Negative-parity nucleon resonance in the QCD sum rule

D. Jido, N. Kodama, and M. Oka
Department of Physics, Tokyo Institute of Technology, Meguro, Tokyo 152, Japan
(Received 9 April 1996)

The negative-parity baryons are studied by a novel approach in the QCD sum rule. It is found that the parity of the ground-state nucleon is determined by the sign of the quark condensate. We predict the mass of the negative-parity nucleon. [S0556-2821(96)01719-5]

PACS number(s): 11.55.Hx, 14.20.Gk

I. INTRODUCTION

The QCD sum rule, proposed by Shifman, Vainshtein, and Zakharov [1], connects hadron properties and QCD parameters [2]. The correlation function of an interpolating field for a hadron is expressed in two ways: (1) the operator product expansion (OPE) side, in which the correlation function is calculated perturbatively at deep Euclidean momentum with the help of the operator product expansion, and (2) phenomenological side, expressed in terms of a hadron spectral function in the physical region. Using the analyticity of the correlation function the two expressions are connected in an integral form, which is the sum rule. The time-ordered correlation function is usually employed, but in this paper for a technical reason we use the ''old-fashioned'' correlation function defined by

$$\Pi(p)=i\int d^4x e^{ip\cdot x}\theta(x_0)\langle 0|J(x)\overline{J(0)}|0\rangle, \tag{1}$$

where $J(x)$ is a local operator which annihilates a hadron and is called an interpolation current.

The QCD sum rule is applied to baryons by Ioffe [3,4]. For the octet baryons two independent currents which contain no derivative are available. The general expression of the nucleon current is [5]

$$J_N^\alpha(x)=\varepsilon_{abc}\{[u_a(x)Cd_b(x)][\gamma_5 u_c(x)]^\alpha + t[u_a(x)C\gamma_5 d_b(x)]u_c^\alpha(x)\}, \tag{2}$$

where $u(x)$ and $d(x)$ are field operators of up and down quarks, C is the charge conjugation operator, and abc are color indices. J_N^α ($\alpha=1,2,3,4$) forms a Dirac spinor. A commonly used current assumes $t=-1$ in Eq. (2), which is called ''Ioffe's current.'' It is optimal for the lowest-lying nucleon [5], i.e., it couples strongly to the lowest-lying nucleon state. Because, as we shall see later, the current for baryons couples also to the negative-parity baryons [6], other choices of t enable us to study the negative-parity baryons. In this paper, we extract the mass of the negative-parity nucleon from the sum rule with the nucleon current by choosing t so that the current strongly couples to the negative-parity nucleon. A similar study has been done by the authors of Ref. [6]. They, however, used the current that contains an operator with a derivative. They did not find a Borel stability in the prediction of the negative-parity nucleon mass and, therefore, the results are only qualitative.

In Sec. II, we study the relation between the positive- and negative-parity baryons in the sum rule. We point out that the sum rule for the positive-parity baryon contains the contribution of the negative-parity baryons. We propose a technique to separate the contribution of the negative-parity baryons from the sum rule in Sec. III. In Sec. IV, we apply our formulation to the negative-parity nucleon resonance, and calculate its mass. We study the t dependence [Eq. (2)] of the sum rule in detail. We find that the sign of the quark condensate determines the order of the parity doublet. In Sec. V, roles of the chiral symmetry-breaking quark condensates are studied in the masses of the positive- and negative-parity nucleons. We study the behavior of the masses when the quark condensates are varied. A summary is given in Sec. VI.

II. NEGATIVE-PARITY BARYONS IN THE QCD SUM RULE

A baryon current studied in the QCD sum rule is composed of three quark fields, and it couples to the states with the same quantum number as the current. In the mesonic case, the parity of the meson that couples to the current is directly connected to the parity of the current. That is, the parity of the meson coincides with the parity of the bilinear form $\overline{q}\Gamma q$. For instance, the current for the ρ^+ meson is $\overline{d}\gamma_\mu u$, while the current for a_1^+ meson, which is the chiral partner of ρ, is $\overline{d}\gamma_\mu\gamma_5 u$. It may seem that the QCD sum rule for a negative-parity baryon is similarly given by the current $J_-\equiv i\gamma_5 J_+$ as an interpolating field because multiplying $i\gamma_5$ to J_+ changes the ''parity'' of J_+, where J_+ is the current for the corresponding positive-parity baryon, such as J_N in Eq. (2). Note that both J_+ and J_- are Dirac (four-component) spinors.

Suppose that the correlation function of J_+ is given by

$$\Pi_+(p)=p_\mu\gamma^\mu\Pi_1(p^2)+\Pi_2(p^2), \tag{3}$$

then the correlation function of J_- can be written as

$$\Pi_-(p)=-\gamma_5\Pi_+(p)\gamma_5=p_\mu\gamma^\mu\Pi_1(p^2)-\Pi_2(p^2). \tag{4}$$

The difference between J_+ and J_- appears only in the sign in front of $\Pi_2(p^2)$. That is, the same functions $\Pi_1(p^2)$ and $\Pi_2(p^2)$ appear in $\Pi_+(p)$ and $\Pi_-(p)$. Because we construct

the sum rules separately for $\Pi_1(p)$ and $\Pi_2(p)$, we do not get any independent sum rule from J_-.

In fact, the information about the negative-parity baryons is already in $\Pi_+(p)$ since J_+ couples not only to the positive-parity baryons but also to the negative-parity baryons [6]. It is easy to see this from

$$\langle 0|J_+|B^-\rangle\langle B^-|\overline{J_+}|0\rangle = -\gamma_5\langle 0|J_-|B^-\rangle\langle B^-|\overline{J_-}|0\rangle\gamma_5, \tag{5}$$

where $|B^-\rangle$ denotes a single baryon state with negative parity. J_- couples to the positive-parity states in the same way.

To see concretely how the information of the negative-parity baryons is included in the correlation function $\Pi^+(p)$, we express the time-ordered correlation function as a sum of contributions from zero-width poles:

$$\Pi^T(p) \equiv i\int d^4x e^{ip\cdot x}\langle 0|TJ_+(x)\overline{J_+}(0)|0\rangle = \sum_n \left[\lambda_n^+ \frac{\gamma_\mu p^\mu + m_n^+}{p^2-(m_n^+)^2} + \lambda_n^- \frac{\gamma_\mu p^\mu - m_n^-}{p^2-(m_n^-)^2}\right], \tag{6}$$

where $m_n^\pm$ is the mass of the nth resonance and $\lambda_n^\pm$ is the coupling strength of the current to the resonance. Note that the only difference in the positive-parity part and the negative-parity part is the sign of the mass terms. When we are interested in the lowest-lying baryon with positive parity, we regard excited states as a part of ''continuum'' contribution. Then the terms from the negative-parity baryons cannot be directly seen. In the next section, we propose a formulation for separating the negative-parity contribution from the sum rule.

III. SUM RULE FOR THE NEGATIVE-PARITY BARYON

To separate the terms of negative-parity baryons from those of positive-parity baryons, we use the ''old-fashioned'' correlation function (1). In the zero-width resonance approximation, we write the imaginary part in the rest frame $\vec{p}=0$ as

$$\mathrm{Im}\Pi(p_0) = \sum_n \left[(\lambda_n^+)^2 \frac{\gamma_0+1}{2}\delta(p_0-m_n^+) + (\lambda_n^-)^2 \frac{\gamma_0-1}{2}\delta(p_0-m_n^-)\right] \equiv \gamma_0 A(p_0) + B(p_0) \tag{7}$$

where $A(p_0)$ and $B(p_0)$ are defined by

$$A(p_0) = \frac{1}{2}\sum_n [(\lambda_n^+)^2\delta(p_0-m_n^+) + (\lambda_n^-)^2\delta(p_0-m_n^-)],$$

$$B(p_0) = \frac{1}{2}\sum_n [(\lambda_n^+)^2\delta(p_0-m_n^+) - (\lambda_n^-)^2\delta(p_0-m_n^-)].$$

One can see that the contribution $A(p_0)+B(p_0)$ $[A(p_0)-B(p_0)]$ contains contributions only from the positive-parity (negative-parity) states.

We, however, can no longer construct sum rules in p^2 space, since the ''old-fashioned'' correlation function is not analytic in p^2 space. Instead, a sum rule can be written in the complex p_0 plane because the correlation function (1) is analytic in the upper-half region of the complex p_0 plane. The theoretical side is given by the operator product expansion, which is valid at high energy, i.e., $\Pi^{\mathrm{OPE}}(p_0=Q) \simeq \Pi^{\mathrm{Phe}}(p_0=Q)$ at large $|Q|$. Using the analyticity we obtain independent sum rules

$$\int_0^Q [A^{\mathrm{OPE}}(p_0) - A^{\mathrm{Phe}}(p_0)]W(p_0)dp_0 = 0, \tag{8}$$

$$\int_0^Q [B^{\mathrm{OPE}}(p_0) - B^{\mathrm{Phe}}(p_0)]W(p_0)dp_0 = 0, \tag{9}$$

where $W(p_0)$ is an arbitrary analytic function which is real on the real axis. Note that we use the fact that the imaginary part of the correlation vanishes in negative p_0.

We use the Borel weight $W(p_0)=\exp(-p_0^2/M^2)$. We take the lowest mass pole and approximate others as continuum whose behavior above a threshold $s_0^\pm$ is same as the theoretical side. Then we obtain two sum rules

$$\frac{1}{2}[\widetilde{A}^{\mathrm{OPE}}(M,s_0^+) + \widetilde{B}^{\mathrm{OPE}}(M,s_0^+)] = (\lambda^+)^2\exp\left[-\frac{(m^+)^2}{M^2}\right], \tag{10}$$

$$\frac{1}{2}[\widetilde{A}^{\mathrm{OPE}}(M,s_0^-) - \widetilde{B}^{\mathrm{OPE}}(M,s_0^-)] = (\lambda^-)^2\exp\left[-\frac{(m^-)^2}{M^2}\right], \tag{11}$$

where

$$\widetilde{A}^{\mathrm{OPE}}(M,s_0^+) = \int_0^{s_0^+} dp_0 A^{\mathrm{OPE}}(p_0)\exp\left(-\frac{p_0^2}{M^2}\right),$$

$$\widetilde{B}^{\mathrm{OPE}}(M,s_0^-) = \int_0^{s_0^-} dp_0 B^{\mathrm{OPE}}(p_0)\exp\left(-\frac{p_0^2}{M^2}\right).$$

The first sum rule is for the baryons with positive parity and the second one is for negative-parity baryons. In these sum rules we allow the threshold to be different for each parity.

There are three remarks. First, the imaginary part of our correlation function is written as $1/2[\mathrm{Im}\Pi^{\mathrm{T}}(p_0) + \mathrm{Im}\Pi^{\mathrm{R}}(p_0)]$, where T and R stand for ''time-ordered'' and ''retarded'' functions, respectively. The real parts of time-ordered and retarded functions are the same, but the sign of negative-energy part in their imaginary part is different. It is due to this difference that the time-ordered correlation functions is nonanalytic and the retarded correlation function is analytic in complex p_0 plane. Second, the retarded correlation function, indeed, is analytic on the upper half in complex p_0 plane. But we cannot construct Π^{R} sum rule, since the integral of $A(p_0)$, which is an odd function of p_0, vanishes in the sum rules (10) and (11). At last, from (10) and (11), we see that the term B causes the parity splitting. B is not invariant under the chiral transformation. We, therefore, confirm that the chiral symmetry breaking gives the parity splitting of the baryon.

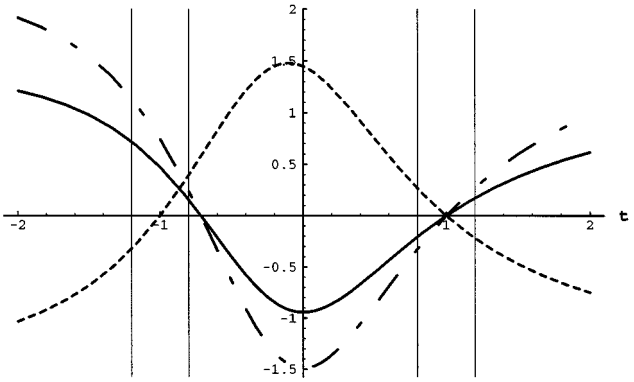

FIG. 1. The t dependence of Borel-transformed power corrections divided by the Wilson coefficient of identity operator at the Borel mass 1.5 GeV. The dot-dashed line is the ratio of the Wilson coefficients of $\langle\overline{qq}\rangle$ and identity operator. The dashed line is for $\langle\overline{q}\sigma\cdot Gq\rangle$. The solid line is the $\langle(\overline{qq})^2\rangle$.

IV. MASS OF THE NEGATIVE-PARITY NUCLEON

In this section we calculate the mass of the negative-parity nucleon N^-, and see that the mass is larger than that of the positive-parity nucleon N^+.

Using the current (12), the theoretical OPE side of the sum rules (8) and (9) up to dimension-six operators are given by

$$\mathrm{Im}A^{\mathrm{OPE}}(p_0)=\frac{5+2t+5t^2}{2^{10}\pi^4}p_0^5\theta(p_0)+\frac{5+2t+5t^2}{2^9\pi^2}p_0\theta(p_0)\times\left\langle\frac{\alpha_s}{\pi}GG\right\rangle+\frac{7t^2-2t-5}{12}\delta(p_0)\langle\overline{qq}\rangle^2, \quad (12)$$

$$\mathrm{Im}B^{\mathrm{OPE}}(p_0)=-\frac{7t^2-2t-5}{32\pi^2}p_0^2\theta(p_0)\langle\overline{qq}\rangle+\frac{3(t^2-1)}{32\pi^2}\theta(p_0)\times\langle\overline{qg}\sigma\cdot Gq\rangle.$$

In these expressions we neglect the up-quark and down-quark masses. We allow to determine t so that the current strongly couples to the negative-parity states and also require that the contributions of higher dimension operators are small in determining t. In Fig. 1 are plotted the t dependencies of the Borel-transformed Wilson coefficients of the operators up to dimension six for the nucleon at the Borel mass $M=1.5$ GeV. Around $t=1$ and $t=-1$, the correction terms of OPE are small compared to the identity operator and the coefficients of the higher-dimensional operators would be small. In view of the convergence of OPE, such t is good for the sum rules.

In order to find t such that the current (2) couples to the negative-parity state, we first apply the finite energy sum rule. It is simple to extract the hadron properties from the finite energy sum rule because it contains no additional parameters such as the Borel mass. The results, however, are only qualitatively reliable, because they are usually contaminated by higher resonance contributions. Concretely we construct three independent sum rules from Eqs. (8) and (9) choosing three weights $W(p_0)=1$, p_0, and $(p_0)^2$. We determine the mass, the coupling, and the threshold of each parity

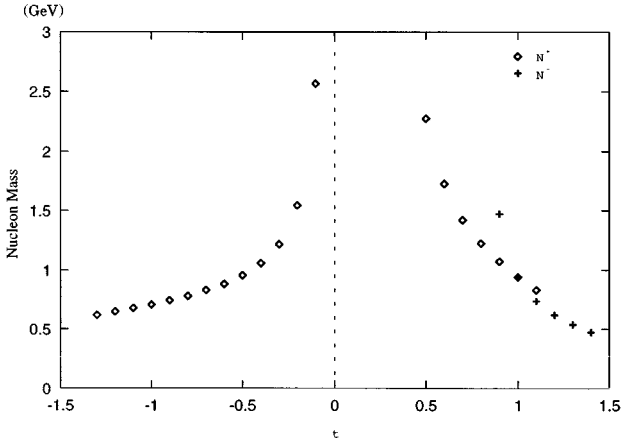

FIG. 2. Masses of negative- and positive-parity nucleons in the finite energy sum rule. The sum rule has no (realistic) solution where no dot is plotted. At $t=1$ the N^+ and N^- have the same mass. The N^+ has no solution at $t>1.1$ and N^- has no solution at $t<0$.

nucleon by solving the three sum rule equations. The t dependence of the masses of N^+ and N^- are plotted in Fig. 2. At $t=1$, the masses of N^+ and N^- are the same because the odd-dimensional operators $(\overline{qq},\ \overline{q}\sigma\cdot Gq)$ do not contribute at $t=1$ as long as we truncate OPE at dimension six. There is no solution for N^- around $t=-1$ although the convergence of OPE would be good. This is because the coefficient of the dimension-three operator $(\overline{qq})$ is positive and large, so that the current couples weakly to the negative-parity states. If one of the correlation functions of N^+ and N^- is enhanced by the odd dimension operators, the other is suppressed, because the contributions from the odd dimension operators have different signs for N^+ and N^-. Thus for the time being we choose $t=0.8$. We shall later study other choices of t around 1.

The other input parameters are chosen as

$$\left\langle\frac{\alpha_s}{\pi}GG\right\rangle=(0.36\ \mathrm{GeV})^4,$$

$$\langle\overline{qq}\rangle=(-0.25\ \mathrm{GeV})^3,$$

$$\langle(\overline{qq})^2\rangle=1.25\langle\overline{qq}\rangle^2,$$

$$\langle\overline{q}\sigma\cdot Gq\rangle=(1.0\ \mathrm{GeV})^2\langle\overline{qq}\rangle,$$

$$m_u=m_d=0.$$

These values are chosen so that the sum rule reproduces the observed mass of $N^+\simeq 940$ MeV. We note that the vacuum saturation hypothesis that can only be justified in the large N_c limit is not appropriate for the nucleon sum rule [7]. Indeed, we take $\langle(\overline{qq})^2\rangle=1.25\langle\overline{qq}\rangle^2$, that is, 25% enhancement of the four-quark condensate than that with the vacuum saturation hypothesis. We also note that the ratio of $\langle\overline{q}\sigma\cdot Gq\rangle$ to $\langle\overline{qq}\rangle$, frequently defined as $m_0^2=\langle\overline{q}\sigma\cdot Gq\rangle/\langle\overline{qq}\rangle$, is consistent with the standard value $m_0^2=0.5-1.0(\mathrm{GeV})^2$ [8,4].

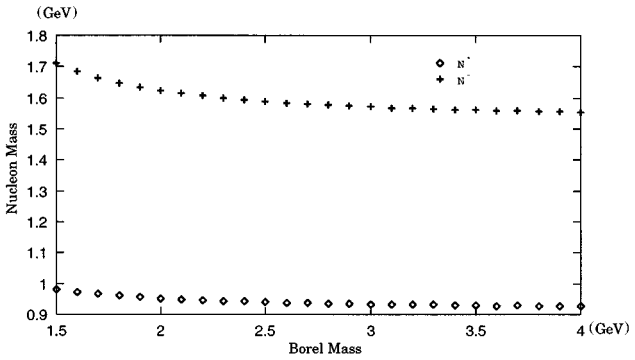

FIG. 3. Masses of N^+ and N^- plotted with $\Delta M = 0.1$ GeV.

We now calculate the mass of N^- in the Borel sum rule. We have three parameters, the mass, the coupling, and the threshold. Usually, one sets up a window in which the QCD sum rules would be effective, and then fits the parameters so that they are stabilized with respect to the Borel mass in the window. It is, however, known that the results are sensitive to the choice of the window, and therefore have significant ambiguity. Instead, we use the following method to fix the parameters. If we choose three arbitrary Borel masses, we can determine, in principle, three parameters from the corresponding sum rules assuming that those parameters should be independent of the Borel mass. This method should work if OPE could be summed up to all orders. In practice, however, we can calculate only a few terms of OPE and, therefore, parameters obtained from the sum rule depend on the Borel masses. In order to see sensitivity of the parameters to the Borel mass, we select three successive Borel masses, each separated by $\Delta M = 0.1$ GeV and solve three parameters from the three sum rules. We label the obtained parameters by the center of these Borel masses.

Iterating this procedure, we get the Borel mass dependence of the masses of N^+ and N^-, plotted in Fig. 3. Both masses are almost independent of the Borel mass. Our sum rule gains extra stability due to the integral measure. The integral measure dp_0^2 in the standard sum rule is $2p_0 dp_0$ in ours, which adds a p_0 enhancement of the continuum term, and makes the pole contribution to the sum rule weaker. By fixing the QCD parameters so as to give the N^+ mass $\sim$ 940 MeV we predict the N^- mass about 1550 MeV. The observed N^- mass is 1535 MeV with the width of 150 MeV $\pm$ 15 MeV [9] and our prediction agrees very well. Note that the $N^+ - N^-$ mass difference is caused by the terms of the odd dimension condensates ($\langle\overline{qq}\rangle$, $\langle\overline{q}\sigma\cdot Gq\rangle$). Thus, one might say that QCD chooses N^+ as the ground state by setting $\langle\overline{qq}\rangle < 0$.

We check the dependence of the results on ΔM and t. We calculate the masses of N^+ and N^- with $\Delta M =$ 0.05, 0.2, and 0.5 GeV in the same way. Although at around $M = 1.5$ GeV the mass obtained from each sum rule is different from the others by a few percent, the masses are stabilized above $M = 2.5$ GeV and each sum rule gives the same result. In order to study the t dependence, we calculate the nucleon masses with other choices of $t =$ 0.9, 1.05, and 1.1. For each t we adjust the QCD parameters so that the N^+ mass is reproduced. For $t = 0.9$ the N^- mass is about 1.4 GeV, and the mass difference of N^+ and N^- becomes smaller for $t = 0.8$. This is because the contribution from the odd-dimensional operators is larger for larger t. We are interested in the case $t > 1$ because in this region the dimension 3, 5, and 6 operators have the opposite sign to those for $t < 1$. Then the mass of N^- could be smaller than that of N^+. But we find that for $t =$ 1.05 and 1.1 the N^- sum rule has no solution when the QCD parameters are adjusted so as to give the mass of N^+. The current with $t > 1$ seems not to couple with the negative-parity nucleon.

V. ROLES OF THE CHIRAL SYMMETRY BREAKING

As we see in Sec. III, the difference of the masses of the positive-parity baryon and the negative-parity baryon is caused by the chirally odd term B in Eq. (7). In this section, we study how the terms breaking the chiral symmetry determine the parity splitting.

In the correlation function of the nucleon Eq. (12) the chiral symmetry is broken by the vacuum expectation values of the operators $\overline{qq}$,$\overline{q}\sigma\cdot Gq$ and a part of $\overline{qqqq}$. The first two are split into two chiral terms,

$$\langle\overline{qq}\rangle = \langle\overline{q_L} q_R\rangle + \langle\overline{q_R} q_L\rangle, \tag{13}$$

$$\langle\overline{q}\sigma\cdot Gq\rangle = \langle\overline{q_L}\sigma\cdot Gq_R\rangle + \langle\overline{q_R}\sigma\cdot Gq_L\rangle, \tag{14}$$

and each term breaks the chiral symmetry. The vacuum expectation value of the four-quark operator $\overline{qqqq}$ in the nucleon can be written as a sum of three terms with different chiral properties:

$$(7t^2-2t-5)\langle\overline{qqqq}\rangle = (t^2-2t+1)4\langle\overline{q_L}q_R\rangle\langle\overline{q_R}q_L\rangle - 6(1-t^2)\,2(\langle\overline{q_L}q_R\rangle^2 + \langle\overline{q_R}q_L\rangle^2). \tag{15}$$

Note that we use the vacuum saturation hypothesis [1] and this formula is only for the nucleon sum rule. The first term is the chiral symmetric term because the term breaks the chiral symmetry twice and the net chirality is preserved. In the second term the chirality is broken. With our choice of $t = 0.8$, Eq. (15) breaks the chiral symmetry strongly since the chiral noninvariant term is dominant. If we choose $t = -1$, the term-breaking chiral symmetry vanishes. So the $\langle\overline{qqqq}\rangle$ term for the Ioffe's current ($t = -1$) is invariant under the chiral symmetry.

In order to see the effect of the chiral symmetry breaking, we vary $\langle\overline{qq}\rangle$ and study its effects. $\langle\overline{q}\sigma\cdot Gq\rangle$ is assumed to be proportional to $\langle\overline{qq}\rangle$ and therefore is varied together with $\langle\overline{qq}\rangle$. As Eq. (15) $\langle qqqq\rangle$ is reduced to the square of $\langle\overline{qq}\rangle$ and we vary only the terms breaking the chiral symmetry. We define the ratio R of $\langle\overline{qq}\rangle$ to its standard value $\langle\overline{qq}\rangle_0$, $R = \langle\overline{qq}\rangle/\langle\overline{qq}\rangle_0$, and choose seven values of $R = 0.3, 0.5, 0.8, 1.0, 1.2, 1.5, 2.0$.

In Fig. 4 are plotted the masses of nucleons with positive and negative parity. One sees that the masses of both N^+ and N^- go towards zero when the ratio R goes to zero. Although we cannot confirm that the N^+ and N^- masses go to zero at $R \to 0$, they should be degenerate because the chiral symmetry-breaking term B vanishes. Both of the N^+ and N^- masses grow for large R and become degenerate, but

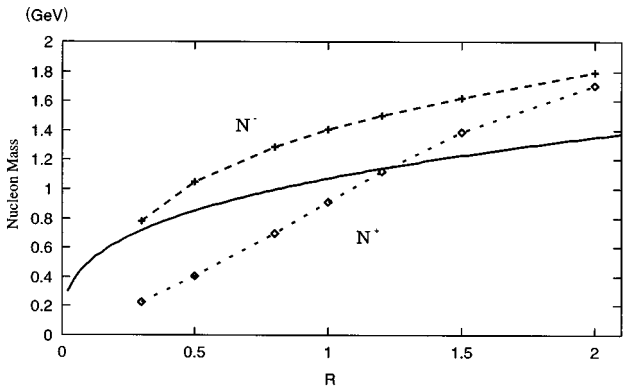

FIG. 4. Masses of N^+ and N^- at $M=2.5$ GeV for various values of the quark condensate. R is the ratio of $\langle\overline{qq}\rangle$ to its standard value $\langle\overline{qq}\rangle_0$. The solid line is the Ioffe's formula (16).

R-dependent behaviors are different. It should be noted that the behavior of the N^+ mass is different from the Ioffe's formula [3]

$$m^+=[-2(2\pi)^2\langle\overline{qq}\rangle]^{1/3}. \tag{16}$$

The reason why the N^+ and N^- masses at large R become degenerate is as follows. Both masses grow with increasing R and the thresholds are simultaneously enhanced. The enhancement of the threshold makes the bare loop term dominant over the others. The correlation functions of N^+ and N^- become similar since the bare loop term contributes to the correlation functions with the same sign, and therefore the masses tend to be degenerate. Behaviors of the N^+ and N^- masses vs R can be explained by realizing that the $\langle\overline{qq}\rangle^2$ term (dimension six) enhances the baryon masses. This is related to the sign of $\langle\overline{qq}\rangle^2$ term, that is negative for both the N^+ and N^- sum rules. Thus the $\langle\overline{qq}\rangle^2$ term is suppressed when R grows and the sum rule tends to increase $s_0^{\pm}$ to compensate its effect. As a result, the baryon mass increases. On the other hand, the B term $(\langle\overline{qq}\rangle+\langle\overline{q}\sigma\cdot Gq\rangle)$ contributes with different signs to N^+ and N^-. For N^+, it tends to suppress the mass increase around $0.3\leqslant R\leqslant 1.0$, while N^- mass is enhanced there. Thus the N^+ mass grows slowly in comparison with the N^- mass.

VI. SUMMARY

The interpolating current for the octet baryons couples also to the negative-parity baryons. We separate the contribution of the negative-parity baryon from the sum rule for the positive-parity baryon. Using the particular correlation function (1), we construct the sum rule for the negative-parity baryons in the p_0 complex plane.

We apply the formulation to the masses of N^-. We obtain the Borel mass stability in a wide region for both the N^+ and N^- masses. We find that the negative $\langle\overline{qq}\rangle$ condensate gives a heavier N^- mass than N^+ mass. We find that the current 12 with $t\simeq 0.8$ couples strongly to the negative-parity state.

In order to see the roles of the chiral breaking to the parity splitting, we study the behavior of the N^+ and N^- masses by varying the quark condensate. The smaller the quark condensate we use, the smaller the masses are, and the N^+ and N^- masses are degenerate when the quark condensate vanishes. At a larger quark condensate the masses are also degenerate, since the dimension-six operator plays the dominant role there.

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