Coupling Constants:

The vertex coupling constant for electromagnetic processes is related to the so-called "fine structure constant,"

$$\alpha = \frac{e^2}{\hbar c} \simeq \frac{1}{137}.$$

We can similarly define α_s, which is about 1, and α_w, which is about 10^{-7}.

HOWEVER:

It is found experimentally that all coupling constants are in fact functions of the process 4-momentum Q!

In the electromagnetic case, it is found that "vacuum polarization" due to virtual pairs screens the "bare charge." This screening gets less and less as we probe shorter and shorter distances, or use larger and larger Q^2, so the result is that the coupling constant α *increases as* Q^2 *increases!* That is, the effective charge we observe becomes larger and larger for larger and larger Q^2.

Something very similar happens for the weak interaction, with the screening of "weak charge" getting less and less, and the overall effect is much stronger than what is seen for electromagnetic processes.

Remarkably, the very opposite thing happens for the strong interaction. While virtual quark-antiquark pairs screen color at large distances, virtual gluon pairs enhance it, and the gluon effect is the most important. The result is that α_s grows WEAKER with increasing Q^2. This leads to the famous phenomenon of **asymptotic freedom**, in which at very short distances strongly interacting particles *behave like free particles!*

So to summarize $\alpha_s(Q^2)$ is a decreasing function, while the other two coupling constants are increasing functions, of Q^2. There is an unattainably high energy (10^{14} GeV) at which all three constants seem to be roughly the same number. This suggests that there exists a unified description of all three interactions in some theory beyond the current "Standard Model."

Note that we have no quantum description of gravity. Several approaches have been put forward over the years, but there is no experimental evidence that one or another approach is the right one.

Magnetic Moment:

Classically, $U = -\vec{\mu} \cdot \vec{B}$.

In quantum physics we define:

$$\vec{\mu} = g \frac{e}{2mc} \vec{S}.$$

The quantity $\mu_0 = (e\hbar)/(2mc)$ is called a magneton (cgs Gaussian units).

The "Bohr Magneton" has $m = m_e$.

The "nuclear magneton" has $m = m_p$.

The Bohr Magneton is thus about 5.8 $\times 10^{-15}$ MeV/G and the nuclear magneton is about 3.15 $\times 10^{-18}$ MeV/G. Remember a Gauss (G) is 10^{-4} Tesla and in Gaussian cgs units $e^2 = 1.44$ MeV-fm, while $\hbar c = 197$ MeV-fm.

Relativistic quantum mechanics predicts the value of g for pointlike charged spin-1/2 particles. The measured value is not precisely what RQM predicts unless the EM field is also treated as a quantum field, using Feynman techniques or Quantum Field Theory.

FUNDAMENTAL POINT PARTICLES:

• ***Vector or Gauge Bosons:*** 12 uncharged particles responsible for strong, electromagnetic and weak forces.

• ***Higgs Boson:*** uncharged scalar particle; the Higgs field gives point particles their mass.

• ***Leptons:*** 3 charged members of the electron family, 3 uncharged members of the neutrino family.

• ***Quarks:*** 6 particles carring color, and fractional charge; cannot be observed as individual free particles.

COMPOSITE SYSTEMS, THE HADRONS:

• ***Baryons:*** particles consisting of three "valence" quarks, plus unlimited numbers of virtual particles, gluons and quark-antiquark pairs. All baryons have infinite binding energy, and the proton is the only stable baryon. There are presumably an infinite number of baryons. Essentially all the baryon mass is due to the virtual particles.

• ***Mesons:*** particles consisting of a "valence" quark-antiquark pair, plus unlimited numbers of virtual gluons and quark-antiquark bairs. All mesons have infinite binding energy, and there are no stable mesons. There are presumably an infinite number of mesons. Essentially all the meson mass is due to the virtual particles.

Scattering and Reactions, Ch. 6:

Nomenclature: • Elastic Scattering— projectile comes out with same energy it went in with; target system still in its ground state. $a + A \to a + A$.

• Inelastic Scattering— projectile comes out with less energy than it came in with; target system is put into an excited state. $a + A \to a + A^*$.

• Deep Inelastic Scattering— projectile scatters from a pointlike constituent *inside* the target particle.

• Reaction— the particles outgoing are different from the particles incoming, $a + b \to c + d$.

With scattering you can explore:

Mass distributions of hadrons and nuclei.

Charge distributions of hadrons and nuclei.

Magnetic moments of point particles.

Magnetic moments of baryons and nuclei.

Charges of pointlike constituents of baryons.

Spins of pointlike constituents of baryons (using a polarized beam).

Momenta of pointlike constituents of baryons.

Remember from the introductory course in physics that you took, a transition from one state to another in QM satisfies

$$N(t) = N(0)\exp(-t/\tau),\ \ \tau = t_{1/2}/(\ln 2).$$

For an energy eigenstate

$$< t|\psi >= \psi(0)\exp(-iEt/\hbar).$$

Let's define $\Gamma = \hbar/\tau$. Let $E \to E_0 - i\Gamma/2$. Then we get an exponential decay:

$$< t|\psi >= \psi(0)\exp(-iE_0 t/\hbar)\exp(-\Gamma t/(2\hbar)).$$

To understand what this means, take a Fourier transform:

$$< E|\psi >= \int_0^\infty < E|t >< t|\psi > dt.$$

The result is

$$< E|\psi >= \frac{\psi(0)}{2\pi}\frac{i\hbar}{(\hbar\omega - E_0) + i\Gamma/2},\ \ \omega = E/\hbar.$$

The corresponding probability is proportional to

$< \psi|E >< E|\psi >$ which is proportional to

$$\frac{|\psi(0)|^2}{(E - E_0)^2 + (\Gamma/2)^2}.$$

When normalized it looks like

$$\frac{(\Gamma/2)^2}{(E - E_0)^2 + (\Gamma/2)^2}.$$

The total cross section is this expression times appopriate phase-space factors.