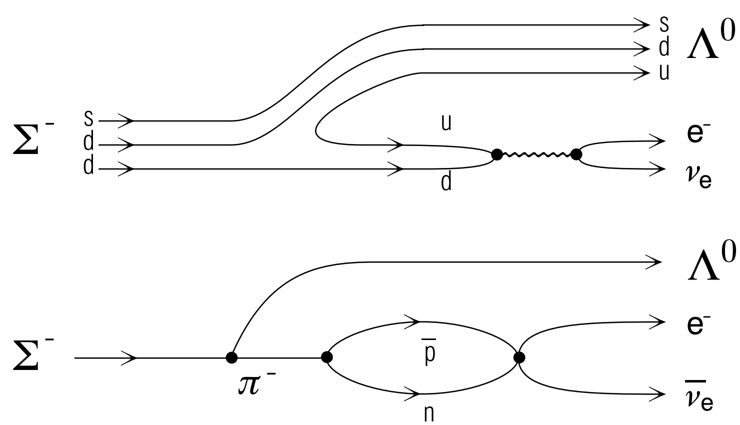
MISN-0-274

PARTICLES STABLE AGAINST THE STRONG FORCE



Project PHYSNET Physics Bldg. Michigan State University East Lansing, MI

PARTICLES STABLE AGAINST THE STRONG FORCE

by

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Title: **Particles Stable against the Strong Force**

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Input Skills:

1. Express the mass, spin (angular momentum) and charge of a particle in units of MeV, $\hbar$, and e respectively (MISN-0-273).
2. Give the typical decay times of particles which decay via the strong, weak, and electromagnetic interactions (MISN-0-273).

Output Skills (Knowledge):

K1. Define: hadron, lepton, fermion, boson.

K2. List the names of the elementary particles, and write their symbols and the symbols for their antiparticles.

K3. For each strong-stable particle, state the name of the family and the family group to which it belongs.

K4. List the names of the absolutely stable particles.

K5. List the names of the zero mass particles and give the orders of magnitude of the particle masses in each family.

K6. Give the spin of each particle.

Output Skills (Problem Solving):

S1. Given the typical decay mode for a particle, write the corresponding decay mode for its antiparticle.

External Resources (Required):

1. K.W. Ford, *Classical and Modern Physics*, Vols. 1 and 3, John Wiley and Sons (l972).

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1. Introduction

This module deals with some of the basic "facts" about those particles that are stable under strong interactions (strong interactions cannot cause them to spontaneously decay). Elsewhere we will discuss theories built on those facts.

2. Readings

1. Ford, Vol. 1, Sect. 3.1 - 3.5, and Vol. 3, Sect. 27.2 - 27.4, on reserve for you in the Physics-Astronomy Library. Ask for them as "Ford, Volume 1," and "Ford, Volume 3."

3. Classification

3a. Explanation of the Table. Refer to the table at the end of this module. It lists important properties of all particles which do not decay via the strong interaction. There are, of course, many more particles than these but their lifetimes are extremely short ($\approx 10^{-22}$ sec), and the strong interaction brings about their decay.

In the table there is a quantity called *mass*. In high energy physics the quantity called "mass" is really mass energy: to obtain mass itself, divide by the square of the speed of light ($1\,\text{MeV} = 10^6\,\text{eV}$ and $1\,\text{eV} = 1.60 \times 10^{-19}\,\text{J}$). *Time* indicates the particle's lifetime. The second column in the table shows the symbol used to represent the particle.

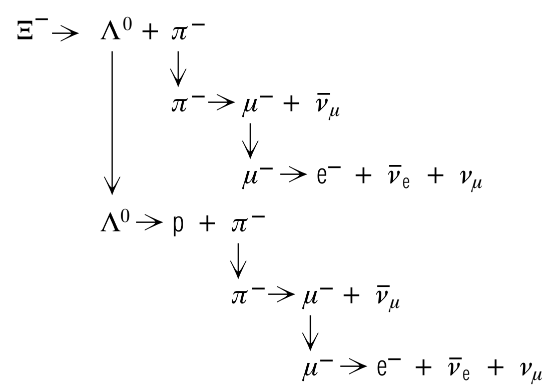
3b. Families of Particles. The particles can be classified according to family: electron, muon, meson, and baryon. The photon does not have any brethren (although some have been postulated). There are also names for groups of families. Members of the electron, muon, and tau families are collectively called *leptons*. Mesons and baryons are collectively called *hadrons*.

3c. Antiparticles. An antiparticle is associated with each particle. The antiparticle is usually denoted by the same symbol as the particle but with a bar over it. For some particles (the photon and some mesons), the antiparticle is indistinguishable from the same or another particle: $\bar{\gamma} = \gamma$, $\bar{\pi}^- = \pi^+$, $\bar{\pi}^+ = \pi^-$, $\bar{\pi}^0 = \pi^0$, and $\bar{\eta} = \eta$. The distinction between particle and antiparticle is to some extent an arbitrary one, but we shall see that in the case of baryons, electrons, and muons, the classification leads to a conservation law. For the mesons, no such conservation law exists and it is immaterial whether π^- is listed as a separate particle or as the antiparticle associated with π^+.

3d. Particle/Antiparticle Properties. A particle and its associated antiparticle have exactly the same mass, spin angular momentum, and lifetime. They have the same magnitude, but opposite sign, for charge, and the typical decay mode of the antiparticle can be found from that of the particle by putting a bar over all un-barred symbols and removing the bar over barred symbols.

3e. Baryons. Baryons are particles whose final decay products include one, or some other odd number, of protons and antiprotons.

For example:



The final products of a Ξ decay are a proton, 2 electrons, and 6 neutrinos. The key to the classification of a Ξ as a baryon is the appearance of a proton among the final products.

3f. Hadrons. Mesons and baryons, collectively called hadrons, participate in the strong interaction. That is, these particles interact with each other via the strong interaction, although the hadrons listed do not *decay* via the strong interaction. No other particles, except the hadrons, participate in the strong interaction and this interaction may be taken as the definition of a hadron. (Mesons are then hadrons which are not baryons; they are hadrons which do not decay to protons or antiprotons.)

3g. Absolutely Stable Particles. The photon, electron, electron's neutrino, muon's neutrino, the tau's neutrino, and the proton are absolutely stable. They do not decay under any interaction, as far as is known. Lower limits on the lifetimes of these particles are suspected to exceed the age of the universe.

4. Particle Decay

4a. Lifetimes and Interactions. Most of the unstable particles on the list decay on the order of 10^{-10} to 10^{-8} sec after they are produced. These are characteristic times for decay via the weak interaction. Muon decay is also via the weak interaction but it is slowed by a factor which has to do with the muon's mass. The π^0 and ηparticles, which decay via the electromagnetic interaction, have much shorter lifetimes. (At fist glance, the lack of charge would seem to preclude an electromagnetic decay for these particles. We shall see later that the electromagnetic decay is preceded by a strong decay to positive and negative charged particles. These charged particles then decay to the final products we see.)

4b. Lifetime to Interaction Strength. The strength of an interaction can be inferred from typical decay times. For strong decays, the particle lifetime is on the order of 10^{-23} sec, for electromagnetic decays the particle lifetime is on the order of 10^{-21} sec, and for weak decays the particle lifetime is on the order of 10^{-10} sec. The ratio of strengths is roughly

$$\text{strong: em: weak } = 1 : \ 10^{-2} : \ 10^{-13} \, .$$

For particular decays, other factors (such as mass) may alter the lifetime from the typical value. Stronger interactions can mask weaker interactions. Foe example, if a particle can decay via more than one route it will be observed to go via the faster route more often than via the slower route. In fact, the slower route may be too slow to be seen.

4c. Spin and Fermions/Bosons. Each particle has associated with it a specific amount of intrinsic angular momentum, called *spin angular momentum* or, usually, just *spin*.[1] *Spin* is always either an integer or a half integer times $\hbar$. Particles with integer spin (including zero) are said to obey Bose-Einstein statistics and are called *bosons*. Particles with half odd integer spin are said to obey Fermi-Dirac statistics and are called *fermions*. The significance of this classification will be discussed later.

Acknowledgments

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[1] For a discussion of spin, see "Spin" (MISN-0-244). For quantized angular momenta in general and a discussion of $\hbar$, see "Quantized Angular Momentum" (MISN-0-251).

A. Table of Particle Properties

These are particles stable against decay via the strong interaction.[2]

Name		Mass (MeV)	Spin ($\hbar$)	Charge ($\|Q_e\|$)	Time (sec)	Dominant Decay
Photons						
Photon	γ	0	1	0	∞	
e Family						
Electron	e	.511	1/2	-1	∞	
e's neutrino	ν_e	0	1/2	0	∞	
μ Family						
Muon	μ	105.66	1/2	-1	10^{-6}	$\mu^- \rightarrow \mathrm{e}^- + \bar{\nu}_\mathrm{e} + \nu_\mu$
μ's neutrino	ν_μ	0	1/2	0	∞	
τ Family						
Tau	τ	1784	1/2	-1	10^{-13}	$\tau^- \rightarrow \mathrm{e}^- + \bar{\nu}_\mathrm{e} + \nu_\tau$ (not dominant)
τ's neutrino	ν_τ	0	1/2	0	∞	
Mesons						
Pion	π^+	139.57	0	1	10^{-8}	$\pi^+ \rightarrow \mu^+ + \nu_\mu$
	π^-	139.57	0	-1	10^{-8}	$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$
	π^0	134.97	0	0	10^{-16}	$\pi^0 \rightarrow \gamma + \gamma$
Kaon	K^+	493.6	0	1	10^{-8}	$\mathrm{K}^+ \rightarrow \pi^+ + \pi^0$
	K^-	493.6	0	-1	10^{-8}	$\mathrm{K}^- \rightarrow \pi^- + \pi^0$
	K^0	497.7	0	0	10^{-10}	$\mathrm{K}^0 \rightarrow \pi^+ + \pi^-$
Eta	η	549	0	0	10^{-19}	$\eta \rightarrow \gamma + \gamma$
Baryons						
Nucleon	p	938.27	1/2	1	∞	
	n	939.57	1/2	0	10^3	$\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^- + \bar{\nu}_\mathrm{e}$
Lambda	Λ^0	1115.6	1/2	0	10^{-10}	$\Lambda^0 \rightarrow \mathrm{p} + \pi^-$
Sigma	Σ^+	1189.4	1/2	1	10^{-10}	$\Sigma^+ \rightarrow \mathrm{n} + \pi^+$
	Σ^-	1197.4	1/2	-1	10^{-10}	$\Sigma^- \rightarrow \mathrm{n} + \pi^-$
	Σ^0	1192.6	1/2	0	10^{-20}	$\Sigma^0 \rightarrow \Lambda^0 + \gamma$
Xi	Ξ^-	1321.3	1/2	-1	10^{-10}	$\Xi^- \rightarrow \Lambda^0 + \pi^-$
	Ξ^0	1314.9	1/2	0	10^{-10}	$\Xi^0 \rightarrow \Lambda^0 + \pi^0$
Omega	Ω^-	1672.4	3/2	-1	10^{-10}	$\Omega^- \rightarrow \Xi^0 + \pi^-$

[2]Lifetimes have been rounded to the nearest power of ten. All values are from "Review of Particle Properties," R. Gatto et al., *Physics Letters B*, **204**, 1988.