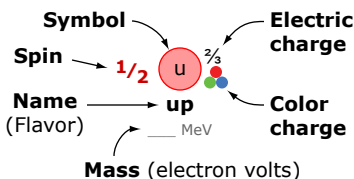


# Particles

Everything is made of particles.



**Antiparticles.** Each particle has an antiparticle with the same mass and spin, but opposite charge.  
 A particle with no charge may be its own antiparticle.

**Mixtures.** Some elementary particles are mixtures (linear superpositions) of other elementary particles.

**Hypothetical.** Postulated particles that many physicists expect will be discovered.

**Spin.** Spin is a quantum property of particles. Bosons have integer spin. Fermions have half-integer spin. A particle with non-zero spin has left- or right-handed chirality.

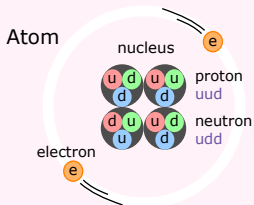
**Electric Charge.** Each particle has positive, negative, or zero electric charge.

**Color Charge.** A quark has one of three color charges called red, green, or blue. An anti-quark has an anti-color. A gluon has a color and an anti-color.

## Elementary Particles

This shows all the elementary particles in the standard model (SM) of particle physics plus the hypothetical graviton.

**Fermions** half-integer spin  $1/2, 3/2$   
**Matter** is made of fermions.  
 Fermions obey the exclusion principle.

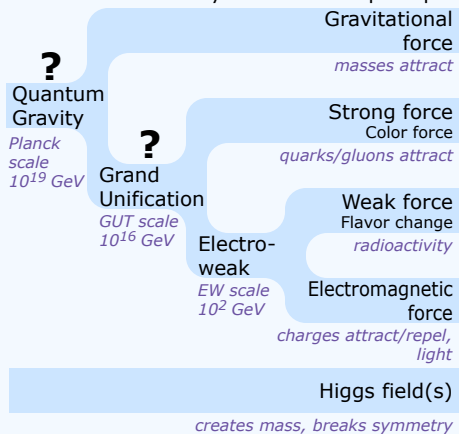


## Fermions

Spin	Quarks	Leptons
$1/2$	<b>up</b> (u) 1.7-3.1 MeV	<b>electron</b> ( $e^-$ ) 511 keV
	<b>charm</b> (c) 1.1-1.4 GeV	<b>muon</b> ( $\mu^-$ ) 106 MeV
	<b>down</b> (d) 4.1-5.7 MeV	<b>electron neutrino</b> ( $\nu_e$ ) <1 eV?
	<b>strange</b> (s) 80-130 MeV	<b>muon neutrino</b> ( $\nu_\mu$ ) <1 eV?
	<b>top</b> (t) 171-175 GeV	<b>tau</b> ( $\tau^-$ ) 1.8 GeV
	<b>bottom</b> (b) 4.1-4.4 GeV	<b>tau neutrino</b> ( $\nu_\tau$ ) <1 eV?

## Bosons

**Forces** are carried by gauge bosons.  
 Bosons do not obey the exclusion principle.



Unified forces split by symmetry breaking.

## Bosons

Spin	Force Carriers	Scalar Bosons
2	<b>graviton</b> (G) massless Gravitational force	
1	<b>gluon</b> (g) massless Strong force	
1	<b>Weak Isospin</b> ( $W_i$ ) W, Z massless Weak force	
1	<b>Weak Hypercharge</b> (B) B, photon massless Electromagnetic force	
0	<b>Higgs</b> ( $H^0, H^\pm$ ) massive Higgs field	<b>Higgs</b> (H) 124-127 GeV Electroweak symmetry breaking

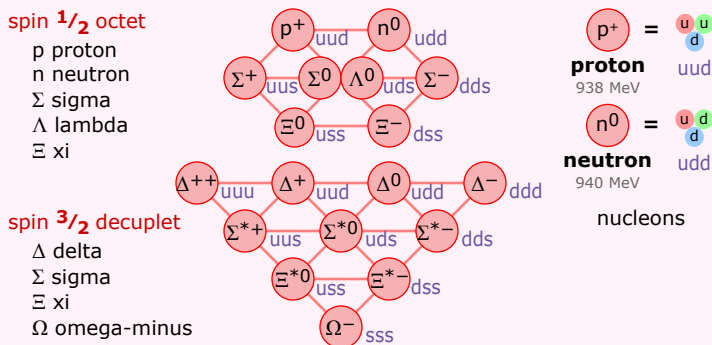
**Other elementary particles** may yet be discovered. **Supersymmetry (SUSY)** proposes that every elementary particle has a superpartner. **String theory** proposes that all elementary particles are actually tiny vibrating strings.

## Composite Particles — Hadrons

Composite particles are composed of two or more elementary particles. This shows some of the hundreds of known composite particles.

### Composite Fermions — Baryons

Baryons are fermions composed of three quarks. This shows only the baryons made of u, d, and s quarks.



### Composite Bosons — Mesons

Mesons are bosons composed of a quark and an antiquark. This shows only the mesons made of u, d, and s quarks.

