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Nucleon octet in a relativistic logarithmic potential

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Abstract. A simple independent-quark-model based on the Dirac equation with logarithmic potential is used to calculate several properties of octet baryons such as magnetic moment, the axial vector coupling constant $g_A(n)$ for neutron β-decay and the charge radius of the proton. In view of the simplicity of the model, the results obtained are quite good.

Keywords. Independent quark model; Dirac equation logarithmic potential; octet baryons; magnetic moments; axial vector coupling constant; proton charge radius.

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1. Introduction

Considerable progress has been made in the study of the static properties of baryons by virtue of dynamical theory of quarks; however the results obtained differ from the experimental values. The quarks are believed to be light in the case of ordinary hadrons and so a relativistic description seems to be appropriate. The MIT bag model (Chodos *et al* 1974a, b; De Grand *et al* 1975) describing the static properties of baryons is one such relativistic quark model. The original bag model calculations, however, give a proton magnetic moment $\mu_p \simeq 1{\cdot}9\,\mu_N$ (μ_N = nuclear magneton) which is quite different from the experimental value of $\mu_p = 2{\cdot}79\,\mu_N$. The predictions could be improved to $\mu_p = 2{\cdot}24\,\mu_N$ (Donoghue and Johnson 1980) if one takes into account the recoil corrections and to $\mu_p \simeq 2{\cdot}6\,\mu_N$ in the cloudy-bag-model (CBM) (Thomas *et al* 1981; Theberge and Thomas 1982) with the inclusion of pion-loop corrections. There is still an appreciable discrepancy which should not be overlooked. Moreover the bag model is based upon spherical cavity approximation. While probing the electromagnetic properties of the nucleons by CBM one faces the difficulty of separating quark core contributions from those parts arising from the charged pion cloud surrounding this core. Bag models which couple a phenomenological pion field to the quarks at the bag boundary put considerable emphasis on this point. Secondly finite momentum transfer to the quark core requires an accurate treatment of nucleon recoil, or equivalently a proper description of the nucleon centre of mass motion. It is extremely difficult to achieve this in standard bag models (Branhil 1979).

Therefore it is worthwhile to try an alternative scheme which can provide a simple approach to the understanding of constituent quark dynamics, particularly in the context of magnetic moment study of the octet baryons and yet preserving the essential features of the otherwise successful bag model. In the present work we adopt a picture where the bag boundary conditions are replaced by an appropriately chosen confinement potential. Several authors have followed such a scheme (Ferreira 1977; Ferreira and Zagury 1977; Ferreira *et al* 1980; Barik and Das 1983a, b) and have used some average potential with suitable Lorentz structure to achieve the confinement of the individual constituent quarks in hadrons. Here the confinement potential replaces the effects of the external pressure on the bag. Such a scheme in the context of quark confinement and relativistic consistency has been studied by Magyari (1980) in relation to heavy meson spectra and it has been found that the logarithmic potential with a Lorentz structure in the form of an equal admixture of scalar and vector parts not only can guarantee relativistic quark confinement but also can generate $c\bar{c}$ and $b\bar{b}$ bound state masses in reasonable agreement with experimental values. Quigg and Rosner (1977) investigated the logarithmic potential with success in the non-relativistic potential model studies of the heavy mesons. The successful application of this purely phenomenological potential in the above mentioned studies tempts one to use the logarithmic potential for the study of baryons in the nucleon octet. Therefore in the present work we have studied the static properties of the octet baryons in the framework of independent quark model based on Dirac equation with the confining logarithmic potential.

2. Theoretical framework

In this section we outline the framework based on our potential model and discuss its implications with regard to the constituent quark magnetic moments which finally yield the baryon magnetic moments.

2.1 *Potential model*

We assume that the constituent quarks of baryons move independently in an average potential of the form

$$V_q(r) = (1+\gamma^0)V(r) = (1+\gamma^0)[a\ln(r/b)], \tag{1}$$

where $a, b > 0$ and r the radial distance from the baryon centre of mass. It is further assumed that the independent quark of rest mas m_q obeys the Dirac equation so that the four-component quark wave function $\psi_q(\mathbf{r})$ satisfies the equation (with $\hbar = c = 1$)

$$[\gamma^0 E_q - \gamma\cdot\mathbf{p} - m_q - V_q(r)]\psi_q(\mathbf{r}) = 0. \tag{2}$$

As in bag models we assume that the three quarks of the baryons are in their ground state with $J^P = 1/2^+$ and $J_z = 1/2$. A solution to the independent quark wave function $\psi_q(\mathbf{r})$ can be written in the two-component form as (Ferreira 1977; Ferreira and Zagury 1977; Ferreira *et al* 1980; Barik and Das 1983a, b)

$$\psi_q(\mathbf{r}) = N_q\begin{bmatrix}\psi_A(\mathbf{r})\\ \psi_B(\mathbf{r})\end{bmatrix} = N_q\begin{bmatrix}\phi_q(\mathbf{r})\\ \dfrac{\sigma\cdot\mathbf{p}}{\lambda_q}\phi_q(\mathbf{r})\end{bmatrix}\chi\uparrow, \tag{3}$$

where

$$\phi_q(\mathbf{r}) = \frac{A\,U_q(r)}{r} y_0^0(\theta, \phi) \tag{4}$$

is the normalized radial angular part of $\psi_q(\mathbf{r})$ with the normalization constant A. Here $\lambda_q = (E_q + M_q)$ and N_q is the overall normalization constant of $\psi_q(\mathbf{r})$ which can be easily obtained as

$$N_q^2 = [1 + (E_q - m_q + 2a\ln b - 2a\langle \ln r\rangle_q)/\lambda_q]^{-1}, \tag{5}$$

where $\langle \ln r\rangle_q$ means the expectation values with respect to $\phi_q(\mathbf{r})$. Finally the reduced radial part $U_q(r)$ corresponding to the ground state wave function of the confined quark in (4) is found to satisfy the equation

$$\frac{\mathrm{d}^2 U_q(r)}{\mathrm{d}r^2} = \lambda_q(E_q - m_q + 2a\ln b - 2a\ln r)U_q(r) = 0. \tag{6}$$

Now we choose a suitable length scale

$$r_{0q} = (2a\,\lambda_q)^{-1/2} \tag{7}$$

and express (6) in terms of a dimensionless variable

$$\rho = (r/r_0) \quad \text{as}$$

$$\frac{\mathrm{d}^2 U_q(\rho)}{\mathrm{d}\rho^2} + (\varepsilon_q - \ln\rho)U_q(\rho) = 0, \tag{8}$$

where $$\varepsilon_q = \left[\left(\frac{E_q - m_q}{a}\right) + \ln(2ab^2\lambda_q)\right]\Big/2. \tag{9}$$

Although numerical solution to (8) is possible, we prefer for simplicity the WKB (Wentzel – Kramers – Brillouin) solution to the numerical solution. The WKB solution of (8) is found as

$$\varepsilon_q = \ln(3\sqrt{\pi}/2) \tag{10}$$

and

$$U_q(\rho) = [D_q/(\varepsilon_q - \ln\rho)^{1/4}]\cos\left[\int_0^\rho \mathrm{d}\rho'(\varepsilon_q - \ln\rho')^{-1/2} - \pi/4\right], \tag{11}$$

where the normalization constant D_q is given by

$$D_q^2 = (8a\lambda_q/\pi)^{1/2}\exp(-\varepsilon_q). \tag{12}$$

Once ε_q is known, (9) can be used to give the individual quark binding energy E_q, which now depends on the parameters a, m_q and b through the relation

$$E_q = m_q - a\ln c + aX_q, \tag{13}$$

where $c = 2a^2b^2$ and X_q is the solution of the root equation obtained through substitution from (9) in the form

$$X_q + \ln\left[X_q + 2\left(m_q - \frac{a}{2}\ln c\right)\Big/ a\right] = 2\varepsilon_q. \tag{14}$$

Now in this independent-quark model approach the baryonic ground-state masses is given by the sum total of the constituent quark binding energies in the form

$$M_B = \sum_q E_q. \tag{15}$$

Thus the simple model provides a complete description of the relativistic bound states of the confined constituent quarks of the baryons with the quark wave function $\psi_q(\mathbf{r})$ as given in (3) and (4). The corresponding energy E_q is given by (13). It can be pointed out here that an ultra-relativistic limit to these solutions also exists when $m_q \to 0$, implying thereby that massless quarks can also be confined in such a potential model, as in the case of bag model. Also when $m_q \to \infty$ ($m_q \gg a \ln c$) we have the non-relativistic limit to the solution. In such a case we can neglect X_q and $(a \ln c)/2$ inside the square brackets of (14) as compared to m_q and obtain the value of X_q and hence E_q in a reasonably good approximation as

$$E_q \simeq m_q - a \ln c + a[2\varepsilon_q - \ln(2\, mq/a)]. \tag{16}$$

This result is well in accord with the expectation that the confined particle energy must approach the free particle mass in this limit. Now making the approximation $\lambda_q = (E_q + m_q) \simeq 2m_q$ and putting $E'_q = (E_q - m_q)$ and $V'(r) = 2a \ln\,(r/b)$ in (6) we obtain a Schrödinger type equation

$$\frac{d^2 U_q(r)}{dr^2} + 2m_q[E'_q - V'(r)]U_q(r) = 0. \tag{17}$$

The solution of this equation would ultimately yield the normalized upper component $\psi_A(\mathbf{r})$ of $\psi_q(\mathbf{r})$ which obviously in this limit must be appreciably large compared to $\psi_B(\mathbf{r})$. This can be made more clear by inspecting the expression for N_q^2 in (5). The value of $\langle \ln r \rangle_q$ in (5) can be easily obtained through WKB method as

$$\langle \ln r \rangle_q = \ln r_{0q} + \varepsilon_q - 1/2. \tag{18}$$

With this value of $\langle \ln r \rangle_q$ (5) simplifies to

$$N_q^2 = (1 + a/\lambda_q)^{-1}. \tag{19}$$

But in the limit $m_q \to \infty$, the ratio a/λ_q which approximates to $a/2m_q$ approaches to zero, leading to the limiting value of $N_q^2 = 1$. This implies that $|\psi_B(\mathbf{r})|^2 \ll |\psi_A(\mathbf{r})|^2$. Hence, a reasonable description of the confined-quark wave function by the normalized two-component function $\psi_A(\mathbf{r})$ is possible in this non-relativistic limit.

2.2 *Magnetic moment of confined quarks*

We investigate here the effect of confinement on the apparent magnetic moment of constituent quarks. With the ground state wave function $\psi_q(\mathbf{r})$ of the quark known in the form given by (3) and (4) it is straightforward to compute the magnetic moment $\boldsymbol{\mu}_q = \mu_q \boldsymbol{\sigma}$ of the quarks. By this, one introduces into the original Dirac equation a minimal coupling of an external electromagnetic field with the vector potential

$$\mathbf{A} = 1/2(-yB, XB, 0), \tag{20}$$

so that $$\mathbf{B} = \nabla \times \mathbf{A} = \hat{K}B \tag{21}$$

and the change in quark binding energy is given by

$$\Delta E_q = \int \mathrm{d}^3\mathbf{r}[\mathbf{A}(\mathbf{r})\cdot\mathbf{J}_q(\mathbf{r})] = \langle -\boldsymbol{\mu}_q\cdot\mathbf{B}\rangle. \tag{22}$$

Hence the confined-quark magnetic moment can be obtained from the relation

$$\mu_q\langle\sigma_z\rangle = |\Delta E_q|/B. \tag{23}$$

Using the relation $\mathbf{J}_q(\mathbf{r}) = e_q\psi_q(\mathbf{r})\gamma\psi_q(\mathbf{r})$ in (22), expression (23) can be simplified to

$$\mu_q\langle\sigma_z\rangle = \frac{e_q}{2}\int \mathrm{d}^3\mathbf{r}\psi_q^\dagger(\mathbf{r})[(\mathbf{r}\times\mathbf{d})_z]\psi_q(\mathbf{r}). \tag{24}$$

Using the expression for $\psi_q(\mathbf{r})$ as given in (3) and (4) and after some algebra one can show that in the units of nuclear magneton μ_N the confined quark magnetic moment

$$\mu_q = \left(\frac{2M_p e_q}{q}\right)N_q^2\mu_N, \tag{25}$$

where M_p is the proton mass and e_q is the electric charge of the quark in the unit of proton charge.

To compare with the corresponding expression obtained in the bag model it is worthwhile to remind ourselves of the expression

$$\mu_q^{\text{bag}} = \frac{e_q R}{6m_q}f(WR), \tag{26}$$

where $$f(WR) = \frac{4WR + 2m_qR - 3}{2(WR)^2 - 2WR + m_qR}, \tag{27}$$

and R is the hadronic bag radius, W is the binding energy of the quark in the lowest mode given by

$$W = [x^2 + (mR)^2]^{1/2}/R. \tag{28}$$

Here x is the root of the transcendental equation

$$\tan x = x/[1 - mR - (x^2 + m^2R^2)^{1/2}]. \tag{29}$$

If we accept the energy W here to play the role of an effective mass for the confined quarks and then compare the magnetic moment of the confined quark with the Dirac moment μ_q^D of a free quark we arrive at the useful ratio

$$R_{2q} = (\mu_q^{\text{bag}}/\mu_q^D) = \frac{WR}{3} f(WR). \tag{30}$$

Quigg (1981) pointed out that although obviously at the non-relativistic limit, this ratio is equal to unity, the two moments do not differ by more than 20% even for the extreme case of a confined massless quark. Therefore he concluded that it may not be nonsensical for the confined quarks to display Dirac-moments characteristic of their constituent masses.

In the present model when we make a similar investigation we find

$$R_{2q} = (\mu_q/\mu_q^{D'}) = \frac{2E_q}{\lambda_q} N_q^2. \tag{31}$$

In the non-relativistic limit since

$$\lambda_q \simeq 2E_q \simeq 2m_q \quad \text{and} \quad N_q^2 \Rightarrow 1,$$

the constituent quark moment approaches the Dirac moment characteristic of the constituent mass. However, in the ultra-relativistic limit when $m_q \to 0$ using (19) we find

$$R_{2q} = 2/(1 + a/E_q). \tag{32}$$

Since $(a/E_q) > 0$ for the present potential model, if we take $(a/E_q) < 1$ then the ratio R_2 takes the values in the range $1 < R_{2q} < 2$ suggesting that the two moments would differ significantly. Therefore we expect that the situation in a similar relativistic potential model describing hadrons may be quite different from what one encounters in bag models, where the relativistic effects seem to be apparently suppressed. Hence, we believe that the relativistic expression (25) for the magnetic moment of light constituent quarks in particular may bring forth some significant improvement in the proton magnetic moment as well as in the moments for the rest of baryons in the nucleon octet.

2.3 *Magnetic moments of octet baryons*

We assume that SU(3) is broken in the quark rest masses $m_u = m_d \neq m_s$ and present some consequences of the model in terms of derived expressions for some of the measurable quantities of the S-wave baryons in the nucleon octet. Also if we assume that the baryon moments arise solely from the constituent quark moments then following Johnson and Shah Jahan (1977); Bose and Singh (1980); Pandit *et al* (1981) and also the earlier work of Franklin (1968) we can obtain expressions for the magnetic moment of octet baryons in the following manner

$$\mu_B = \sum_q \langle B\uparrow|\mu_q \sigma_z^q|B\uparrow\rangle, \tag{33}$$

where $|B\uparrow\rangle$ represents the regular SU (6) state vectors of octet baryons. Then the well-known relations between the baryon magnetic moments and the corresponding constituent quark moments can be obtained as (Franklin 1968; Ferreira 1977; Ferreira and Zagury 1977; Ferreira *et al* 1980; Barik and Das 1983a, b)

$$\begin{aligned} \mu_p &= (4\mu_u - \mu_d)/3, & \mu_n &= (4\mu_d - \mu_u)/3, \\ \mu_{\Sigma^+} &= (4\mu_u - \mu_s)/3, & \mu_{\Sigma^-} &= (4\mu_d - \mu_s)/3, \\ \mu_{\Sigma^0} &= (2\mu_u + 2\mu_d - \mu_s)/3, & \mu_{(\Sigma^0,\lambda)} &= (\mu_d - \mu_u)/3, \\ \mu_{\Xi^-} &= (4\mu_s - \mu_d)/3, & \mu_{\Xi^0} &= (4\mu_s - \mu_u)/3, \end{aligned} \tag{34}$$

where $\mu_{u,\,d,\,s}$ are the magnetic moments of the constituent quarks u, d, s respectively.

2.4 *Axial vector coupling constant for neutron β-decay*

We find in the present model the expressions for the axial vector coupling constant $g_A(n)$ for neutron β-decay. Interpreting the weak β-decay of the neutron $n \to p + e^- + \nu_e^-$ as quark β decay like $d \to u + e^- + \nu_e^-$ occurring inside the neutron core, then as in bag model calculation (Chodos *et al* 1974; Donoghue and Johnson 1980) one can obtain the axial vector coupling constant $g_A(n)$ for neutron β-decay as

$$g_A(n) = g_A^{\mathrm{SU(6)}}(n)\, N_u^2 \left(1 - \frac{1}{3\lambda_u^2} \int \mathrm{d}^3 r |\phi'(\mathbf{r})|^2\right) \tag{35}$$

where $g_A^{\mathrm{SU(6)}}(n)$ stands for the matrix element $\langle n\uparrow|\sigma'_{uu}\tau/2|n\uparrow\rangle$.
Equation (35) after simplification reduces to

$$g_A(n) = g_A^{\mathrm{SU(6)}}(n)\,[1/3(4N_u^2 - 1)]. \tag{36}$$

Then with $g_A^{\mathrm{SU(6)}}(n) = 5/3$ the axial vector coupling constant for neutron β-decay is obtained as

$$g_A(n) = 5(4N_u^2 - 1)/9. \tag{37}$$

2.5 *Mean-square charge radius of the proton*

Finally the mean-square charge radius of the proton can be obtained from the expression (Ferreira 1977; Ferreira and Zagury 1977; Ferreira 1980; Barik and Das 1983a, b)

$$\begin{aligned} \langle r^2\rangle_p &= \langle p\uparrow|\sum_q e_q \int \mathrm{d}^3\mathbf{r}\, r^2 \psi_q^\dagger(\mathbf{r})\psi_q(\mathbf{r})|p\uparrow\rangle \\ &= \sum_q e_q \langle r^2\rangle_q = \langle r^2\rangle_u, \end{aligned} \tag{38}$$

where $\langle r^2\rangle_u$ is the individual contribution of u-quark obtained through WKB method as

$$\langle r^2\rangle_u = r_{0u}^2 \exp(2\varepsilon_q)/\sqrt{3}. \tag{39}$$

3. Results and conclusion

The outcome of the present model depends very much on our choice of the potential parameters a and b and the quark mass parameters $m_u (= m_d)$ and m_s. Although these parameters are *a priori* unconstrained, we have to make a suitable choice by a reasonable fit. First of all we make the usual assumption that the average potential taken in this model for the confined independent quarks inside the baryons is flavour-independent. Therefore with the values of parameters a and b suitably fixed, the values of $m_u = m_d$ and m_s have to be adjusted properly so that when confined within the nucleon by an average potential given by (1) the up and down quark would have the binding energy $E_u = E_d = M_p/3$ and the strange quark would have the binding energy $E_s = (M_\Lambda - 2E_u)$ where M_Λ is the mass of Λ. Since we are not particularly interested here in the detailed baryonic mass spectrum, we choose the parameters a, b, $m_u = m_d$ and m_s and hence $E_u = E_d$ and E_s appropriately to obtain the values of the static quantities M_p, $g_a(n)$, μ_p and μ_Λ in agreement with experiment. We find that with

$$(a, b) = (124{\cdot}768 \text{ MeV}, 5{\cdot}255 \times 10^{-3} \text{ MeV}^{-1}) \tag{40}$$

and

$$(m_u = m_d, m_s) = (234{\cdot}35, 438{\cdot}62) \text{ MeV}, \tag{41}$$

the energy eigen value condition (13) yields

$$(E_u = E_d, E_s) = (312{\cdot}76, 455{\cdot}71) \text{ MeV}, \tag{42}$$

which give the values of the static nucleon properties as

$$M_p = 938{\cdot}28 \text{ MeV}, \qquad g_a(n) = 1{\cdot}254,$$
$$\mu_p = 2{\cdot}793\, \mu_N, \qquad \mu_\Lambda = -0{\cdot}6138\, \mu_N. \tag{43}$$

Here the values of E_s are somewhat smaller than the value given by $E_s = (M_\Lambda - 2E_u) = 490{\cdot}07$ MeV. The parameters (40), (41) and (42) also yield from (25) the constituent quark magnetic moments as

$$\mu_u = -2\, \mu_d = 1{\cdot}862\, \mu_N \quad \text{and} \quad \mu_s = -0{\cdot}6138\, \mu_N. \tag{44}$$

In order to realize the significance of the relativistic effects on the constituent quark magnetic moments, we first compare our results with the corresponding Dirac moment μ_q^D of the free quarks with mass m_q, in terms of the ratio given

$$R_{1q} = (\mu_q/\mu_q^D) = \frac{2m_q}{\lambda_q} N_q^2. \tag{45}$$

However, if we argue that the binding energy E_q here plays the role of effective mass for the confined quarks, we obtain the ratio as given by (31).

Our calculated values of R_{1q} and R_{2q} are

$$R_{1u} = R_{1d} = 0{\cdot}697, \qquad R_{1s} = 0{\cdot}86,$$
$$R_{2u} = R_{2d} = 0{\cdot}93, \qquad R_{2s} = 0{\cdot}894. \tag{46}$$

We observe that in terms of the ratio R_{1q}; the two moments differ quite significantly with the difference varying between 25% and 30%. However, in terms of the ratio R_{2q} we find that the difference between the two moments are of the order of 10% to 7% which is unlike the observation suggested by Quigg (1981) for bag model results. Hence we may conclude that unlike bag model calculations, the relativistic effects in the present model appear to have quite a significant bearing on the constituent-quark magnetic moment. Therefore we expect that by making use of the individual quark magnetic moment so obtained, the situation for predicting the baryon moments may be improved. Once we have the right constituent-quark moments, it is straightforward to compute the magnetic moments of baryons in the nucleon octet using the expressions (34).

The results obtained in this manner are presented in table 1 along with a comparison of the results of CBM (Thomas *et al* 1981; Theberge and Thomas 1982) and the experimental data. We find that our results compare reasonably well with available experimental data.

In the present model the value of root-mean-square charge radius of the proton is found to be

$$\langle r^2 \rangle_p^{1/2} = 1{\cdot}072\ \text{fm} \tag{47}$$

as compared to its experimental value of $(0{\cdot}88 \pm 0{\cdot}03)$ fm. The neutron charge radius is obviously zero here contrary to the experimental value $\langle r^2 \rangle_n^{1/2} = -0{\cdot}12$ fm. This is of course the case with most similar models including the bag model.

We may point out here that we have not given much emphasis on the mass spectrum of octet baryons which become highly degenerate. However the degeneracy can be removed by considering the possible gluonic corrections as has been done in bag model calculations of De Grand *et al* (1975) and Chodos *et al* (1974a, b). The zero point energy is of little importance in this present model, as the potential with a Lorentz structure is operative in an infinite volume unlike the case of bag model, where the volume is finite, and one arrives at a finite zero point energy.

In any case it is found that the nucleon properties such as the magnetic moment, the axial vector coupling constant $g_A(n)$ for neutron β-decay and the charge radius of

Table 1. Magnetic moments of the nucleon octet calculated by the present model as compared with the results of the Cloudy Bag Model (CBM) (Ferreira 1977; Ferreira and Zagury 1977; Ferreira *et al* 1980; Barik and Das 1983a, b) and the experimental data (all numbers are in nuclear magnetons).

Baryons	Present calculation	CBM calculation	Experimental resuls	References for experimental results
p	2·7930	2·60	2·7928	(Particle Data Group 1982)
n	−1·8620	−2·01	−1·9130	(Particle Data Group 1982)
Λ	−0·6138	−0.58	$-0.613 \pm 0{\cdot}004$	(Particle Data Group 1982)
Σ^+	2·6872	2·34	$2{\cdot}33 \pm 0{\cdot}13$	(Particle Data Group 1982)
Σ^0	0·8253	—	$0{\cdot}46 \pm 0{\cdot}28$	(Overseth 1981)
Σ^-	−1·0367	−1·08	$-1{\cdot}10 \pm 0{\cdot}03$	(Thomas 1983)
			$-0{\cdot}89 \pm 0{\cdot}14$	(Deck *et al* 1983)
Ξ^0	−1·4391	−1·27	$-1{\cdot}25 \pm 0{\cdot}014$	(Particle Data Group 1982
Ξ^-	−0·5081	−0·51	$-0{\cdot}69 \pm 0{\cdot}04$	(Particle Data Group 1982)
(Λ, Σ)	−1·6125	—	$-1{\cdot}82^{+0{\cdot}18}_{-0{\cdot}25}$	(Dydak *et al* 1977)

proton can be well calculated by this simple independent-quark model in Dirac equation with logarithmic potential (1). In view of the simplicity of the model, the results obtained appear to be quite encouraging.

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