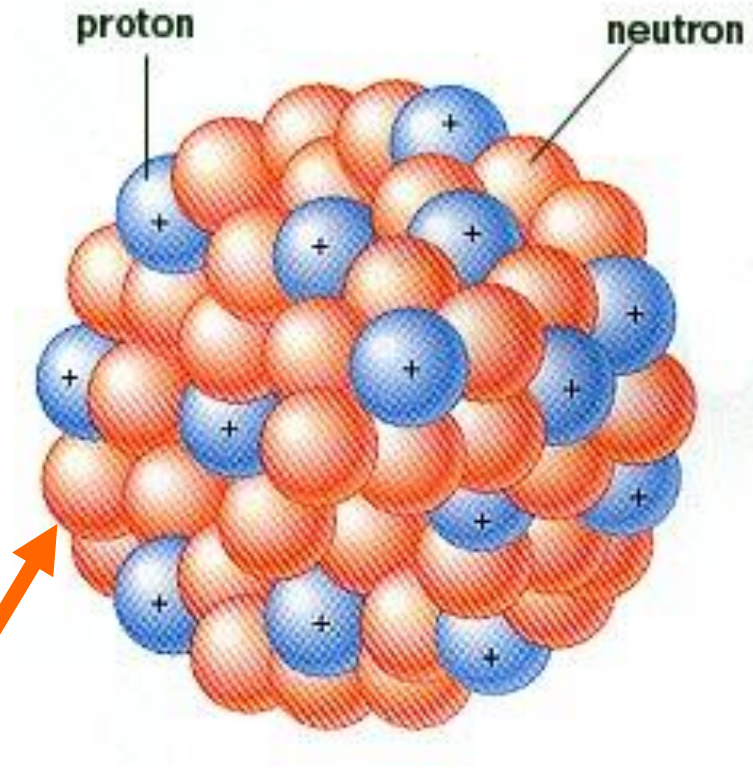
Electromagnetic Force

Gravitational Force

Weak Nuclear Force

Unstable Nuclei

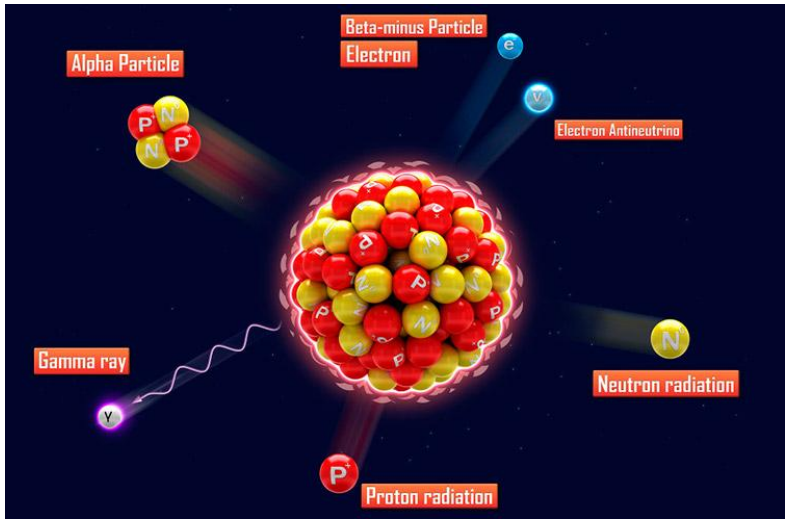




Neutrons serve as a buffer between repelling protons

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**

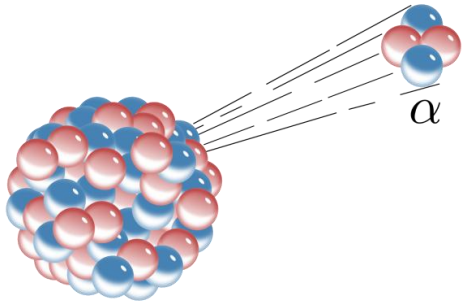
$$\mathrm{{}^{A}_{Z}X} \rightarrow \mathrm{{}^{A-4}_{Z-2}X} + \mathrm{{}^{4}_{2}He}$$

α

Parent Nuclide

Daughter Nuclide

Alpha Particle



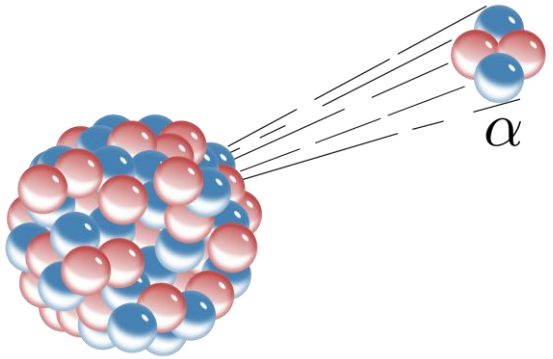
Complete the missing notation:

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

Alpha Decay - Predict

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

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



Beta-Negative Decay

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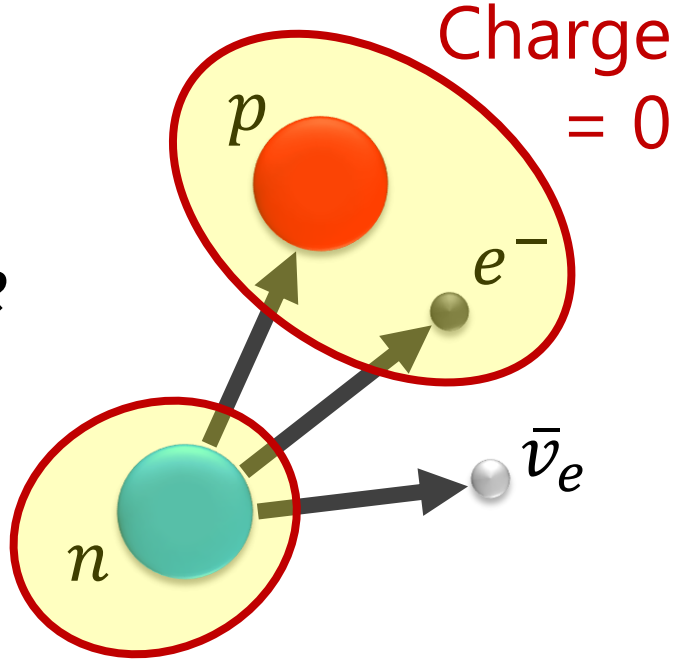
In an unstable nucleus, sometimes a neutral neutron is converted into a positive proton and negative electron. When this happens, another particle called an antineutrino ($\bar{\nu}_e$) is also formed

"anti-"

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



Beta-Negative Decay

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BETA-DECAY SET WITH MINI PARTICLES

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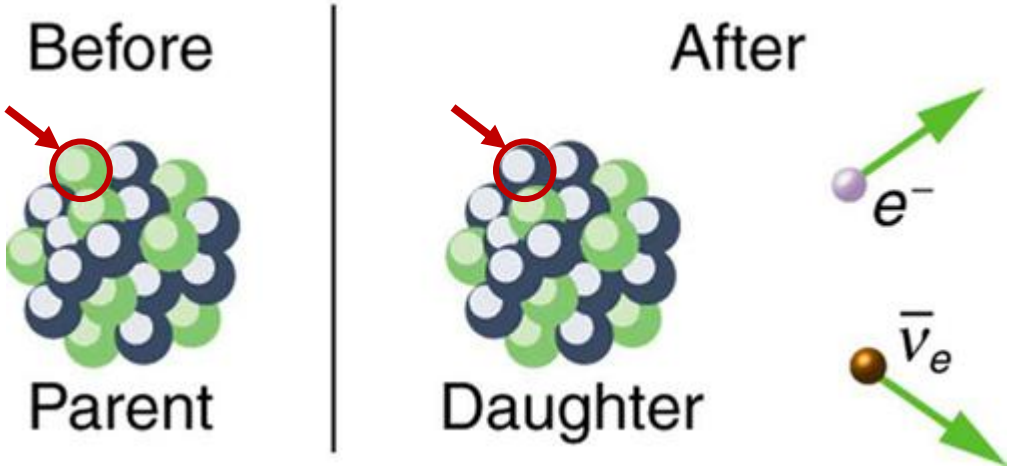
Beta-Negative Decay

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

Parent Nuclide | Daughter Nuclide | Electron | Antineutrino

β^-

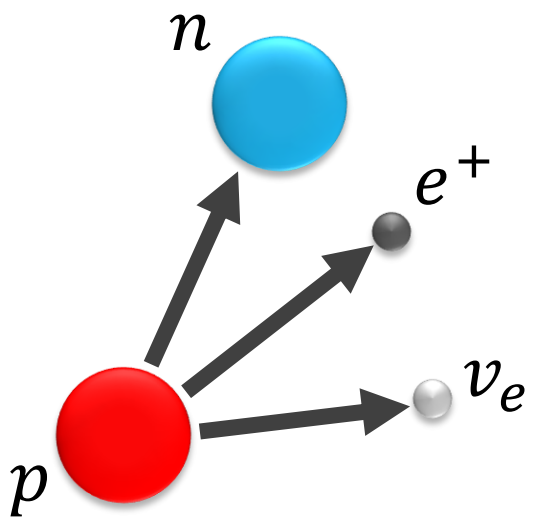
**The proton stays and the electron and antineutrino flies away as "radiation"



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 (ν_e) is also formed

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



Beta-Positive Decay

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

Parent Nuclide

Daughter Nuclide

Positron

Neutrino

β^+

Beta Decay - Predict

E.2

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

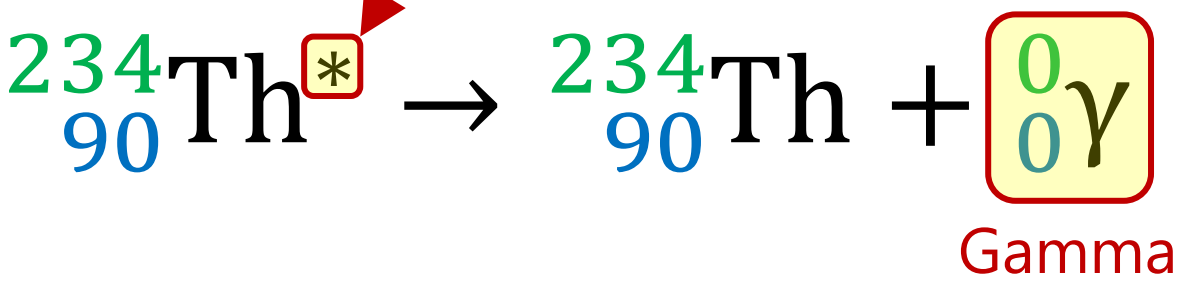
$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e} + \bar{\nu}_e$$

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

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

Gamma Decay

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



This energy often accompanies alpha or beta particles

The Math Always Adds Up

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

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

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

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

E.2

Particle Review

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

Sample IB Question

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

A. α, β^-, γ

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

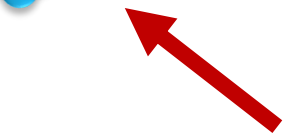
C. $\alpha, \gamma, \bar{\nu}$

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

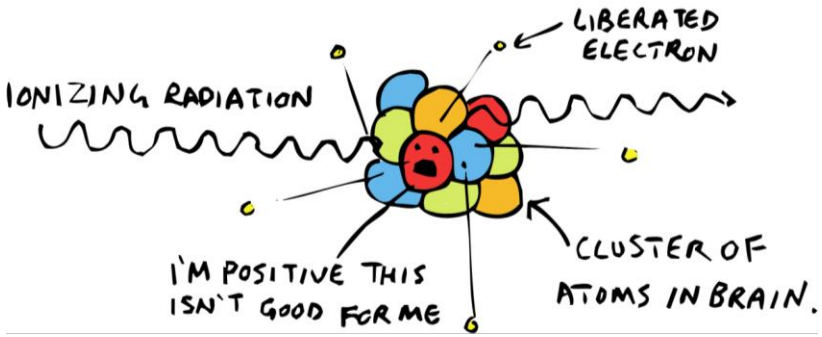
β^-

$$^{45}_{20}\text{Ca} \rightarrow {}^{45}_{21}\text{Sc} + {}^{0}_{-1}\text{e} + \bar{\nu}_e + {}^{0}_{0}\gamma$$

Ionizing Radiation

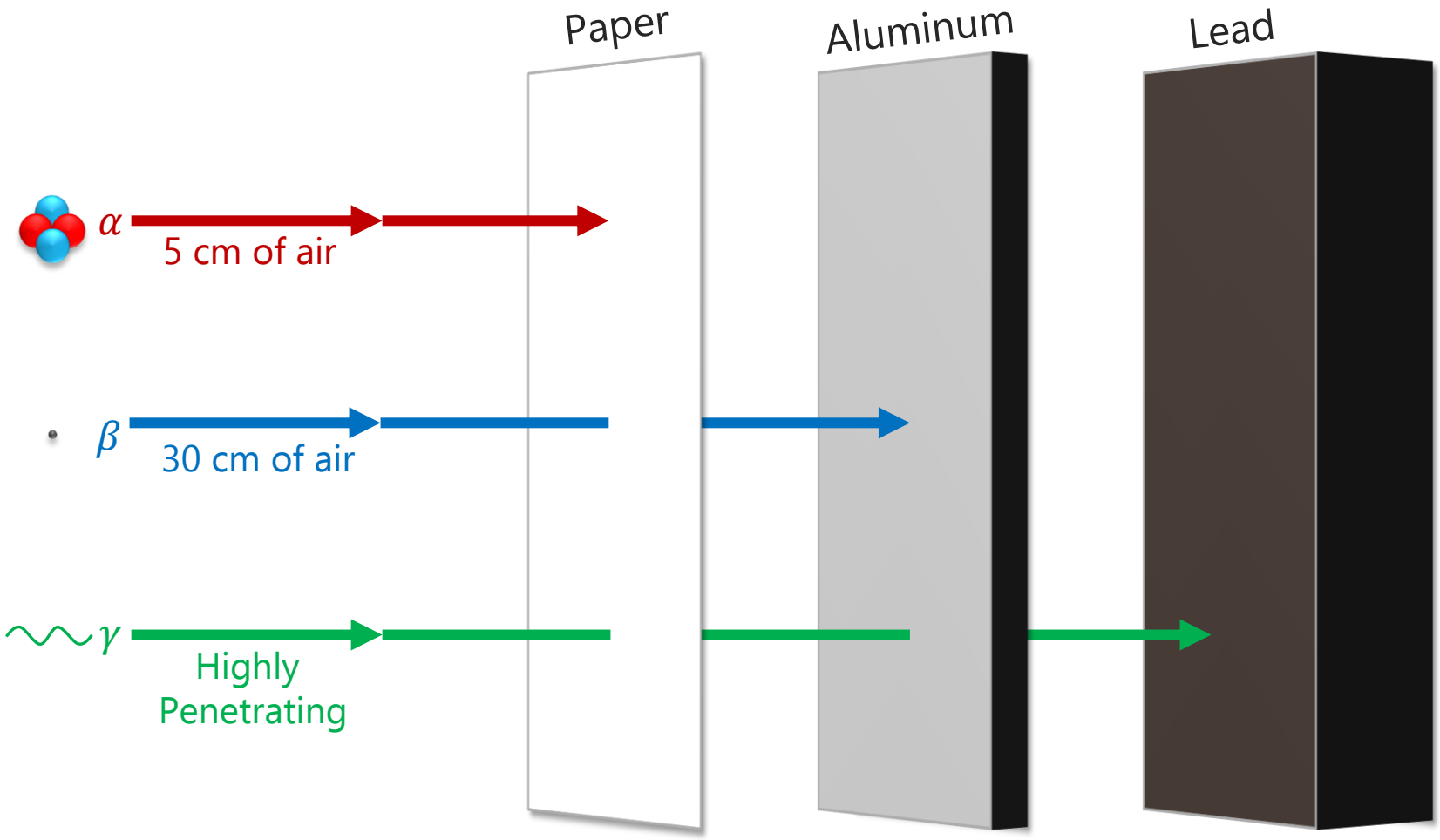


Most mass
Most ionizing

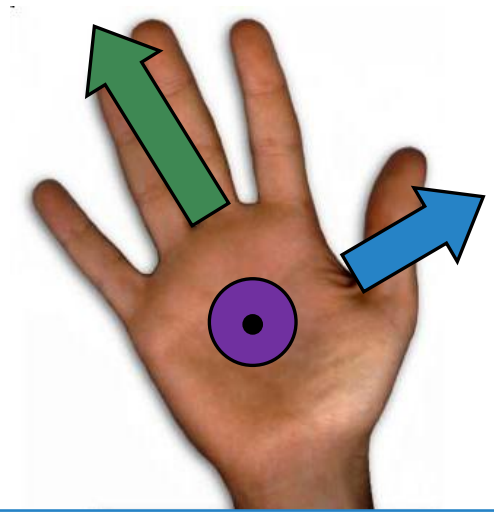


More mass allows particles to more efficiently transfer energy and ionize an atom

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

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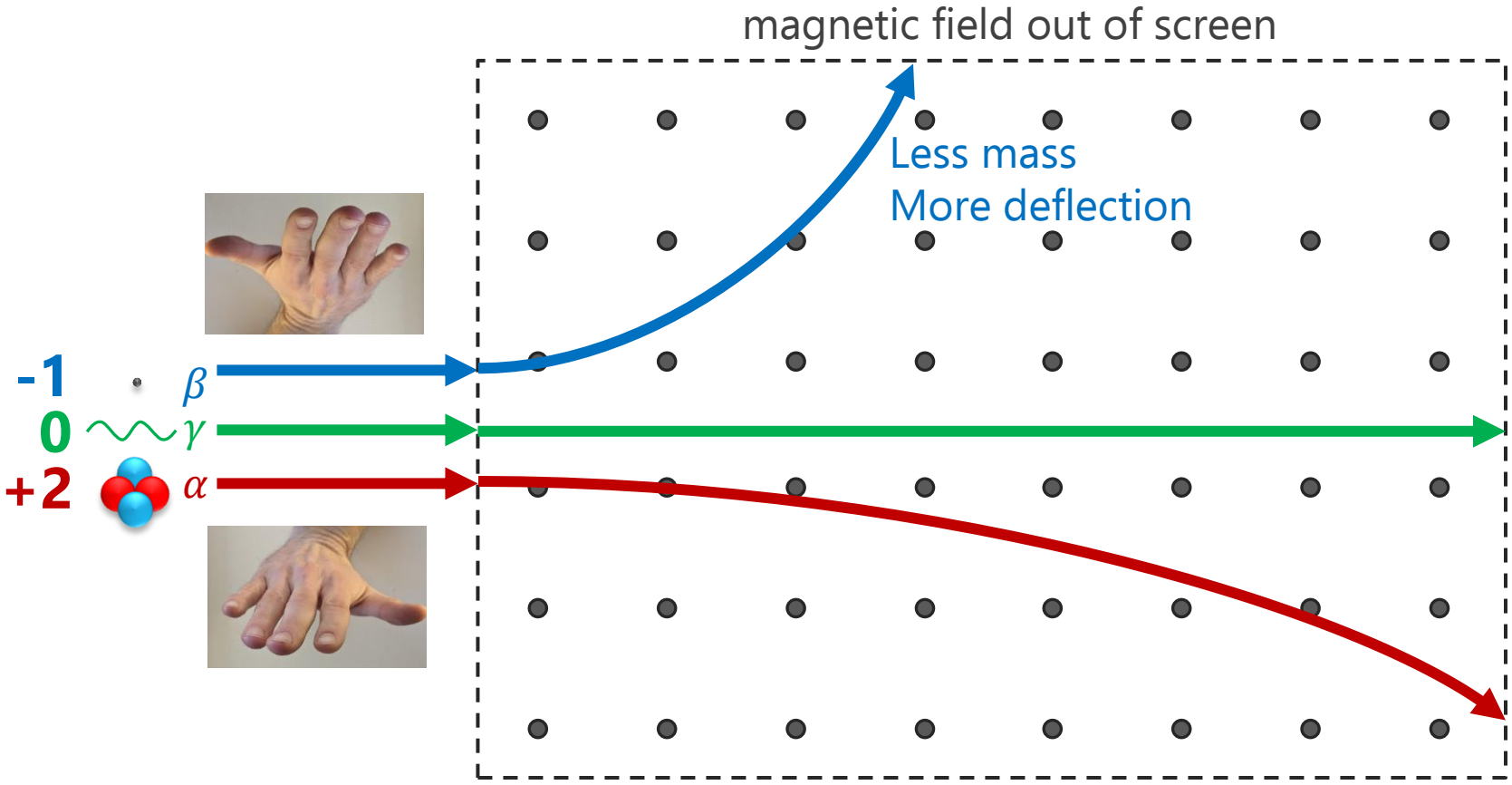
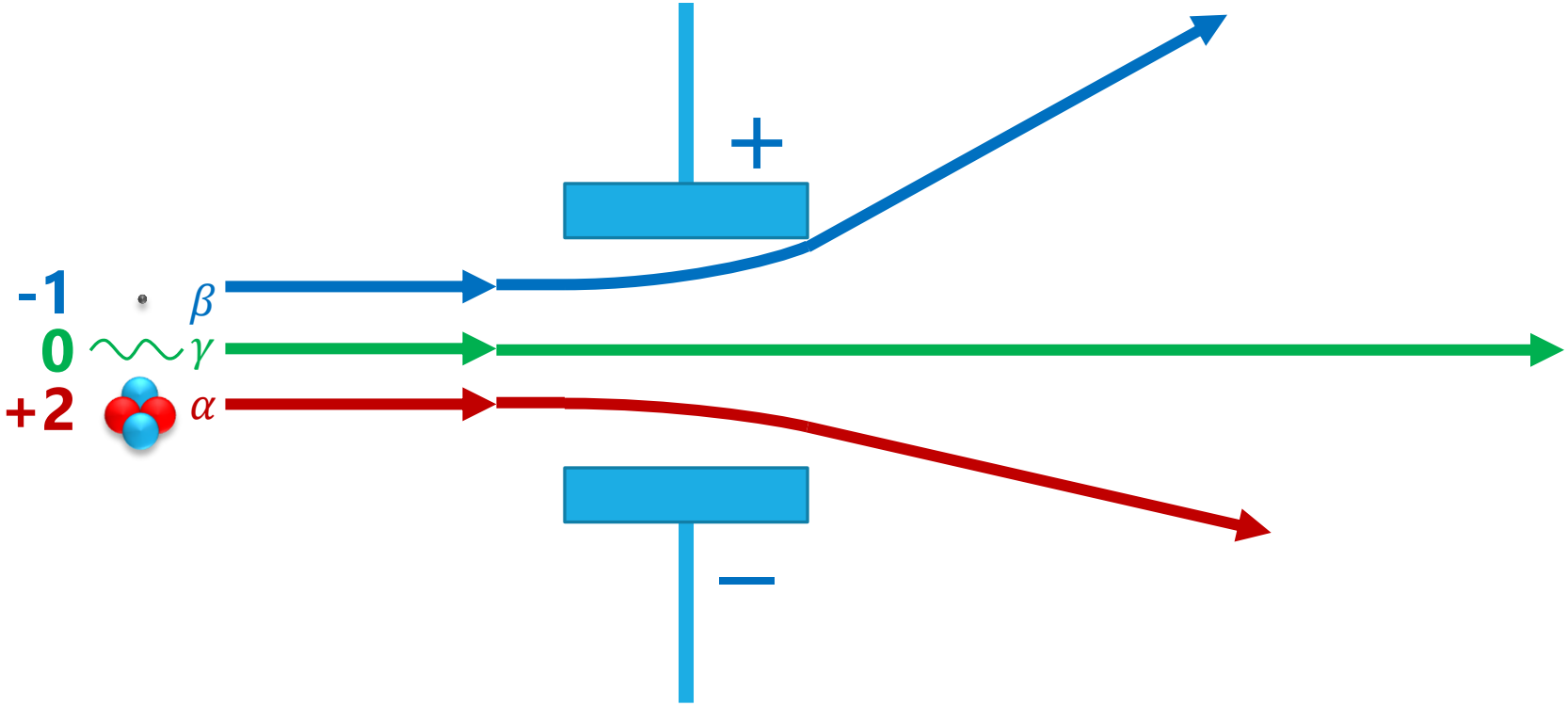


Radiation Deflection

E.2

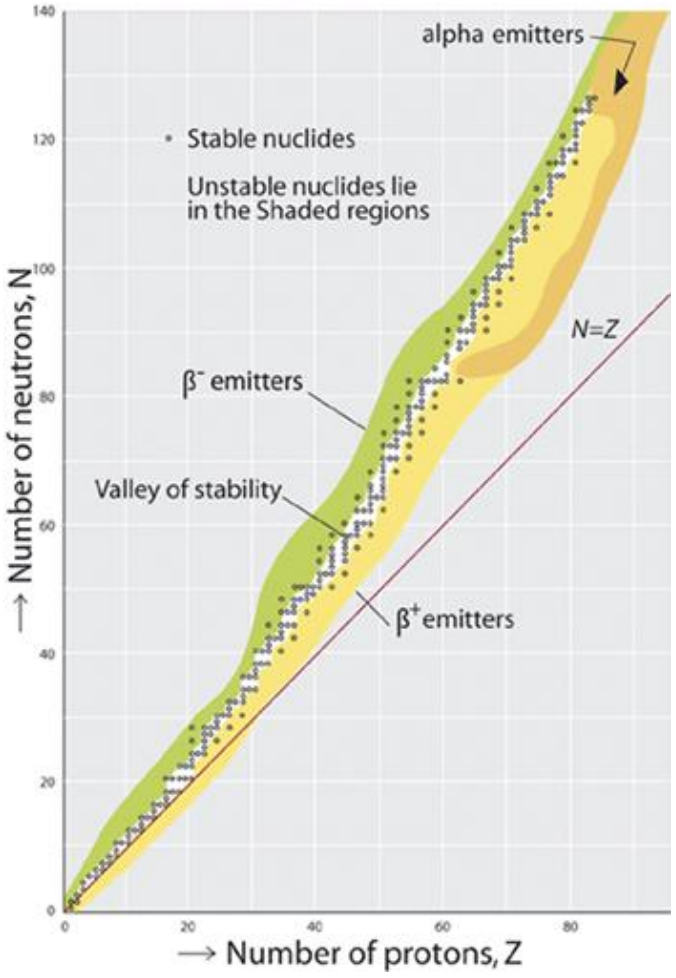


E.2

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

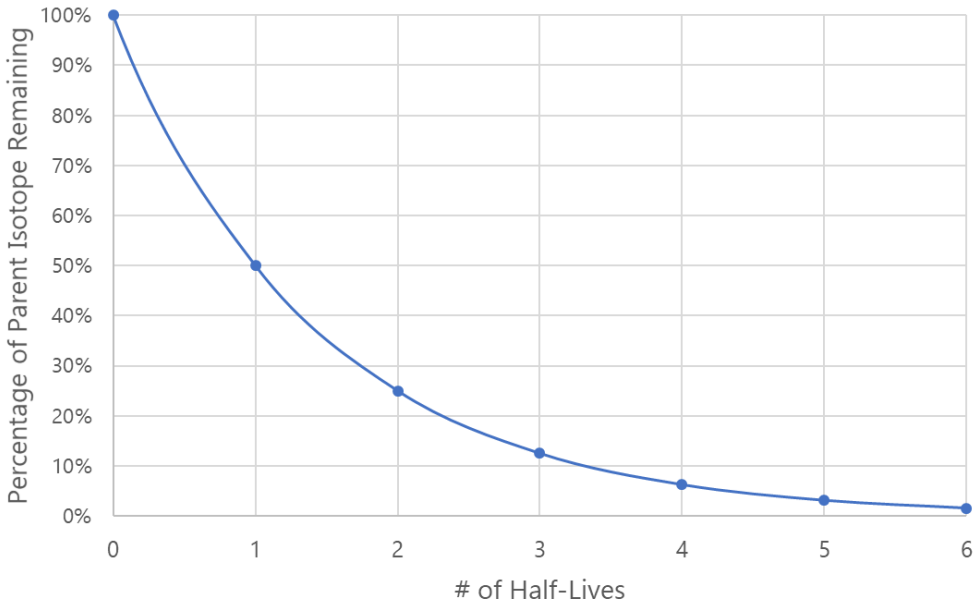


Half-Life

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!



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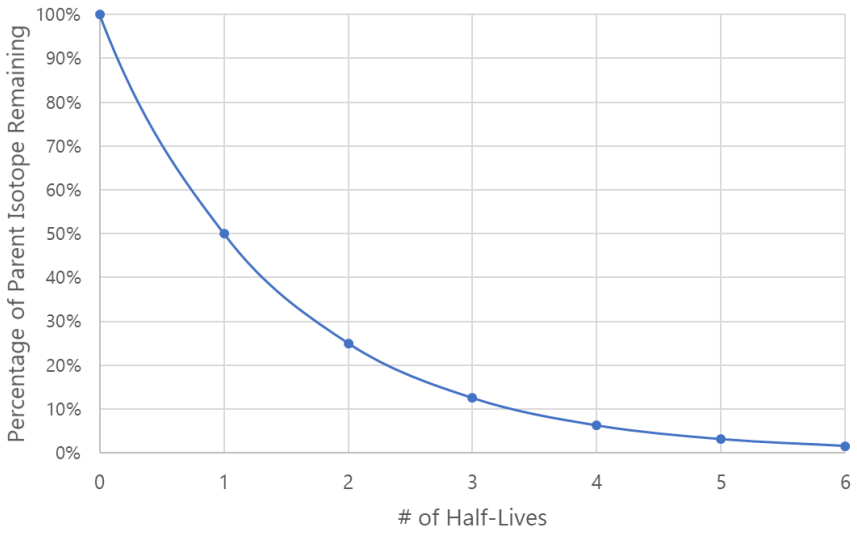
Half-Life Example

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

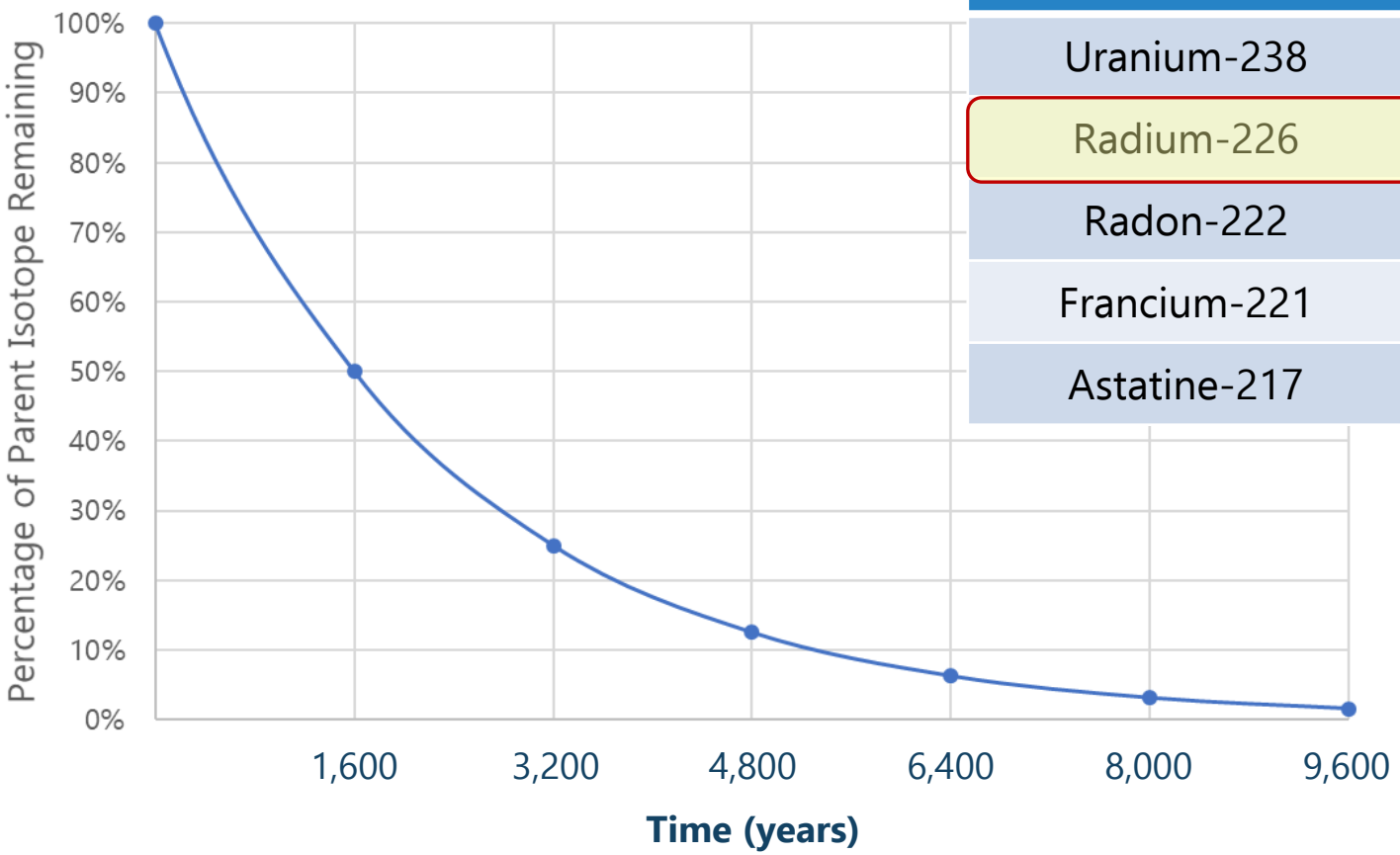
25% /2 = 12.5% remains after 3 half-lives

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…

E.2



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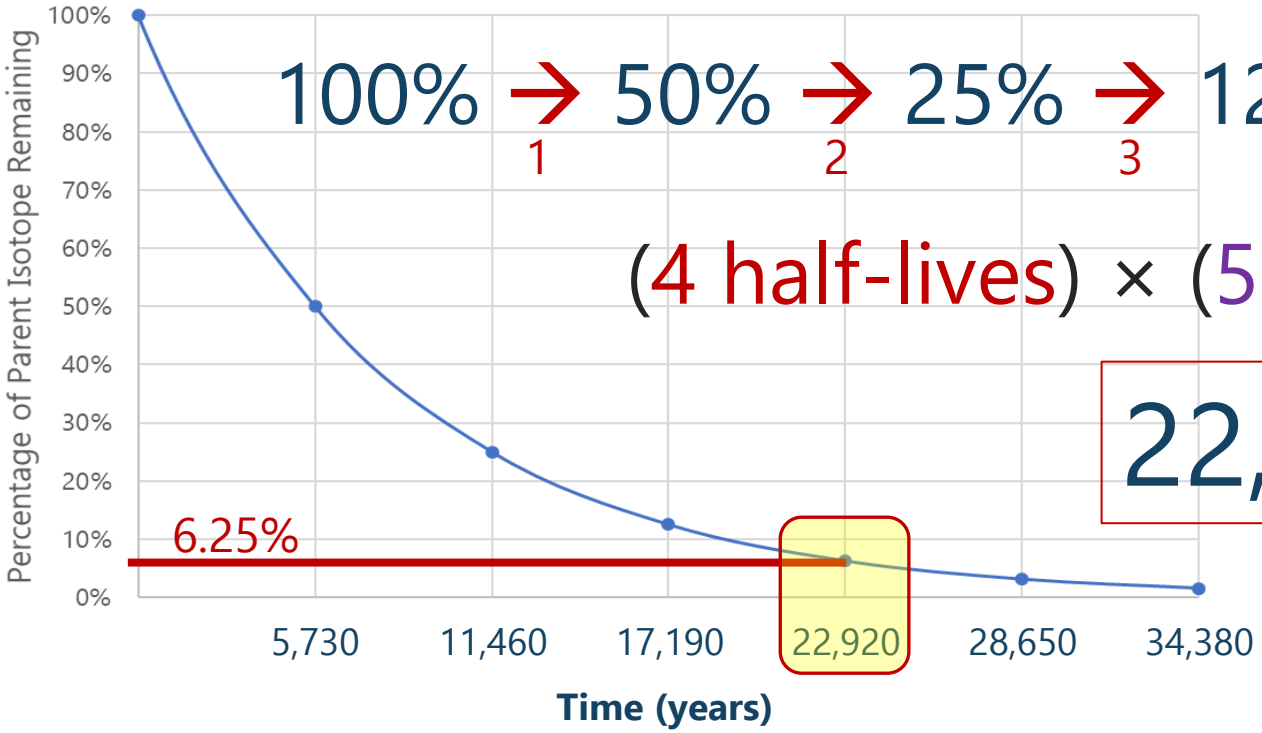
Uranium-238	4.5×10^9 years
Radium-226	1,600 years
Radon-222	3.8 days
Francium-221	4.8 minutes
Astatine-217	0.03 seconds

Radiocarbon Dating

E.2

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

E.2

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?

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

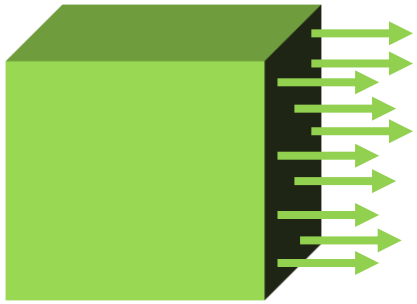
The half-life of radium-226 is 1600 years. What percentage remains undecayed after 3200 years?

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

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

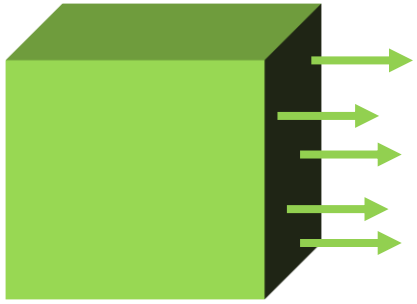
Activity

Radioactive half-life can be observed through **activity**

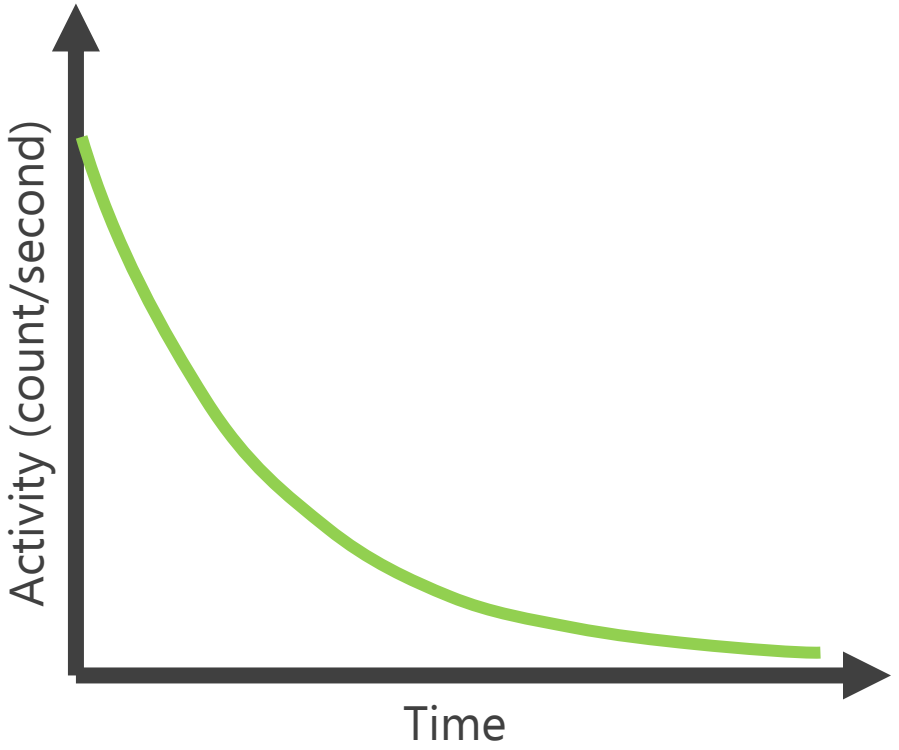


10 counts/sec

Some time later....



5 counts/sec



Natural Background Radiation

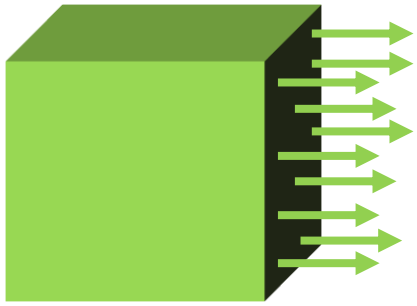
E.2

There is a natural amount of background activity always present

40 counts per second

What is the activity of the sample once the background is factored in?

400 – 40 = **360 counts/sec**



400 counts per second

What would the measured activity be one half life later?

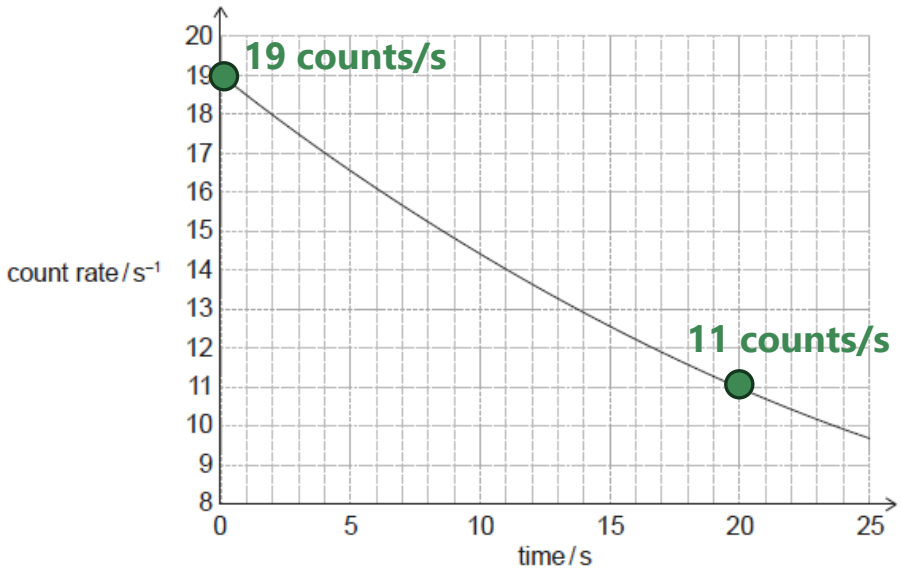
Sample activity = 360 / 2 = **180**

+ Background = 180 + 40 = **220**

Example IB Question

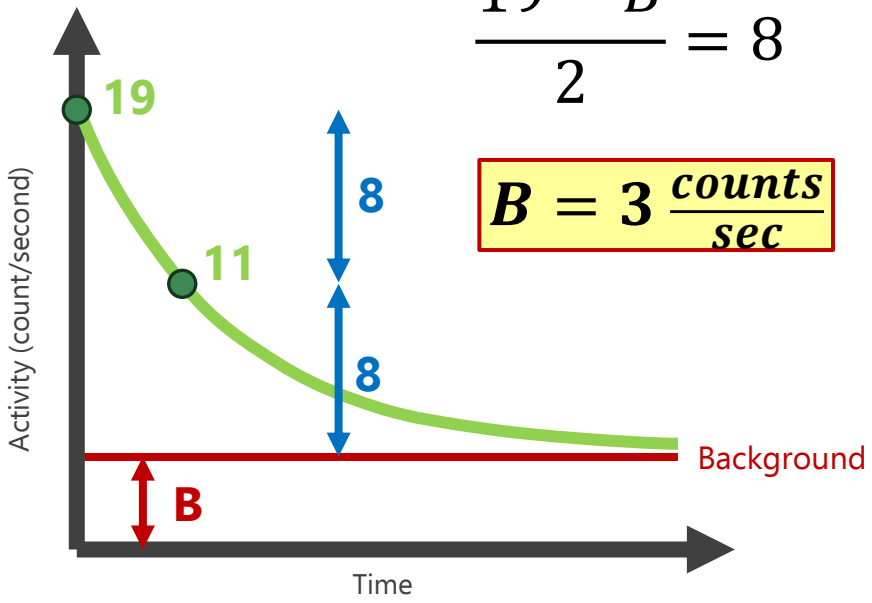
A detector measures the count rate from a sample of a radioactive nuclide. The graph shows the variation with time of the count rate.

The nuclide has a half-life of 20 s. The average background count rate is constant. What is the average background count rate?



$$\frac{19 - B}{2} = 8$$

$$B = 3 \frac{counts}{sec}$$



E.1

Lesson Takeaways

- ❑ I can describe the role of the strong force and explain how nuclei can become unstable
- ❑ I can predict the products of radioactive alpha, beta, and gamma decay
- ❑ I can compare and contrast the properties of alpha, beta, and gamma particles
- ❑ I can conceptually describe the meaning of half-life
- ❑ I can calculate the % of a substance remaining after a given number of half lives
- ❑ I can adjust for natural background in half-life problems