Extension to Spins

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HEP

Nov 2, 2004

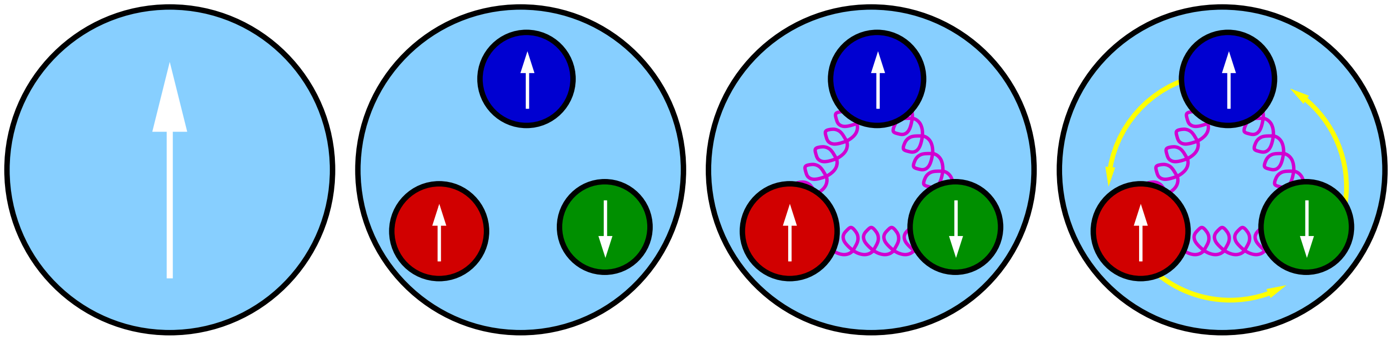
Spin of the Nucleon

- One of the basic property of the nucleon
- Fermion with spin 1/2
- Well established fact
- Internally, composite particle
  - quarks: spin 1/2 (fermions)
  - gluons: spin 1 (bosons)
  - orbital angular momentum: L
- In addition to three *valence* quarks
  - Almost infinite number of soft gluons
  - Sea quarks ($q\overline{q}$ pairs)
- Puzzle: *how* do all these constituents combine to give final spin of 1/2?

Case of Charge

- Again, one of the basic property
- Either 0 (neutron) or +1 (proton)
- Again, very well established (H_2 is neutral)
- Internally, composite particle
  - quarks: charge +2/3 (u) or -1/3 (d)
  - gluons: charge 0
  - orbital angular momentum: no contribution
- In addition to three *valence* quarks
  - Almost infinite number of soft gluons (charge 0)
  - Sea quarks ($q\overline{q}$ pair - net charge 0)
- Not a puzzle: total charge of the nucleon *do* come from valence quarks.

Conceptual Decomposition



$$\frac{1}{2} = \Delta q + \Delta g + L$$

- Δq - Contribution from the quarks (polarized electron scattering)
- Δg - Contribution from the gluons (polarized proton scattering)
- L - Contribution from the orbital angular momentum (Generalized Parton Distribution)

Quark Spins

In analogy of the parton distribution functions $q(x)$, consider $q_\uparrow(x)$ and $q_\downarrow(x)$

$q(x)$	:	probability to find a quark (any spin direction) with momentum fract
$q_\uparrow(x)$	:	probability to find a quark with *up*-spin with momentum fraction x i
$q_\downarrow(x)$	:	probability to find a quark with *down*-spin with momentum fraction

From the definitions,

$$
\begin{aligned}
q(x) &= q_\uparrow(x) + q_\downarrow(x) \\
\Delta q(x) &\equiv q_\uparrow(x) - q_\downarrow(x) \\
q_\uparrow(x) &= \frac{1}{2}\left[q(x) + \Delta q(x)\right] \\
q_\downarrow(x) &= \frac{1}{2}\left[q(x) - \Delta q(x)\right]
\end{aligned}
$$

Enough to measure $q(x)$ and $\Delta q(x)$

Polarized Nucleon?

- $\Delta q(x) = 0$ in *un*polarized nucleons (of course!)
- Aren't nucleons *always* polarized? (spin 1/2)
- What is *polarization*?
  - True: each individual nucleons *are* polarized
  - either *up* or *down* with respect to polarization axis
  - Consider a large number of nucleons.
  - Statistically, *equal* number of nucleons in *up* and *down* polarization
  - Polarization is defined as

$$P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$

– For example, if 30% of the nucleons are *definitely* in *up* state and the rest 70% are equally ditributed among *up* and *down* states,

$$\begin{aligned} N_\uparrow &= 0.3N + 0.35N = 0.65N \\ N_\downarrow &= 0.35N \\ P &= \frac{0.65N - 0.35N}{0.65N + 0.35N} = 30\% \end{aligned}$$