

Problem 1.

- (a) The deuteron's mass is $1875.6 \text{ MeV}/c^2$. What is its binding energy? Is this a relativistic system?
- (b) If you take the up- and down-quark masses to be those given in Table 4.4, what is the binding energy of a pion? Is this a relativistic system?

Solution

(a) One neutron + One proton - $1875.6 \text{ MeV}/c^2$

Neutron : $939.565 \text{ MeV}/c^2$

Proton : $938.272 \text{ MeV}/c^2$

Mass difference = $2.2 \text{ MeV}/c^2$

Q. A relativistic system?

A. mass difference $\times c^2$ = binding energy = 2.2 MeV (in wikipedia, it says 2.2 MeV , yes)

(b) Figure 1 Quark masses.

$$M(\text{meson}) = m_1 + m_2 + A \frac{(S_1 \cdot S_2)}{m_1 m_2} \quad (5.48)$$

This is because of the fact that the pseudoscalar and vector mesons have different masses even though they have the same quark contents while their spin orientations are different.

$$S_1 \cdot S_2 = \frac{1}{2}(S^2 - S_1^2 - S_2^2) = \begin{cases} \frac{1}{4}\hbar^2, & \text{for } s = 1 \text{ (vector mesons)} \\ -\frac{3}{4}\hbar^2, & \text{for } s = 0 \text{ (pseudoscalars)} \end{cases} \quad (1)$$

$$m_u = m_d = 308 \text{ MeV}/c^2, m_s = 483 \text{ MeV}/c^2, A = 159 \text{ MeV}/c^2$$

$$\begin{cases} |1\ 1\rangle = -u\bar{d} \\ |1\ 0\rangle = (u\bar{u} - d\bar{d})/\sqrt{2} \\ |1\ -1\rangle = d\bar{u} \end{cases} \quad (2)$$

Table 4.4 Quark masses (MeV/c^2)

| Quark flavor | Bare mass | Effective mass |
|--------------|-----------|----------------|
| u | 2 | 336 |
| d | 5 | 340 |
| s | 95 | 486 |
| c | 1300 | 1550 |
| b | 4200 | 4730 |
| t | 174 000 | 177 000 |

Warning: These numbers are somewhat speculative and model dependent [12].

Figure 1: Table4.4.