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Electromagnetic form factors of Λ_c in the space-like momentum region*

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Abstract: We studied the electromagnetic form factors (EMFFs) of Λ_c and the contributions of the quark and diquark currents to the EMFFs of Λ_c in the space-like region in the Bethe–Salpeter equation approach with instantaneous approximation. In this picture, baryon Λ_c can be regarded as a two-body $c(ud)$ system. We found that for different values of parameters the contribution of quark and diquark currents to the EMFFs of Λ_c is very different, while their total contribution to the EMFFs of Λ_c is similar. The EMFFs of Λ_c are similar to those of other baryons (proton, Ξ^-, and Σ^+) with a peak at $\omega=1$, where $\omega=v'\cdot v$ is the velocity transfer between the initial state (with velocity v) and the final state (with velocity v') of Λ_c.

Keywords: Bethe-Salpeter equation, Λ_c baryon, electromagnetic form factors, quark-diquark model

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1 Introduction

The quark–diquark model has been successful in describing nucleon properties [1]. A fully relativistic description of baryons can be accomplished by an approach, where baryons are considered as bound states of diquarks and quarks. Ref.[2] has given a detailed overview of the quark–diquark model and the electromagnetic form factors (EMFFs) for the nucleon and Δ baryon is presented in Ref. [2], where the author provided the properties of diquark in different models. Evidence for correlated diquark states in baryons was found in deep-inelastic lepton scattering [3–5] and in hyperon weak decays [6]. Attempts have been made to describe diquarks and baryons in non-local approximations in quantum chromodynamics (QCD) [7]. Diquark bound states were studied in Ref. [8] while the diquark EMFFs in a Nambu–Jona–Lasinio model were studied in Ref. [9]. The spin-1 diquark contribution to the formation of tetraquarks in light mesons was investigated in Rer. [10] and the properties of diquark in the rainbow-ladder framework were studied in Ref. [11].

In the past two decades, certain theoretical investigations on the EMFFs in both space-like (SL) and time-like (TL) regions [12–17] and several experimental results on the EMFFs of baryons [18–30] and mesons [31–34] have been performed. The SL region EMFFs of Λ and Σ were calculated in the framework of the light-cone sum rule (LCSR) up to twist 6 terms [35, 36]. It is found that the Q^2-dependent magnetic form factor of Λ approaches zero faster than the dipole formula with the increase of Q^2.

In previous works [37–42], we studied certain properties of Λ_b in the quark and diquark model. In the present paper we study the EMFFs of Λ_c in the quark–diquark picture and calculate the contributions of the quark and diquark currents to the EMFFs of Λ_c in the SL region in the Bethe–Salpeter (BS) equation approach. In our model, Λ_c is regarded as a bound state of two particles: one is a heavy quark and the other is a $(ud)_{00}$ (the first and second subscripts correspond to the spin and the isospin, respectively) diquark [43–46]. In this picture, the BS equation for Λ_b has been studied extensively [37–42]. Following the introduction of our model, we calculate the EMFFs of Λ_c by a covariant instantaneous approximation and apply the kernel, which includes the scalar confinement and the one-gluon exchange terms.

This paper is organized as follows: in Sec. 2, we intro-

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duce the formalism, our numerical analysis is presented in Sec. 3, while our summary and discussion can be found in Sec. 4.

2 Formalism

2.1 BS equation for Λ_c

As can be seen in Fig. 1, in momentum space the BS equation for the $Q(ud)_{00}$ (Q is b or c quark) system satisfies the homogeneous integral equation [37–42, 47]

$$\chi_P(p) = \mathrm{i}S_F(p_1)\int\frac{\mathrm{d}^4q}{(2\pi)^4}[I\otimes IV_1(p,q)+\gamma_\mu\otimes\Gamma^\mu V_2(p,q)] \times\chi_P(q)S_D(p_2), \tag{1}$$

where $P = Mv$ is the momentum of Λ_c, the quark momentum $p_1 = \eta_1P+p$ and the diquark momentum $p_2=\eta_2P-p$, $S_F(p_1)$ and $S_D(p_2)$ ($\eta_1 = m_c/(m_c+m_D)$, $\eta_2=m_D/(m_c+m_D)$) are propagators of the quark and the scalar diquark, respectively, $\Gamma^\mu=(p_2+q_2)^\mu\frac{\alpha_{\mathrm{seff}}Q_0^2}{Q^2+Q_0^2}$ ($Q=p_2+q_2$, p_2 and q_2 are the momenta flowing into the diquark vertex) is introduced to describe the structure of the scalar diquark [38, 48, 49], and Q_0^2 is a parameter in the form factor of the diquark, which is related to the overlap integral of the diquark wave functions. By analyzing the EMFFs of the proton, it is found that Q_0^2=3.2 GeV^2 can provide consistent results with the experimental data [48] and the value of Q_0^2 was in the order of 1 GeV^2 in different models [37]. V_1 and V_2 are the scalar confinement and one-gluon exchange terms. It has been shown that in the quark–diquark model, the $c(ud)_{00}$ system requires two scalar functions to describe the BS wave function as [37, 40]

$$\chi_P(p)=(f_1(p_{\mathrm{t}}^2)+\not{p}_{\mathrm{t}}f_2(p_{\mathrm{t}}^2))u(v), \tag{2}$$

where f_1 and f_2 are the Lorentz-scalar functions of p_{t}^2, $u(v)$ is the spinor of Λ_c, p_{t} is the transverse projection of the relative momenta along momentum P, and $p_{\mathrm{t}}^\mu=p^\mu-p_lv^\mu$ and $p_l=v\cdot p$. According to the potential model, V_1 and V_2 have the following forms in the covariant instantaneous approximation (p_l=q_l) [38, 39, 42, 50]:

$$\tilde{V}_1 = \frac{8\pi\kappa}{[(p_{\mathrm{t}}-q_{\mathrm{t}})^2+\mu^2]^2}-\delta^3(p_{\mathrm{t}}-q_{\mathrm{t}})\int\frac{8\pi\kappa}{(k^2+\mu^2)^2}\mathrm{d}^3k, \tag{3}$$

$$\tilde{V}_2 = -\frac{16\pi\alpha_{\mathrm{seff}}Q_0^2}{3[(p_{\mathrm{t}}-q_{\mathrm{t}})^2+\mu^2]}, \tag{4}$$

where q_{t}^μ=q^μ–q_lv^μ is the transverse projection of the relative momenta along momentum P and q_l=$v q$. The second term of $\tilde{V}_1$ is introduced to avoid the infrared divergence at point p_{t}=q_{t} and μ is a small parameter to avoid the divergence in numerical calculations. Parameters κ and α_{seff} are related to the scalar confinement and the one-gluon exchange diagram, respectively. The parameter of scalar confinement κ' for mesons is $\sim$0.2 GeV^2, while for baryons the dimension of parameter κ is three, and the extra dimension in κ probably results from nonperturbative diagrams, which include the frozen form factor at the low momentum region. As Λ_{QCD} is the only parameter related to the confinement, we expect that $\kappa\sim\Lambda_{\mathrm{QCD}}\kappa'$; thus, the parameter κ needs to be in the order of 0.01 GeV^3. By analyzing the average kinetic energy of Λ_b [41], it is found that κ was in the range of 0.02–0.08 GeV^3. Therefore, in our numerical calculations we assumed κ to be in this range.

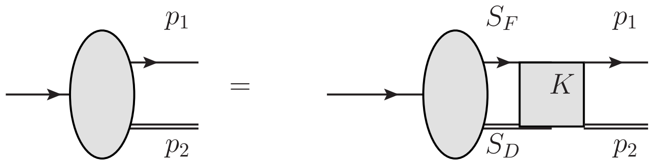

Fig. 1. BS equation for the $Q(ud)_{00}$ system in momentum space (K is the interaction kernel).

The diquark and quark propagators can be written as

$$S_D(p_2)=\frac{\mathrm{i}}{2\omega_D}\left[\frac{1}{\eta_2M-p_l-\omega_D+\mathrm{i}\epsilon}-\frac{1}{\eta_2M-p_l+\omega_D-\mathrm{i}\epsilon}\right], \tag{5}$$

$$S_F(p_1)=\mathrm{i}\not{v}\left[\frac{\Lambda_c^+}{\eta_1M+p_l-\omega_c+\mathrm{i}\epsilon}+\frac{\Lambda_c^-}{\eta_1M+p_l+\omega_c-\mathrm{i}\epsilon}\right], \tag{6}$$

where $\omega_{(c,D)}=\sqrt{m_{(c,D)}^2-p_{\mathrm{t}}^2}$ and $\Lambda_c^\pm=1/2\pm\not{v}(\not{p}_{\mathrm{t}}+m_c)/(2\omega_c)$ are projection operators satisfying the relations $\Lambda_c^\pm\Lambda_c^\pm=\Lambda_c^\pm$ and $\Lambda_c^\pm\Lambda_c^\mp=0$.

As in our previous works [37, 40], the BS wave functions of the $c(ud)_{00}$ system can be written as

$$\tilde{f}_1(p_{\mathrm{t}})=\int\frac{\mathrm{d}^3q_{\mathrm{t}}}{(2\pi)^3}[M_{11}\tilde{f}_1(q_{\mathrm{t}})+M_{12}\tilde{f}_2(q_{\mathrm{t}})], \tag{7}$$

$$\tilde{f}_2(p_{\mathrm{t}})=\int\frac{\mathrm{d}^3q_{\mathrm{t}}}{(2\pi)^3}[M_{21}\tilde{f}_1(q_{\mathrm{t}})+M_{22}\tilde{f}_2(q_{\mathrm{t}})], \tag{8}$$

where

$$M_{11} = \frac{(\omega_c+m_c)(\tilde{V}_1+2\omega_D\tilde{V}_2)-p_{\mathrm{t}}\cdot(p_{\mathrm{t}}+q_{\mathrm{t}})\tilde{V}_2}{4\omega_D\omega_c(-M+\omega_D+\omega_c)}-\frac{(\omega_c-m_c)(\tilde{V}_1-2\omega_D\tilde{V}_2)+p_{\mathrm{t}}\cdot(p_{\mathrm{t}}+q_{\mathrm{t}})\tilde{V}_2}{4\omega_D\omega_c(M+\omega_D+\omega_c)}, \tag{9}$$

$$M_{12} = \frac{-(\omega_c+m_c)(q_{\mathrm{t}}+p_{\mathrm{t}})\cdot q_{\mathrm{t}}\tilde{V}_2+p_{\mathrm{t}}\cdot q_{\mathrm{t}}(\tilde{V}_1-2\omega_D\tilde{V}_2)}{4\omega_D\omega_c(-M+\omega_D+\omega_c)}-\frac{(m_c-\omega_c)(q_{\mathrm{t}}+p_{\mathrm{t}})\cdot q_{\mathrm{t}}\tilde{V}_2-p_{\mathrm{t}}\cdot q_{\mathrm{t}}(\tilde{V}_1+2\omega_D\tilde{V}_2)}{4\omega_D\omega_c(M+\omega_D+\omega_c)}, \tag{10}$$

$$M_{21} = \frac{(\tilde{V}_1+2\omega_D\tilde{V}_2)-(-\omega_c+m_c)\frac{(p_t+q_t)\cdot p_t}{p_t^2}\tilde{V}_2}{4\omega_D\omega_c(-M+\omega_D+\omega_c)} - \frac{-(\tilde{V}_1-2\omega_D\tilde{V}_2)+(\omega_c+m_c)\frac{(p_t+q_t)\cdot p_t}{p_t^2}\tilde{V}_2)}{4\omega_D\omega_c(M+\omega_D+\omega_c)}, \tag{11}$$

$$M_{22} = \frac{(m_c-\omega_c)(\tilde{V}_1+2\omega_D\tilde{V}_2)\frac{p_t\cdot q_t}{p_t^2}-(q_t^2+p_t\cdot q_t)\tilde{V}_2}{4\omega_D\omega_c(-M+\omega_D+\omega_c)} - \frac{(m_c+\omega_c)(-\tilde{V}_1-2\omega_D\tilde{V}_2)\frac{p_t\cdot q_t}{p_t^2}+(q_t^2+p_t\cdot q_t)\tilde{V}_2)}{4\omega_D\omega_c(M+\omega_D+\omega_c)}. \tag{12}$$

2.2 SL EMFFs of Λ_c

In general, the SL EMFFs of Λ_c with Dirac spinor $u_{\Lambda_c}(P,s)$ and mass M, can be defined by the matrix elements of the electromagnetic current between the baryon states [33, 35–37] as

$$\langle\Lambda_c(P',s')|j_\mu(x=0)|\Lambda_c(P,s)\rangle = \bar{u}_{\Lambda_c}(P',s')\left[\gamma_\mu F_1(Q^2)+\mathrm{i}\frac{\sigma_{\mu\nu}q^\nu}{2M}F_2(Q^2)\right]u_{\Lambda_c}(P,s), \tag{13}$$

where $F_1(Q^2)$ and $F_2(Q^2)$ are Dirac and Pauli form factors, respectively, $Q^2=-q^2=-(P-P')^2$ is the squared momentum transfer, and j_μ is the electromagnetic current relevant to the baryon. In particular, similarly to the nucleus, the form factors F_1 and F_2 when $Q^2\to 0$, which corresponds to the exchange of low virtuality photons, have values of

$$F_1(0)=1, \quad F_2(0)=\kappa_{\Lambda_c}, \tag{14}$$

where $\kappa_{\Lambda_c}=\mu_{\Lambda_c}$–1 (where μ_{Λ_c} is the magnetic momentum of Λ_c). Generally, considering perturbative QCD and helicity, $F_1(Q^2)$ and $F_2(Q^2)$ at high Q^2 behave as [51–59]

$$F_1\sim\frac{1}{Q^4}, \quad F_2\sim\frac{1}{Q^6}. \tag{15}$$

In general, we employed two linear combinations of F_1 and F_2

$$G_\mathrm{E}(Q^2) = F_1(Q^2)-\frac{Q^2}{4M^2}F_2(Q^2), \tag{16}$$

$$G_\mathrm{M}(Q^2) = F_1(Q^2)+F_2(Q^2), \tag{17}$$

where G_E is known as electric form factor (EFF) and G_M is known as magnetic form factor (MFF).

Considering Eqs. (15)–(16), at the large momentum transfer $|G_\mathrm{E}|/|G_\mathrm{M}|$ needs to be a stable value. It should be noted that Eq. (13) represents the microscopic description of the SL form factors of Λ_c, which include two contributions originated from the quark and the diquark currents. As shown in Fig. 2, the following relation can be obtained [33]:

$$j_\mu = j_\mu^q+j_\mu^D. \tag{18}$$

Here, $j_\mu^D=\bar{D}\Gamma_\mu D$, Γ_μ is the vertex among the photon and diquarks, which includes the scalar diquark form factor, and $j_\mu^q=\bar{c}\gamma_\mu c$. The quark and diquark current contributions can be written as

$$\langle\Lambda_c(v',s')|j_\mu^{(q,D)}|\Lambda_c(v,s)\rangle = \bar{u}(v',s')[g_{1(q,D)}(\omega)\gamma_\mu+g_{2(q,D)}(\omega)(v'+v)_\mu]u(v,s), \tag{19}$$

where $v^{(')}=P^{(')}/M$ is the velocity of Λ_c, $\omega=v'\cdot v=\frac{Q^2}{2M^2}+1$ is the velocity transfer, while $g_{1(q,D)}$ and $g_{2(q,D)}$ are the functions of ω [37, 38, 40, 61]. When $\omega=1$, the following relation can be obtained [38]:

$$g_{1q}(1)+2g_{2q}(1) = 1+\mathcal{O}(1/M_{\Lambda_c}^2). \tag{20}$$

In the present work, we use Eq. (20) to normalize the BS wave functions and to neglect the $1/M^2$ corrections [61]. This relation has been proven to be an appropriate approximation [61] for a heavy baryon and proposed in Ref. [62–65] for mesons. As shown in our previous works [37, 38], considering that the quark and diquark have the same charge sign in the $c(ud)_{00}$ system, g_1 and g_2 can be calculated as follows:

$$g_{(1,2)}(\omega) = g_{(1,2)q}(\omega)+g_{(1,2)D}(\omega). \tag{21}$$

Comparing Eqs. (19) and (21), the following can be written:

$$\bar{u}(v',s')[g_{1D}(\omega)\gamma_\mu+g_{2D}(\omega)(v'+v)_\mu]u(v,s) = \int\frac{\mathrm{d}^4p}{(2\pi)^4}\bar{\chi}(p')\Gamma_\mu\chi(p)S_q^{-1}(p_1). \tag{22}$$

$$\bar{u}(v',s')[g_{1q}(\omega)\gamma_\mu+g_{2q}(\omega)(v'+v)_\mu]u(v,s) = \int\frac{\mathrm{d}^4p}{(2\pi)^4}\bar{\chi}(p')\gamma_\mu\chi(p)S_D^{-1}(p_2), \tag{23}$$

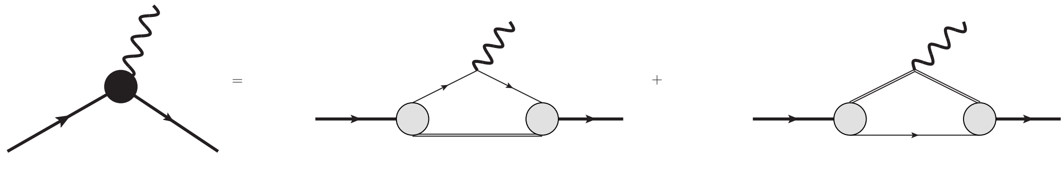

Fig. 2. Electromagnetic current as the sum of the quark and the diquark currents [60].

3 Numerical analysis

3.1 Solution of the BS wave functions

In order to solve Eqs. (7) and (8), we defined the mass of Λ_c, as $M=m_c+m_D+E$ (where E is the binding energy). By assuming $m_c=1.586$ GeV, $M=2.286$ GeV we obtained $m_D+E=0.7$ GeV for Λ_c [39]. We varied the diquark mass m_D in the range of 0.83–0.89 GeV for Λ_c; thus, the binding energy E varied between -0.2 and -0.1 GeV. Therefore, we choose the diquark mass m_D to changes in the reasonable range from 0.83 to 0.89 GeV in our model. The parameter κ was varied in the range of 0.02–0.08 GeV^3 [41]. Thus, for each m_D, we can obtain the best value of $\alpha_{\rm seff}$ corresponding to a value of κ when solving Eqs. (7) and (8). Solving the integral equations Eqs. (7) and (8) we can find numerical solutions of the BS wave functions. In Table 1, the values of $\alpha_{\rm seff}$ are given for m_D=0.83, 0.86, 0.89 GeV for different κ values at Q_0^2=3.2 GeV^2, while in Table 2, the values of $\alpha_{\rm seff}$ are given for Q_0^2=1.0, 3.2, 10.0 GeV^2 for different κ values at m_D=0.86 GeV.

In Fig. 3, we plot $\tilde{f}_i$ (i=1,2) as a function of $|p_{\rm t}|$. It can be seen in these figures that for different $\alpha_{\rm seff}$ and κ values, the shapes of the BS wave functions are similar. All wave functions decrease to zero when $|p_{\rm t}|$ is greater than $\sim$2.0 GeV due to the confinement interaction. We found that the uncertainly of m_D has a smaller effect on the BS wave function than that of Q_0^2 for the same κ value.

3.2 The EMFFs of Λ_c

In order to solve Eq. (23), the relation of p and p' needs to be found. We define α as the angle between $p_{\rm t}$ and $v'_{\rm t}$, where $v'_{\rm t}=v'-(v\cdot v')v$; thus, $|v'_{\rm t}|=\sqrt{\omega^2-1}$ and $p_{\rm t}\cdot v'_{\rm t}=-|p_{\rm t}||v'_{\rm t}|\cos\alpha$. Considering $p_2=p'_2$, the following relations can be obtained:

$$p'_{\rm t}\cdot v = p_l(1-\omega^2)+m_D(\omega-1)^2+|p_{\rm t}|\omega\sqrt{\omega^2-1}\cos\alpha, \quad (24)$$

$$p_{\rm t}\cdot p'_{\rm t} = |p_{\rm t}|(p_l\omega-|p_{\rm t}|\sqrt{\omega^2-1}\cos\alpha-m_D\omega)\times\sqrt{\omega^2-1}\cos\alpha-|p_{\rm t}|^2. \quad (25)$$

Substituting Eqs. (6), (5), (24), and (25) into Eq. (23), g_{1q} and g_{2q} can be expressed by $\tilde{f}^{(\prime)}_{(1,2)}$. Similarly, to solve Eq. (22), we repeat the above process with $S_F^{-1}(p_1)$ being replaced by $S_D^{-1}(p_2)$ and the relation $p_2=p'_2$ is replaced by $p_1=p'_1$.

As in our previous work [37], the EMFFs $G_{\rm E}$ and $G_{\rm M}$ for Λ_c can be written as

$$G_{\rm E} = g_{1q}-2\omega(g_{2q}+g_{2D}), \quad (26)$$

$$G_{\rm M} = g_{1q}+6(g_{2q}+g_{2D}). \quad (27)$$

Table 1. Values of $\alpha_{\rm seff}$ at Q_0^2=3.2 GeV^2 for Λ_c with different m_D (GeV) and κ (GeV^3) values.

	$\alpha_{\rm seff}(\kappa=0.02)$	$\alpha_{\rm seff}(\kappa=0.04)$	$\alpha_{\rm seff}(\kappa=0.06)$	$\alpha_{\rm seff}(\kappa=0.08)$
m_D=0.83	0.78	0.80	0.84	0.86
m_D=0.86	0.80	0.84	0.86	0.88
m_D=0.89	0.84	0.86	0.88	0.90

Table 2. Values of $\alpha_{\rm seff}$ at m_D=0.86 GeV for Λ_c with different Q_0^2 (GeV^2) and κ (GeV^3) values.

	$\alpha_{\rm seff}(\kappa=0.02)$	$\alpha_{\rm seff}(\kappa=0.04)$	$\alpha_{\rm seff}(\kappa=0.06)$	$\alpha_{\rm seff}(\kappa=0.08)$
Q_0^2=1.0	0.86	0.90	0.94	0.96
Q_0^2=3.2	0.80	0.82	0.86	0.88
Q_0^2=10.0	0.78	0.80	0.82	0.84

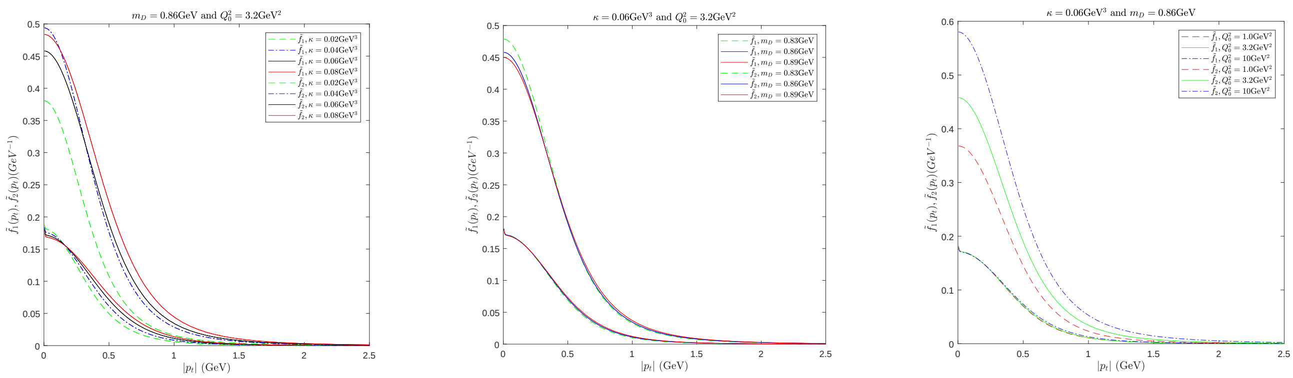

Fig. 3. (color online) BS wave functions of Λ_c.

In Figs. 4–6, the ω-dependence of G_{E} and G_{M} is plotted for different parameters, and it can be seen that the shapes of G_{E} and G_{M} are similar. For ω in the range of 1.0–3.0, the trends of G_{E} and G_{M} for Λ_c are similar to those for the proton, Ξ^-, and Σ^+ [35, 66]. The EFF, G_{E}, decreases more rapidly than G_{M} as ω increases. For G_{E}, κ results in the smallest uncertainly; however, for the MFF, G_{M}, m_D results in the smallest uncertainly. This trend is different from that of Λ_b [37]. In the dipole model, $G_{\mathrm{M}}(Q^2)=\frac{\mu}{(1+Q^2/m_0^2)^2}$, $\mu\propto 1/M$ (for $\Lambda_{(c)}$, M is the mass of the $s(c)$ quark) corresponds to the baryon magnetic moment and parameter $m_0=\sqrt{0.89}$ GeV for Λ [36]. At present, there is no data available for the EMFFs of Λ_c. However, for Λ and Λ_c baryons the ratio of $|G_{M\Lambda}|$ and $|G_{M\Lambda_c}|$, RM, needs to be in the order of M_s/M_c.

$$RM=\left|\frac{G_{M_{\Lambda_c}}}{G_{M_{\Lambda}}}\right|\propto\frac{M_s}{M_c}\approx 0.3. \tag{28}$$

As given in Ref. [35], $G_{M\Lambda}$ decreases faster than that in the dipole model. Therefore, the ratio RM needs to be in the order of 0.1. When ω changes from 1.0 to 2.5, the MFFs for $|G_{M\Lambda_c}|$ varies from $\sim$0.38 to 0.0. In different

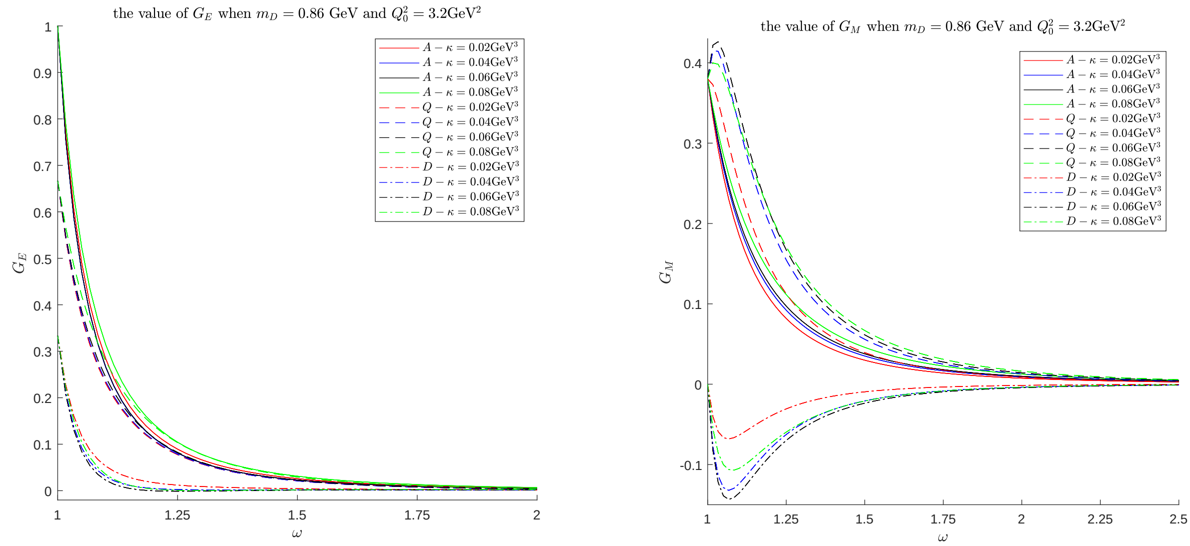

Fig. 4. (color online) ω-dependence of the EMFFs of Λ_c with different κ values ("Q" and "D" denote quark and diquark current contributions, respectively, "A" denotes the total contribution).

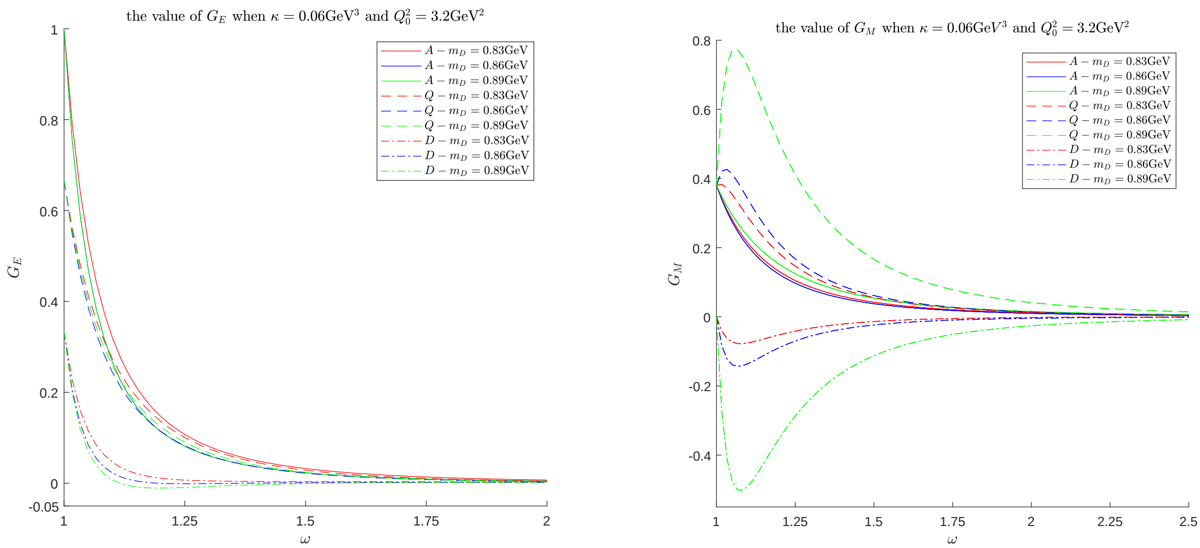

Fig. 5. (color online) ω-dependence of the EMFFs of Λ_c with different m_D values ("Q" and "D" denote quark and diquark current contributions, respectively, "A" denotes the total contribution).

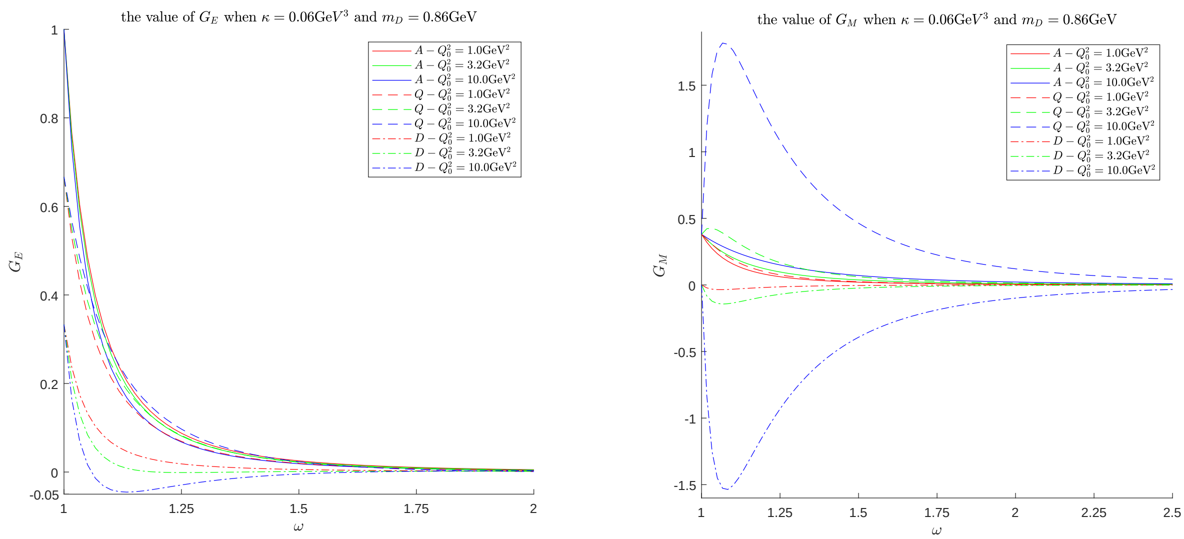

Fig. 6. (color online) ω-dependence of the EMFFs of Λ_c with different Q_0^2 values (“Q” and “D” denote quark and diquark current contributions, respectively, “A” denotes the total contribution).

models [35, 66–68], $|G_{M\Lambda}|$ varies from the range ∼0.43–0.75 to 0.0. The *RM* ratio we obtained is in the range of ∼ 0.26–0.47. For the magnetic moment of Λ_c, the traditional QCD sum rules [69] give the value $\mu_{\Lambda_c} = 0.15\pm0.05\mu_N$ (where μ_N is the nucleon magnetic moment), while in the light-cone QCD sum rules, Ref. [70] gives $\mu_{\Lambda_c} = 0.40\pm0.05\mu_N$. In our model, we obtained $\mu_{\Lambda_c} \approx 0.38\mu_N$, which roughly agrees with the above result.

It can be seen in Figs. 4–6 that the EMFFs of Λ_c from the quark and diquark current contributions are very different. The smallest uncertainly results from κ, while Q_0^2 has the greatest effect. As can be seen in Fig. 4, for different κ values the EMFFs of Λ_c primarily originated from the quark contribution. Figure 6 shows, that for different Q_0^2 the contributions of the quark and diquark currents are very different. However, we found that the total contributions of quark and diquark currents to the EMFFs of Λ_c do not change significantly compared with those in the left pane of Fig. 4 and the right pane of Fig. 5.

4 Summary and discussion

In the quark–diquark model, Λ_c can be regarded as a bound state of a c-quark and a scalar diquark. We established the BS equation for this system and solved the BS equation numerically by applying a kernel, which includes the scalar confinement and the one-gluon exchange terms. Then, we calculated the EMFFs of Λ_c including both the c-quark and the $(ud)_{00}$ diquark current contributes. Finally, we compared our results with those of other baryons. We found that the shapes of the EMFFs of Λ_c are similar to those of other baryons [35, 66–68]. For different m_D and κ values, G_{E} changes in the range from ∼1.0 to ∼0.0 as ω is varied in the range of 1.0–2.0 and G_{M} changes from ∼0.4 to ∼0.0 as ω is varied in the range of ∼1.0–2.5. For different parameters, especially for Q_0^2, we found that the contributions of quark and diquark currents are very different; however, the total contributions of the quark and diquark currents do not change significantly. We found that the contributions from the c-quark and the diquark for MFFs have opposite signs for the diquark with an internal structure, and the MFF of the diquark is related to its internal structure. Therefore the MFFs of the diquark and the c-quark do not necessarily have the same sign. As it is known, the MFF of the neutron is negative, and not zero as theoretically required by the charge of the neutron. Nevertheless, the magnetic moment of spin-1/2 particles $\mu\propto 1/M$;thus, the MFF of the c-quark needs to be larger than that of Λ_c. Therefore, the contribution of the diquark current to the MFF of Λ_c needs to have opposite sign to that of c-quark current.

In our work, the results as a function of parameters, such as κ, m_D, and Q_0^2 vary in certain ranges. We estimated the uncertainties of G_{E} and G_{M} due to these parameters. It is found that these uncertainties are less than 27% due to κ, 20% due to m_D, and 40% due to Q_0^2.

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