Atomic Physics

IB Physics Content Guide

Big Ideas

- Atomic nuclei decay to form more stable configurations and produce radiation in the process
- The rate of decay can be predicted for different materials and used to determine age based on isotope count
- Mass and energy are different manifestations of the same thing
- More energy efficient configurations mean that fission and fusion reactions release energy

1 – Structure of the Atom

I can describe how the historical understanding of the atom has changed over time			
I can describe the Rutherford-Geiger-Marsden experiment and how it helped discover the nucleus			
I can interpret isotope notation to determine the number of protons and neutrons			
I can describe electron energy levels and how transitions between these absorb and emit energy			
I can calculate the energy, frequency, and wavelength of light emitted by transitioning electrons			
I can identify and calculate the emission wavelengths for different elements			

2 – Radioactive Decay

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 calculate the age of a sample when given the percentage of an isotope remaining			

3 – Energy and Mass Defect

I can relate units of mass between kilograms (kg) and atomic mass units (u)			
I can use the mass/energy equivalence to mathematically relate mass and energy			
I can define mass defect and explain how it is related to energy			
I can calculate the mass defect of a nuclide			
I can calculate binding energy from mass defect			

4 – Nuclear Power

I can describe the chain reaction that occurs to support a self-sustaining fission reactor			
I can describe the concentration of U-235 as a sample is enriched into fuel-grade uranium			
I can outline the process of enriching uranium			
I can explain how a nuclear reactor transforms the energy of a fission reaction into electricity			
I can describe the role of the moderator and control rods in a nuclear reactor			
I can discuss the challenges of disposing of nuclear waste			

Atomic Spectra

	Variable Symbol	Description	Unit
$E = hf$ $E = \frac{hc}{\lambda}$ $h = 6.63 \times 10^{-34}$ J s $c = 3.00 \times 10^{8}$ m s^{-1}	E	Energy	[J] or [eV]
	h	Planck's Constant	[J s]
	f	Frequency	[Hz]
	c	Speed of Light	[m s^{-1}]
	λ	Wavelength	[m]

hc	1.99×10^{-25} J m	1.24×10^{-6} eV m

Radioactive Decay

Alpha

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

Parent Nuclide | Daughter Nuclide | Alpha Particle

Beta-Negative

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

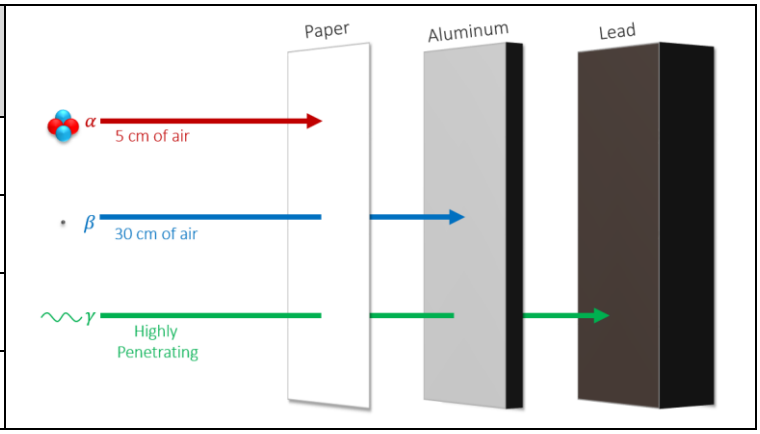
Parent Nuclide | Daughter Nuclide | Electron | Anti-neutrino

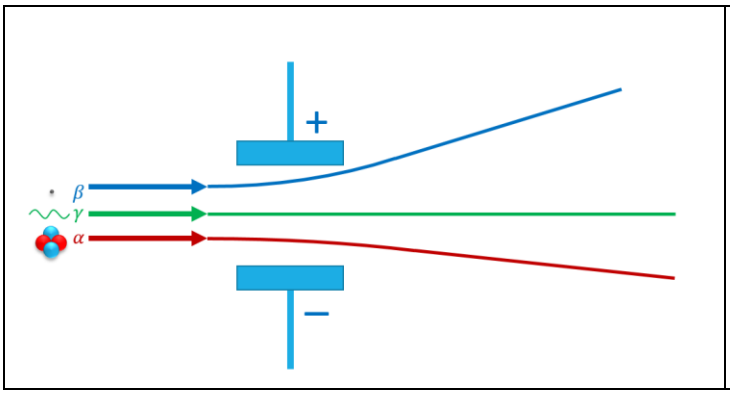
Beta-Positive

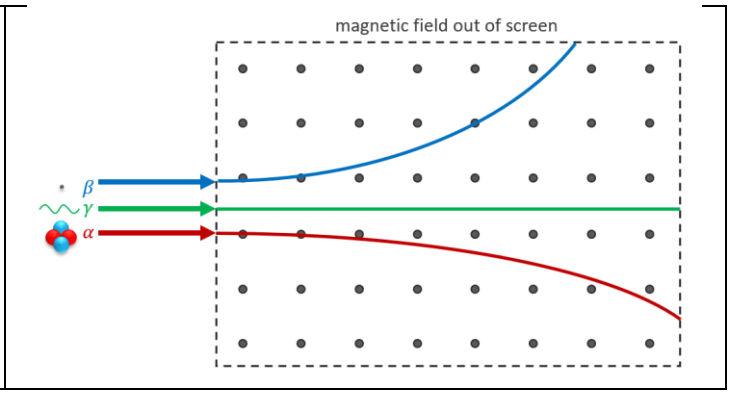
$${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}X + {}^{0}_{+1}e + \nu_e$$

Parent Nuclide | Daughter Nuclide | Positron | Neutrino

Property	Alpha (α)	Beta (β+ or β-)	Gamma (γ)
Relative Charge	+2	+1 or -1	0
Relative Mass	4	0.0005	0
Typical Speed	10^7 m s^{-1}	2.5×10^8 m s^{-1}	3.0×10^8 m s^{-1}
Ionizing Effect	Strong	Weak	Very Weak

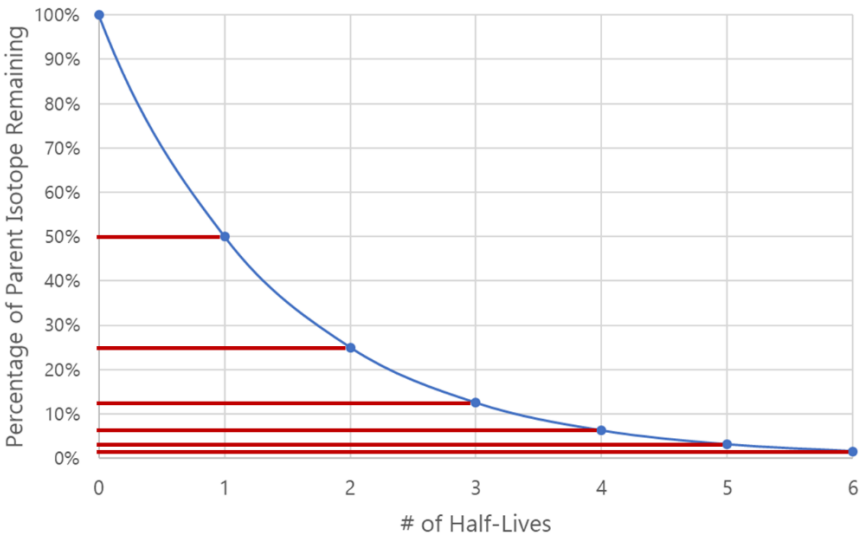






Half Life

# of Half-Lives	Fraction Remaining	Percentage Remaining
0	1	100%
1	1/2	50%
2	1/4	25%
3	1/8	12.5%
4	1/16	6.25%
5	1/32	3.125%
6	1/64	1.5625%



Mass-Energy Equivalence

	Variable Symbol	Description	Unit
$E = mc^2$ $c = 3.00 \times 10^8\ m\ s^{-1}$	E	Energy	[J]
	m	Mass	[kg]
	c	Speed of Light	[m s^{-1}]

Unified Atomic Mass Unit	u	1.661 × 10^{-27} kg	1.000000 u	931.5 MeV c^{-2}

Electron Rest Mass	m_e	9.110 × 10^{-31} kg	0.000549 u	0.511 MeV c^{-2}
Proton Rest Mass	m_p	1.673 × 10^{-27} kg	1.007276 u	938 MeV c^{-2}
Neutron Rest Mass	m_n	1.675 × 10^{-27} kg	1.008665 u	940 MeV c^{-2}

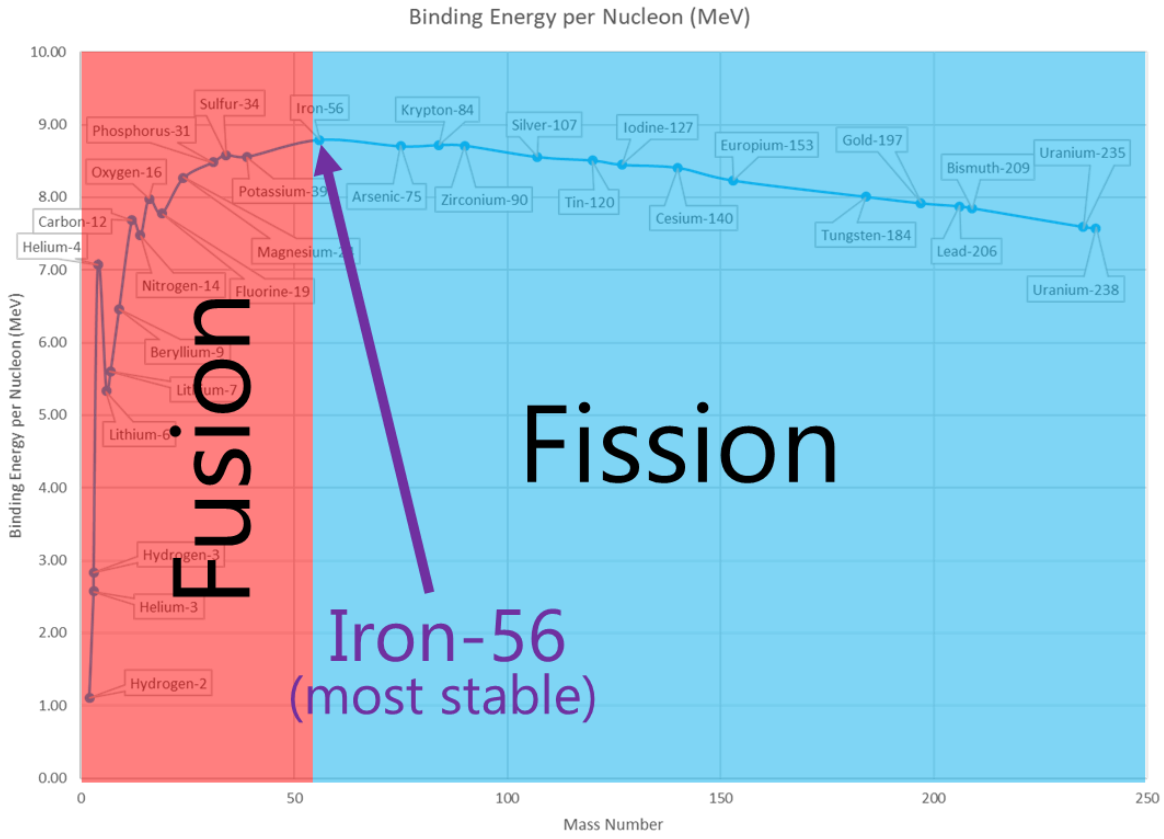
Converting between Joules and Electron-Volts

$\{Energy\ in\ eV\} = \frac{\{Energy\ in\ J\}}{1.60 \times 10^{-19}}$	$\{Energy\ in\ J\} = \{Energy\ in\ eV\} \times 1.60 \times 10^{-19}$

Process for Calculating Binding Energy

1. Add up the "before and after" masses
2. Find the mass defect by taking the difference
3. Convert atomic mass units (u) into MeV c^{-2} by using the conversion factor 1 u = 931.5 MeV c^{-2}
4. The c^{-2} cancels out when converting to energy using $E = mc^2$ so this is your binding energy

Binding Energy per Nucleon



Nuclear Power

	Describe	Examples	Challenges
Fission	Lighter elements are created by splitting heavier elements	Nuclear Power Nuclear Weapons	Proper amounts of fissionable elements required to maintain chain reaction
Fusion	Heavier elements are created by combining lighter elements	The Sun/Stars	Requires high heat and high pressure

	% of U-235
Uranium Ore	0.7%
Fuel-Grade	3.5%
Weapons-Grade	90%

Why is the concentration of U-235 important?

Only U-235 can undergo a fission chain reaction

What is done with the nuclear waste?

Stored on-site in spent fuel pools and/or concrete dry cask storage

Moderator	Control Rods
Slows down neutrons to be absorbed by U-235 Made from Water or Graphite (carbon)	Absorbs neutrons to limit number of chain reactions Made from Boron