

Nuclear Physics

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1 Particles and their properties

1.1 The atomic mass unit

The atomic mass unit (also AMU) is defined as $1.6605390710^{-27} \text{ Kg}$. It has the unit u . It was defined such that the mass of a proton (and a neutron, which has the same mass) is $1u$.

1.2 The electron

The electron is an *elementary particle*, which is a particle that has no building blocks, but is itself among the smallest possible building blocks. The mass of an electron is $0.000548579909 u$, and it has a charge of $1.60217663 \times 10^{-19} C$, which is equal to the elementary charge e .

1.3 The proton

The proton is a *non-elementary* particle, which consists of *quarks* which are elementary particles. It has a mass of $1 u$, and is positively charged by $+1 e$.

1.4 The neutron

The neutron is, as its name implies, neutrally charged, meaning it has a charge of 0, it does however have the same mass as a *proton*, i.e. $1 u$.

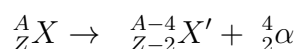
1.5 The positron

The *positron* is something which may also be encountered, and can easily be confused with the proton. It is significant to note that the positron is an *elementary particle*, and is the anti-matter form of the *electron*, so it has the same mass ($0.000548579909 u$), and a charge of $+1 e$.

2 Types of radiation

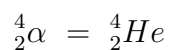
2.1 α -radiation

Alpha Radiation or *Alpha Decay* is when a particle releases another particle, a so-called α -particle as it decays.



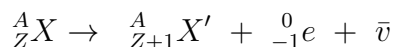
What is an α -particle?

An alpha-particle looks exactly like a *He*-nucleus, that is, two protons & 2 neutrons. Ignoring the amount of electrons, following is true:



2.2 β -radiation

Beta Radiation or *Beta Decay* is when a particle releases an electron and a neutrino as it decays, by a neutron splitting into an electron and a proton.



Sidenote:

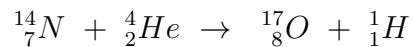
Since elements release electrons as they decay, and gain a proton, the element itself changes to the next element over in the periodic table.

2.3 γ -radiation

3 Nuclear Reactions

3.1 Transmutation

It is possible to transmute one particle into the other by fusion. For example:



3.2 Energy released

In nuclear reactions, there is often a *mass deficit* (Δm), which is then related to a certain energy which that mass converts into, ΔE . Said energy is provided by Albert Einstein's famous equation:

$$E = mc^2$$

Which can be translated into:

$$\Delta E = \Delta mc^2$$

3.3 Binding Energy

It has been found by scientists that there is more energy in an atom than the sum of all its *nucleons*¹, this mass represents the *binding energy*, which is the energy that is contained by the bonds which hold the neutrons particles together in the nucleus. This means that we can conclude following for an element A_ZX :

$$m_X - \Delta m = (Z)m_p + (A - Z)m_n$$

NOTE: Binding energy is almost always the *energy released* (see 3.2)

Example:

${}^{54}_{Fe}$ has a mass of 53.9396082 u, a proton (with accompanying electron) has a mass of 1.0078250319 u, and a neutron has a mass of 1.0086649 u.

Q: Find the binding energy of iron-54

Let E_b be *binding energy*

$$m_{Fe} - \Delta m = 53.9396 \text{ u} = 26(m_p) + (54 - 26)(m_n)$$

$$53.9396082 - \Delta m = 26(1.0078250319) + 28(1.0086649)$$

$$53.9396082 - \Delta m = 52.42873823$$

$$\Delta m = 53.9396082 - 52.42873823$$

$$\Delta m = 1.51086997 \text{ u}$$

$$\therefore (\Delta E = \Delta m \times c^2) \wedge (\Delta E = E_b)$$

$$E_b = \Delta m \times c^2$$

Convert m from *AMU* to *Kg*.

$$m = 1.51086997 \times 1.66053907 \times 10^{-17} = 2.50885861 \times 10^{-17}$$

$$E_b = 2.50885861 \times 10^{-17} (299792458)^2$$

$$E_b = 2.254849673 \text{ J}$$

¹A *nucleon* is either a *proton* or *neutron*, i.e. a component of the nucleus