Conservation laws

Double β-disintegration:

$^{100}\text{Mo} \Rightarrow {}^{100}\text{Ru} + 2e^- + 2\bar{\nu}$

This process does not break the concervation laws, but has a half-life of 10^{20} years. It has been predicted for long, but was first shown by Elliot and Moe in 1987. Later on, several examples are found (see chart of nuclides)

Delayed neutron emission

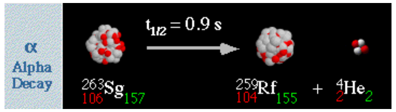
$^{137}\text{I} \Rightarrow {}^{136}\text{Xe} + e^- + \bar{\nu} + n + (\gamma)$

Exists several places, far from stability

Conservation laws

- α-disintegration is a two-particlel process, f.exs.:

  $^{263}\text{Sg} \Rightarrow {}^{259}\text{Rf} + {}^{4}\text{He}$
- Fulfills all conservation laws



Gives line spectrum

Nuclear forces:

The nuclear forces are mediated through the exchange of virtual mesons (Yukawa 1936)

Simple estimation:

$\Delta E \Delta t = \hbar c/R$

$\Delta t = R/c = 1.5 \bullet 10^{-15}$ m$/3.0 \bullet 10^{8}$ (ms^{-1})

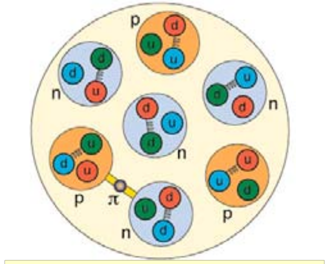
$M = \Delta E = \hbar c/R$

$$= \frac{1.05 \bullet 10^{-34}\ (\text{Js}) \bullet 3.0 \bullet 10^{8}\ (\text{ms-1})}{1.5 \bullet 10^{-15}\ (\text{m})}$$

$= 2.1 \bullet 10^{-11}$J = 131 MeV

Correct value: π^{o} = 135 MeV
$\pi^{\pm}$ = 140 MeV

Quark structure on nucleons



- The nucleons have internal structure
  - Composed by quarks held together by exchange of virtual gluons
  - Nucleons are separate entities also in a normal nucleus
  - Under extreme conditions it is attempted to observe a continuous state, quark/gluon plasma

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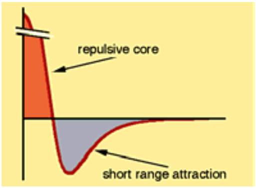


- Important properties of the nuclear forces
  - Short range, rapid to zero
  - Strongly attractive at short distance
  - Repulsive at very short distance
  - Spin dependent
  - Roughly similar for proton and neutron (except for the coulomb repulsion)
  - Strong (~MeV/nucleon)
  - Not accurately known, but good models

Quarks

There are in total 6 quarks and 6 antiquarks, i.e. twelve.

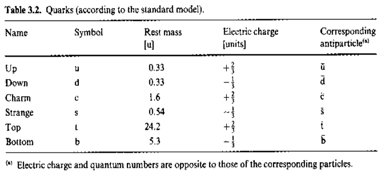


Table 3.2. Quarks (according to the standard model).

Name	Symbol	Rest mass [u]	Electric charge [units]	Corresponding antiparticle[a]
Up	u	0.33	$+\frac{2}{3}$	$\bar{u}$
Down	d	0.33	$-\frac{1}{3}$	$\bar{d}$
Charm	c	1.6	$+\frac{2}{3}$	$\bar{c}$
Strange	s	0.54	$-\frac{1}{3}$	$\bar{s}$
Top	t	24.2	$+\frac{2}{3}$	$\bar{t}$
Bottom	b	5.3	$-\frac{1}{3}$	$\bar{b}$

[a] Electric charge and quantum numbers are opposite to those of the corresponding particles.

These quarks are the basis for the standard model of the elementary particles

Hadrons are built up by quarks

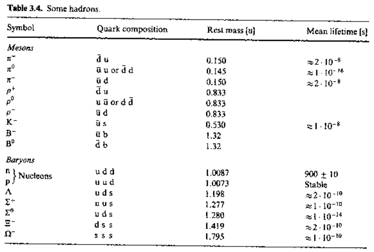


Table 3.4. Some hadrons.

Symbol	Quark composition	Rest mass [u]	Mean lifetime [s]
Mesons			
π^-	$\bar{d}\,u$	0.150	$\approx 2\cdot 10^{-8}$
π^0	$\bar{u}\,u$ or $\bar{d}\,d$	0.145	$\approx 1\cdot 10^{-16}$
π^-	$\bar{u}\,d$	0.150	$\approx 2\cdot 10^{-8}$
ρ^+	$\bar{d}\,u$	0.833	
ρ^0	$u\,\bar{u}$ or $d\,\bar{d}$	0.833	
ρ^-	$\bar{u}\,d$	0.833	
K^-	$\bar{u}\,s$	0.530	$\approx 1\cdot 10^{-8}$
B^-	$\bar{u}\,b$	1.32	
B^0	$\bar{d}\,b$	1.32	
Baryons			
n } Nucleons	u d d	1.0087	900 ± 10
p	u u d	1.0073	Stable
Λ	u d s	1.198	$\approx 2\cdot 10^{-10}$
Σ^+	u u s	1.277	$\approx 1\cdot 10^{-10}$
Σ^0	u d s	1.280	$\approx 1\cdot 10^{-14}$
Ξ^-	d s s	1.419	$\approx 2\cdot 10^{-10}$
Ω^-	s s s	1.795	$\approx 1\cdot 10^{-10}$

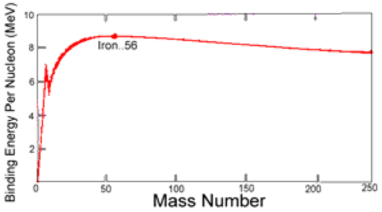
The quark structure of some important hadrons and mesons

Leptons

Particle		Mass(u)	$T_{1/2}$
Electron	e^-	0.000546	stab.
Electron neutrino	ν_e	disputed	stab.
Muon	μ^-	0.1144	2 µs
Muon neutrino	ν_μ	disputed	stab
Heavy lepton	τ^-	1.915	3 ps
Tau neutrino	ν_τ	<0.18	?

It is now shown that there are 3 and only 3 classes of neutrinos.

Binding energy



Binding energy pr. nucleon as function of the mass number

Rises rapidly at the light masses,
Maximum at ^{56}Fe
Declines slowly towards higher masses.

A simple description of the nucleus; The liquid drop model

- Liquid drop model:
  - Describes:Masses,i.e. binding energies
  - Does not describe levels
  - A simple physical modell
  - Early version: von Weiszäcker, Bethe (1932)
  - Shell correktions, Myers, Swiatecki (50s)
  - Deformation, Möller, Nix (1970 - 1990)

Nobel prize 1967

Hans Albrecht Bethe
1906 -

Bethe-Weisäcker-formula

$BE = E_v + E_a + E_c + E_s + E_{\delta\pm}$

$E_v = aA$

$E_a = bA^{2/3}$

$E_s = d\,\frac{(N-Z)^2}{A} = d\,\frac{(A-2Z)^2}{A}$

$E_c = c\,\frac{Z(Z-1)}{A^{1/3}}$

$E_{\delta\pm} = e\delta_\pm\, A^{-1}$

- Odd-even parameter
- $\delta_\pm$ =
  - 1 for even-even nuclei
  - 0 for even-odd nuclei
  - 0 for odd-even nuclei
  - -1 for odd-odd nuclei

Bethe-Weisäcker-formula.

If we assume that A = constant we get the following general expression:

$BE = a_1Z^2 + a_2Z + a_3 + a_4\delta_\pm$

This implies that along an isobaric chain, the mass will be given as a parabola, and will vary with the odd-even parameter.

A consequence of this is that one gets one parabola for odd masses and two for even masses.

Masses in isobaric chains