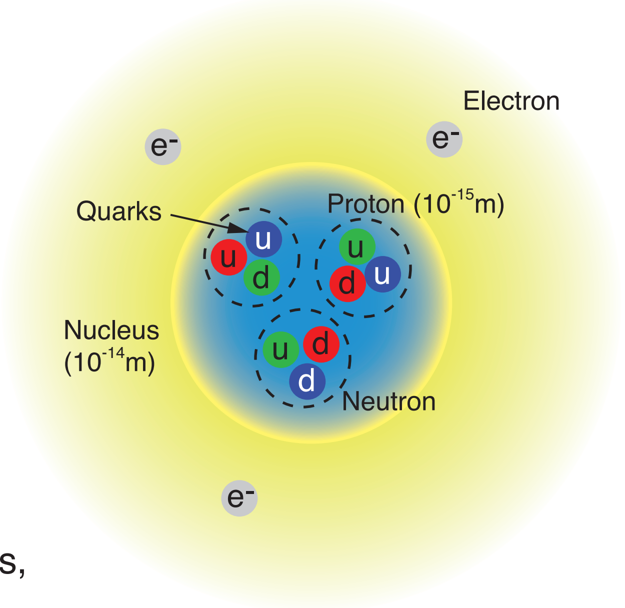
Quantum Chromodynamics (QCD)

The Standard Model of physics quantitatively describes most phenomena from the smallest known scales of matter comprised of quarks and gluons (10^{-18} meters) to the large scale structure of the present-day universe (10^{28} cm). The Model combines the forces of the strong interactions, electromagnetism, and the weak interactions, with the weakest force gravity treated separately.

The underlying theory of the strong interactions is Quantum Chromodynamics (QCD), with as its fundamental constituents the quarks and gluons. Unlike any other known electrically charged object, quarks carry fractional electric charge (±1/3 or 2/3). There are six different quark “flavors”: charge 2/3 up, charm and top quarks, and charge -1/3 down, strange and bottom quarks. The up and down quark flavors are by far the most common in nature.

Structure of an Atom



In addition to electric charge, quarks carry a “color” charge, which plays a role in QCD analogous to electric charge in electromagnetism. Quarks can have one of three colors: red, green, or blue. Their anti-matter partners - anti-quarks - carry the referring anti-colors.

Just as photons are transmitting the electromagnetic force between charges, gluons mediate the strong forces among colored quarks. However, in a key twist, because the gluons carry a mix of color and anti-color charge they can also interact among each other.

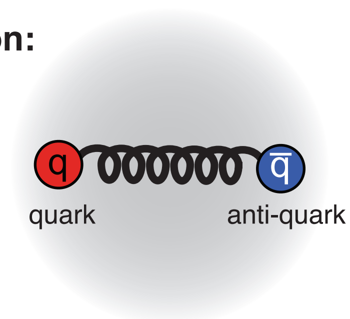
Quarks (spin = ½)			
Flavor	Approx. Mass (MeV/c^2)*	Electric Charge	Color Charge
u (up)	3	2/3	red *or* green *or* blue
d (down)	6	-1/3	
s (strange)	100	-1/3	
c (charm)	1270	2/3	
b (bottom)	4200	-1/3	
t (top)	172000	2/3	

* 1 MeV/c^2 = 1.782×10^{-27} g

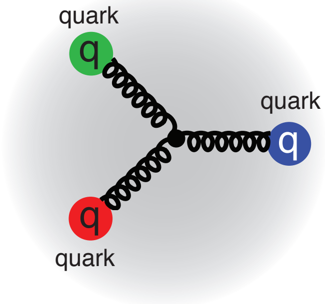
Gluon (spin = 1)		
Mass	Electric Charge	Color Charge
0	0	8 different color “states” each carrying a different combination of color and anti-color

How Quarks Form Hadrons and Gluons Hold Them Together

Meson:



Baryon:



Neither fractional electric charges nor color charges have ever been experimentally measured. Scientists explain this by stating that colored quarks and gluons cannot be probed in isolation, and are confined in color neutral objects, called hadrons. Hadrons are classified into mesons (quark + anti-quark) and baryons (three quark states such as the proton and the neutron). They comprise all visible matter in the universe from a very early stage (< 10^{-6} seconds after the Big Bang) to the present day (13.8 billion years).

The picture of hadrons as made up of quarks grew out of successful attempts in the so-called Static Quark Model to classify the large number of mesons and baryons (approximately 300 by now) measured in strong interaction experiments.

Despite its original text book success, the Static Quark Model does not explain many experimental results. In short, it missed the gluons and their dynamics which we know now are responsible for the mass of the visible universe.