Höhere Hadronenphysik

Julian Bergmann
Christian Lang

Problem 2.1

$$m_q = \frac{1}{3} m_N \quad , \quad \mu_q = \frac{Q_q \hbar}{2 m_q c}$$

$$\mu_{3q} = 2 \langle q_1 q_2 q_3 | \mu_1 S_{z1} + \mu_2 S_{z2} + \mu_3 S_{z3} | q_1 q_2 q_3 \rangle$$

$$|N_\uparrow\rangle = \sqrt{\frac{2}{9}} \left(|\uparrow_1 \uparrow_2 \downarrow_3\rangle + |\downarrow_3 \uparrow_1 \uparrow_2\rangle + |\uparrow_2 \downarrow_3 \uparrow_1\rangle \right) - \sqrt{\frac{1}{18}} \left(|\downarrow_1 \uparrow_2 \uparrow_3\rangle + |\uparrow_3 \downarrow_1 \uparrow_2\rangle + |\uparrow_2 \uparrow_3 \downarrow_1\rangle + |\uparrow_1 \downarrow_2 \uparrow_3\rangle + |\uparrow_3 \uparrow_1 \downarrow_2\rangle + |\uparrow_2 \uparrow_3 \downarrow_1\rangle \right)$$

$$p: |\uparrow 2 3\rangle = |uud\rangle \quad , \quad n: |\uparrow 2 3\rangle = |ddu\rangle$$

$$\mu_u = \frac{2}{3} e \frac{\hbar}{2 m_q c^2} = 2 \frac{e\hbar}{6 m_q c^2} =: 2\mu_N$$

$$\mu_d = -\frac{1}{3} e \frac{\hbar}{2 m_q c^2} = -\frac{e\hbar}{6 m c^2} =: -\mu_N$$

$$|p_\uparrow\rangle = \sqrt{\frac{2}{9}} \left(|uud_\uparrow\rangle + |d u u_\uparrow\rangle + |u d u_\uparrow\rangle \right) - \sqrt{\frac{1}{18}} \left(|uud_\downarrow\rangle + |d u u_\downarrow\rangle + |u d u_\downarrow\rangle + |uud_\uparrow\rangle + |d u u_\uparrow\rangle + |u d u_\uparrow\rangle \right)$$

$$\langle uud_\uparrow | T_\mu | uud_\uparrow \rangle = 2 \langle uud | 2\mu_N \cdot \tfrac{1}{2} + 2\mu_N \cdot \tfrac{1}{2} + \mu_N \cdot \tfrac{1}{2} | uud \rangle = 5\mu_N$$

$$\langle uud_\downarrow | T_\mu | uud_\uparrow \rangle = 2 \langle uud | 2\mu_N \cdot \tfrac{1}{2} - 2\mu_N \cdot \tfrac{1}{2} - \mu_N \cdot \tfrac{1}{2} | uud \rangle = -\mu_N$$

$$\mu_p = \langle p_\uparrow | p_\uparrow \rangle = \sqrt{\frac{2}{9}}^2 \cdot 3 \cdot \langle uud_\uparrow | T_\mu | uud_\uparrow \rangle + \sqrt{\frac{1}{18}} \cdot 6 \cdot \langle uud_\downarrow | T_\mu | uud_\uparrow \rangle$$

$$= \frac{2}{9} \cdot 3 \cdot 5\mu_N + \frac{1}{18} \cdot 6 \cdot (-\mu_N) = 3\mu_N$$

$$\langle ddu_\downarrow | T_\mu | ddu_\uparrow \rangle = 2 \langle ddu | -\mu_N \cdot \tfrac{1}{2} + (-\mu_N) \cdot \tfrac{1}{2} - \frac{2\mu_N}{2} | ddu \rangle = -4\mu_N$$

$$\langle ddu_\uparrow | T_\mu | ddu_\uparrow \rangle = 2 \langle ddu | \mu_N \cdot \tfrac{1}{2} + (-\mu_N) \cdot \tfrac{1}{2} + \frac{2\mu_N}{2} | ddu \rangle = 2\mu_N$$

$$\mu_n = \sqrt{\frac{1}{9}}^2 \cdot 3 \cdot \langle ddu_\downarrow | T_\mu | ddu_\uparrow \rangle + \sqrt{\frac{1}{18}} \cdot 6 \cdot \langle ddu_\uparrow | T_\mu | ddu_\uparrow \rangle$$

$$= \frac{2}{9} \cdot 3 \cdot (-4\mu_N) + \frac{1}{18} \cdot 6 \cdot 2\mu_N = -2\mu_N$$

$\Rightarrow$

magnetic moments	calculated	measured
μ_p	$3\mu_N$	$2{,}793\,\mu_N$
μ_n	$-2\mu_N$	$-1{,}913\,\mu_N$

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Problem 2.3

Due to energy conservation the highest amount of energy available after collision is the cinetic energy of our fired proton (300 MeV) plus the resting masses of our particles.
However, as the initial particles (p+p) are found again after the collision we measured, only the initial cinetic energy is available to distribute to the two particles momentum after collision and to particle production.
Therefore the difference between the initial cinetic energy of 300 MeV and the sum of the finally measured cinetic energies of both protons is the available energy for particle production if both measured cinetic energies are equal.
In case they are not equal, energy has been released by one in form of a photon. This is the reason why in our calculation the upper cinetic energy is used to calculate the available energy for particle production while the difference is assumed to be the result of photon production.

T_3(MeV)	T_4(MeV)	reaction	particle
80,9	80,9	particle product.	300 MeV → 161,8 MeV : 138,2 MeV $\hat{=}$ π^0
70	70	particle prod.	160 MeV $\hat{=}$ π^0
50,2	50,2	particle prod.	199,6 $\hat{=}$ π^0
64,2	77,1	part. + phot. prod.	158,7 = 145,8 + 12,9 $\hat{=}$ $\pi^0 + \gamma$ (145,8: part., 12,9: phot.)
78,4	83,3	phot. prod.	138,3 = 133,4 + 4,9 $\hat{=}$ γ ⇒ π^0 has m = 134,98 ⇒ no π^0
38,5	64,6	part. + phot. prod.	196,9 = 170,8 + 25,9 $\hat{=}$ $\pi^0 + \gamma$
60,7	84,7	phot. prod.	154,6 = 130,6 + 14 $\hat{=}$ γ
75,5	85,7	phot. prod.	138,8 = 128,6 + 10,2 $\hat{=}$ γ
29,7	80,5	part. + phot. prod.	189,8 = 139 + 50,8 $\hat{=}$ $\pi^0 + \gamma$
59,7	88,1	phot. prod.	152,2 = 123,8 + 28,4 $\hat{=}$ γ
73,7	87,3	phot. prod.	139 = 125,4 + 4,6 $\hat{=}$ γ
25,9	90,1	phot. prod.	184 = 119,8 + 64,2 $\hat{=}$ γ
23,7	96,4	phot. prod.	179,9 = 107,2 + 72,7 $\hat{=}$ γ