Lecture 9/10

Strong interaction

Quantum chromodynamics (QCD)

- gluons couple to colour, interact with each other
- interaction strong at long distances/low momenta
  weaker at short distances/high momenta (asymptotic freedom)
- gluon fields form flux tubes between quarks with $F \sim 1$ GeV/fm
- at $d \sim 1$ fm, strings break $\longrightarrow$ jets of hadrons
- quarks (and gluons) confined inside colourless hadrons

Nuclear forces

General features

- longest range: exchange of pions (colourless $q\bar{q}$ pairs)
- intermediate: two-pion exchange $\longrightarrow$ strong attraction
- short range: repulsion
- three-body forces also important

Approximate symmetries of potentials $V_{NN}(\mathbf{r})$

- charge independence (isospin)

$$V_{pp} \simeq V_{np} \simeq V_{nn} \qquad \text{(good)}$$

- charge symmetry (swap all $p \leftrightarrow n$)

$$V_{pp} \simeq V_{nn} \qquad \text{(better)}$$

Cross sections

Reaction r : $A + B \longrightarrow C + D$

- rate (W_r) per unit beam flux (J_A), per target particle (N_B)

$$\sigma_r = \frac{W_r}{J_A N_B}$$

- units of area: 1 b (barn) $= 10^2$ fm^2
- probability, related to QM amplitude A_r by $\sigma_r \propto |A_r|^2$

Differential cross section, $\dfrac{\mathrm{d}\sigma_r}{\mathrm{d}\Omega}$

- rate into element of solid angle $\mathrm{d}\Omega = \sin\theta\,\mathrm{d}\theta\,\mathrm{d}\phi$ around direction (θ, ϕ)

Nuclear sizes

Elastic electron scattering on nucleus ${}^{A}Z$

- differential cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} \propto \frac{Z^2}{q^4}\left[F(q^2)\right]^2 (\times \text{relativistic corrections})$$

- momentum transfer (squared) $q^2 = 4k^2 \sin^2(\theta/2)$
  where $k \simeq E/\hbar c$
- form factor $F(q^2) = \frac{1}{Z}\int \rho(r)\, \mathrm{e}^{\mathrm{i}\mathbf{q}\cdot\mathbf{r}}\, \mathrm{d}^3\mathbf{r} \simeq 1 - \frac{1}{6} r_c^2 q^2$
- rms charge radius r_c: $\quad r_c^2 = \frac{1}{Z}\int r^2 \rho(r)\, \mathrm{d}^3\mathbf{r}$

Fit to many heavy nuclei: $r_c \propto A^{1/3}$

- density $\sim$ constant $\longrightarrow$ nuclear forces saturate
- model nucleus as uniform sphere ($\sim$ liquid drop) with radius

$$R = R_0 A^{1/3} \qquad \text{where } R_0 \simeq 1.2 \text{ fm}$$