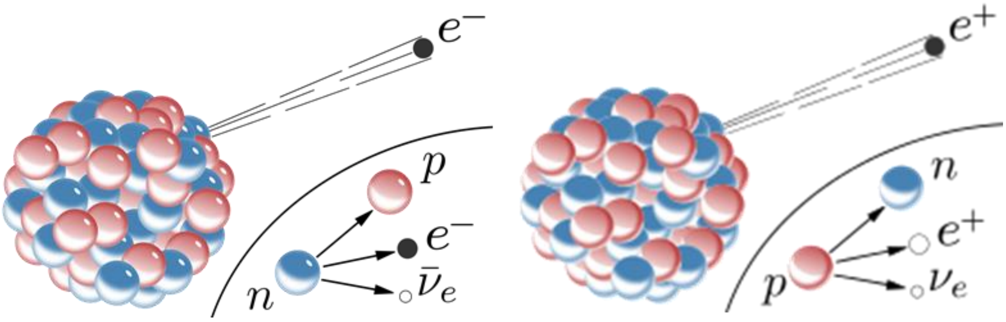
# VISUAL PHYSICS ONLINE

## BETA DECAY




Suppose now that a nucleus exists which has either too many or too few neutrons relative to the number of protons present for stability. Stability can be achieved by the conversion inside the nucleus of a proton into a neutron or a neutron into a proton. In this transmutation:

Charge is conserved $\Rightarrow$

a beta particle ($\beta^+$ or $\beta^-$) is emitted from the nucleus

Energy and momentum are conserved $\Rightarrow$

a particle called a **neutrino** ($\nu_e$ or $\bar{\nu}_e$) must also be emitted from the nucleus. Greek letter nu ($\nu$)

**Reduction of a neutrons & increase in a proton inside nucleus**

**N / Z too large**

$$n \to p^+ + e^- + \bar{\nu}_e \qquad e^- \equiv \beta^-$$

N → N – 1   Z → Z + 1   A → A

$^{A}P_{Z} \to {}^{A}D_{Z+1} + e^{-} + \bar{\nu}_e$

$^{14}C_{6} \to {}^{14}N_{7} + e^{-} + \bar{\nu}_e$

The electron $e^-$ emitted in β decay is not an orbital electron, the electron is created in the nucleus itself. We use the term β particle for the electron to show its origin, nonetheless it is indistinguishable from an orbital electron. The symbol $\bar{\nu}_e$ represents the particle called the **electron antineutrino** (antiparticle of the electron neutrino).

A free neutron can also decay but not a free proton (on average a free neutron at rest lives for ~15 minutes)

$$n \to p^+ + e^- + \bar{\nu}_e$$

**Reduction of a proton & increase in a neutron inside nucleus**

**N / Z too small**

$$p^+ \rightarrow n + e^+ + \nu_e \qquad e^+ \equiv \beta^+$$

$$N \rightarrow N+1 \quad Z \rightarrow Z-1 \quad A \rightarrow A$$

$${}^{A}P_{Z} \rightarrow {}^{A}D_{Z-1} + e^+ + \nu_e$$

$${}^{19}Ne_{10} \rightarrow {}^{19}F_{9} + e^+ + \nu_e$$

To conserve charge, the beta particle emitted is the **positron $e^+$**. The positron is identical to an electron except that its charge is positive and is the antiparticle of the electron. In this transmutation, an electron neutrino $\nu_e$ is also emitted.

## Electron capture

Besides $\beta^-$ and $\beta^+$ emissions, there is a third process called **electron capture** and occurs when a nucleus captures (absorbs) one of its orbiting electrons

$$N \rightarrow N+1 \quad Z \rightarrow Z-1 \quad A \rightarrow A$$

$$^{A}P_{Z} + e^- \rightarrow {}^{A}D_{Z-1} + \nu_e$$

$$^{7}Be_{4} + e^- \rightarrow {}^{7}Li_{3} + \nu_e$$

Beta rays are more penetrating than alpha rays and move at a very high speed.

## THE NEUTRINO

In beta decay, a more stable nucleus is produced and hence in the process energy is liberated as kinetic energy of the products. It was first envisaged that the products of beta decay were the only the daughter nucleus and an electron. Since daughter nucleus has a mass much larger than that of an electron it would recoil only very slowly with small energy whereas the electron would gain most of the energy liberated. Hence, it was expected that the emitted electrons in beta decay would have a fixed kinetic energy in each beta decay transmutation. But it was found experimentally that the kinetic energy of the emitted electron could have any value from zero up to the maximum value. It was if the law of conservation of energy was violated. Careful measurements indicated that linear and angular momentum were also not conserved.

Figure (1) shows the energy spectrum for the decay of bismuth into polonium.

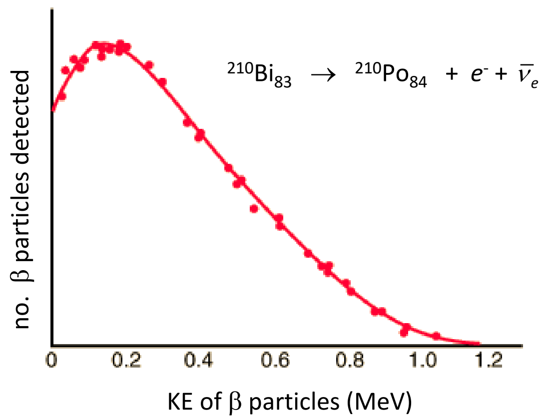



Fig. 1. Beta decay of bismuth-210 into polonium-210 where a neutron changes into a proton.

The need to account for the energy distribution of electrons emitted in beta decay (figure 1) and to satisfy the laws of conservation of energy, linear and angular momentum, Austrian physicist **Wolfgang Pauli** in 1930 proposed that a neutral particle was emitted along with the $\beta$ particle. This particle would have no charge and zero rest mass (hence, travel at the speed of light) but would possess spin, energy and momentum. For each beta emission, the total energy carried away from the decaying nucleus would be shared between the beta particle and the neutral particle emitted with it - it would be expected that the beta particles emitted would have a range of energies depending on the energies of the neutral particles emitted with them.

In 1934, Italian physicist **Enrico Fermi** (1901 - 1954) named Pauli's particle the neutrino ($\nu$), meaning "little neutral one" in Italian, and formulated a theory of $\beta$ decay using this particle. Fermi's theory successfully explained all experimental observations. For instance, the shape of the energy curve shown in figure (1) for Bi-210 can be predicted from the Fermi Theory of beta decay.

Despite several ingenious attempts, the neutrino was not experimentally observed until 1956. In that year, two American Physicists, Cowan and Reines successfully identified the neutrino by detecting the products of a reaction that could only have been initiated by the neutrino.

It was **Fermi** who, in this theory postulated the existence of the fourth force in nature – the **weak nuclear force**. In beta decay, it is the weak nuclear force that plays the crucial role. $\beta$ decay is often referred to as the weak interaction because it is $10^{12}$ times weaker than the strong nuclear force that holds the nucleus together. The neutrino is unique in that it interacts with matter only via the weak nuclear force, which is why it is so hard to detect.

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If you have any feedback, comments, suggestions or corrections please email:

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