|  |  |
| --- | --- |
| **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 |  | Beta-Negative |  | Beta-Positive |
| $$$$ | $$\rightarrow $$ | $$$$ | $$+$$ | $$$$ |  | $$$$ | $$\rightarrow $$ | $$$$ | $$+$$ | $$$$ | $$+$$ | $$\overbar{v}\_{e}$$ |  | $$$$ | $$\rightarrow $$ | $$$$ | $$+$$ | $$$$ | $$+$$ | $$v\_{e}$$ |
| ParentNuclide |  | Daughter Nuclide |  | Alpha Particle |  | ParentNuclide |  | Daughter Nuclide |  | Electron |  | Anti-neutrino |  | ParentNuclide |  | 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 | 107m s-1 | 2.5 × 108 m s-1 | 3.0 × 108 m s-1 |
| Ionizing Effect | Strong | Weak | Very Weak |

|  |  |
| --- | --- |
|  |  |

## Half Life

|  |  |  |  |
| --- | --- | --- | --- |
| # ofHalf-Lives | FractionRemaining | 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 |  | *Data Booklet Equation:* |
| Energy | E | J |  | $$E=mc^{2}$$ |
| Mass | m | kg |  |
| Speed of Light | c | m s-1 |  | $$c=3.00×10^{8} m s^{-1}$$ |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 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

|  |  |
| --- | --- |
| $$\left\{Energy in eV\right\}=\frac{\left\{Energy in J\right\}}{1.60×10^{-19}}$$ | $$\left\{Energy in J\right\}=\left\{Energy in eV\right\}×1.60×10^{-19}$$ |

## 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 = mc2 so this is your binding energy

# Atomic Spectra

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Variable Symbol | Unit |  | *Data Booklet Equations:* |
| Energy | E | J or eV |  | $$E=hf$$ |
| Planck’s Constant | h | J s |  | $$λ=\frac{hc}{E}$$ |
| Frequency | *f* | Hz |  |
| Speed of Light | c | m s-1 |  | $$h=6.63×10^{-34} J s$$ |
| Wavelength | λ | m |  | $$c=3.00×10^{8} m s^{-1}$$ |

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

# Fundamental Particles

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Charge | Quarks | Baryon Number |  | Charge | Leptons |
| $$\frac{2}{3}$$ | $$u$$ | $$c$$ | $$t$$ | $$\frac{1}{3}$$ |  | $$-1$$ | $$e$$ | $$μ$$ | $$τ$$ |
| $$-\frac{1}{3}$$ | $$d$$ | $$s$$ | $$b$$ | $$\frac{1}{3}$$ |  | $$0$$ | $$v\_{e}$$ | $$v\_{μ}$$ | $$v\_{τ}$$ |
| All quarks have a strangeness number of 0 except the strange quark that has a strangeness number of –1 |  | All leptons have a lepton number of 1 and antileptons have a lepton number of –1 |

|  |  |  |
| --- | --- | --- |
| Quarks |  | Leptons |
| Symbol | Name | Charge | Baryon # |  | Symbol | Name | Charge | Lepton # |
| $$u$$ | Up | $$+\frac{2}{3}$$ | $$\frac{1}{3}$$ |  | $$e$$ | Electron | $$-1$$ | $$1$$ |
| $$d$$ | Down | $$-\frac{1}{3}$$ | $$\frac{1}{3}$$ |  | $$μ$$ | Muon | $$-1$$ | $$1$$ |
| $$c$$ | Charm | $$+\frac{2}{3}$$ | $$\frac{1}{3}$$ |  | $$τ$$ | Tau | $$-1$$ | $$1$$ |
| $$s$$ | Strange | $$-\frac{1}{3}$$ | $$\frac{1}{3}$$ |  | $$v\_{e}$$ | Electron Neutrino | $$0$$ | $$1$$ |
| $$t$$ | Top | $$+\frac{2}{3}$$ | $$\frac{1}{3}$$ |  | $$v\_{μ}$$ | Muon Neutrino | $$0$$ | $$1$$ |
| $$b$$ | Bottom | $$-\frac{1}{3}$$ | $$\frac{1}{3}$$ |  | $$v\_{τ}$$ | Tau Neutrino | $$0$$ | $$1$$ |
|  |  |  |  |  |  |  |  |  |
| Anti-Quarks |  | Anti-Leptons |
| Symbol | Name | Charge | Baryon # |  | Symbol | Name | Charge | Lepton # |
| $$\overbar{u}$$ | Antiup | $$-\frac{2}{3}$$ | $$-\frac{1}{3}$$ |  | $$\overbar{e}$$ | Antielectron (positron) | $$+1$$ | $$-1$$ |
| $$\overbar{d}$$ | Antidown | $$+\frac{1}{3}$$ | $$-\frac{1}{3}$$ |  | $$\overbar{μ}$$ | Antimuon | $$+1$$ | $$-1$$ |
| $$\overbar{c}$$ | Anticharm | $$-\frac{2}{3}$$ | $$-\frac{1}{3}$$ |  | $$\overbar{τ}$$ | Antitau | $$+1$$ | $$-1$$ |
| $$\overbar{s}$$ | Antistrange | $$+\frac{1}{3}$$ | $$-\frac{1}{3}$$ |  | $$\overbar{v}\_{e}$$ | Electron Antineutrino | $$0$$ | $$-1$$ |
| $$\overbar{t}$$ | Antitop | $$-\frac{2}{3}$$ | $$-\frac{1}{3}$$ |  | $$\overbar{v}\_{μ}$$ | Muon Antineutrino | $$0$$ | $$-1$$ |
| $$\overbar{b}$$ | Antibottom | $$+\frac{1}{3}$$ | $$-\frac{1}{3}$$ |  | $$\overbar{v}\_{τ}$$ | 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 linespropagator2types | 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 |
|  |  |