Quark-sea component of the electric polarizability of hadrons

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The quark sea makes a large negative contribution to the electric polarizability of π^- and K mesons.

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Antipov *et al.*[1] recently measured for the first time the electric polarizability of the π^- meson and reported the value $\alpha_{\pi^-} = 6.8 \pm 1.4 \pm 1.6$ (here and below, in units of 10^{-43} cm^3), in agreement with the predictions of the various quantum-field models with an effective chiral Lagrangian (ECLM).[2–4] This value offers qualitative support to the prediction of the nonrelativistic quark model (NQM).[5] The ECLM and NQM predictions of the polarizabilities of the π^0 and K^0 mesons, however, are seriously at odds; for example,[1)] $\alpha_{\pi^0}^{\rm ECLM} \ll \alpha_{\pi^\pm}^{\rm ECLM} \approx \alpha_{\pi^\pm}^{\rm NQM} < \alpha_{\pi^0}^{\rm NQM}$. In this letter we wish to offer a reason for this discrepancy.

We begin with the most general expression for the electric polarizability of a spin-s hadron (see Ref. 5 and the references there):

$$\alpha = \alpha_0 + \Delta\alpha\,,\ \alpha_0 = \frac{2}{3}\sum_{n\neq 0}\frac{|<n|\mathbf{D}|0>|^2}{E_n - E_0}\,,\ \Delta\alpha = \begin{cases} \dfrac{e^2}{3m} r_E^2\,, & s=0 \\[2ex] \dfrac{e^2}{3m} r_E^2 + \dfrac{e^2(\lambda^2+1)}{4m^3}\,, & s=1/2 \end{cases} \quad (1)$$

Here α_0 is a quantum-field generalization of the nonrelativistic expression for the electric polarizability of an atom (the notation is standard); the term $\Delta\alpha$ is a correction for recoil; and e, m, r_E, and λ are the charge, mass, Sachs electric radius, and the anomolous magnetic moment of the hadron in the $|0\rangle$. We break α_0 up into two terms, $\alpha_0 = \alpha^{\rm VQ} + \alpha^{\rm QS}$, where $\alpha^{\rm VQ}$ is the component resulting from the radial and orbital excitations of the valence (structural) quarks in the hadron, and $\alpha^{\rm QS}$ is the component which results from the excitation of the quark sea and the quark condensate in the hadron. An approximate value for $\alpha^{\rm VQ}$ can be found by saturating the α_0 sum by the low-lying, two-quark resonances (A_1, B,...) with masses $E_n \lesssim 1.5$ GeV. As expected, the values found for $\alpha^{\rm VQ}$ in this manner agree within relativistic directions with the prediction of the nonrelativistic quark model. In that model we have, ignoring the breaking of SU(3) symmetry,

$$R_\pi \equiv \alpha_{\pi^0}^{\rm VQ} / \alpha_{\pi^\pm}^{\rm VQ} = 10,\ R_K \equiv \alpha_{K^0}^{\rm VQ} / \alpha_{K^\pm}^{\rm VQ} = 4\,,$$

and in the case of oscillatory forces we would have $\alpha_{\pi^\pm}^{VQ} = \alpha_{K^\pm}^{\rm VQ} = e^2 m_q / 18\gamma^4 = 0.7$–$1$,

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where the oscillator parameter is $\gamma^2 = 0.1$–0.12 GeV^2, and the quark mass is $m_q = 0.34$ GeV.

The part of α_0 due to states with $E_n \gtrsim 1.5$ GeV is determined primarily by many-particle states, and the renormalization counterterm implied in (1) may be assumed to be the same as α^{QS}. This contribution is similar to that of the polarization of the e^+e^- vacuum in the problem of the polarizability of a heavy point charged particle[6] or of a hydrogen-like ion with[7] $Ze^2 \gtrsim 1$, which gives rise to scattering of light by the Coulomb field. Since the properties of the quark sea and condensate are determined primarily by the gluon field in the hadron, which is identical for the various members of the isomultiplet, we would expect

$$\alpha^{QS}_{\pi^\pm} \approx \alpha^{QS}_{\pi^0}, \qquad \alpha^{QS}_{K^\pm} \approx \alpha^{QS}_{K^0}. \tag{2}$$

If we rewrite (1) as a dispersion sum rule for a finite energy, and if we identify the corresponding asymptotic contribution with α^{QS}, then (2) results from the predominance of Pomeron exchange in the amplitude for the scattering of a virtual photon by a hadron.

We now substitute into the relations

$$\alpha_{\pi^\pm} = \alpha^{VQ}_{\pi^\pm} + \alpha^{QS}_{\pi} + \Delta\alpha_{\pi^\pm}, \qquad \alpha_{\pi^0} = R_\pi\, \alpha^{VQ}_{\pi^\pm} + \alpha^{QS}_{\pi} \tag{3}$$

and corresponding relations for the kaons the values of the polarizabilities and radii calculated (for definiteness) in the model of Ref. 2, all of whose predictions are in agreement with the data available: $\alpha_{\pi^\pm} = 5.1$; $\alpha_{K^\pm} = 1.2$; $\alpha_{\pi^0} = -0.65$; $\alpha_{K^0} = 0$; $r^2_{\pi^\pm} = 0.42$ F^2, $r^2_{K^\pm} = 0.38$ F^2. If $R_\pi \approx 10$ and $R_K \approx 4$, as in the nonrelativistic quark model, we find from (3)

$$\begin{aligned} &\alpha^{VQ}_{\pi^\pm} = 0.97, \qquad \alpha^{VQ}_{\pi^0} = 9.7, \qquad \alpha^{QS}_{\pi} = -10.3\\ &\alpha^{VQ}_{K^\pm} = 0.82, \qquad \alpha^{VQ}_{K^0} = 3.3, \qquad \alpha^{QS}_{K} = -3.3. \end{aligned} \tag{4}$$

We see that for the values of R chosen the values of α^{VQ} are in approximate agreement with the NQM predictions, while the contributions α^{QS} are unexpectedly large and remain so as R is varied over a reasonable range. The signs of α^{QS} can be understood at a qualitative level by assuming that the typical gluon field in the π^- and K mesons is close to the critical value at which the binding energy of a structural quark and a structural antiquark is equal to the sum of their masses (see Ref. 7). Arguments regarding the existence of near-critical gluon fields and associated quark condensate within mesons have been advanced previously (Refs. 8 and 9; see also Ref. 10).

For nucleons, the binding energy of three structural quarks, $m_N - 3m_q \approx 0.08$ GeV, is small in comparison with their mass, so we should expect the quark sea to have lesser effects. In the NQM the ratio $R_N \equiv \alpha^{VQ}_n/\alpha^{VQ}_p$ is unity,[5] so that equations like (3) cannot distinguish between the contributions of α^{VQ} and α^{QS}. On the other hand, the agreement of the experimental value[5,11] $\alpha_p = 10$–15 with the NQM prediction shows that we have $\alpha^{QS}_N \approx 0$, within the experimental errors. If the picture drawn above is correct, we find from it the prediction $\alpha_p - \alpha_n \approx \Delta\alpha_p - \Delta\alpha_n = 3.5$. Unfortunately, the dispersion calculations which have been carried out to date for the nucleon polarizabilities[5] are not accurate enough to test this prediction.

We wish to emphasize again that the polarizabilities of the light mesons are largely determined by the properties of the quark sea and, possibly, by the structure of the vacuum, so that a further study of these polarizabilities is of much interest.

[1)] S. B. Gerasimov has pointed out that the condition $\alpha_{\pi^\pm} < \alpha_{\pi^0}$ also holds in his relativistic potential quark model.

[1] Yu. M. Antipov *et al.*, Preprint 85–120, Institute of High-Energy Physics [in Russian], 1982; Pis'ma Zh. Eksp. Teor. Fiz. **35**, 302 (1982) [JETP Lett. **35**, 375 (1982)]; Phys. Lett. (in press).

[2] M. K. Volkov and V. N. Pervushin, Sushchestvenno nelineĭnye kvantovye teorii, dinamicheskie simmetrii i fizika mezonov (Highly Nonlinear Quantum Theories, Dynamic Symmetries, and the Physics of Mesons), Atomizdat, Moscow, 1978.

[3] M. K. Volkov and D. Ebert, Yad. Fiz. **34**, 182 (1981) [Sov. J. Nucl. Phys. **34**, 104 (1981)].

[4] A. I. L'vov, Yad. Fiz. **34**, 522 (1981) [Sov. J. Nucl. Phys. **34** 289 (1981)].

[5] V. A. Petrun'kin, Fiz. Elem. Chastits At. Yadra. **12**, 692 (1981) [Sov. J. Part. Nucl. **12**, 278 (1981)].

[6] S. B. Gerasimov, A. I. Lebedev, and V. A. Petrun'kin, Zh. Eksp. Teor. Fiz. **43**, 1872 (1962) [Sov. Phys. JETP **16**, 1321 (1963)].

[7] E. I. Gol'braĭkh, A. I. L'vov, and V. A. Petrun'kin, Preprint 1 No. 171, P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow [in Russian], 1982; Yad. Fiz. (1983) (in press).

[8] V. A. Miransky, V. P. Gusynin, and Y. A. Sitenko, Phys. Lett. **100B**, 157 (1981); V. A. Miranskiĭ and P. I. Fomin, Yad. Fiz. **35**, 1563 (1982) [Sov. J. Nucl. Phys. **35**, 913 (1982)].

[9] J. R. Finger and J. E. Mandula, Nucl. Phys. **B199**, 168 (1982).

[10] A. I. Vaĭnshteĭn, V. I. Zakharov, V. A. Novikov, and M. A. Shifman, Fiz. Elem. Chastits At. Yadra. **13**, 542 (1982) [Sov. J. Part. Nucl. **13**, 224 (1982)].

[11] P. S. Baranov *et al.*, Yad. Fiz. **21**, 689 (1975) [Sov. J. Nucl. Phys. **21**, 281 (1975)]; A. I. L'vov, Yad. Fiz. **34** 1075 (1981) [Sov. J. Nucl. Phys. **34**, 597 (1981)].

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