IS THERE A NEW MAGNETIC-TYPE INTERACTION BETWEEN NUCLEONS?

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(Received January 22, 1990)

It is suggested to experimental physicists to look for a magnetic-type deviation from the familiar magnetic interaction between nucleons. Such a deviation would give us a strong indication that quarks would be composed of some more elementary constituants bound by a new Abelian gauge force, since then quarks and hence also nucleons should display a new magnetic-type interaction.

PACS numbers: 14.20.Dh, 12.50.Ch. 12.90.+h

The aim of the present paper is to suggest to experimental physicists that it is worth while to design and perform some experiments where the long-range, spin-dependent interaction between nucleons could be measured with a reasonable precision. In fact, a considerable, magnetic-type deviation of this interaction from the familiar magnetic interaction (produced by the known magnetic moments of nucleons) would give us a strong indication that quarks would not be elementary but rather composed [1, 2] of some more elementary constituents (preons) bound by a new *Abelian gauge force*. It is so, because then quarks, though expected to be neutral with respect to the corresponding new Abelian charge, should display new magnetic-type moments leading to a new magnetic-type interaction between quarks. Hence, also nucleons, as being composed of quarks, should get new magnetic-type moments implying a new magnetic-type interaction between nucleons.

In order to dispose of a convenient term for the hypothetical new Abelian gauge force let us call it the *ultraelectromagnetic force*, and the corresponding new Abelian charge, the *ultracharge* [3] (an alternative prefix "super" used in the first Ref. [3] may be somewhat misleading as having nothing to do with supersymmetry). The ultraelectromagnetic force

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would be transmitted through the *ultraelectromagnetic field* satisfying new Maxwell-type equations. The new massless gauge boson may be referred to as the *ultraphoton* Γ.

It is natural to assume that all the presently known particles would be neutral with respect to the ultracharge. But, some of them might be composed of ultracharged preons whose ultracharges would be then neutralized. It is important to point out that due to the Abelian character of ultraelectromagnetic force the ultracharge-neutral fermions, if composed in this way, would possess nonzero *ultramagnetic moments* $\mu^{(u)}$ coupled to the part of the ultra-electromagnetic field that may be called the ultramagnetic field. The corresponding part of the ultraelectromagnetic force may be referred to as the ultramagnetic force. Therefore, macroscopic polarized systems of composite fermions of this kind — call these system *ultramagnets* — could be used to create and eventually detect the ultramagnetic field in laboratory.

Since the ultraelectromagnetic binding of preons within quarks should be stronger than the electromagnetic binding of an electron and a positron within positronium, the ultramagnetic constant $\alpha^{(u)}$ should be larger than the electromagnetic constant α. Thus, the generic ultramagnetic moments should be expected to prevail over the magnetic moments of the same composite fermions. As the ultramagnetic moments are not observed for leptons, it is reasonable to assume that *leptons are elementary* and so avoid possessing ultramagnetic moments. On the other hand, assuming that *quarks are composed of ultracharged preons*, we must take into account their ultramagnetic moments larger (in magnitudes) than their magnetic moments. In this case also nucleons, as being composed of quarks, ought to have ultramagnetic moments of considerable magnitudes. For instance, if $\alpha < \alpha^{(u)} \leqslant 2$ [3] the proton ultramagnetic moment is expected to be larger (in magnitude) than the proton magnetic moment by a factor of the order of $1 < (\alpha^{(u)}/\alpha)^{1/2} \leqslant 16.6$, but smaller (in magnitude) than the electron magnetic moment by a factor of the order of $0.000545 < (\alpha^{(u)}/\alpha)^{1/2}(m_e/m_p) \leqslant 0.00902$.

In nucleons systems, the new interaction of nucleon ultramagnetic moments with the ultramagnetic field contributes a long-range part (and a contact term),

$$H_{\rm umag} = -\frac{\mu_1^{(u)}\mu_2^{(u)}}{r^3} S_{12} - \frac{8\pi\mu_1^{(u)}\mu_2^{(u)}}{3} \vec{\sigma}_1 \cdot \vec{\sigma}_2 \delta(\vec{r}), \tag{1}$$

to the effective spin-spin interaction whose short-range part is provided by meson exchanges caused by the conventional strong interaction. In Eq. (1) $S_{12} = 3(\vec{\sigma}_1 \cdot \hat{r})(\vec{\sigma}_2 \cdot \hat{r}) - \vec{\sigma}_1 \cdot \vec{\sigma}_2$. Another long-range part (and another contact term) is obviously contributed by the familiar magnetic spin-spin interaction

$$H_{\rm mag} = -\frac{\mu_1\mu_2}{r^3} S_{12} - \frac{8\pi\mu_1\mu_2}{3} \vec{\sigma}_1 \cdot \vec{\sigma}_2 \delta(\vec{r}). \tag{2}$$

For nucleons, the ultramagnetic moments $\mu_p^{(u)}$ and $\mu_n^{(u)}$ are expected to be larger (in magnitudes) than the magnetic moments μ_p and μ_n. Note that the familiar magnetic spin-orbit interaction gets no its ultramagnetic counterpart both for quarks and nucleons because, in contrast to preons, they are ultracharge-neutral (of course, for them there is also no ultraelectric counterpart of the Coulomb interaction, so important for preons).

A macroscopic system of polarized protons or neutrons is expected to act as an ultramagnet. Two such systems will attract or repulse each other very much like two ordinary magnets do. However, forces acting between two macroscopic ultramagnets seem to be too weak for direct measurements. Therefore, in order to detect the existence of the ultramagnetic interaction we have to study a microscopic system in which the distance between particles possessing ultramagnetic moments is small.

One of such systems which can be studied experimentaly is an antiprotonic atom, in particular protonium i.e., the $p\bar{p}$ atom. The spectra of X-rays emitted by protonium have been measured [4, 5]. These show characteristic maxima which have been attributed to *K* and *L* transitions between different energy levels of protonium. The present accuracy of measurements does not allow yet to observe the structure of these levels. For our purpose two conditions are to be met. At first, the fine and hyperfine structure must be resolved. Secondly, the strong interaction effects must be small or, at least, well controlled. The best candidate seems to be the 2P level of protonium. The electromagnetic structure is due to the spin-orbit coupling and the interaction (2) between magnetic moments of the proton and antiproton. These effects can be calculated. For protonium both are comparable and the result is shown in Fig. 1a. If the proton and antiproton carry also ultramagnetic moments, the hyperfine splitting of protonium energy levels will be influenced by the ultramagnetic force. Since the interaction between ultramagnetic moments is expected to be stronger than the interaction of magnetic moments, the existence of ultramagnetic interaction will result in a larger splitting of energy levels than that expected for magnetic interaction only.

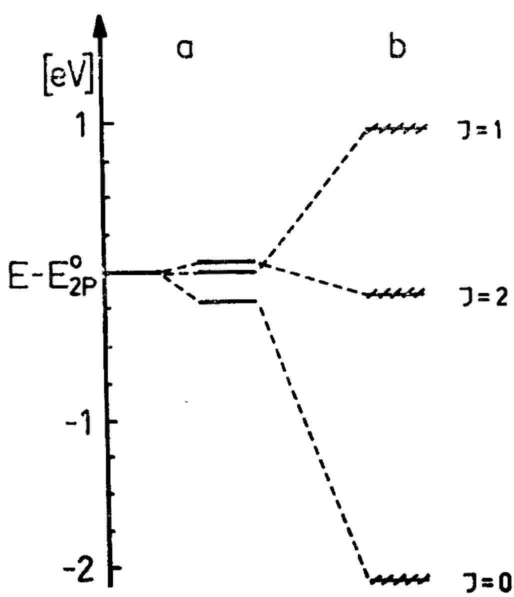

Fig. 1. Splitting of the 2^3P_J levels of protonium. Part a shows fine and hyperfine electromagnetic splitting. Part b indicates expected effects of the ultramagnetic interaction for $\alpha^{(u)} = 1$. The broadenings are due to strong interactions [4, 5]. Strong level shifts, apparently of a similar magnitude, are not marked. E^0_{2P} denotes the nonrelativistic energy level

In the case of an antiprotonic atom (odd-even nucleus) Eq. (1) yields for $L > 0$

$$\Delta E(J, L, S) = \frac{\alpha^{(u)}}{4m_N^2} \langle JLS| \frac{1}{r^3} S_{12}|JLS\rangle$$

$$= \frac{\alpha^{(u)} m_N}{4} \left(\frac{Z\alpha A}{A+1}\right)^3 \frac{\langle JLS|S_{12}|JLS\rangle}{n^3 L(L+1)(L+\frac{1}{2})}, \tag{3}$$

where n, J, L, S are the atomic quantum numbers, while Z and A denote the atomic and baryonic numbers of the nucleus. Putting for instance $\alpha^{(u)} = 1$ one obtains for protonium the result given in Fig. 1b. This can be verified experimentally provided the X-ray spectra are measured with an accuracy of 0.2 eV e.g. with a bent-crystal spectrometer [4].

Ultramagnetic effects in the antiprotonic deuterium would be ca. 4 times larger due to smaller Bohr radius ($A/A+1$ factor in Eq. (3)) and larger ultramagnetic moment of the deuteron (it is natural to assume that $\mu_p^{(u)} \simeq \mu_n^{(u)}$). In heavy antiprotonic atoms ($Z \sim 70$, odd-even nucleus), where the electromagnetic fine structure is resolved [7], one expects from Eq. (3) for $\alpha^{(u)} = 1$ about 0.1 keV splitting in the "upper" measurable levels ($n = 9$, $L = 8$). This is only slightly less then the now available 0.2 keV X-ray resolution.

Another effect which can be used to verify the existence of ultramagnetic moments of nucleons is the emission of ultraphotons in spin-flip nuclear transitions. In such transitions both photons and ultraphotons can be emitted from nuclei. The radiation of ultraphotons is generated by the spin flip of one nucleon what means also the change of the orientation of its ultramagnetic moment. Free ultraphotons would be absorbed in the matter much weaker than ordinary photons are. This is so as the later interact mainly with charged particles — electrons and nuclei. Contrary to that, ultraphotons do not meet in the matter any particles with an ultraelectric charge because both electrons and nuclei are ultraelectrically neutral. The absorption of ultraphotons in the matter would be similar to the absorption of photons in the matter composed only of neutrons. The relatively weak absorption of ultraphotons by nuclei makes it difficult to observe them, especially that they are accompanied by much more strongly interacting photons. Nevertheless, if the ultraelectromagnetic forces exist, spin-flip nuclear transition should emit not only ordinary photons but also ultraphotons. The former can be easily absorbed. Therefore, ultraphotons will manifest their existence as a penetrating component of the nuclear radiation which nevertheless interacts with nuclear matter and, therefore, can be detected.

A simple case of the spin-flip baryonic transition is the decay $\Sigma^0 \to \Lambda + \gamma$. Provided the $\Sigma^0 - \Lambda$ transition ultramagnetic moment is of a considerable magnitude, it can be also the source of ultraphotons from the decay $\Sigma^0 \to \Lambda + \Gamma$. We know that $\Sigma^0 \to \Lambda + \gamma$ is the dominant decay mode of Σ^0. Studies of Σ^0 decays with only hyperon Λ detected as a decay product could put the upper limit on the decay occuring with the emission of an ultraphoton.

Because of its long range tail the potential (1) may produce noticeable effects in the nucleon-nucleon scattering at very low energies. Indeed, we estimate that for $E_{kin} \lesssim 1$ MeV the P and higher wave scattering phases due to H_{umag} ($\alpha^{(u)} = 1$) exceed those due to the one-pion exchange potential. However, we cannot check such effects at these energies. It is only at higher energies, say 5 MeV, that the existing phase analysis of Ref. [8] and in particular the error matrix given there allows us to set a limit of $\alpha^{(u)} \lesssim 1$. In this context it would be interesting to perform a new low-energy phase analysis including also our $H_{\rm umag}$.

The discussion presented in this paper is motivated by the idea of ultracharge-neutral quarks composed of ultracharged preons bound by ultraelectromagnetic attraction. Such an idea can be pedagogically illustrated in the composite model of quarks described in Ref. [3] to which the reader interested in building of specific models may be referred. Of course, if the idea of Abelian compositeness of quarks turned out be to true, the formulation of the correct model of quarks should be one's next aim.

There are, however, two important questions concerning our Abelian composite picture of quarks which we would like to comment on briefly in this paper.

The first question is why composite quarks have so small radii (that they are still not observed experimentally) and, at the same time, small masses (much smaller than the scale of inverse radii). This question, common for all composite models of leptons and/or quarks, was discussed in the first Ref. [3] in the spirit of Abelian picture. To repeat the argument in short, assume that u and d quarks are relativistic bound states of a spin-1/2 preon (existing in two flavors) and a spin-0 preon (existing in three colors) held together by an Abelian attraction described, on the potential-theory level, by $V = -\alpha^{(u)}/r$. Then, using for the system the appropriate relativistic two-body wave equation introduced in Ref. [9] and putting tentatively masses of both preons equal to m, one obtains a Sommerfeld-type energy spectrum. This gives for ground states (i.e., $n = 1$, $j = 1/2$), intended to represent u and d quarks, the mass $m_{\rm u} = m_{\rm d} = E_{1\frac{1}{2}} = 2m\gamma_{1/2}$ where $\gamma_{1/2} = \sqrt{1-(\alpha^{(u)}/2)^2}$, while the mass of the first radially excited states (i.e., $n = 2, j = 1/2$) is $E_{2\frac{1}{2}} = m\sqrt{2(1+\gamma_{1/2})}$. Hence, irrespectively of how big the preon mass m may be, $m_{\rm u} \to 0$ and $m_{\rm d} \to 0$ if $\alpha^{(u)} \to 2$, while $E_{2\frac{1}{2}} \to m\sqrt{2}$. On the other hand, the radius of u and d quarks is given by the relativistic wave function $\psi_{1\frac{1}{2}} \sim \exp[-\sqrt{m^2-(E_{1\frac{1}{2}}/2)^2}r]$ at $r \to \infty$, so it is $1/m$ if $\alpha^{(u)} \to 2$ with m as large as needed. Thus, the critical, relativistic two-body mechanism related to $\alpha^{(u)} \to 2$ may be an answer to our first question.

The second question concerns the scale of nucleon ultramagnetic moments. In this paper we used for $\mu_{\rm p}^{(n)}$ and $\mu_{\rm n}^{(u)}$ the estimation $\sqrt{\alpha^{(u)}}/2m_{\rm N}$ suggested by the analogy with the nucleon magnetic moments $\mu_{\rm p} = 2.8\,(\sqrt{\alpha}/2m_{\rm N})$ and $\mu_{\rm n} = -1.9(\sqrt{\alpha}/2m_{\rm N})$ which are of the order of $\sqrt{\alpha}/2m_{\rm N}$. Here, the charge-neutral neutron is an analogue of ultracharge--neutral quarks and nucleons. The above estimation for $\mu_{\rm p}^{(u)}$ and $\mu_{\rm n}^{(u)}$ is not in contradiction with the expected very low estimate $\sqrt{\alpha^{(u)}}/2m_{\rm preon}$ for the spin-1/2-preon ultramagnetic moment $\mu_{\rm preon}^{(u)}$ ($m_{\rm preon} = m$) since, in the relativistic point-like bound states with total spin 1/2, constituent magnetic (as well as ultramagnetic) moments are not additive. In fact, when combining, they scale with the inverse mass of the resulting bound states. This is clear enough for the Dirac normal magnetic moments of charged states such as the proton, though less obvious (but still true) for anomalous magnetic moments of charged or neutral states such as the proton or neutron.

At the very end we would like to call the reader's attention to the molecular radiofrequency experiments determining H_2 rotational levels in external magnetic fields [10, 11]. They measured hfs effects in H_2 molecules, consistent with the conventional magnetic dipole-dipole interaction (2) of two protons involved. Of course, these experiments concern proton-proton distances that are three orders of magnitude larger than proton-antiproton distances within protonium discussed in the present paper. For such molecular distances a possible nonzero ultraphoton rest mass might be strongly manifested. In fact, the discussed value of $\alpha^{(u)} \simeq 1$ is still consistent with the negative result of the molecular experiments, provided our ultraphoton is given a rest mass $\gtrsim 5\%$ of the electron mass [10]. In this case, however, our Abelian ultracharge gauge symmetry should be spontaneously broken (by the Higgs mechanism).

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