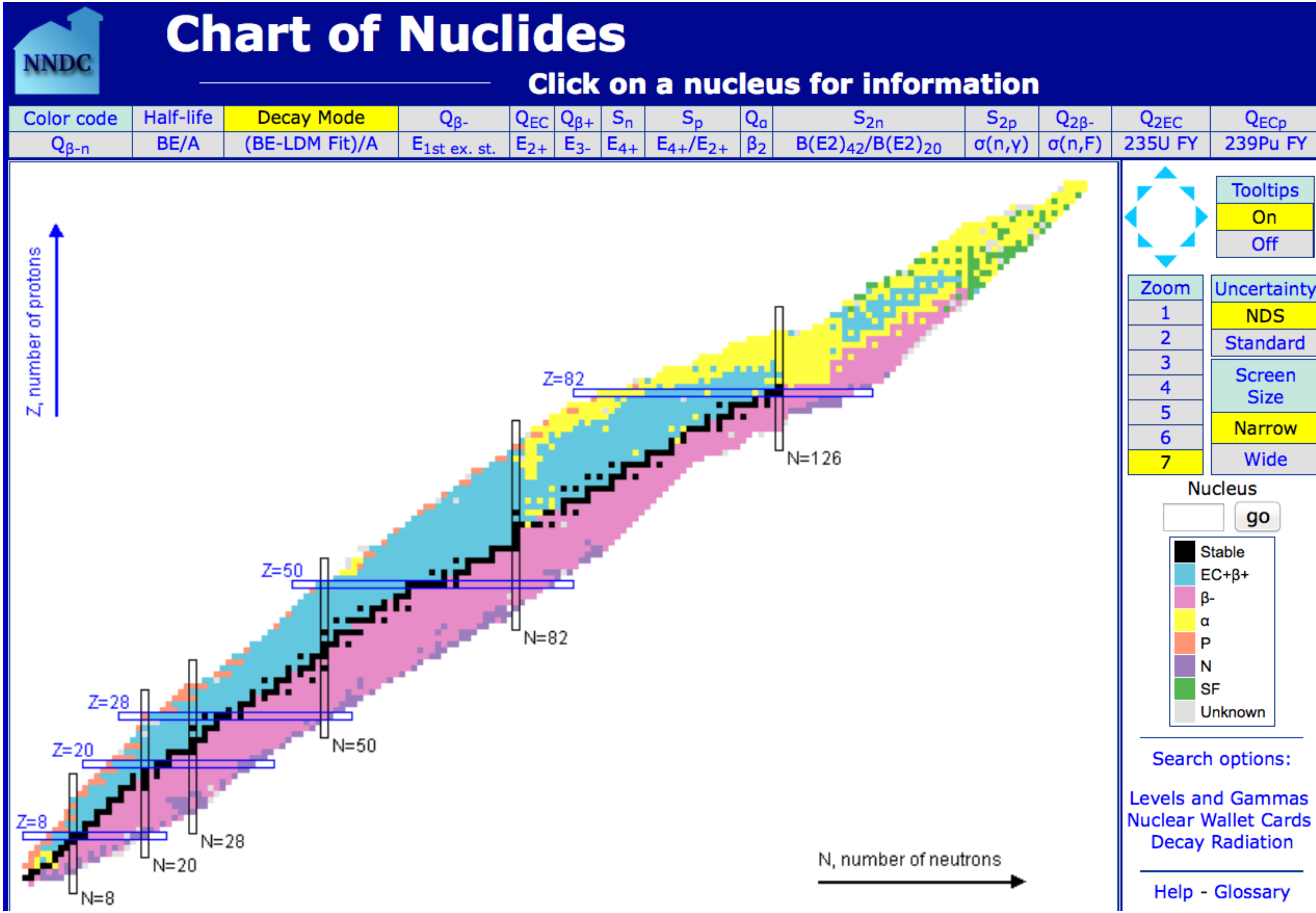
Beta decay

Coupling between nucleons and weak field

One of the puzzles in understanding beta-decay was the emission of particles (electron, positron, neutrino) that are not present in the atomic nucleus.

- 1899 Rutherford discovers beta radiation
- 1900 Becquerel suggests that beta particle is an electron
- 1901 Rutherford and Soddy discover that beta radioactivity involves transmutation
- 1911 Meitner and Hahn show that beta spectrum is continuous
- 1930 Pauli postulates neutrino
- 1931 Fermi names the new particle neutrino
- 1933 quantum theory of radiation developed
- 1934 Fermi theory of beta decay (based on relativistic formalism). The original Fermi's idea was that the weak force responsible for beta decay had essentially zero range.
- 1934 Wick develops theory of electron capture
- 1937 Electron capture observed by Alvarez
- 1956 Neutrino detected by Cowan and Reines
- 1957 Fall of parity conservation. Fermi theory revisited.
- 1961 Glashow, introduces neutral intermediate boson of weak interactions
- 1962 Three types on neutrino (Lederman, Schwartz and Steinberger)
- 1974 Pati-Salam GUT model
- 1984 GUT. Georgi and Glashow
- 1983 W and Z bosons discovered at CERN


NNDC
Chart of Nuclides
Click on a nucleus for information
Color code
Half-life
Decay Mode
Qβ-
QEC
Qβ+
Sn
Sp
Qα
S2n
S2p
Q2β-
Q2EC
QECp
Qβ-n
BE/A
(BE-LDM Fit)/A
E1st ex. st.
E2+
E3-
E4+
E4+/E2+
β2
B(E2)42/B(E2)20
σ(n,γ)
σ(n,F)
235U FY
239Pu FY
Z, number of protons
Z=82
Z=50
Z=28
Z=20
Z=8
N=126
N=82
N=50
N=28
N=20
N=8
N, number of neutrons
Tooltips
On
Off
Zoom
1
2
3
4
5
6
7
Uncertainty
NDS
Standard
Screen Size
Narrow
Wide
Nucleus
go
Stable
EC+β+
β-
α
P
N
SF
Unknown
Search options:
Levels and Gammas
Nuclear Wallet Cards
Decay Radiation
Help - Glossary

Dear radioactive ladies and gentlemen,

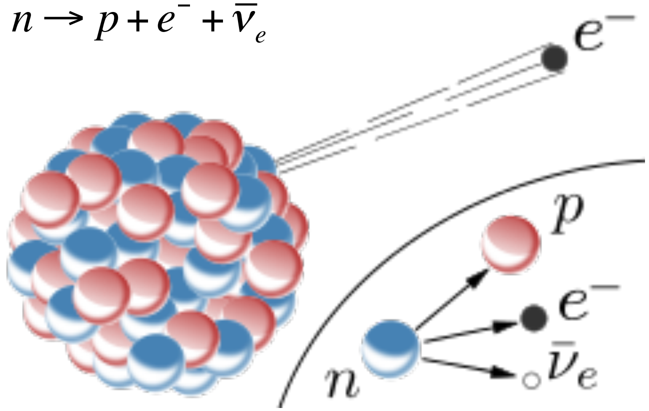
As the bearer of these lines [...] will explain more exactly, considering the 'false' statistics of N-14 and Li-6 nuclei, as well as the continuous β-spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the energy theorem. Namely [there is] the possibility that there could exist in the nuclei electrically neutral particles that I wish to call neutrons, which have spin 1/2 and obey the exclusion principle, and additionally differ from light quanta in that they do not travel with the velocity of light: The mass of the neutron must be of the same order of magnitude as the electron mass and, in any case, not larger than 0.01 proton mass. The continuous β-spectrum would then become understandable by the assumption that in β decay a neutron is emitted together with the electron, in such a way that the sum of the energies of neutron and electron is constant. [...]
But I don't feel secure enough to publish anything about this idea, so I first turn confidently to you, dear radioactives, with a question as to the situation concerning experimental proof of such a neutron, if it has something like about 10 times the penetrating capacity of a γ ray.

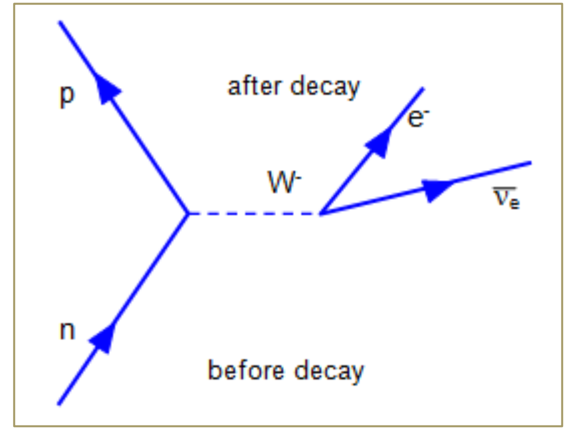
I admit that my remedy may appear to have a small a priori probability because neutrons, if they exist, would probably have long ago been seen. However, only those who wager can win, and the seriousness of the situation of the continuous β-spectrum can be made clear by the saying of my honored predecessor in office, Mr. Debye, [...] "One does best not to think about that at all, like the new taxes." [...] Therefore one should seriously discuss every way of rescue. Thus, dear radioactive people, scrutinize and judge. -
Unfortunately, I cannot personally appear in Tübingen since I am indispensable here in Zürich because of a ball on the night from December 6 to 7.

With many greetings to you, also to Mr. Back, your devoted servant,

W. Pauli

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





The bilinear combinations ("currents") of the fermion fields are Lorentz *four-vectors*, similarly to the electromagnetic current (coupled to vector four-potential) familiar from QED:

$$\mathcal{L}_{\text{int}}^{(Fermi)} = -G\left(\bar{\psi}_p \gamma^\mu \psi_n\right)\left(\bar{\psi}_e \gamma^\mu \psi_\upsilon\right) + h.c.$$

Four-fermion Lagrangian

an annihilation operator for particle
or
a creation operator for antiparticle

Why is it called antineutrino?

Nuclear beta decay is one of the many facets of weak interaction. The basic reactions involving weak interactions in nuclei may be characterized by the decay of a neutron and a (bound) proton:

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

$$p_{bound} \quad \rightarrow \quad n + e^{+} + \nu_e$$

A free proton cannot beta decay since a free neutron is more massive (939.566 MeV) than a free proton (938.272 MeV).

There are many other examples of weak decays:

a) semi-leptonic processes (both hadrons and leptons are involved)

$$\pi^+ \to \begin{cases} \mu^+ + \nu_\mu \\ e^+ + \nu_e \end{cases} \qquad \pi^- \to \begin{cases} \mu^- + \bar{\nu}_\mu \\ e^- + \bar{\nu}_e \end{cases}$$

b) purely-leptonic processes

$$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$$

The coupling constant (Fermi coupling constant): $G_F = 1.16639(2) \times 10^{-11} (\hbar c)^3 \mathrm{MeV}^{-2}$

Force carriers:

$$m_W c^2 = 80.36 \pm 0.12\,\mathrm{GeV}$$
$$m_Z c^2 = 91.187 \pm 0.07\,\mathrm{GeV}$$

interaction range is very short ~10^{-3} fm
(weak interactions can be considered as zero-range in nuclear physics!)