

Elementary Particles

The Standard Model of fundamental particles and interactions is an attempt to explain and predict particle interactions within the nucleus of an atom and during nuclear decay processes. This model describes the atom as being made up of combinations of smaller, more fundamental particles called leptons and quarks.

LEPTONS

Leptons are fundamental particles that are believed to have no internal structure. In other words, they cannot be further broken down. Leptons are completely unaffected by the strong nuclear force and interact by way of the weak nuclear force. They are grouped into three pairs, each containing one charged particle and one neutrino. Neutrinos have an extremely small rest mass (possibly zero), no charge and travel at speeds close to that of light.

There is also evidence that each lepton has an associated antiparticle. In fact, all subatomic particles have an associated antiparticle of the same mass and opposite charge.

Particle	Symbol	Antiparticle	Mass (MeV/c ²)	Charge	Spin
Electron	e^-	e^+	0.511	-1	$\frac{1}{2}$
Electron neutrino	ν_e	$\bar{\nu}_e$	~ 0	0	$\frac{1}{2}$
Muon	μ^-	μ^+	105.7	-1	$\frac{1}{2}$
Muon neutrino	ν_μ	$\bar{\nu}_\mu$	~ 0	0	$\frac{1}{2}$
Tauon	τ^-	τ^+	1784	-1	$\frac{1}{2}$
Tauon neutrino	ν_τ	$\bar{\nu}_\tau$	~ 0	0	$\frac{1}{2}$

QUARKS

All other matter is made up of quarks. Quarks were first theorized in the 1960's and were confirmed experimentally in linear accelerators around the world starting in the 1970's. The last quark to be discovered was the top quark in 1995. The most massive of all quarks, it had been predicted for a long time before finally being observed.

Name	Symbol	Mass (GeV/c ²)	Charge
Up	u	0.004	$\frac{2}{3}$
Down	d	0.008	$-\frac{1}{3}$
Strange	s	0.15	$-\frac{1}{3}$
Charm	c	1.5	$\frac{2}{3}$
Bottom	b	4.7	$-\frac{1}{3}$
Top	t	176	$\frac{2}{3}$

For every quark, there is also an antiquark that has the same mass but opposite charge.

HADRONS

Hadrons are subatomic particles that are made up of quarks. There are two kinds of hadrons: baryons and mesons.

Baryons are made up of three quarks in varying combinations. There are approximately 120 types of baryons. Examples of baryons are protons and neutrons. A proton is made up of two *up* (*u*) quarks and one *down* (*d*) quark. The proton's total charge is then:

$$\left(\frac{2}{3}e\right) + \left(\frac{2}{3}e\right) + \left(-\frac{1}{3}e\right) = e$$

It can be seen that the mass of a proton ($938.3 \text{ MeV}/c^2$) is much greater than the sum of the masses of its three quark components ($4 \text{ MeV}/c^2 + 4 \text{ MeV}/c^2 + 8 \text{ MeV}/c^2 = 16 \text{ MeV}/c^2$). This difference suggests that the proton has a mass defect of $922.3 \text{ MeV}/c^2$, which accounts for the strong nuclear force experienced within the nucleus of atoms.

Mesons are made up of one quark and one antiquark. There are approximately 140 types of mesons. An example of a meson is the pion. The quark combination for a positive pion (π^+) is one *up* quark and one *down antiquark*. The pion's total charge is then:

$$\left(\frac{2}{3}e\right) + \left(\frac{1}{3}e\right) = e$$

BOSONS

In terms of field theory, a mass or charge creates a field that causes a force to be exerted on any other mass or charged placed in that field. In terms of the Standard Model, forces are considered to be the interactions between fundamental particles exchanging force carrying particles. Masses and charges are continuously emitting and absorbing force carrying particles called ***bosons***. Each of the four fundamental forces has its own specific boson.

Force	Relative Strength	Field Particle	Symbol	Decay lifetime (s)
Gravitational	10^{-39}	Graviton	?	?
Electromagnetic	10^{-2}	Photon	γ	$10^{-16} - 10^{-18}$
Strong nuclear	1	Gluon	g	$10^{-20} - 10^{-23}$
Weak nuclear	10^{-15}	W, Z	W^-, Z^0	$10^{-8} - 10^{-10}$

Each subatomic particle is surrounded by a cloud of swarming bosons that determine its interactions with other subatomic particles. For example, electrons are surrounded by virtual photons that form the electromagnetic force.