Light-and Strange-Baryon Spectra in a Relativistic Potential Model

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Abstract: Light- and strange-baryon spectra are studied in a relativistic potential model of independent quarks taking into account perturbatively the correction due to one-gluon-exchange interaction along with that due to Goldstone boson exchange interaction between the constituent quarks and that due to center-of-mass motion. The baryons are assumed here as an assembly of independent quarks confined in a first approximation by an effective linear potential which presumably represents the non-perturbative multigluon interactions including the gluon self-couplings. The model yields the ground states and excitation spectra of baryons in close agreement with experiment and also explains the correct level ordering of positive-and negative-parity excitations in the N, Δ and Λ spectra. The model also reproduces the mass spectra for some of the other four and three star resonances of the particle data group.

1. INTRODUCTION

Several papers based on the non-relativistic quark models have appeared [1-3] in the literature in connection with the study of the mass spectra of light and strange baryons. The constituent quark models (CQM's) which adapted one-gluon exchange (OGE) [4] as the hyperfine interaction between constituent quarks(Q) have been suggested in the study of light baryon spectroscopy but these models faced some intriguing problems such as (i) the wrong level ordering of positive- and negative-parity excitations in the N, Δ,Λ, and ∑ spectra, (ii) the missing flavor dependence of the Q-Q interaction necessary for a simultaneous description of the correct level ordering in the N and Λ spectra and (iii) the strong spin-orbit splitting that are produced by the OGE interaction but not found in the empirical spectra. All of these effects have been explained to be due to [5-8] inadequate symmetry properties inherent in the OGE interaction. Several hybrid models advocating meson-exchange Q-Q interactions in addition to the OGE dynamics of CQM's have been suggested for baryons [9]. In the study of N and Δ spectra, especially π and σ exchanges have been introduced to supplement the interaction between constituent quarks.

A few years back, two groups, viz. Valcarce, Gonzalez, Fernandez and Vento [10] and Dziembowski, Fabre and Miller [11] came up with versions of hybrid constituent quark models. They have presented a reasonable description of N and Δ excitation spectra taking into account a sizeable contribution from the OGE interaction. However, the performance of the hybrid constituent quark models has been studied in detail by Glozman *et al*. [5-8] by using the calculations based on accurate solutions of the three quark systems in both variational Schroedinger and a rigorous Faddeev approach. It has been argued that hybrid Q-Q interactions with a sizeable OGE component encounter difficulties in describing baryon spectra due to the specific contributions from one-gluon- and meson- exchanges together. On the contrary, Glozman *et al*. [5-8] have shown that a chiral constituent quark model with a Q-Q interaction relying solely on Goldstone-boson-exchange (GBE) is capable of providing a unified description not only of the N and Δ spectra but also of all strange baryons in good agreement with phenomenology. They have also presented a constituent quark model with the confinement potential in linear and harmonic [5-8] forms for the light and strange baryons providing a unified description of their ground states and excitation spectra. Their model which relies on constituent quarks and Goldstone bosons arising as effective degrees of freedom of low energy quantum chromo-dynamics (QCD) from the spontaneous breaking of chiral symmetry (SBCS) has been found to be quite proficient in reproducing the spectra of the three quark systems from a precise variational solution of a Schroedinger equation with a semi-relativistic Hamiltonian.

Although the phenomenological picture is reasonable at the non-relativistic level, a relativistic approach is quite indispensable on this account in view of the fact that the baryonic mass splittings are of the same order as the constituent quark masses. Of course, the chiral constituent quark model which has been constructed by Glozman *et al.* [5-8] in a semi-relativistic framework is a step in this direction and shows an essential improvement over non-relativistic approaches. As another step in this direction, recently the scope of a relativistically covariant constituent quark model of baryons based on Bethe-Salpeter equation in instantaneous approximation has been illustrated [12] by a discussion of various baryon resonance observables. The MIT bag model [13-15] has also been found to be relatively

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successful in this respect. In its improved versions, the Chiral Bag Model (CBM) [16] have included the effect of pion self-energy due to baryon-pion coupling at the vertex to provide a better understanding of the baryon masses. Nevertheless, such models still contain some dubious phenomenological elements which are objectionable. The sharp spherical bag boundary, the zero point energy, the exclusion of pions from within the bag or ad hoc inclusion of pions within it, are a few such points to be noted in this context. Furthermore it is somewhat difficult to believe that the static spherical bag remains unperturbed even after the creation of a pion. However, the sharp spherical bag boundary in the bag confinement, which is at the root of all objections and difficulties encountered by the otherwise successful CBM, is nonetheless arbitrary and phenomenological in nature and should therefore be replaced by an alternative and suitable phenomenological average potential for individual quarks, presuming at the same time its good features together with its successful predictions in the study of light baryons in their ground states. The chiral potential models [17-19] which are comparatively more straight-forward in the above respects are obviously attempts in this direction. In such models the confining potentials which basically represent the interaction of quarks with the gluon field are usually assumed phenomenologically as Lorentz scalars in harmonic and cubic forms. Potentials of a different type of Lorentz structure with equally mixed scalar and vector parts in harmonic [20-23], non-Coulombic power-law [24-31], square-root [32-34], and logarithmic [35-39] form are also used in this context. The term in the Lagrangian density for quarks corresponding to the effective scalar part of the potential in such models being chirally non-invariant through all spaces requires the introduction of an additional pionic component everywhere in order to preserve chiral symmetry. The effective potential of individual quarks in these models, which is basically due to the interaction of quarks with the gluon field, may be thought of as being mediated in a self-consistent manner through Nambu-Jona-Lasino (NJL)-type models [40-43] by some form of instanton induced effective quark-quark contact interaction with position-dependent coupling strength. The position-dependent coupling strength, supposedly determined by the multi-gluon mechanism, is impossible to calculate from first principles, although it is believed to be small at the origin and increases rapidly towards the hadron surface. Therefore, one needs to introduce the effective potential for individual quarks in a phenomenological manner to seek a posteriori justification in finding its conformity with the supposed qualitative behavior of the position-dependent coupling strength in the contact interaction.

However, with no theoretical prejudice in flavors of any particular mechanism for generating confinement of individual quarks, we prefer to work in an alternative, but similar scheme based on Dirac equation with a purely phenomenological individual quark potential of the form

$$V_q(r) = \frac{1}{2}(1+\gamma^0)(a^2 r + V_0) \quad (1)$$

with $a > 0$. Here $\boldsymbol{a}$ and $\boldsymbol{V_0}$ are potential parameters and γ^0 is Dirac's gama matrix. Such a model takes the Lorentz structure of the potential as an equal admixture of scalar and vector parts because of the fact that both the scalar and vector parts in equal proportions at every point render the solvability of the Dirac equation for independent quarks by reducing it to the form of a Schrodinger-like equation. This Lorentz structure of the potential also has an additional advantage of generating no spin-orbit splitting, as observed in the experimental baryon spectrum.

This potential has been used in the past to study successfully the static baryon properties [44, 45], the weak-electric and -magnetic form factors for the semileptonic baryon decays [46], electromagnetic properties of nucleons [47, 48] and the magnetic moments of the baryons in the nucleon octet [49] in reasonable agreement with the experimental data. This model has also been adapted to study reasonably well the mass and decay constant of the $(q\bar{q})$ pion [50], S-state mass splittings of the mesons of $s\bar{s}$, $c\bar{c}$ and $b\bar{b}$ systems, ground state mass splittings of the heavy non-self-conjugate mesons in strange, charm and bottom flavor sector [51] and electromagnetic decays of mesons [51,52]. This model has also been employed to explain reasonably well the mass spectrum of octet baryons [53] taking into account the contributions due to the color-electric and -magnetic energies arising out of the residual OGE interaction along with that due to the residual quark-pion coupling arising out of the requirement of the chiral symmetry and the necessary centre-of-mass (c.m) motion. But in this work the interactions between the constituent quarks arising out of the Goldstone-boson exchange (GBE) which are considered to play an important role in contributing to the energy of the baryon core were not taken into account. Therefore in the present work we wish to take into account the GBE contributions along with OGE contribution in a perturbative manner to study the excitation spectra of octet baryons. Very recently [54] we have also found that the present model can be used successfully to describe the ground state mass spectra of light- and strange baryons taking into account the correction due to the energy arising out of the GBE interactions along with those due to the energy associated with the residual OGE interaction and c.m motion. In view of this success, we intend to extend the application of the present model to the study of the excitation spectra of light- and strange-baryons in the present work. Here we are interested to study the ground states and the excitation spectra of baryons in the framework of the potential model (Eq. 1) taking into account the contributions from GBE and OGE interactions between the constituent quarks over and above the centre-of-mass motion. In the present work we also intend to extend the applicability of this model to the study of the mass spectra for some of the other four and three star resonances of baryons [55, 56].

In the present model, baryons are considered as systems of three constituent quarks with dynamical masses which are confined in a first approximation by an effective linear potential and are subjected to interaction by GBE. For the inclusion of the GBE contributions in this model we have followed the guidelines of the chiral constituent quark models suggested by Glozman *et al*. [5-8]. However, we use these contributions in a perturbative manner along with OGE contributions. In this context we may point out that we consider the constituent quarks of flavors u, d, and s with masses considerably larger than the corresponding current quark masses so that the underlying chiral symmetry of QCD is spontaneously broken. As a consequence of SBCS, at the same time Goldstone bosons appear which couple directly to the constituent quarks [5-8, 57-59]. Hence, beyond the scale of SBCS one is left with constituent quarks with dynamical masses related to $\langle\bar{q}q\rangle$ condensates and with Goldstone bosons as the effective degrees of freedom. This feature, that in the Nambu-Goldstone mode of chiral symmetry constituent quark and Goldstone boson fields prevail together, is well supported, e.g., by the σ model [60] or the NJL model [40-43]. In the same framework also with the spin and flavor content of the nucleon are naturally resolved [61].

The work is organized as follows. In section-2 we outline the potential model with the solutions for the relativistic bound states of the individually confined quarks in the 1S, 2S, 1P, 1D and 1F states of baryons and the energy corrections due to the spurious center-of-mass motion are briefly discussed. Section-3 provides a brief account of the corrections due to Goldstone Boson or (π, η and K-meson) exchange interactions between the constituent quarks in a generalized way. This section also deals with a further correction to the baryon masses due to color-electric and magnetic interaction energies originating from the hopefully weak residual OGE interactions, treated perturbatively. Finally, in section-4 we present the results for the masses of the ground states and excited states of light-and strange-baryons, which are in reasonable agreement with the corresponding experimental values. The results for the mass spectra of some of the other four and three star resonances of baryons are also presented in this section.

2. RELATIVISTIC POTENTIAL MODELS

Leaving behind for the moment the quark-gluon interaction originating from OGE at short distances and the interaction of the quarks due to GBE arising from SBCS to be treated perturbatively, we begin with the confinement part of the interaction which is believed to be dominant in baryonic dimensions. This particular part of the interaction which is believed to be determined by the multi-gluon mechanism is impossible to calculate theoretically from first principles. Therefore from a phenomenological point of view we assume that the constituent quarks in a baryon core are independently confined by an average flavor-independent relativistic potential of the form given in equation (1). Hence, to a first approximation, the confining past of the interaction represented here by an average flavor-independent potential is believed to provide zeroth order constituent quark dynamics inside such baryons. We further assume that the constituent independent quarks obey the Dirac equation with potential $V_q(r)$ implying there by a Lagrangian density of zeroth order as

$$\mathcal{L}_q^0(x) = \bar{\psi}_q(x)\left[\frac{i}{2}\gamma^\mu \overleftrightarrow{\partial}_\mu - m_q - V_q(r)\right]\psi_q(x) \tag{2}$$

which leads to Dirac equation for individual quark of mass m_q as

$$\left[\gamma^0 E_q - \vec{\gamma}.\vec{p} - m_q - V_q(r)\right]\psi_q(\vec{r}) = 0 \tag{3}$$

where the normalized quark wave function $\psi_q(\vec{r})$ can be written in two component form as

$$\psi_{nlj}(\vec{r}) = N_{nl}\begin{pmatrix} if_{nlj}(r)/r \\ (\vec{\sigma}.\hat{r})g_{nlj}(r)/r \end{pmatrix} y_{nlj}(\hat{r}). \tag{4}$$

Here, the normalized spin angular part is

$$y_{ljm}(\hat{r}) = \sum_{m_l m_s} \langle l, m_l, \frac{1}{2}, m_s | j, m_j\rangle Y_l^{m_l} \chi_{\frac{1}{2}}^{m_s} \tag{5}$$

and N_{nl} is the overall normalization constant. The reduced radial part $f_{njl}(r)$ of the upper component of Dirac spin or $\psi_{njl}(\vec{r})$ statics the equation

$$f''_{nlj}(r) + \left[\lambda_{nl}\{E_{nl}^q - m_q - V(r)\} - \frac{l(l+1)}{r^2}\right]f_{nlj}(r) = 0 \tag{6}$$

where

$$\lambda_{nl} = E_{nl}^q + m_q \tag{7}$$

The present model can in principle provide the quark orbitals $\psi_{njl}(\vec{r})$ and the zeroth order binding energies of the confined quark for various possible eigen modes through equations (4)-(7). However, for the ground state baryons, in which all the constituent quarks are in their lowest eigenstates, the corresponding quark orbital's can be expressed as

$$\psi_{1s}(\vec{r}) = N_{nl}\begin{pmatrix} \phi_{1s}(\vec{r}) \\ \frac{\vec{\sigma}.\vec{p}}{\lambda_{nl}}\phi_{1s}(r) \end{pmatrix}\chi\uparrow \tag{8}$$

where $\phi_{1s}(\vec{r})$ is the radial angular part of the upper component $\psi_{1s}(\vec{r})$ and is given by $\phi_{1s}(\vec{r}) = \frac{i}{\sqrt{4\pi}}f_{1s}(r)/r$. For the ground state equation (6) reduces to

$$f''_{1s}(r) + \left[\lambda_{1s}(E_{1s}^q - m_q - a^2 r - V_0)\right]f_{1s}(r) = 0 \tag{9}$$

which can be transformed into a convenient dimensionless form

$$f''_{1s}(\rho) + (\epsilon_{1s} - \rho)f_{1s}(\rho) = 0 \tag{10}$$

where $\rho = r/r_{0q}$ is a dimensionless variable with $r_{0q} = (\lambda_q a^2)^{-1/3}$ and

$$\epsilon_{1s} = \left(\frac{\lambda_{1s}}{a^4}\right)^{\frac{1}{3}}(E_{1s}^q - m_q - V_0) \tag{11}$$

The equation (10) is the basic eigenvalue equation, which can be solved as follows: With $z = \rho - \epsilon_q$, $f_q = f_{1s}$ and $\epsilon_q = \epsilon_{1s}$ equation (10) reduces to the Airy equation

$$f''_q(z) - z f_q(z) = 0 \tag{12}$$

The solution $f_q(z)$ of equation (12) is the Airy function $Ai(z)$. Since at $r = 0$ we require $f_q(z) = 0$ we have $Ai(z) = 0$ at $z = -\epsilon_q$. If Z_n are the roots of the Airy function such that $Ai(z_n) = 0$, then we have $z = -\epsilon_q = z_n$. For the ground state of quarks, the ϵ_{1s} value is given by the first root z_1 of the Airy function so that

$$\epsilon_q = \epsilon_{1s} = -z_1 \tag{13}$$

The value of this root $z_1 = -2.33811$ and hence $\epsilon_{1s} = 2.33811$ Now the individual quark binding energy E^q_{1s} of zeroth order in the baryon ground state can be obtained from equation (11) through the relation

$$E^q_{1s} = m_q - V_0 + a x_q \tag{14}$$

where x_q is the solution of the root equation obtained through substitution from equation (11) in the form

$$x_q^4 + b x_q^3 - \epsilon_q^3 = 0 \tag{15}$$

with $b = \frac{2E_q + V_0}{a}$. Solution for the quark binding energy E^q_{1s} in the zeroth order corresponding to the ground state of the baryon immediately leads to the ground state mass of the baryon core in zeroth order as

$$M^0_B = E^0_B = \sum_q E^q_{1s} \tag{16}$$

In this model equation (6) is then solved for 2S, 1P, 1D and 1F states to obtain the individual quark binding energy E^q_{2S}, E^q_{1P}, E^q_{1D} and E^q_{1F} respectively, with the help of a standard numerical method which yields ϵ_{2S}= 4.08741, ϵ_{1P}= 3.3611, ϵ_{1D}= 4.2480 and ϵ_{1F}= 5.05069. These values lead to the corresponding masses of the excited states of baryon core in zeroth order in the same way as in case of the ground state. The overall normalization constant N_{nl} of $\psi_{nlj}(\vec{r})$ appearing in equation (4) is of the form

$$N^2_{nl} = \left[1 + \frac{\left(E^q_{nl} - m_q - V_0 - a \langle\langle r \rangle\rangle_{nl}\right)}{\lambda_{nl}}\right]^{-1} \tag{17}$$

where $\langle\langle r \rangle\rangle_{nl}$ is the expectation value of r with respect to $\phi_{nlj}(\vec{r})$. In this model there would be a sizeable spurious contribution to the energy E^q_{nl} from the motion of the centre-of-mass of the three-quark system. Unless this aspect is duly accounted for, the concept of the independent motion of quarks inside the baryon core will not lead to a physical baryon state of definite momentum. Although there is still some controversy on this subject, we follow the technique adopted by Bartelski *et al.* and E.Eich *et al.* [62, 63], which is just one way of accounting for the c.m motion. Following their prescription a ready estimate of the c.m momentum $\vec{P}_B$ of the baryon core can be obtained as

$$< \vec{P}^2_B >_{nl} = \sum_q < \vec{P}_q^{\,2} >_{nl} \tag{18}$$

where $< \vec{P}_q^{\,2} >_{nl}$ is the average value of the square of the individual quark momentum taken over the single quark states and is given in this model as

$$\langle \vec{P}_q^{\,2} \rangle_{nl} = N^2_{nl}[2E^q_{nl}(E^q_{nl} - m_q) - (3E^q_{nl} - m_q - V_0)V_0$$
$$- (3E^q_{nl} - m_q - 2V_0)a^2\langle\langle r \rangle\rangle_{nl} + a^4\langle\langle r^2 \rangle\rangle_{nl}] \tag{19}$$

where the double angular brackets represent the expectation values with respect to $\phi_{nl}(\vec{r})$

Therefore, if E^0_B is the energy of the baryon core in zeroth order then the centre of-mass correction to baryon mass is

$$(\Delta E_B)_{cm} = E_B - E^0_B = \left[{E^0_B}^2 - \langle \vec{P}^2_B \rangle_{nl}\right]^{\frac{1}{2}} - E^0_B \tag{20}$$

where E_B is the c.m corrected mass of the baryon core.

3. CORRECTIONS DUE TO GOLDSTONE BOSON EXCHANGE (GBE) INTERACTIONS

The $SU(3)_L \times SU(3)_R$ chiral symmetry of QCD Lagrangian is spontaneously broken down to $SU(3)_V$ by the QCD vacuum [in the large N_c limit it would be $[U(3)_L \times U(3)_R \rightarrow U(3)_V]$. There are two important generic consequences of the SBCS. The first one is an appearance of the octet of pseudoscalar mesons of low mass, π, K, η, which represent the associated approximate Goldstone bosons (in the large N_c limit the flavor singlet state η' should be added). The second one is that valence (partially massless) quarks acquire a dynamical mass, which has been called historically constituent mass. Indeed, the nonzero value of quark condensate, $< \bar{q}q > \sim -(250\ MeV)^3$, itself implies at the formal level that there must be at low momenta a rather big dynamical mass, which should be a momentum dependent quantity. Such a dynamical mass is now directly observed on the lattice [64]. Thus the constituent quarks should be considered as quasi-particles whose dynamical mass at low momenta comes from the non-perturbative gluon and quark anti quark dressing. The flavor-octet axial current conservation in the chiral limit tells that the constituent quarks and Goldstone bosons should be coupled with the strength $g = g_A M/f_\pi$, [57-59] which is a quark analog of the famous Goldberger-Treiman relation. It has been recently suggested that in the low-energy regime, below the chiral symmetry breaking scale~$1GeV$, the low lying light and strange baryons should be predominantly viewed as systems of three constituent quarks with an effective confining interaction and a chiral interaction mediated by GBE between the constituent quarks [5-8].

The coupling of Goldstone bosons (π, η and K mesons) to the constituent quarks arising from SBCS in QCD can be taken into account in a perturbative manner in the same way as it has been done in the study of the effect of quark-pion coupling in the CBM [16]. Here the fields of the Goldstone bosons may be treated independently without any constraint and their interactions with the quarks can be assumed to be linear as it is done in case of the pion [16].

Following the Hamiltonian technique [16] as has been used in the CBM, we can describe the effect of goldstone bosons (i.e. mesons $\chi = \pi, \eta, K$) in low-order perturbation theory as follows. The mesonic self-energy of the baryons can be evaluated with the help of the single-loop self-energy diagram (Fig. **1**) as:

$$\sum_{B}(E_B) = \sum_{k}\sum_{B'} \frac{V^{\dagger BB'} V^{BB'}}{(E_B - \omega_k - M_{B'}^0)} \tag{21}$$

where $\sum_k = \sum_j \int \frac{d^3\vec{k}}{(2\pi)^3}$. Here j corresponds to the meson-isospin index and B' is the intermediate baryon state. $V^{BB'}(\vec{k})$ is the general baryon-meson absorption vertex function obtained [65, 66] in this model as

$$V_j^{BB'}(\vec{k}) = i\sqrt{4\pi}\frac{f_{BB'\chi}}{m_\chi}\frac{ku(k)}{\sqrt{2\omega_k}}\left(\vec{\sigma}^{BB'}.\hat{k}\right)\tau_j^{BB'} \tag{22}$$

where $\vec{\sigma}_j^{BB'}$ and $\vec{\tau}_j^{BB'}$ are spin and isospin matrices and the form $\omega_k^2 = \vec{k}^2 + m_\chi^2$ factor $u(k)$ in this model can be expressed as

$$u(k) = \frac{5N_{nl}^2}{3\lambda_{nl}g_A}[(2m_q + V_0) \ll j_0(|\vec{k}|)r \gg + a^2 \ll rj_0(|\vec{k}|r) \gg$$

$$+a^2 << j_1(|\vec{k}|r)/k >>] \tag{23}$$

where $j_0(|\vec{k}|r)$ and $j_1(|\vec{k}|r)$ represent the zeroth and first order spherical Bessel functions, respectively. The double angular brackets stand for the expectation values with respect to $\phi_{nl}(r)$. In this model the axial vector coupling constant g_A for the beta decay of the neutron is given by

$$g_A = \frac{5}{9}\left(\frac{8E_{nl}^q + 10m_q + V_0}{4E_{nl}^q + 2m_q - V_0}\right) \tag{24}$$

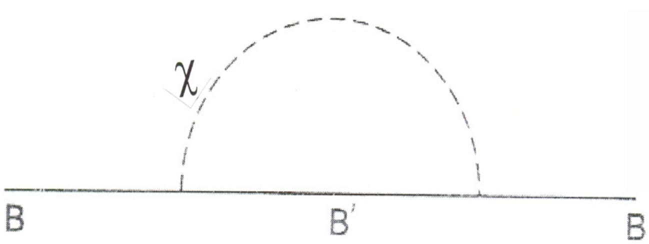


Fig. (1). Baryon self-energy due to coupling with meson.

Now with the vertex function $V_j^{BB'}(\vec{k})$ at hand, it is possible to calculate the mesonic self-energy for various baryons with appropriate baryon intermediate states contributing to the process. For degenerate intermediate states on mass shell with $M_B^0 = M_{B'}^0$ the self-energy correction becomes

$$(\delta M_B)_\chi = \sum_{B}(E_B^0 = M_B^0 = M_{B'}^0) = -\sum_{k,B'}\frac{V^{\dagger BB'} V^{BB'}}{\omega_k} \tag{25}$$

Now using equation (22), we find

$$(\delta M_B)_\chi = \frac{-I_\chi}{B'}\sum_{B'} C_{BB'} f_{BB'\pi}^2 \tag{26}$$

where

$$C_{BB'} = \left(\vec{\sigma}^{BB'}.\vec{\sigma}^{B'B}\right)\left(\vec{\tau}^{BB'}.\vec{\tau}^{B'B}\right) \tag{27}$$

and

$$I_\chi = \frac{1}{\pi m_\chi^2}\int_0^\infty \frac{dk k^4 u^2(k)}{\omega_k^2} \tag{28}$$

where $\chi = \pi, \eta, k$

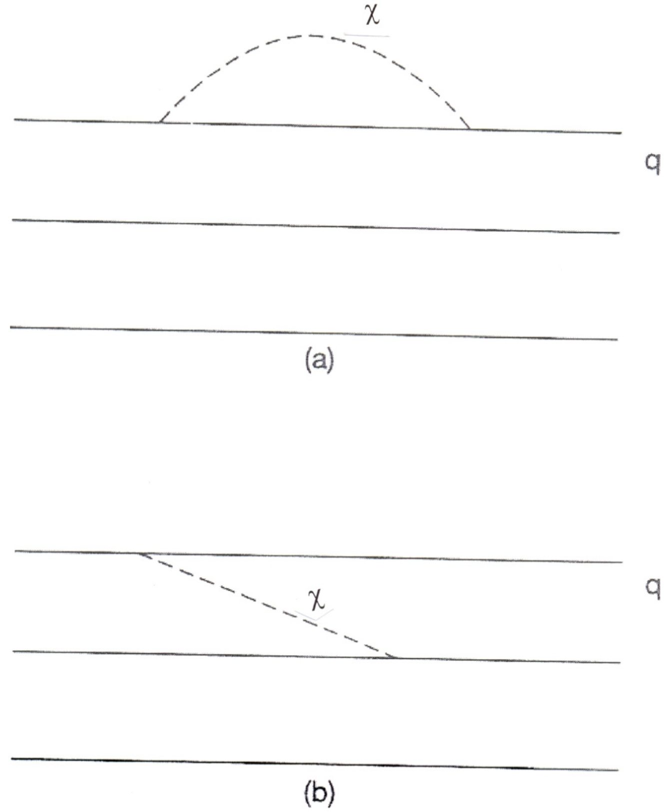


Fig. (2). (**a**) Mesonic self energy contribution. (**b**) One-meson-exchange contribution.

The self-energy $(\delta M_B)_\chi$ for different baryons can be computed by using the values of $f_{BB'\chi}$ and $C_{BB'}$ [1-3] as has been done in our earlier works [57-59]. The self-energy $(\delta M_B)_\chi$ calculated here contains both the quark self-energy (Fig. **2a**) and the one-meson-exchange contributions (Fig. **2b**). It must be noted here that this method ignores to a large extent the short-range part of the pion exchange interaction, which is of crucial importance for splittings. Only when the complete infinite set of all radially excited intermediate state B' is taken into account, the method could be adequate [31].

Following the discussions given in ref. [1-3] the baryon-meson coupling constant $f_{BB'\chi}$ can be expressed in terms of the nucleon-meson coupling constant $f_{NN\chi}$. Pion exchange interaction acts only between light quarks whereas η-exchange is allowed in all quark pair states. The kaon exchange interaction takes place in u-s and d-s pair states.

4. CORRECTION DUE TO OGE INTERACTION

The individual quarks in a baryon core are considered so far to be experiencing forces coming from the Potential $V_q(r)$ in Eq. (1) which is assumed to provide a suitable phenomenological description of the non-perturbative gluon interaction including gluon self-couplings. Besides the GBE interaction all that remains inside the baryon is the hopefully weak OGE interaction provided by the interaction Lagrangian density

$$\mathcal{L}_I^g = \sum_{\alpha=1}^{8} J_i^{\mu\alpha}(x)A_\mu^\alpha(x) \tag{29}$$

where $A_\mu^\alpha(x)$ the eight-vector gluons are fields and $J_i^{\mu\alpha}(x)$ is the i-th quark color current. Since at small distances the quarks should almost be free, it is reasonable to calculate the energy shift in the mass spectrum arising out of the quark interaction energy due to their coupling to the coloured gluons, using a first-order perturbation theory. If we only keep the terms of order α_c, the problem reduces to evaluating the diagrams shown in Fig. (**3**), where Fig. (**3a**) corresponds to the OGE part and Fig. (**3b**) implies the quark self-energy that normally contributes to the renormalization of quark masses. If $\vec{E}_i^\alpha$ and $\vec{B}_i^\alpha$ are the colour-electric and -magnetic fields, respectively, generated by the i-th quark colour-current

$$J_i^{\mu\alpha}(x) = g_c\bar{\psi}_i(x)\gamma^\mu\lambda_i^\alpha\psi_i(x) \tag{30}$$

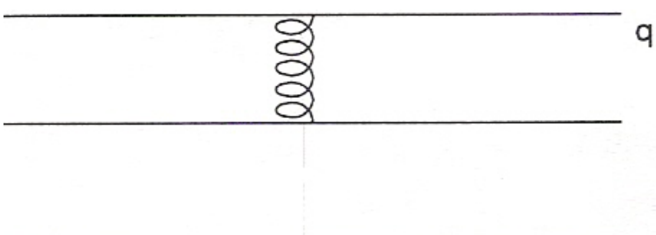
with $\vec{\lambda}_i^\alpha$ being the usual Gell-Mann SU (3) matrices and $\alpha_c = (g_c^2/4\pi)$, then the contribution to the mass can be written as a sum of the color-electric and –magnetic parts as

$$(\Delta E_B)_g = (\Delta E_B)_g^e + (\Delta E_B)_g^m \tag{31}$$

where

$$(\Delta E_B)_g^e = \frac{1}{8\pi}\sum_{i,j}\sum_{\alpha=1}^{8}\int\int\frac{d^3\vec{r}_i d^3\vec{r}_j}{|\vec{r}_i - \vec{r}_j|} < B|J_i^{0\alpha}(\vec{r}_i)J_j^{0\alpha}(\vec{r}_j)|B > \tag{32}$$

$$(\Delta E_B)_g^m = \frac{-1}{4\pi}\sum_{i<j}\sum_{\alpha=1}^{8}\int\int\frac{d^3\vec{r}_i d^3\vec{r}_j}{|\vec{r}_i - \vec{r}_j|} < B|\vec{J}_i^\alpha(\vec{r}_i).\vec{J}_j^\alpha(\vec{r}_j)|B > \tag{33}$$



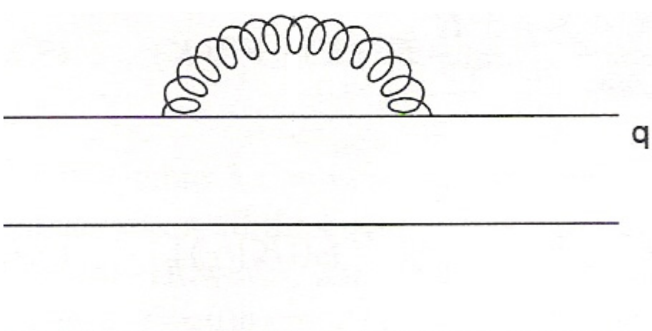


Fig. (3). (**a**) One-gluon-exchange contribution. (**b**) Gluonic self energy contribution.

We have not included the self-energy in the calculation of the magnetic part of the interaction, which contributes to the renormalization of the quark masses and can possibly be accounted for in the phenomenological quark masses. The exclusion of this diagram, however, requires that each $\vec{B}_i^\alpha$ should satisfy the boundary condition $\hat{r}\times\vec{B}_i^\alpha = 0$, separately at the edge of the confining region, which is a possible case. On the other hand, as the electric field $\vec{E}_i^\alpha$ is necessarily in the radial direction, it is only possible to satisfy the boundary condition $\hat{r}\times\sum_i\vec{E}_i^\alpha = 0$ for a colour singlet state $|B\rangle$ for which $\sum_i\lambda_i^\alpha = 0$. Therefore, in order to preserve the boundary conditions we are forced to take into account the self-energy in the calculation of the electric part only. Now using Eq. (4) in Eq. (30) we find

$$J_i^{0\alpha}(\vec{r}_i) = g_c\lambda_i^\alpha N_i^2\left[\phi^2(r_i) + \frac{\phi'^2(r_i)}{\lambda_i^2}\right]$$

$$J_i^\alpha(\vec{r}_i) = -2g_c\lambda_i^\alpha N_i^2(\vec{\sigma}_i\times\hat{r}_i)\frac{\phi(r_i)\phi'(r_i)}{\lambda_i} \tag{34}$$

Again using Eq. (34) together with the identity

$$\frac{1}{|\vec{r}_i - \vec{r}_j|} = \frac{1}{2\pi^2}\int\frac{d^3\vec{k}}{k^2}e^{-i\vec{k}.(\vec{r}_i - \vec{r}_j)} \tag{35}$$

in Eqs. (32) and (33), we obtain

$$(\Delta E_B)_g^e = \frac{\alpha_c}{4\pi^2}\sum_{i,j}\langle\sum_\alpha\lambda_i^\alpha\lambda_j^\alpha\rangle N_i^2N_j^2\int\frac{d^3\vec{k}}{k^2}F_i^e(k)F_j^e(k) \tag{36}$$

$$(\Delta E_B)_g^m = \frac{-2\alpha_c}{\pi^2}\sum_{i<j}\langle\sum_\alpha\lambda_i^\alpha\lambda_j^\alpha\rangle\frac{N_i^2N_j^2}{\lambda_i\lambda_j}\int\frac{d^3\vec{k}}{k^2}\vec{F}_i^m(k).\vec{F}_j^m(k) \tag{37}$$

where

$$F_i^e(k) = \frac{1}{\lambda_i^2}\left[\left((2E_i - V_0)\lambda_i - k^2\right)\langle\langle j_0(|\vec{k}|r_i)\rangle\rangle - \lambda_i a^2\langle\langle r_i j_0(|\vec{k}|r_i)\rangle\rangle\right] \tag{38}$$

$$\vec{F}_i^m(k) = \frac{i}{2}\langle\langle j_0(|\vec{k}|r_i)\rangle\rangle(\vec{\sigma}_i\times\vec{k}) \tag{39}$$

Then eqs. (36) and (37) can be written as

$$(\Delta E_B)_g^e = \frac{\alpha_c}{\pi}\sum_{i,j}\langle\sum_\alpha\lambda_i^\alpha\lambda_j^\alpha\rangle N_i^2N_j^2 I_{ij}^e \tag{40}$$

$$(\Delta E_B)_g^m = \frac{-4\alpha_c}{3\pi}\sum_{i<j}\langle\sum_\alpha\lambda_i^\alpha\lambda_j^\alpha(\vec{\sigma}_i.\vec{\sigma}_j)\rangle\frac{N_i^2N_j^2}{\lambda_i\lambda_j}I_{ij}^m \tag{41}$$

where

$$I_{ij}^e = \int_0^\infty dk F_i^e(k)F_j^e(k) \tag{42}$$

$$I_{ij}^m = \int_0^\infty dk k^2\langle\langle j_0(|\vec{k}|r_i)\rangle\rangle\langle\langle j_0(|\vec{k}|r_j)\rangle\rangle \tag{43}$$

Finally, by taking into account the specific quark flavor and spin configurations in various states of the baryon and using the relations $\langle\sum_\alpha(\lambda_i^\alpha)^2\rangle = \frac{16}{3}$ and $\langle\sum_\alpha\lambda_i^\alpha\lambda_j^\alpha\rangle_{i\neq j} = \frac{-8}{3}$ for baryons, in general one can write the energy correction due to OGE as

$$(\Delta E_B)_g^e = \alpha_c(a_{uu}T_{uu}^e + a_{us}T_{us}^e + a_{ss}T_{ss}^e) \tag{44}$$

$$(\Delta E_B)_g^m = \alpha_c(b_{uu}T_{uu}^m + b_{us}T_{us}^m + b_{ss}T_{ss}^m) \tag{45}$$

where a_{ij} and b_{ij} are the numerical coefficients depending on each baryon listed in Table **1** and the terms $T_{ij}^{e,m}$ are

$$T_{ij}^e = \frac{48(E_i + m_i)(E_j + m_j)}{\pi(4E_i + 2m_i - V_0)(4E_j + 2m_j - V_0)}I_{ij}^e \tag{46}$$

$$T_{ij}^{m} = \frac{32}{\pi(4E_i + 2m_i - V_0)(4E_j + 2m_j - V_0)} I_{ij}^{m} \tag{47}$$

Table 1. The coefficients *aij* and *bij* used in calculation of the color-electric and Colour-magnetic energy contributions due to one-gluon exchange

Baryons	a_{uu}	a_{us}	a_{ss}	b_{uu}	b_{us}	b_{ss}
N	0	0	0	-3	0	0
Δ	0	0	0	+3	0	0
Ë	1	-2	1	-3	0	0
∑	1	-2	1	1	-4	0
∑*	1	-2	1	0	-4	1
Ξ	1	-2	1	1	2	0
Ξ*	1	-2	1	0	2	1
Ω^-	0	0	0	0	0	+3

From Table **1** one can note that the color-electric contribution for the baryon masses vanishes when all the constituent quark masses in a baryon are equal, whereas it is non-zero otherwise. However, even in the case of strange baryons, it would subsequently be seen that the color-electric contribution is quite small. Therefore, the degeneracy among the baryons is essentially removed through the spin-spin interaction energy in the color-magnetic part.

5. RESULTS AND DISCUSSION

In the preceding section it has been shown that zeroth-order mass $M_B^0 = E_B^0$ of different states of a baryon arising out of the binding energies of the constituent quarks, confined independently by a phenomenological average potential $V_q(r)$ which presumably represents the dominant non-perturbative multi-gluon interactions is subjected to certain corrections due to the residual quark-gluon interaction and GBE interaction between the constituent quarks, together with that due to the spurious centre-of-mass motion. All of these corrections can be treated independently, as though they are of the same order of magnitude, so that the physical mass of a baryon can be obtained as

$$M_B = E_B^0 + (\Delta E_B)_{cm} + (\delta M_B)_\chi + (\Delta E_B)_g^m + (\Delta E_B)_g^e \tag{48}$$

where $(\Delta E_B)_{cm}$ is the c.m correction to baryon mass (eq. 20), $(\delta M_B)_\chi$ with $(\chi = \pi, \eta, K)$ is the GBE correction (Eq. 26), and $[(\Delta E_B)_g^m + (\Delta E_B)_g^e]$ is the colour magnetic and electric interaction energies arising out of OGE interactions (Eqs. 44 and 45).

The quantitative evaluation of the zeroth order energy E_B^0 of the baryon core, the c.m correction $(\Delta E_B)_{cm}$, the GBE correction $(\Delta E_B)_\chi$ and OGE correction (ΔE_B) within the frame-work of the model primarily involves the potential parameters (a, V_0), the quark masses m_q and the corresponding binding energy E_{nl}^q along with the other relevant model quantities. In the present model, the quark masses m_q and the potential parameter $'a'$ are suitably chosen and different values of the potential parameter V_0^{nl} are appropriately fixed for 1S, 2S, 1P, 1D and 1F states of baryons so as to obtain a reasonable fit to the mass spectra of the ground states as well as the excited states of baryons taking into account the energy corrections due to the GBE and OGE interactions between the constituent quraks together with that due to c.m motion. Here we choose the quark masses m_q and the potential parameter $'a'$ as

$$(m_u = m_d, m_s) = (280{,}442) MeV \tag{49}$$

$$a = 180\, MeV \tag{50}$$

and fix the values of the parameters V_0^{nl}

$$(V_0^{1S}, V_0^{2S}, V_0^{1P}) = (-200, -114, -66) MeV \tag{51}$$

$$(V_0^{1D}, V_0^{1F}) = (-74, -89) MeV \tag{52}$$

for 1S, 2S, 1P, 1D and 1F baryon states respectively. With these values of the parameters the solution of the energy eigen values equation (6) yields the individual quark binding energies E_{nl}^q for 1S, 2S, 1P, 1D and 1F states respectively as

$$(E_{1S}^u = E_{1S}^d, E_{1S}^S) = (356.278{,}485.650) MeV \tag{53}$$

$$(E_{2S}^u = E_{2S}^d, E_{2S}^S) = (599.56{,}722.81) MeV \tag{54}$$

$$(E_{1P}^u = E_{1P}^d, E_{1P}^S) = (574.04, 702.56) MeV \tag{55}$$

$$(E_{1D}^u = E_{1D}^d, E_{1D}^S) = (648.53, 772.63) MeV \tag{56}$$

$$(E_{1F}^u = E_{1F}^d, E_{1F}^S) = (706.62, 827.11) MeV \tag{57}$$

We then evaluate the integral expressions for $I_{ij}^{e,m}$ in eqn. (42) and (43) with the help of a standard numerical method and calculate the terms $T_{ij}^{e,m}$ from eqn. (46) and (47) which are necessary for computing the corrections due to OGE and GBE interactions respectively. These expressions are calculated for 1S, 2S, 1P, 1D and 1F states and are displayed in Table **2**.

Indeed, in the chiral limit there is only one coupling constant for all Goldstone bosons. Due to explicit chiral symmetry breaking the coupling constant for π, η and K may become different. However, in order to prevent a proliferation of the free parameters we try to keep the number of free parameters as small as possible and assume a single phenomenological pion-nucleon coupling constant $f_{NN\pi} = 0.283$ for all mesons (π, η, K) and this value is used here to compute the GBE corrections. The calculated results for the contribution from the GBE interaction to the ground states as well as the excited states of baryons are presented in Tables **3** and **4**. The energy corrections and the results obtained for the mass spectra of light and strange baryons are displayed in Tables **5** and **6**. The calculated values of mass spectra of baryons are found to agree reasonably well with the experiment. It is found that the OGE corrections require a value of quark-gluon coupling consistent $\alpha_c = 0.50$ which

Table 2. The Calculated Values of $T_{ij}^{e,m}$ and I_χ Required, Respectively for OGE and GBE Contributions in *MeV*

`	T_{ij}^{m}			T_{ij}^{e}			I_x		
	T_{uu}^{m}	T_{us}^{m}	T_{ss}^{m}	T_{uu}^{e}	T_{us}^{e}	T_{ss}^{e}	I_π	I_K	I_η
1S	73.85	64.63	62.90	375.67	402.20	443.76	431.90	26.29	20.49
2S	5.47	5.16	5.20	279.25	291.54	306.08	43.81	1.83	1.37
1P	13.72	12.70	12.55	328.93	345.20	364.96	124.88	6.42	4.90
1D	4.61	4.34	4.31	274.28	285.66	298.96	40.26	1.65	1.23
1F	2.11	1.99	1.96	235.97	244.78	254.89	16.47	0.54	0.390

Table 3. GBE Corrections $(\delta M_B)_\chi$ (where $\chi = \pi, \eta, K$) for the 1S, 2S and 1P States of Light- and Strange-Baryons in *MeV*

LS Multiplet	$(\delta M_B)_\pi$	$(\delta M_B)_K$	$(\delta M_B)_\eta$				$(\delta M_B)_\chi$
			$(\delta M_B)_\eta^{uu}$	$(\delta M_B)_\eta^{us}$	$(\delta M_B)_\eta^{ss}$	Total	
N	-236.60	0	313.30	0	0	313.30	76.70
Δ	-136.98	0	284.12	0	0	284.12	147.14
Ë	-149.43	199.46	14.86	46.92	0	61.78	111.81
∑	-83.02	188.88	14.86	46.92	0	61.78	167.64
∑*	-83.02	188.88	14.86	46.92	0	61.78	167.64
Ξ	-37.35	84.99	0	46.91	74.06	120.97	168.61
Ξ*	-37.35	84.99	0	46.91	74.06	120.97	168.61
Ω⁻	0	0	0	0	222.18	222.18	222.18
$\frac{1}{2}^+, N(1140)$	-23.99	0	-204.37	0	0	-204.37	-228.36
$\frac{3}{2}^-, N(1520)$; $\frac{1}{2}^-, N(1535)$	-68.41	0	-5.08	0	0	-5.08	-73.49
$\frac{3}{2}^+, \Delta(1600)$	-13.89	0	-70.88	0	0	-70.88	-84.77
$\frac{1}{2}^-, \Delta(1620)$; $\frac{3}{2}^-, \Delta(1700)$	-39.60	0	57.94	0	0	57.94	18.34
$\frac{1}{2}^-, \Lambda(1405)$; $\frac{3}{2}^-, \Lambda(1520)$	-43.20	-216.58	-2.19	-6.32	0	-8.51	-268.29
$\frac{1}{2}^+, \Lambda(1660)$	-15.16	-152.59	-6.40	-20.20	0	-26.60	-194.35
$\frac{1}{2}^-, \Lambda(1670)$; $\frac{3}{2}^-, \Lambda(1690)$	-43.20	-2.22	-2.19	-6.32	0	-8.51	-53.93
$\frac{3}{2}^+, \Sigma(1660)$	-8.42	-99.51	-6.40	-20.20	0	-26.60	-134.53
$\frac{3}{2}^-, \Xi(1820)$	-10.80	-49.47	0	7.18	0	7.18	-53.09

is consistent with the idea of treating OGE effects in low order perturbation theory.

It must be mentioned here that the evaluation of the energy contribution from GBE interaction in the Section 3 ignores to a large extent the short range part of the meson exchange interactions which are of crucial importance in

Table 4. GBE Corrections $(\delta M_B)_\chi$ (where $\chi = \pi, \eta, K$) for the 1D and 1F States of light- and Strange-Baryons in *MeV*

LS Multiplet	$(\delta M_B)_\pi$	$(\delta M_B)_K$	$(\delta M_B)_\eta$				$(\delta M_B)_\chi$
			$(\delta M_B)_\eta^{uu}$	$(\delta M_B)_\eta^{us}$	$(\delta M_B)_\eta^{ss}$	Total	
$\frac{5}{2}^+, N(1680)$; $\frac{3}{2}^+, N(1720)$ $\frac{1}{2}^+, N(1710)$;	-22.06	0	-115.687	0	0	-115.68	-137.74
$\frac{5}{2}^-, N(2070)$	-9.02	0	102.20	0	0	102.10	93.08
$\frac{5}{2}^+, \Delta(1905)$; $\frac{3}{2}^+, \Delta(1920)$ $\frac{1}{2}^+, \Delta(1910)$	-12.77	0	86.18	0	0	86.18	73.41
$\frac{5}{2}^-, \Delta(1930)$	-5.22	0	-49.04	0	0	-49.04	-54.26
$\frac{5}{2}^-, \Lambda(1830)$; $\frac{1}{2}^-, \Lambda(1800)$	-5.70	-284.65	2.44	7.77	0	10.21	-280.14
$\frac{5}{2}^+, \Lambda(1820)$; $\frac{3}{2}^+, \Lambda(1890)$ $\frac{1}{2}^+, \Lambda(1810)$;	-13.93	-25.45	-3.54	-11.19	0	-14.73	-54.11
$\frac{7}{2}^-, \Lambda(2100)$	-5.70	-2.20	2.44	7.77	0	10.21	2.31
$\frac{5}{2}^+, \Sigma(1915)$	-7.74	-16.27	-3.54	-11.19	0	-14.73	-38.74
$\frac{3}{2}^-, \Sigma(1940)$	-3.16	-146.59	2.44	7.77	0	10.21	-139.54
$\frac{5}{2}^+, \Xi(2030)$	-3.48	-7.32	0	-11.19	-17.66	-28.85	-39.65

baryonic mass splittings. Only when the complete infinite set of all radially excited intermediate states B' is taken into account, this method could be adequate [Glozman L. Ya. hep- ph / 0004229 (unpublished) (2000)]. For example, the meson exchange contribution to the N-Δ difference will become much larger. It will also be strongly enhanced when the meson exchange contribution is calculated non-perturbatively. The meson exchange contribution is strongly dependent on the radius of the bare wave function also, i.e., on the type confinement. However this dependence is included phenomenologically in the present model through the potential parameter V_0^{nl} which has been suitably fixed at different values for 1S, 2S, 1P, 1D and 1F states of baryons so as to obtain the baryonic mass spectra in reasonable agreement with the experiment. The values of V_0^{nl} as fixed for different states in equations (51) and (52) indicate that the short range part of the meson exchange contribution is large for the ground state and decreases for the excited states of baryons in our model.

In the present model we find that the SU(3), breaking effect due to the quark masses $m_u = m_d \neq m_s$ lifts the degeneracy in the ground state baryon masses through the center-of-mass corrected energy term E_B among the groups (N, Δ), (Λ, ∑, ∑*), (Ξ, Ξ*) and Ω^- Then in the next step, the GBE corrections $(\delta M_B)_\chi$ in QCD remove the degeneracy partially between N and Δ; Λ and (∑, ∑*). However, the energy contribution due to OGE, particularly the color magnetic interaction energy removes the mass degeneracy completely among these baryons. It should be pointed out

Table 5. Energy Corrections $(\Delta E_B)_{cm}$, $(\Delta E_B)_g$, $(\delta M_B)_\chi$ and Physical Masses (M_B) of 1S, 2S and 1P States of Light- and Strange-Baryons in MeV

LS Multiplet	E_B^0	$(\Delta E_B)_{cm}$	$(\Delta E_B)_g$			$(\delta M_B)_\chi$	M_B	
			$(\Delta E_B)_g^m$	$(\Delta E_B)_g^e$	Total		Cal.	Expt.
N	1068.83	-94.75	-110.78	0	-110.78	76.70	940	940
Δ	1068.83	-94.75	110.78	0	110.78	147.14	1232	1232
Ë	1198.21	-90.75	-110.78	7.51	-103.27	111.81	1116	1116
∑	1198.21	-90.75	-92.34	7.51	-84.82	167.64	1190.27	1193
∑*	1198.21	-90.75	101.56	7.50	109.06	167.64	1384.16	1385
Ξ	1327.60	-87.60	-97.81	7.51	-90.30	168.61	1318.31	1321
Ξ^*	1327.60	-87.60	96.08	7.50	103.58	168.61	1512.21	1533
Ω^-	1456.95	-85.04	94.35	0	94.35	222.18	1688.44	1672
$\frac{1}{2}^+, N(1440)$	1798.69	-122.12	-8.21	0	-8.21	-228.36	1440.00	1440
$\frac{3}{2}^-, N(1520);$ $\frac{1}{2}^-, N(1535)$	1722.12	-101.04	-20.58	0	-20.58	-73.49	1527.01	1527
$\frac{3}{2}^+, \Delta(1600)$	1798.69	-122.12	8.20	0	8.20	-84.77	1600.00	1600
$\frac{1}{2}^-, \Delta(1620);$ $\frac{3}{2}^-, \Delta(1700)$	1722.12	-101.04	20.58	0	20.58	18.34	1660.00	1660
$\frac{1}{2}^-, \Lambda(1405);$ $\frac{3}{2}^-, \Lambda(1520)$	1850.64	-99.51	-20.58	1.74	-18.84	-268.29	1464.00	1462
$\frac{1}{2}^+, \Lambda(1600)$	1921.94	-120.51	-8.21	1.13	-7.08	-194.35	1600.00	1600
$\frac{1}{2}^-, \Lambda(1670);$ $\frac{3}{2}^-, \Lambda(1690)$	1850.64	-99.51	-20.58	1.74	-18.84	-53.93	1678.36	1680
$\frac{1}{2}^+, \Sigma(1660)$	1921.94	-120.50	-7.59	1.13	-6.64	-134.53	1660.45	1660
$\frac{3}{2}^-, \Xi(1820)$	1979.16	-98.20	-19.12	1.74	-17.38	-53.09	1810.47	1820

here that the color-electric interaction energy due to OGE being minimal in case of excited states is ignored in this model.

We thus find the linear potential model which takes into account the GBE contribution together with the contribution from OGE and c.m. motion provides the ground states and excitation spectra of light and strange baryons in reasonable agreement with the experiment. This model explains successfully the correct level ordering of positive-negative parity excitation in N, Δ and Λ spectra. The present model is also capable of reproducing reasonably well the mass spectra for some of the other four and three resonances of the particle data group [56]. Undoubtedly the study of these resonances in the present work demonstrates the usefulness of this model in a convincing way. It may be pointed out that the mass spectra of baryons have been studied in noncoulombic power low potential model in an earlier work [31] using such an approach. This model could reproduce successfully the ground state mass spectra of baryons but failed to explain the correct level ordering of excited states in N, Δ and Λ spectra. Therefore we find that the present model which treats the meson degree of freedom perturbatively in the manner like it is done in CBM [16], can describe the ground state and excited state mass spectra of light and strange baryons in reasonable agreement with experiment.

Table 6. Energy Corrections $(\Delta E_B)_{cm}$, $(\Delta E_B)_g$, $(\delta M_B)_\chi$ and Physical Masses (M_B) of 1D and 1F States of Light- and Strange-Baryons in *MeV*

LS Multiplet	E_B^0	$(\Delta E_B)_{cm}$	$(\Delta E_B)_g$			$(\delta M_B)_\chi$	M_B	
			$(\Delta E_B)_g^m$	$(\Delta E_B)_g^e$	Total		Cal.	Expt.
$\frac{5}{2}^+, N(1680)$; $\frac{3}{2}^+, N(1720)$ $\frac{1}{2}^+, N(1710)$;	1945.60	-120.93	-6.92	0	-6.92	-137.74	1680.01	1703
$\frac{5}{2}^-, N(2070)$	2119.86	-138.77	-3.17	0	-3.17	93.08	2071	2070
$\frac{5}{2}^+, \Delta(1905)$; $\frac{3}{2}^+, \Delta(1920)$ $\frac{1}{2}^+, \Delta(1910)$	1945.60	-120.93	6.92	0	6.92	73.41	1905	1911
$\frac{5}{2}^-, \Delta(1930)$	2119.86	-138.77	3.17	0	3.17	-54.26	1930	1930
$\frac{5}{2}^-, \Lambda(1830)$; $\frac{1}{2}^-, \Lambda(1800)$	2240.03	-137.62	-3.17	0	-3.17	-280.14	1819.10	1815
$\frac{5}{2}^+, \Lambda(1820)$; $\frac{3}{2}^+, \Lambda(1890)$ $\frac{1}{2}^+, \Lambda(1810)$;	2069.60	-119.64	-6.92	0	-6.92	-54.11	1888.93	1840
$\frac{7}{2}^-, \Lambda(2100)$	2240.03	-137.62	-3.17	0	-3.17	2.31	2101.55	2100
$\frac{5}{2}^+, \Sigma(1915)$	2069.60	-119.64	-6.37	0	-6.37	-38.74	1904.85	1915
$\frac{3}{2}^-, \Sigma(1940)$	2240.03	-137.62	-2.92	0	-2.92	-139.54	1959.95	1940
$\frac{5}{2}^+, \Xi(2030)$	2193.81	-118.49	-6.52	0	-6.52	-39.65	2029.15	2030

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ABBREVIATIONS

c.m = centre of mass

CBM = Chiral Bag Model

CQM = Constituent Quark Model

GBE = Goldstone Boson Exchange

NJL = Nambu-Jona-Lasino

OGE = One – Gluon- Exchange

QCD = Quantum Chromo-Dynamics

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