

Electromagnetic form factors of baryons in nuclear medium

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The electromagnetic structure of the baryons is modified in the nuclear medium. The modifications can be inferred from the comparison between the electromagnetic form factors in medium with the respective form factor in vacuum. Of particular interest is the ratio between the electric and magnetic form factors in medium (G_E^*/G_M^*) and vacuum (G_E/G_M) of the octet baryons. The deviation of the double ratios (G_E^*/G_M^*)/(G_E/G_M) from unity measures the impact of the medium modification of the electromagnetic structure in a nuclear medium. Measurements of the double ratios (G_E^*/G_M^*)/(G_E/G_M) for different nuclear densities may become available in the near future using the polarization-transfer method developed at Jefferson Lab. We present estimates of the double ratios of octet baryons based on a covariant constituent quark model, which takes into account pion cloud excitations of the baryon cores, for different nuclear densities. Our results manifest different features, namely, enhancement or quenching depending on the baryon flavor content.

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1. Introduction

Since the discovery of the EMC effect [1] it has been known that the hadrons change their properties in a nuclear medium [2, 3]. The natural interpretation is that a strong mean field modifies the properties of the degrees of freedom of QCD, the quarks and gluons. In these conditions, we can expect that the electromagnetic form factors of the baryons are modified compared to the vacuum and that the impact of the changes increase with the nuclear density ρ .

The modification due to the nuclear medium can be quantified comparing the measured form factors in medium with the measured form factors in vacuum. The open question is: can we measure the electric and magnetic form factors of baryons in medium, when measurements in vacuum are at the moment restricted to the nucleon (proton and neutron). The answer is, the individual form factors cannot be measured directly, but, with the polarization-transfer method, it is possible to measure the ratio G_E/G_M in vacuum and in medium [4, 5]. To represent the electric and magnetic form factors in medium we use G_E^* and G_M^* , respectively.

The polarization-transfer method has been applied at Jefferson Lab to measure the ratio G_E/G_M of the proton and neutron in vacuum [4]. In the experiments the nucleon is scattered by polarized electrons and the polarization of the outgoing nucleons is measured (reaction $N(\vec{e}, e'\vec{N})$, where N is a nucleon). The ratio G_E/G_M is proportional to the ratio between the transverse and longitudinal nucleon polarizations [4, 5].

In the proton case, the generalization to the nuclear medium is based on the reaction $A(\vec{e}, e'\vec{p})B$, where B is obtained from A by a proton knockout in a quasi-elastic reaction [5, 6]. Although the final proton is in vacuum, one can still assume that the polarization-transfer coefficients carry the information of the bound proton, since the photon coupling with the proton occurs in a nuclear environment, and the polarization is conserved. The medium modification of the electromagnetic form factors can then be identified using the double ratio $(G_E^*/G_M^*)/(G_E/G_M)$ between the electric and magnetic form factor ratios in medium and in vacuum. If medium modifications are small, the double ratio is close to unity. Otherwise, one can have an enhancement or a suppression of (G_E/G_M) due to medium modifications.

Measurements of the proton electromagnetic form factor double ratio were performed already at MAMI [5] and Jefferson Lab [6] using the ${}^4\text{He}(\vec{e}, \vec{p}){}^3\text{H}$ reaction (proton in medium). The data show signs of medium modifications, but the small magnitude of the effect may be a consequence of the averaged low density of the ${}^4\text{He}$ system compared with the normal nuclear density $\rho_0 = 0.15 \text{ fm}^{-3}$ [2, 3]. The extension of the method to the neutron is planned for the future (${}^4\text{He}(\vec{e}, \vec{n}){}^3\text{He}$ reaction) [7]. In progress at MAMI are knockout experiments of the proton on ${}^{14}\text{C}$ [8, 9].

The new experiments motivated further theoretical studies of the medium modification of the electromagnetic form factors, not only for the proton, but also for the neutron based on different frameworks [3, 10, 11]. Anticipating future experimental developments, we calculate the double ratios for all baryon octet members for different values of the nuclear density. We consider in particular $\rho = 0.5\rho_0$ and $\rho = \rho_0$.

In our calculations of the octet baryon electromagnetic form factors, we use the covariant spectator quark model [12]. In the covariant spectator quark model the baryons are described as systems of three constituent quarks, where two of the quarks are on-mass-shell and can be regarded as an effective diquark, and the off-shell quark interacts with the electromagnetic fields in relativistic

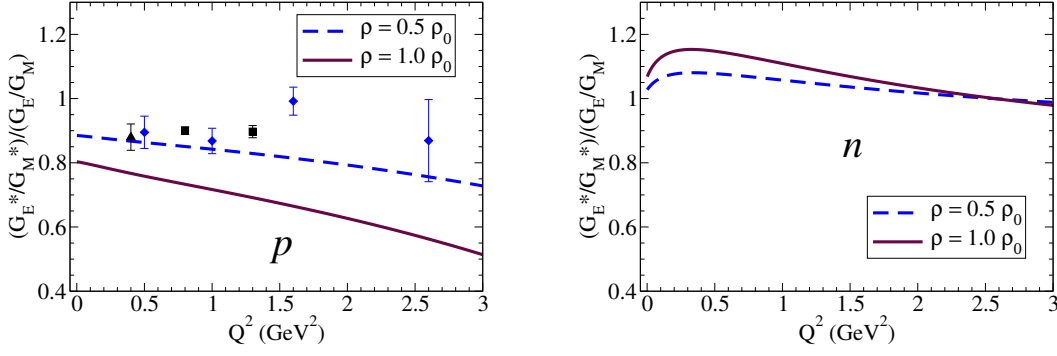


Figure 1: Electromagnetic form factor doubles ratios in symmetric nuclear matter calculated for proton and neutron. Experimental data for proton are from Refs. [5, 6].

impulse approximation [12, 13]. The electromagnetic structure of the quark is parametrized using a vector meson dominance (VMD) form, which includes contributions of vector meson poles depending on the $SU(3)$ channel (isovector, isoscalar and strange quark) [3, 13]. The radial wave functions are parametrized in terms of two momentum range scales according to the number of strange quarks ($SU(3)$ symmetry breaking) [2, 13]. To determine the parameters of the radial wave functions, we extend the model to the lattice QCD regime, in a region where meson cloud effects are suppressed (large pion mass region). The parameters are then adjusted to the lattice QCD data (details can be found in Refs. [2, 3, 13, 14]). In addition to the valence quarks, we consider also contributions associated to pion cloud dressing of the baryon cores determined by the cloudy bag model [15], using the $SU(3)$ pion-baryon interaction [16], with a Q^2 -dependence calibrated by the physical data for the nucleon and by the hyperon magnetic moments [3, 13].

The generalization to the symmetric nuclear matter is performed with the assistance of the quark-meson coupling (QMC) model [1], which has been successfully applied to the study of baryons and mesons in nuclei and nuclear medium. The QMC model is used to estimate the effective masses of the baryons and mesons in medium in terms of the nuclear density, and furthermore to calculate the effect of those modifications on the quark currents and radial wave functions in medium [2, 3]. The second step is to infer the effect of the medium on the pion cloud contributions, which is a consequence of the modification of the pion-baryon coupling constants in medium [3]. The electromagnetic form factors in medium are then obtained combining the valence quark and pion cloud contributions.

2. Results and Conclusions

We calculated the double ratios to all members of the baryon octet in symmetric nuclear matter for nuclear densities of $0.5\rho_0$ and ρ_0 (normal nuclear density) [2]. The method can be extended in the future to higher densities, and be applied in studies of heavy-ion collisions, neutron stars and compact stars.

In the calculations, we use the covariant constituent quark model and the quark-meson-coupling model to take into account medium modifications on the valence quarks and on the pion cloud contributions. Our estimates of the proton and neutron, and the Σ^+ and Σ^- double ratios, are presented in Figs. 1 and 2, respectively.

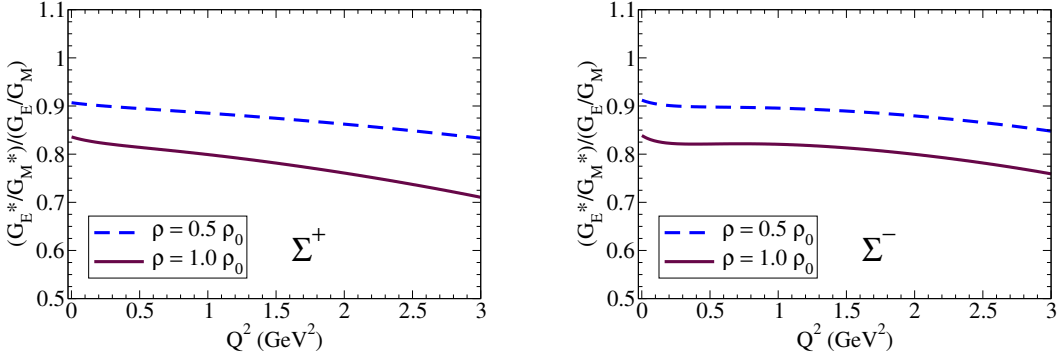


Figure 2: Electromagnetic form factor doubles ratios in symmetric nuclear matter calculated for Σ^+ and Σ^- .

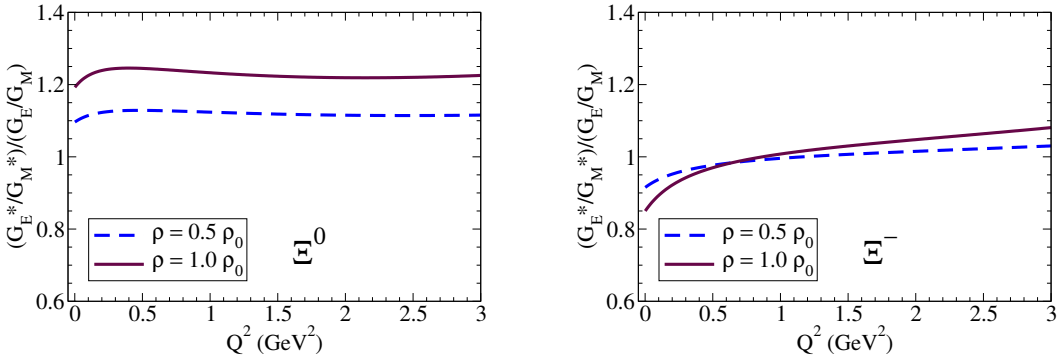


Figure 3: Electromagnetic form factor doubles ratios in symmetric nuclear matter calculated for Ξ^0 and Ξ^- .

In the case of the proton and Σ^\pm , one observes a clear suppression of the ratio G_E/G_M in the nuclear medium. The suppression increases with the nuclear density. In our formalism this suppression is mainly a consequence of the dominance of the valence quark effects and the properties of the VMD parametrization of the quark currents [2].

As for the neutron, we predict an enhancement of the ratio below 2.5 GeV^2 . This effect is also predicted by other groups [11]. Our prediction may be tested in a near future at Jefferson Lab [7].

The results for the cascade Ξ^0 and Ξ^- , are presented in Fig. 3. From the figure, we can conclude that the Q^2 -dependence is weak, as expected, since the systems are dominated by strange quarks. The results for the Λ and Σ^0 and more detailed discussions about the present results can be found in Ref. [2].

Within the scope of the PANIC 2021 conference, we also emphasize that the present formalism can be used to calculate the effective electromagnetic form factor $|G(q^2)|$ of baryons at very large q^2 , in the timelike region [17].

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