Nuclear exchange force model

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General features of nuclear force

- Dominates Coulomb force in nuclei: stronger than electromagnetic forces.

- Short range: $F \to 0$ when $r >$ few fm. Repulsive at less than ~ 0.4 fm.

- Has a dependence on spin orientation of nucleons.

- Independent of charge: structure of nucleus is due to *superposition* of Coulomb and nuclear interactions.

Exchange force model

Two nucleons interact through the exchange of a massive particle.

This particle is *virtual*—it "exists" only for a lifetime and energy permitted by the uncertainty principle. Not *directly* observable in the interaction.

This is the pattern for dealing with quantization of various fields in high-energy physics—using Feynmann diagrams, etc.

Virtual particles

The uncertainty principles $\Delta E \Delta t \geq \hbar/2$ and $\Delta p_x \Delta x \geq \hbar/2$ allow

- Energy conservation to be violated by ΔE for a short Δt, and

- Momentum conservation to be violated by an amount Δp_x over a small region of size Δx.

If the virtual particle does acquire $E > \Delta E$, it can become real and detectable in the lab.

Estimate of nuclear exchange particle mass

We "borrow" $\Delta E = mc^2$ using uncertainty principle, so

$$\Delta t \approx \frac{\hbar}{\Delta E} = \frac{\hbar}{mc^2}$$

The maximum distance the particle can travel is $d = c\Delta t$, so

$$d_{\mathsf{max}} = c\left(\frac{\hbar}{mc^2}\right) = \frac{\hbar}{mc}$$

So the range is inversely proportional to the mass of the exchange particle.

Yukawa's estimate

We can estimate the rest energy as

$$mc^2 \approx \frac{\hbar c}{d_{\text{max}}} = 1.6 \times 10^{-11}\ \text{J}\ = 100\text{MeV}$$

Hideki Yukawa made this estimate in 1935, and 12 years later mesons* of energy ≈ 140 MeV were detected in cosmic rays.

*Now known as pions: the π^+, π^-, π^0.

Problems

In chapter 13: 5,12,13,15,17.

Problem 17 is a basic estimate for the energy yield of fission.