Massachusetts Institute of Technology

Department of Physics

Course: 8.701 – Introduction to Nuclear and Particle Physics
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Discussion Problems

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Problem 1: Gell-Mann Nishijima equation

Check that the Gell-Mann Nishijima formula works for the quarks u, d, and s.

What are the appropriate isospin assignments for $\bar{u}$, $\bar{d}$, and $\bar{s}$? Check you answer with the Gell-Mann Nishijima formula.

- Reminder: the Gell-Mann Nishijima formula goes as follows
$Q = I_3 + \frac{1}{2}(A + S)$

(a)

$$u: \quad Q = \frac{1}{2} + \frac{1}{2}\left(\frac{1}{3} + 0\right) = \frac{2}{3} \quad \checkmark$$

$$d: \quad Q = -\frac{1}{2} + \frac{1}{2}\left(\frac{1}{3} + 0\right) = -\frac{1}{3} \quad \checkmark$$

$$s: \quad Q = 0 + \frac{1}{2}\left(\frac{1}{3} - 1\right) = -\frac{1}{3} \quad \checkmark$$

(b)

$$\bar{u} = |\tfrac{1}{2}\ -\tfrac{1}{2}\rangle; \quad Q = -\frac{1}{2} + \frac{1}{2}\left(-\frac{1}{3} + 0\right) = -\frac{2}{3} \quad \checkmark$$

$$\bar{d} = |\tfrac{1}{2}\ \tfrac{1}{2}\rangle; \quad Q = \frac{1}{2} + \frac{1}{2}\left(-\frac{1}{3} + 0\right) = \frac{1}{3} \quad \checkmark$$

$$\bar{s} = |0\,0\rangle; \quad Q = 0 + \frac{1}{2}\left(-\frac{1}{3} + 1\right) = \frac{1}{3} \quad \checkmark$$

Figure 1: Answer.

Problem 2: The alpha particle

The α particle is a bound state of two protons and two neutrons, that is, a ^{4}He nucleus. There is no isotope of hydrogen with an atomic weight of four (^{4}H), nor of lithium ^{4}Li. What do you conclude about the isospin of an α particle?

The reaction $d + d \to \alpha\pi^0$ has never been observed. Explain why.
Would you expect ^{4}Be to exist? How about a bound state of four neutrinos?

- Isospin must be zero.

The deuterons carry $I = 0$, so the isospin on the left is zero. The α has $I = 0$, and π has $I = 1$, so the isospin on the right is one. This process does not conserve isospin, and hence is not a possible strong interaction.

There are five possible 4-nucleon states: $(nnnn)$, $(nnnp) =^4 H$, $(nnpp) =^4 He$, $(nppp) =^4 Li$, $(pppp) =^4 Be$. In principle they could form an $I = 2$ multiplet, but since ^4H and ^4Li do not exist, this is out. The answer is no: ^4Be and $(nnnn)$ should not exist. (^{4}H, ^{4}He, and ^{4}Li could make an $I = 1$ multiplet, but, again, ^{4}H and ^{4}Li do not exist, so this too is out. Evidently four nucleons bind only in the $I = 0$ combination, making ^{4}He.)

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