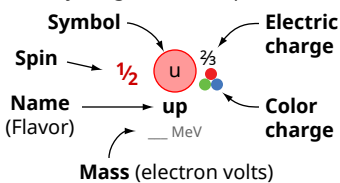


Particles

Everything is made of particles.



A particle is a wave in a quantum field.

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.

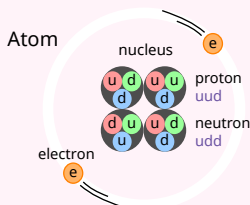
Hypothetical. Postulated particles that many physicists expect will be discovered.

- 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 some hypothetical particles.

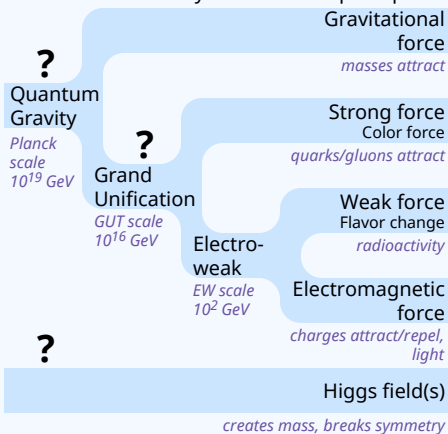
Fermions half-integer spin $\frac{1}{2}$ $\frac{3}{2}$
Matter is made of fermions. Fermions obey the exclusion principle.



Fermions

generation	I	II	III
Quarks	up u 1.7-3.1 MeV spin $\frac{1}{2}$	charm c 1.1-1.4 GeV spin $\frac{1}{2}$	top t 171-175 GeV spin $\frac{1}{2}$
	down d 4.1-5.7 MeV spin $\frac{1}{2}$	strange s 80-130 MeV spin $\frac{1}{2}$	bottom b 4.1-4.4 GeV spin $\frac{1}{2}$
	electron e ⁻ 511 keV spin $\frac{1}{2}$	muon μ ⁻ 106 MeV spin $\frac{1}{2}$	tau τ ⁻ 1.8 GeV spin $\frac{1}{2}$
Leptons	electron neutrino ν _e <1 eV? spin $\frac{1}{2}$	muon neutrino ν _μ <1 eV? spin $\frac{1}{2}$	tau neutrino ν _τ <1 eV? spin $\frac{1}{2}$

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.

Bosons

spin	Force Carriers	Force
2	graviton (G) massless	Gravitational force
1	gluon (g) massless	Strong force
1	W_i (W [±] , Z) massless	Weak force
1	B (B, γ) massless	Electromagnetic force
0	Higgs (H ⁰ , H [±] , H) massless	Higgs field

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).
? **Supersymmetry (SUSY)** proposes that every elementary particle has a superpartner.
? **String theory** proposes that all elementary particles are tiny vibrating strings.

Composite Particles — Hadrons

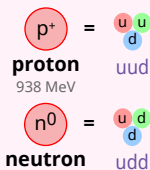
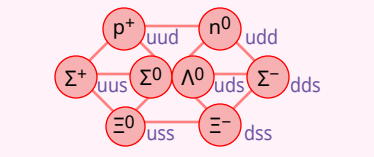
Composite particles are composed of two or more elementary particles. This shows some of the hundreds of known composite particles.

Composite Fermions — Baryons

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

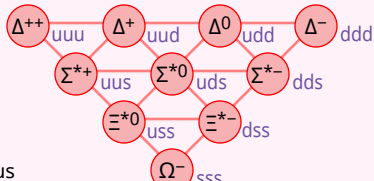
spin $\frac{1}{2}$ octet

- p proton
- n neutron
- Σ sigma
- Λ lambda
- Ξ xi



spin $\frac{3}{2}$ decuplet

- Δ delta
- Σ sigma
- Ξ xi
- Ω omega-minus

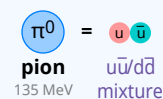
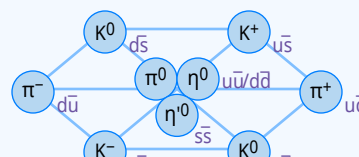


Composite Bosons — Mesons

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



Pions carry the nuclear force between nucleons.

spin 1 nonet

- ρ rho
- ω omega
- φ phi
- K kaon

