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} 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 α-radiation

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

$$ {}^{A}_{Z}X \rightarrow \; {}^{A-4}_{Z-2}X' + {}^{4}_{2}\alpha $$

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:

$$ {}^{4}_{2}\alpha \; = \; {}^{4}_{2}He $$

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.

$$ {}^{A}_{Z}X \rightarrow \; {}^{A}_{Z+1}X' \; + \; {}^{0}_{-1}e \; + \; \bar{v} $$

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 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 famos 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 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 ${}^{A}_{Z}X$:

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

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

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

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*

$$m_{Fe} - \Delta m \ = \ 53.9396 \ u \ = \ 26(m_p) + (54 - 26)(m_n)$$
$$53.9396082 - \Delta m \ = \ 26(1.0078250319) + 28(1.0086649)$$
$$53.9396082 - \Delta m \ = \ 52.42873823$$
$$\Delta m \ = \ 53.9396082 - 52.42873823$$
$$\Delta m \ = \ 1.51086997 \ u$$

$$\because \left(\Delta E = \Delta m \times c^2\right) \wedge (\Delta E \ = \ E_b)$$
$$E_b \ = \ \Delta m \times c^2$$

Convert m from AMU to Kg.

$$m = 1.51086997 \times 1.66053907 \times 10^{-17} \ = \ 2.50885861 \times 10^{-17}$$
$$E_b \ = \ 2.50885861 \times 10^{-17}(299792458)^2$$
$$E_b \ = \ 2.254849673 \ J$$

3.3 Reaction Types

3.3.1 Transmutation

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

$$ {}^{14}_{7}N \ + \ {}^{4}_{2}He \ \rightarrow \ {}^{17}_{8}O \ + \ {}^{1}_{1}H $$

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.

$$ {}^{A}_{Z}X \ + \ {}^{0}_{1}n \ \rightarrow \ {}^{A_1}_{Z_1}Y \ + \ {}^{A-A_1}_{Z-Z_1-1}X' \ + \ 2\left({}^{0}_{1}n\right) $$

3.3.3 Fusion

...to be continued