

# 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  $1.00727647 u$ , and is positively charged by  $+1 e$ .

## 1.4 The neutron

The neutron is, as it's name implies, neutrally charged, meaning it has a charge of 0, it has a mass of  $1.008664915 u$ .

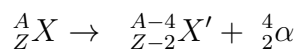
## 1.5 The positron

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 $\alpha$ -radiation

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



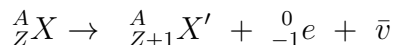
#### What is an $\alpha$ -particle?

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 $\beta$ -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 $\gamma$ -radiation

## 3 Nuclear Reactions

### 3.1 Energy released

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

$$E = mc^2$$

Which can be translated into:

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

### 3.2 Binding Energy

It has been found by scientists that there is more mass in an atom than the sum of all its *nucleons*<sup>1</sup>, 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  ${}_Z^AX$ :

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

NOTE: Binding energy is almost always the *energy released* (see **3.1**)

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

**Example:**

$^{54}\text{Fe}$  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  $Kg$ .

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

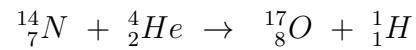
$$E_b = 2.50885861 \times 10^{-17} (299792458)^2$$

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

### 3.3 Reaction Types

#### 3.3.1 Transmutation

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



#### 3.3.2 Fission

A fission reaction is one where an atom is split into other atoms, this is usually done synthetically by bombarding the original atom with neutrons.



#### 3.3.3 Fusion

...to be continued