Research Article

Pentaquark Description of the N(2080) and N(2270)

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A first-order pentaquark model is utilized to model the(2080) 3/2⁻ and N(2270) 3/2⁻ states. The N(2080) 3/2⁻ and N(2270) 3/2⁻ states are modeled as K^{*+} Σ^0 and K^{*0} Σ^+ pentaquarks, respectively. These possible pentaquark states are described as weakly bound meson plus baryon molecular states. The model predicts a set of spin and parity values that includes the experimental 3/2⁻ value. The predicted mass values are within 8% of the experimental values.

1. Introduction

Ben et al. [1] analyzed γ p → K^{*+} Σ^0 and γ p → K^{*0} Σ^+ data by incorporating contributions from the N(2080) 3/2⁻ and N(2270) 3/2⁻ molecules. These data are usually evaluated by incorporating s channel nucleon resonances. Including these molecular states reproduces the cross section data. Ref. [1] concluded that the inclusion of the N(2080) 3/2⁻ and N(2270) 3/2⁻ molecules is consistent with the K^* Σ photoproduction data. In view of the analysis of Ben et al. [1], this paper analyzes these N(2080) 3/2⁻ and N(2270) 3/2⁻ molecular states in terms of a first-order pentaquark model. First-order models were previously used to reasonably describe other possible pentaquarks [2][3][4][5][6][7][8].

The N(2080) and N(2270) states are investigated in terms of a first-order pentaquark mass formula. The N(2080) 3/2⁻ and N(2270) 3/2⁻ states are modeled as K^{*+} Σ^0 and K^{*0} Σ^+, respectively. These states are described as weakly bound meson plus baryon molecular states. The meson and baryons are defined utilizing the methodology of Zel'dovich and Sakharov [9][10].

2. Formalism

The first-order pentaquark model weakly couples a meson (m) and baryon (b). Mesons and baryons are modeled using the approach of Refs. 9 and 10 to determine their respective masses

$$\mathbf{M_m = \delta_m + m_1 + m_2 + b\,(m_0^2 / m_1 m_2)\,\sigma_1 \cdot \sigma_2} \quad (1)$$

$$\mathbf{M_b = \delta_b + m_1 + m_2 + m_3 + (b/3)\,[(m_0^2 / m_1 m_2)\,\sigma_1 \cdot \sigma_2}$$

$$\mathbf{+ (m_0^2 / m_1 m_3)\,\sigma_1 \cdot \sigma_3 + (m_0^2 / m_2 m_3)\,\sigma_2 \cdot \sigma_3]} \quad (2)$$

where δ_m = 40 MeV/c^2, δ_b = 230 MeV/c^2, m_i is the mass of the quark comprising the meson (i = 1, 2) or baryon (i = 1, 2, 3), m_0 is the average mass of a first generation quark, and b = 615 MeV/c^2. In Eq. 1, $\sigma_1 \cdot \sigma_2$ = -3/4 or 1/4 for a pseudoscalar or

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vector meson, respectively. In Eq. 2, the values of $\sigma_i \cdot \sigma_j$ depend on the baryon spin. If the total baryon spin is 1/2 and it has two *identical* quarks q_2 and q_3, the values of $\sigma_i \cdot \sigma_j$ are

$\boldsymbol{\sigma_2 \cdot \sigma_3 = 1/4}$ and $\boldsymbol{\sigma_1 \cdot \sigma_2 = \sigma_1 \cdot \sigma_3 = -1/2}$ (3)

If the J = 1/2 baryon contains three different quarks, then the values of $\sigma_i \cdot \sigma_j$ are defined by the methodology of Refs. 9 and 10.

The first-order mass formula assumes that the meson and baryon reside in their ground states. If excited states are involved, the difference in masses between the excited and ground states must be considered.

Eqs. 1 and 2 utilize effective quark masses. These masses were determined by Griffiths [11] for d, u, s, c, b, and t quarks that have the values 340, 336, 486, 1550, 4730, and 177000 MeV/c^2, respectively. Using the convention of the Standard Model [11][12], the quarks are grouped into three generations: [d(-1/3), u(+2/3)], [s(-1/3), c(+2/3)], and [b(-1/3), t(+2/3)] [11][12]. Quark charges are given within the parentheses in terms of the unit charge e.

3. Results and Discussion

The N(2080) $3/2^-$ and N(2270) $3/2^-$ states are modeled as $K^{*+}\ \Sigma^0$ and $K^{*0}\ \Sigma^+$ pentaquarks, respectively. Masses and spin and parity assignments of these states are described in subsequent discussion.

3.1. N(2080) Modeled as a Pentaquark

The N(2080) pentaquark is modeled as a $K^{*+} + \Sigma^0$ that have the J^π values of 1^- and $1/2^+$, respectively. Given these values, the total spin of the N(2080) is

$J^\pi (N(2080)) = J^\pi (K^{*+}) \times 0 \times J^\pi (\Sigma^0) = 1^- \times 0 \times 1/2^+ = 1/2^-, 3/2^-$ (4)

The value of $3/2^-$ is in agreement with experiment [1]. Since the first-order model only permits a primitive structure with zero angular momentum between the clusters, a unique spin structure is not defined within the scope of the model. Therefore, the model also predicts a $1/2^-$ assignment.

The M(2080) mass predicted by the model is given by the relationship

$\mathbf{M(2080) = M(K^+) + M(\Sigma^0) + \Delta(K^{*+} - K^+)}$ (5)

where $\Delta(K^{*+} - K^+)$ is the mass difference between the $K^{*+} - K^+$ [12]. Using Eq. 5 and the first order methodology of Eqs. 1 and 2, lead to a predicted N(2080) mass of 2238 MeV/c^2. This model result is about 8% larger than the measured experimental value [1].

3.2. N(2270) Modeled as a Pentaquark

The N(2270) pentaquark is modeled as a $K^{*0} + \Sigma^+$ that have the J^π values of 1^- and $1/2^+$, respectively. Given these values, the total spin of the N(2270) is

$J^\pi (N(2270)) = J^\pi (K^{*0}) \times 0 \times J^\pi (\Sigma^+) = 1^- \times 0 \times 1/2^+ = 1/2^-, 3/2^-$ (6)

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The experimental value of $3/2^-$ is in agreement with experiment [1]. As noted previously for the N(2080), a $1/2^-$ assignment is also predicted by the first-order pentaquark mass formula.

The N(2270) mass predicted by the model is given by the relationship

$$\mathbf{M(2270) = M(K^0) + M(\Sigma^+) + \Delta(K^{*0} - K^0)} \quad (7)$$

where $\Delta(K^{*0} - K^0)$ is the mass difference between the $K^{*0} - K^0$ [12]. Using Eq. 7 and the first order methodology of Eqs. 1 and 2, lead to a predicted N(2270) mass of 2241 MeV/c^2. This result is about 2% smaller than the measured experimental value [1].

4. Conclusions

A first-order pentaquark approach is utilized to model the (2080) $3/2^-$ and N(2270) $3/2^-$ molecular states. The N(2080) $3/2^-$ and N(2270) $3/2^-$ are modeled as $K^{*+}\ \Sigma^0$ and $K^{*0}\ \Sigma^+$ pentaquarks, respectively. These resonances are described as weakly bound meson plus baryon pentaquark molecular states. The model incorporates a primitive coupling structure that predicts a set of spin and parity values including the experimental $3/2^-$ value and a $1/2^-$ state.

The first-order mass model leads to a predicted N(2080) mass of 2238 MeV/c^2 that is about 8% larger than the measured experimental value. Within the scope of the first-order model, the N(2270) mass is calculated to be 2241 MeV/c^2. This result is about 2% smaller than the measured experimental value.

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Declarations

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