

# Nuclear Physics

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April 12, 2024

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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 its name implies, neutrally charged, meaning it has a charge of 0, it has a mass of  $1.008664915 u$ .

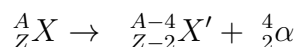
## 1.5 The positron

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.



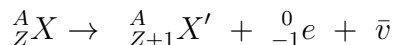
#### What is an $\alpha$ -particle?

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.

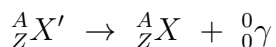


#### Sidenote:

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

*Gamma-radiation* or *gamma decay* is when an excited particle de-excites and releases a photon, i.e. a  $\gamma$ -particle.



## 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  ${}^A_ZX$ :

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

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  $Kg$ .

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

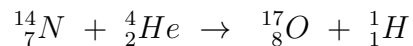
$$E_b = 2.50885861 \times 10^{-17} (299792458)^2$$

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

## 3.3 Reaction Types

### 3.3.1 Transmutation

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



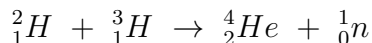
### 3.3.2 Fission

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

A fusion reaction is one where smaller nuclei react and create larger nuclei.



Fusion reactions release very large amounts of energy, but they also require a lot of energy to be started.

#### Sidenote:

Fusion occurs in the sun, it may take place here due to the extreme gravitational pressure exerted upon the core atoms by the rest of the star. The star then dies when the internal pressure from fusion can no longer oppose the gravitation i.e. the core turns into  $Fe$ .

## 4 Half-life

### 4.1 What is half-life?

Half life is *the time it takes for an element to decay into half the element present.*

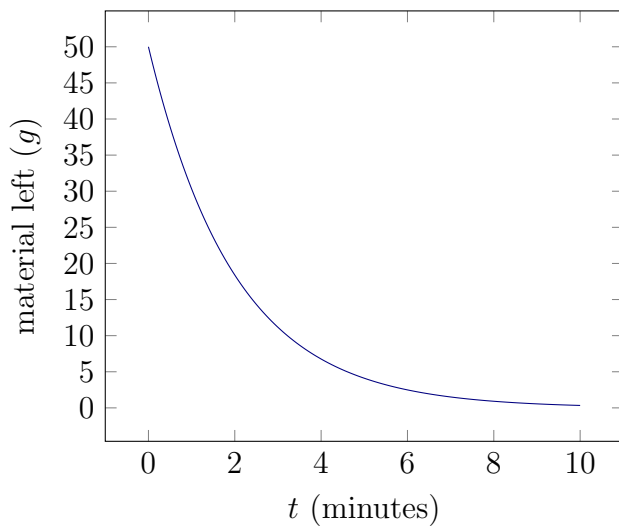
The equation for half-life is as follows:

$$N_0 \left( \frac{1}{2} \right)^{\frac{t}{t_d}}$$

OR

$$e^{-\lambda t}$$

Where  $\lambda = \frac{1}{\tau}$  and  $\tau = \text{half-life}$



### 4.2 Activity

*Activity* is measured in  $\frac{\text{decays}}{\text{second}}$ , or *Becquerelle (Bq)*.