Standard Model of
FUNDAMENTAL PARTICLES AND INTERACTIONS

The "Standard Model" is a term used to describe the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2,...

Leptons spin = 1/2

Flavor	Mass GeV/c²	Electric charge
ν_e electron neutrino	$< 2 \times 10^{-6}$	0
e electron	5.1×10^{-4}	−1
ν_μ muon neutrino	$< 3 \times 10^{-4}$	0
μ muon	0.106	−1
ν_τ tau neutrino	$< 4 \times 10^{-3}$	0
τ tau	1.784	−1

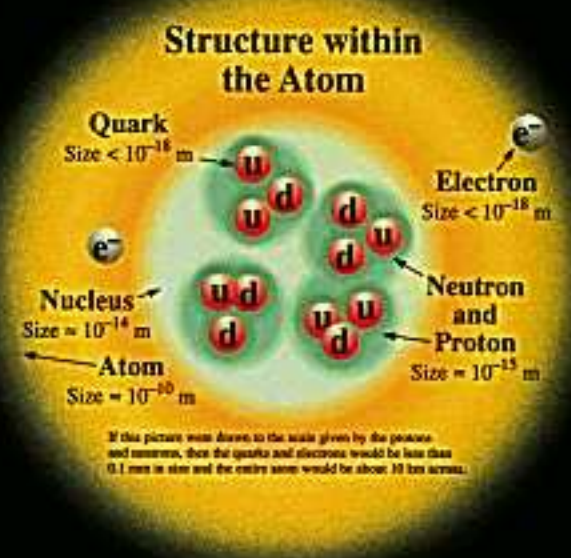
Quarks spin = 1/2

Flavor	Approx. Mass GeV/c²	Electric charge
u up	4×10^{-3}	2/3
d down	7×10^{-3}	−1/3
c charm	1.5	2/3
s strange	0.15	−1/3
t top (not yet observed)	> 89	2/3
b bottom	4.7	−1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58 \times 10^{-22}$ MeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electron volt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in eV/c² (remember $E = mc^2$), where 1 keV = 10^3 eV = 1.60×10^{-16} joule. The mass of the proton is 0.938 GeV/c² = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2...

Unified Electroweak spin = 1	Mass GeV/c²	Electric charge
γ photon	0	0
W^-	80.6	−1
W^+	80.6	+1
Z^0	91.16	0

Strong or color spin = 1	Mass GeV/c²	Electric charge
g gluon	0	0

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically charged particles interact by exchanging photons, so strong-interacting color-charged particles exchange gluons. Leptons, photons and W and Z bosons have no color charge and hence no strong interactions. One cannot isolate quarks and gluons; they are **confined** into color-neutral hadrons. This confinement (binding) results from multiple exchanges of gluons among the color-charged objects.

Confinement

As color-charged particles (quarks and gluons) are separated, the color force between them approaches a constant value and the energy in the color force field increases. This energy eventually is converted into additional quark-antiquark pairs (see the figures below). The objects that finally emerge are color-neutral combinations called **hadrons** (mesons and baryons).

Residual Strong Interaction

The strong binding of the color-neutral protons and neutrons in atomic nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction which binds electrically neutral atoms to form molecules. It can be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak	Electromagnetic	Strong	
		(Electroweak)		Fundamental	Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength for two u quarks at: 10^{-18} m (relative to electromagnetic)	10^{-41}	0.8	1	25	Not applicable to quarks
Strength for two u quarks at: 3×10^{-17} m (relative to electromagnetic)	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Sample Fermionic Hadrons

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

Sample Bosonic Hadrons

Mesons $q\bar{q}$

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
D^+	D+	$c\bar{d}$	+1	1.869	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol. Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ and η_c) are, but not K^0 or Λ^0, are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are not exact and have no accompanied scale. Fermion (dashed arcs) represent the cloud of gluons or the gluon field, and lines the quark paths, and black lines the paths of leptons.

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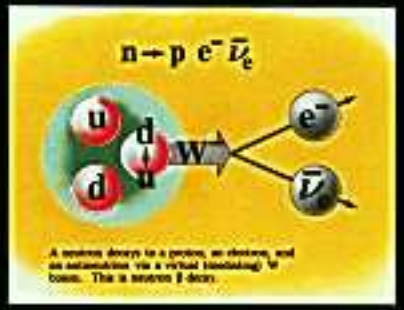

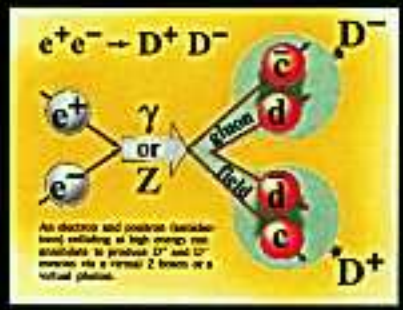

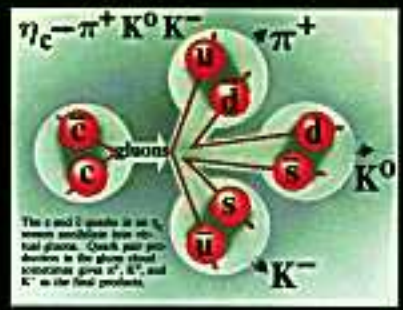

Contemporary Physics Education Project

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Production of this chart was supported by funding from:

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