Introduction to Elementary Particle Physics

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Elementary Particle Physics

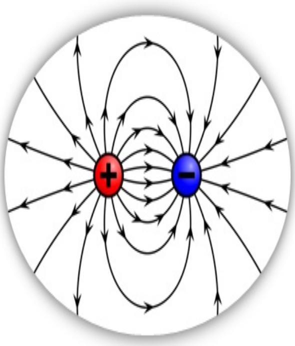
Lecture 3: Bahman 27, 1397

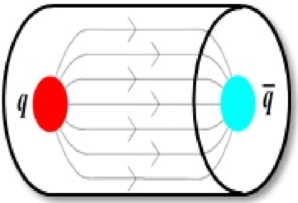
1397-98-II

Strong Force

Strong Force vs. Electromagnetic Force

- Flux line (QED) vs. Flux tube (QCD)

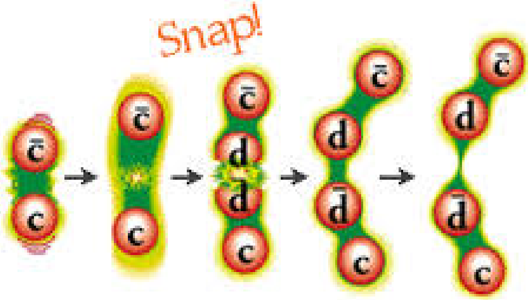




  - Static quark potential: $V(r) = \sigma r + \frac{\alpha(r)}{r}$

Strong Force vs. Electromagnetic Force

- Confinement



Color charges in the singlet state are not free
(at low energy)

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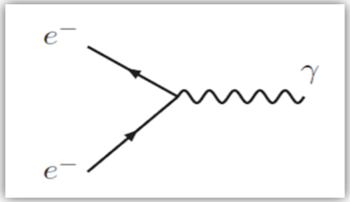
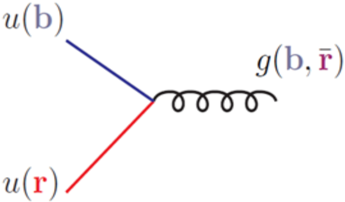
Electromagnetic Force



Strong Force



$\rightarrow$ **Conservation laws at each VERTEX $\leftrightarrow$ Symmetries**

- Conservation of electric charge
- Conservation of energy and momentum

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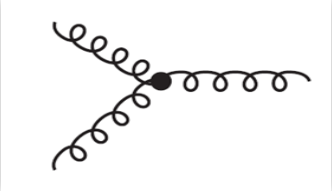
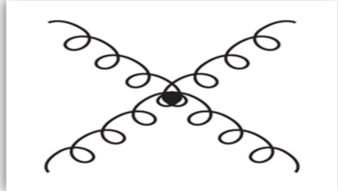
Strong Force

Gluon-Gluon self-interaction





$\rightarrow$ **Conservation laws $\leftrightarrow$ Symmetries**

- Conservation of electric charge
- Conservation of energy and momentum
- **In addition:** Conservation of **color** charge

Weak Force

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The **weak** force controls:

- **Radioactive decay** is the process by which an unstable atomic nucleus loses energy by emitting radiation, such as an α (He nucleus), or β (β^{+} or β^{-}), or a γ-ray and other particles (electrons, neutrinos etc).
- **Nuclear fission** is a process in nuclear physics in which the nucleus of an atom splits into two or more smaller nuclei as fission products, and usually some by-products.
- **Nuclear fusion** is a reaction in which two or more atomic nuclei are combined to form one or more different atomic nuclei and subatomic particles (neutrons or protons). The difference in mass between the reactants and products is manifested as either the **release** or **absorption** of energy.

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The weak force controls the nuclear fusion reactions by which the Sun and other stars shine

- The density and the temperature are so high that nuclei can overcome electrical repulsion force and **release energy** by **fusing** together
- **Neutrinos** are created by this **weak interaction**. They carry energy out of the star and cool it $\Longrightarrow$ The temperature of the star is controlled in this way
- In other reactions photons are also emitted (**Photon Emission**). Photons emitted by the Sun warm Earth surface and help to sustain life

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Example 1: Two protons **fuse** to form a diproton

$$ {}^1_1H + {}^1_1H \rightarrow {}^2_2He + \gamma $$

In a β^+ **decay** a diproton decays to Deuterium

$$ {}^2_2He \rightarrow {}^2_1D + e^+ + \nu_e $$

The overall formula:

$$ \boxed{{}^1_1H + {}^1_1H \rightarrow {}^2_1D + e^+ + \nu_e + 0.42\,\text{MeV}} $$

Example 2: Other nuclear reactions with γ production

$$ {}^2_1D + {}^1_1H \rightarrow {}^3_2He + \gamma + 5.49\,\text{MeV} $$

$$ \ldots $$

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$$^{A=Z+N}_{Z}X$$

- Atomic Number Z: The number of protons in the nucleus of an atom
- N is the number of neutrons in the nucleus of an atom
- Mass number A: $A = Z + N$

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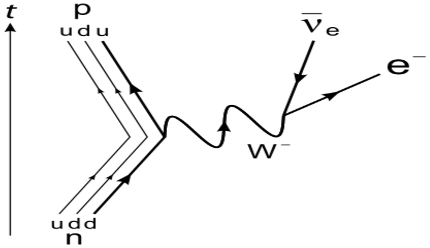
- **β^- decay**: ${}^{A}_{Z}X \to {}^{A}_{Z+1}X' + e^- + \overline{\nu}_e$

$$\boxed{{}^{3}_{1}H \to {}^{3}_{2}He + e^- + \bar{\nu}_e}$$

$$n + p + \mathbf{n} \to n + p + \mathbf{p} + \mathbf{e^-} + \boldsymbol{\bar{\nu}_e}$$

$$u\boldsymbol{d}d \to u\boldsymbol{u}d + \mathbf{?}$$

$$\begin{cases} \quad d \to u + \mathbf{W^-} \\ d + \mathbf{W^+} \to u \end{cases}$$



$$m_W \sim 90 \text{ GeV}$$

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- β^+ **decay**: ${}^{A}_{Z}X \to {}^{A}_{Z-1}X' + e^+ + \nu_e$

  Example:

$$\boxed{{}^{2}_{2}He \to {}^{2}_{1}D + e^+ + \nu_e}$$

$$p + \mathbf{p} \to p + \mathbf{n} + \boldsymbol{e^+} + \boldsymbol{\nu_e}$$

$$u\boldsymbol{u}d \to u\boldsymbol{d}d + \mathbf{?}$$

$$\left\{ \begin{array}{ccccccc} & & u & \to & d & + & \mathbf{W}^+ \\ u & + & \mathbf{W}^- & \to & d & & \end{array} \right.$$

Unification of strong, weak and electromagnetism

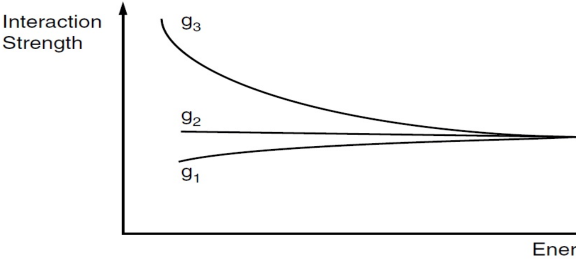

FIGURE 3.9 Unification of strong, weak, and electromagnetic forces. The s
the three forces g_1, g_2, and g_3 depend on the energy at which measurements
This dependence has been observed experimentally and can be calculated th
Values for g_1, g_2, and g_3, measured at the energy scale of weak interactio
extrapolated theoretically to high energies where, if the theory is supersymn
are found to meet, providing a visual picture of the unification of the three fo

Running coupling

... depend on the energy at which ... ???

... energy scale of weak interaction ... ???

... supersymmetry ... ???