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
- It is believed that all matter is made up of fundamental particles called quarks and leptons
- There is a symmetry between all matter with particles and their corresponding anti-particles
- The standard model has helped spur discoveries of new particles, but it may not yet be complete

Content Objectives

1 – Radiation and Decay

I can interpret isotope notation to determine the number of protons and neutrons			
I can describe why the nucleus of an atom stays together despite the electrostatic repulsion			
I can predict the products of alpha and beta decay			
I can describe the impact of ionizing radiation and the ionizing effect of different types of decay			
I can predict the penetration of the radiation byproducts of nuclear decay			
I can describe the deflection of the radiation byproducts moving through a magnetic or electric field			
I can predict the percentage of an isotope remaining after a given number of half-lives			
I can calculate the age of a sample when given the percentage of an isotope remaining			

2 – Energy and Mass Defects

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 convert between Joules (J) and electron-volts (eV)			
I can describe how MeV c^{-2} is a valid unit for mass			
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			
I can interpret a chart showing binding energy per nucleon to locate stable nuclei			

3 – Atomic Spectra

I can describe the concept of emission and absorption spectra and their role in identifying elements			
I can describe what it means for light to be quantized			
I can mathematically relate energy and frequency by Planck's constant			
I can describe the process of electrons dropping energy levels and emitting photons			
I can calculate the energy and wavelength emitted from an electron as it transitions			
I can use the wavelength of light to determine the electron transition			

4 – Particles & the Standard Model

I can identify the general categories of particles in the standard model			
I can classify particle categories into an organized family tree with examples of each			
I can describe how quarks can be combined to create whole number charges			
I can identify the quarks required to form protons and neutrons			
I can calculate the charge of a given baryon or meson			
I can describe the phenomenon of Quark Confinement			
I can analyze a reaction based on conservation of Baryon #, Lepton #, Charge, and Strangeness			
I can describe forces in terms of exchange particles			
I can rank the fundamental forces based on strength			
I can describe the role of the Standard Model in the discovery of new particles			

5 – Feynman Diagrams and the Higgs Boson

I can describe key features of the Large Hadron Collider and its role in the Higgs Boson discovery			
I can follow the general rules for creating a Feynman Diagram			
I can describe a particle interaction using Feynman Diagram			

Atomic Physics

Shelving Guide

Types of Decay

Alpha

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

Parent Nuclide	Daughter Nuclide	Alpha Particle

Beta-Negative

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

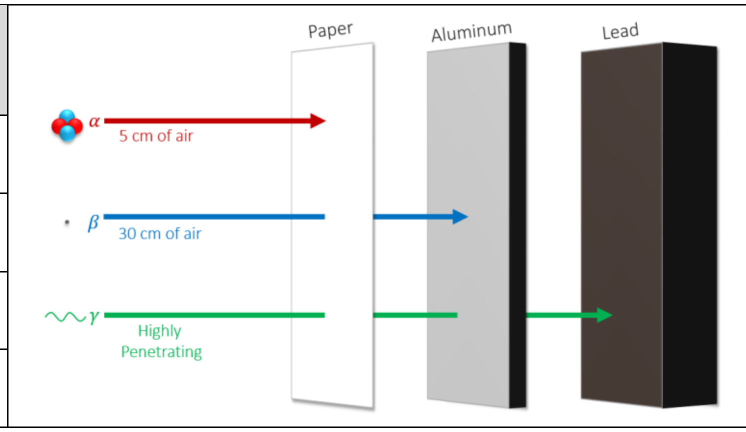
Parent Nuclide	Daughter Nuclide	Electron	Anti-neutrino

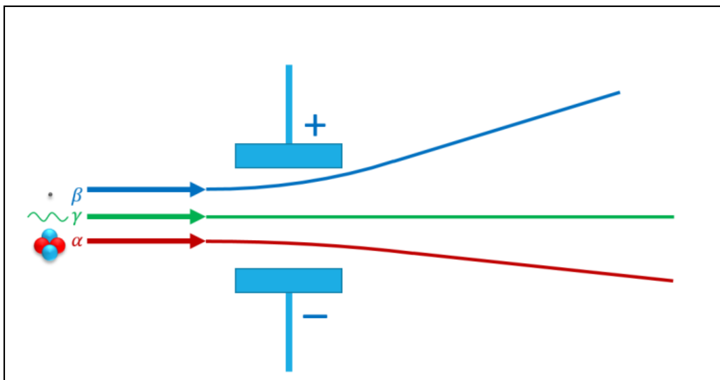
Beta-Positive

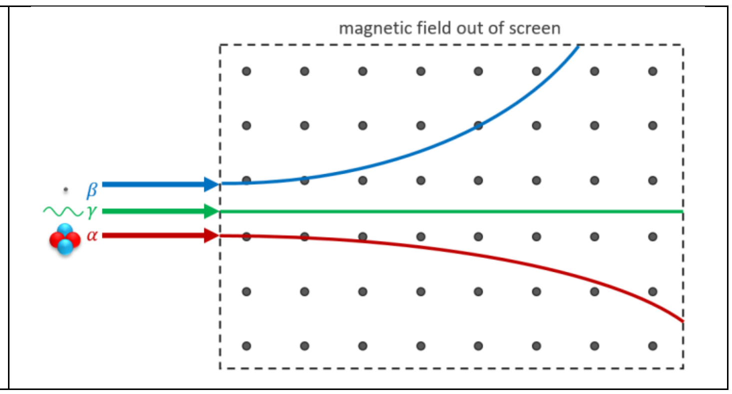
$${}^{A}_{Z}X \rightarrow {}_{Z-1}^{A}X + {}_{+1}^{0}e + \nu_e$$

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

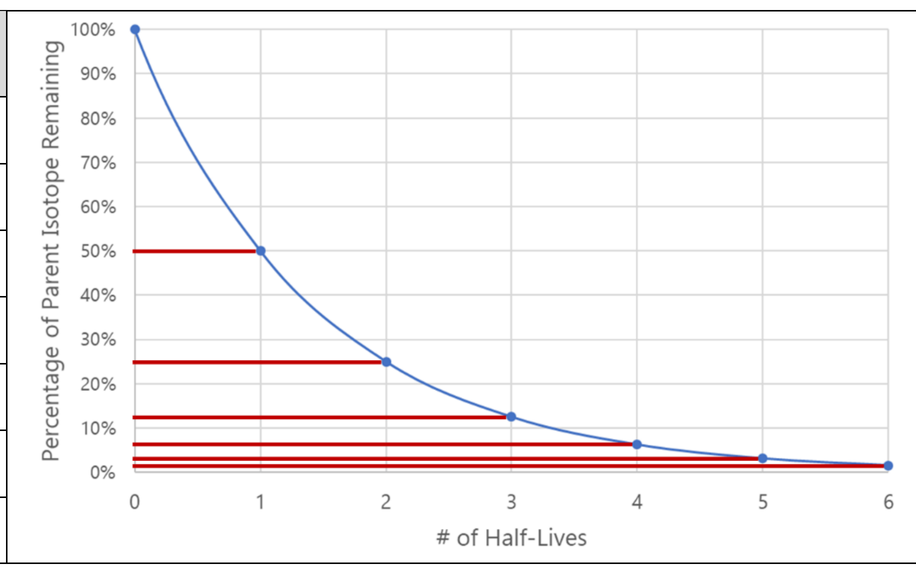






Half Life

# 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	Unit
Energy	E	J
Mass	m	kg
Speed of Light	c	$m\ s^{-1}$

Data Booklet Equation:

$$E = mc^2$$

$$c = 3.00 \times 10^8\ m\ s^{-1}$$

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

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

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

Atomic Spectra

	Variable Symbol	Unit
Energy	E	J or eV
Planck's Constant	h	J s
Frequency	*f*	Hz
Speed of Light	c	$m\ s^{-1}$
Wavelength	λ	m

Data Booklet Equations:

$$E = hf$$

$$\lambda = \frac{hc}{E}$$

$$h = 6.63 \times 10^{-34}\ \mathrm{J\ s}$$

$$c = 3.00 \times 10^8\ \mathrm{m\ s^{-1}}$$

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

Fundamental Particles

The following two tables are provided in the IB Physics Data Booklet

Charge	Quarks			Baryon Number
$\frac{2}{3}$	u	c	t	$\frac{1}{3}$
$-\frac{1}{3}$	d	s	b	$\frac{1}{3}$
All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1				

Charge	Leptons		
-1	e	μ	τ
0	ν_e	ν_μ	ν_τ
All leptons have a lepton number of 1 and antileptons have a lepton number of –1			

Quarks			
Symbol	Name	Charge	Baryon #
u	Up	$+\frac{2}{3}$	$\frac{1}{3}$
d	Down	$-\frac{1}{3}$	$\frac{1}{3}$
c	Charm	$+\frac{2}{3}$	$\frac{1}{3}$
s	Strange	$-\frac{1}{3}$	$\frac{1}{3}$
t	Top	$+\frac{2}{3}$	$\frac{1}{3}$
b	Bottom	$-\frac{1}{3}$	$\frac{1}{3}$

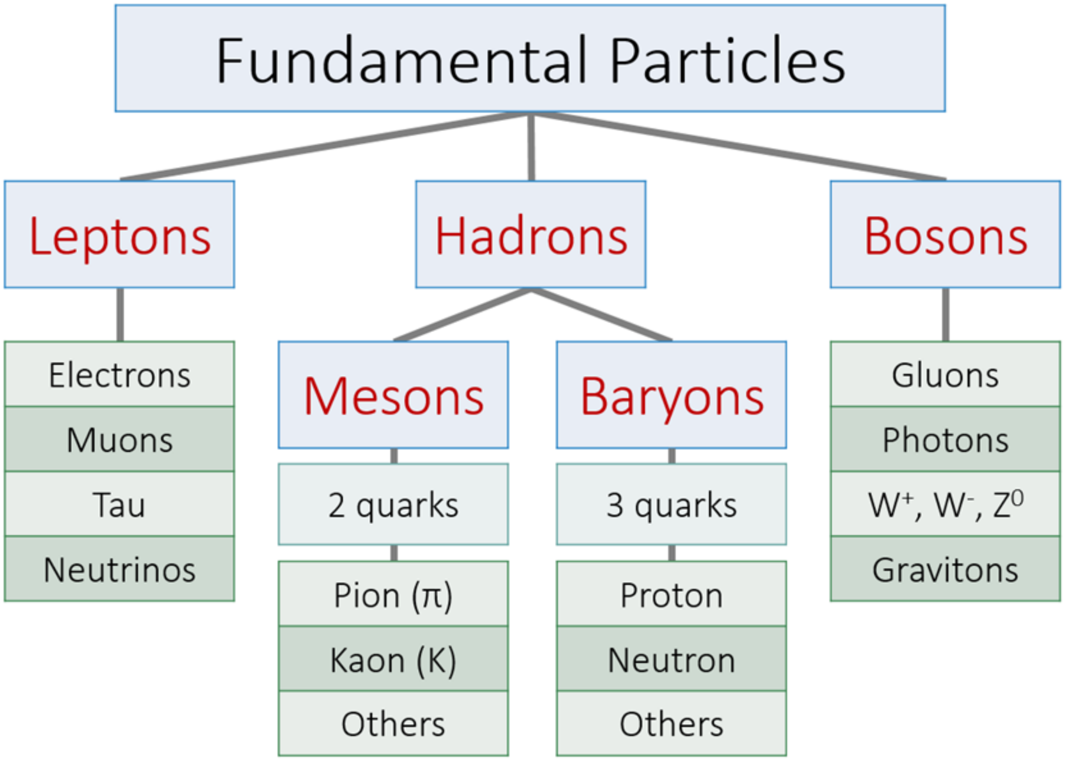
Leptons			
Symbol	Name	Charge	Lepton #
e	Electron	-1	1
μ	Muon	-1	1
τ	Tau	-1	1
ν_e	Electron Neutrino	0	1
ν_μ	Muon Neutrino	0	1
ν_τ	Tau Neutrino	0	1

Anti-Quarks			
Symbol	Name	Charge	Baryon #
$\bar{u}$	Antiup	$-\frac{2}{3}$	$-\frac{1}{3}$
$\bar{d}$	Antidown	$+\frac{1}{3}$	$-\frac{1}{3}$
$\bar{c}$	Anticharm	$-\frac{2}{3}$	$-\frac{1}{3}$
$\bar{s}$	Antistrange	$+\frac{1}{3}$	$-\frac{1}{3}$
$\bar{t}$	Antitop	$-\frac{2}{3}$	$-\frac{1}{3}$
$\bar{b}$	Antibottom	$+\frac{1}{3}$	$-\frac{1}{3}$

Anti-Leptons			
Symbol	Name	Charge	Lepton #
$\bar{e}$	Antielectron (positron)	$+1$	-1
$\bar{\mu}$	Antimuon	$+1$	-1
$\bar{\tau}$	Antitau	$+1$	-1
$\bar{\nu}_e$	Electron Antineutrino	0	-1
$\bar{\nu}_\mu$	Muon Antineutrino	0	-1
$\bar{\nu}_\tau$	Tau Antineutrino	0	-1

Explain the phenomenon of **Quark Confinement**:

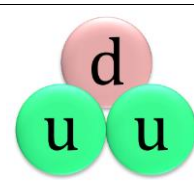
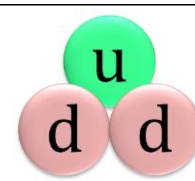
Quarks have never been observed on their own. The amount of energy required to overcome the strong nuclear force holding the quarks together gets converted into mass and forms a new quark pair.



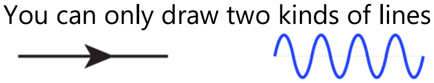
Fundamental Forces

	Strength	Distance
Gravitational	Weakest	Long Range
Weak	Weak	Short Range
Electromagnetic	Strong	Very Long Range
Strong	Strongest	Very Short Range

Particle Configurations

Proton		Neutron	
			
Total Charge	+1	Total Charge	0

Feynman Diagrams

You can only draw two kinds of lines 	You can *only* connect these lines if you have two lines with arrows meeting a single wiggly line	The x-axis represents time and is read from left to right. Everything left of the vertex is the "before" condition.

Beta-Negative Decay	Beta-Positive Decay