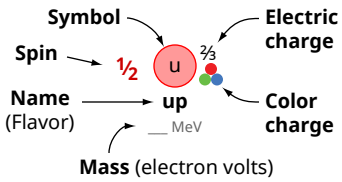
Particles

Everything is made of particles.



A particle is a wave in a quantum field.

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.

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.

Elementary Particles

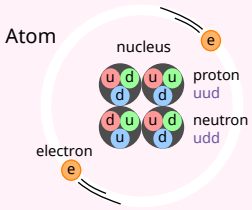
This shows all the elementary particles in the standard model (SM) of particle physics plus some hypothetical particles.

Supersymmetry (SUSY) theory proposes a partner boson for each fermion and a partner fermion for each boson.

Fermions

half-integer spin ½ ³⁄₂

Matter is made of fermions.
Fermions obey the exclusion principle.



Standard Fermions

spin		generation I	generation II	generation III
Quarks	½	u ⅔ up 1.7–3.1 MeV	c ⅔ charm 1.1–1.4 GeV	t ⅔ top 171–175 GeV
	½	d -⅓ down 4.1-5.7 MeV	s -⅓ strange 80–130 MeV	b -⅓ bottom 4.1–4.4 GeV
Leptons	½	e^- electron 511 keV	μ^- muon 106 MeV	τ^- tau 1.8 GeV
	½	ν_e electron neutrino <1 eV?	ν_μ muon neutrino <1 eV?	ν_τ tau neutrino <1 eV?

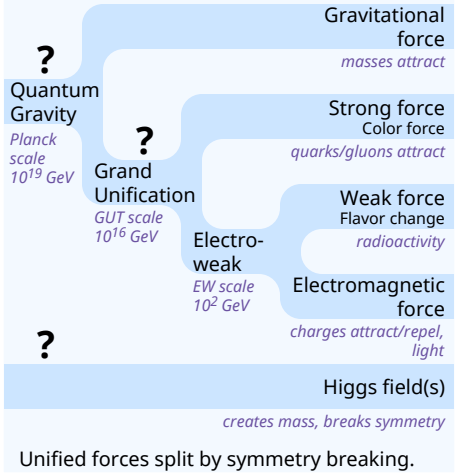
? Superpartner Bosons — Sfermions

spin		generation I	generation II	generation III
Squarks	0	$\tilde{u}$ ⅔ sup	$\tilde{c}$ ⅔ scharm	$\tilde{t}$ ⅔ stop
	0	$\tilde{d}$ -⅓ sdown	$\tilde{s}$ -⅓ sstrange	$\tilde{b}$ -⅓ sbottom
Sleptons	0	$\tilde{e}^-$ selectron	$\tilde{\mu}^-$ smuon	$\tilde{\tau}^-$ stau
	0	$\tilde{\nu}_e$ electron sneutrino	$\tilde{\nu}_\mu$ muon sneutrino	$\tilde{\nu}_\tau$ tau sneutrino

Bosons

integer spin 0 1 2

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



Unified forces split by symmetry breaking.

Standard Bosons

	spin			
Gauge Bosons (Force Carriers)	2		G graviton massless	Gravitational force
	1		g gluon massless	Strong force
	1	Weak Isospin	W_i W massless	$W^\pm$ W 80 GeV, Z 91 GeV
	1	Weak Hyper-charge	B B massless	γ photon massless — Electromagnetic force
Scalar Bosons	0		H^0 $H^\pm$ Higgs massless	H Higgs 124-127 GeV — Higgs field

Electroweak symmetry breaking

? Superpartner Fermions

spin				
Gauginos	³⁄₂		$\tilde{G}$ gravitino	
	½		$\tilde{g}$ gluino	
	½	$\tilde{W}_i$ wino	$\tilde{W}^\pm$ wino, $\tilde{Z}$ zino	mixtures: $\tilde{\chi}^0_i$, $\tilde{\chi}^\pm_i$ neutralino, chargino
	½	$\tilde{B}$ bino	$\tilde{\gamma}$ photino	
	½	$\tilde{H}^0$ $\tilde{H}^\pm$ Higgsino	$\tilde{\chi}^0$ $\tilde{\chi}^\pm$ neutralino, chargino	

Electroweak symmetry breaking

? **Other elementary particles** may yet be discovered.
Dark matter may be elementary particles not yet discovered.

? **Light neutral scalar bosons** are postulated (for example, axions).
String theory proposes that all elementary particles are tiny vibrating strings.

Composite Particles — Hadrons

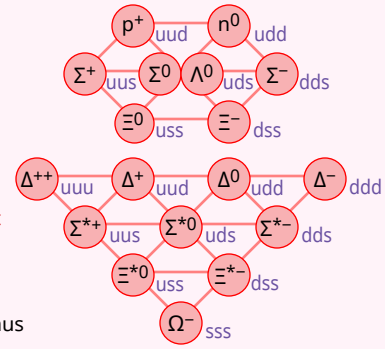
Composite particles are composed of two or more elementary particles. This shows some of the hundreds of known composite particles.

Composite Fermions — Baryons

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

spin ½ octet
- p proton
- n neutron
- Σ sigma
- Λ lambda
- Ξ xi

spin ³⁄₂ decuplet
- Δ delta
- Σ sigma
- Ξ xi
- Ω omega-minus



p^+ = u u d — **proton** 938 MeV — uud

n^0 = u d d — **neutron** 940 MeV — udd

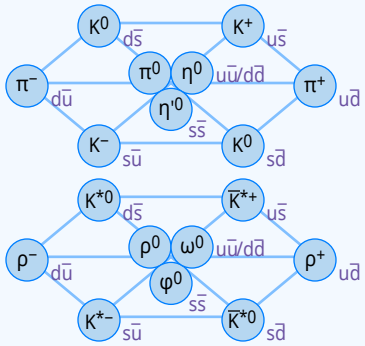
nucleons

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.

spin **0** nonet
- π pion
- η eta
- K kaon

spin **1** nonet
- ρ rho
- ω omega
- φ phi
- K kaon



π^0 = u ū — **pion** 135 MeV — uū/dd̄ mixture

Pions carry the nuclear force between nucleons.