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SUPERELECTROMAGNETISM AND COMPOSITE QUARKS*

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An economical composite model of quarks is constructed, where beside the usual elementary leptons there are their opposite-charged counterparts carrying additionally an Abelian supercharge generating new superelectromagnetic interactions. They are responsible for binding these superleptons and some color-triplet supercharged scalar into supercharge-neutral composites interpreted as the usual quarks, but possessing in addition some supermagnetic moments. The corresponding gauge boson or superphoton as well as the superleptons are not confined, what leads to quark-splitting phenomena. An argument is given that the superelectromagnetic coupling constant α_{SEM} may be as large as 2. The usual gluons and electroweak intermediate bosons are here elementary. If true, the model opens new experimental perspectives.

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1. *Introduction*

The reasons why electromagnetic phenomena have been so familiar to people for a very long time are the tiny ionization energy of atoms and molecules on one hand, and the spontaneous polarization of elementary magnetic dipoles in ferromagnets on the other. If the Sommerfeld constant α were larger and the magnetization of ferromagnetic substances not so easy, the electromagnetic phenomena would be hidden deeper in the structure of matter. In this paper we raise a provocative question whether there could exist new Abelian vectorlike gauge forces, stronger than the electromagnetic ones, that would be still hidden for us in the structure of matter. For the sake of convenience we shall call such hypothetical forces the *superelectromagnetic forces*. It is evident that our question is closely related to the problem of possible compositeness of the so-called elementary particles [1, 2], first of all of leptons and quarks.

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2. *Composite quarks*

To make a case for the superelectromagnetic forces we consider a composite model of quarks, where beside the usual elementary leptons of $N \geqslant 3$ generations, $\nu^{(n)}$ and $e^{(n)}$ ($n = 0, 1, \ldots N-1$), there exist their opposite-charged counterparts, the *superleptons* $U^{(n)}$ and $D^{(n)}$ ($n = 0, 1, \ldots, N-1$), carrying additionally an Abelian vectorlike *supercharge.* It generates the new *superelectromagnetic interactions* whose gauge boson will be called the *superphoton* Γ and the corresponding gauge field — the *superelectromagnetic field.* These interactions are responsible for binding the superleptons and some postulated color-triplet supercharged scalar into supercharge neutral components which we interpret as the usual quarks. The superelectromagnetic field satisfies the Maxwell equations where sources are provided by the four-current of supercharge.

To be more specific we postulate the following quantum-number assignment [3]:

	spin	I^3_L	Y	Q	L	B	color	supercharge
$\nu^{(n)}_{L,R}$	1/2	1/2, 0	−1, 0	0	1	0	**1**	0
$e^{(n)}_{L,R}$	1/2	−1/2, 0	−1, −2	−1	1	0	**1**	0
$U^{(n)}_{L,R}$	1/2	1/2, 0	1, 2	1	−1	0	**1**	−1
$D^{(n)}_{L,R}$	1/2	−1/2, 0	1, 0	0	−1	0	**1**	−1
ϕ	0	0	−2/3	−1/3	1	1/3	**3**	1

Here, $f_{L,R} = \frac{1}{2}(1 \mp \gamma_5)f$, while the charge Q and weak hypercharge Y are given by the formulae

$$Q = I^{(3)}_L + \tfrac{1}{2} Y, \qquad Y = 2I^{(3)}_R + B - L, \tag{1}$$

with the obvious values of $I^{(3)}_R$. Then, the preons $U^{(n)}$, $D^{(n)}$ and ϕ are bound into up and down quarks of $N \geqslant 3$ generations as follows [4]:

$$u^{(n)} = \phi U^{(n)}, \qquad d^{(n)} = \phi D^{(n)}. \tag{2}$$

In analogy with $\nu_e = \nu^{(0)}$, $e = e^{(0)}$ and $u = u^{(0)}$, $d = d^{(0)}$, we shall denote $U = U^{(0)}$, $D = D^{(0)}$. We can see that in the model there are $2N$ Dirac preons and 3 scalar preons resulting into $6N$ Dirac composites that represent up and down color quarks of $N \geqslant 3$ generations (or, counting spin states, there are $4N+3 \geqslant 15$ preon states leading to $12N \geqslant 36$ quark spin states). So, the model is not in a bad situation from the economical point of view.

In addition, there appear some (pseudo)scalar and vector composites. The preons $U^{(n)}$ and $D^{(n)}$ form spin-0 and spin-1 composites $U^{(m)}\overline{D}^{(n)}$, $\frac{1}{\sqrt{2}}(U^{(m)}\overline{U}^{(n)} \mp D^{(m)}\overline{D}^{(n)})$, $D^{(m)}\overline{U}^{(n)}$ with charges 1, 0, −1, respectively. The preon ϕ gives spin-0 color singlet bound states $\phi\bar{\phi}$ and $\phi\phi\phi$ with charge 0 and −1 and supercharge 0 and 3, respectively. The latter state is bound due to the color confinement in spite of the supercharge repulsion which, however, should make this state considerably heavy. All the above composite bosons, except for $\phi\phi\phi$, if their masses are large enough, can decay superelectromagnetically into quark pairs and thus into hadrons. Then, they are highly unstable. When they are charge-neutral and have $m = n$, they can also decay, irrespectively of their masses, into superphotons. The interesting color-singlet $\phi\phi\phi$ boson should lead to the supercharge-neutral excited bound states $p^* = (\phi\phi\phi)UUD$ and $n^* = (\phi\phi\phi)DDU$ with charge 1 and 0 that could decay into the proton $p = uud = (\phi U)(\phi U)(\phi D)$ and neutron $n = ddu = (\phi D)(\phi D) \times (\phi U)$, respectively, plus a number of superphotons. Also another class of excited bound states is possible, where individual quarks $u = \phi U$ and $d = \phi D$ are excited.

It should be emphasized that, due to Bose statistics of the color-triplet ϕ scalars, the wave functions of all $\phi\phi\phi$ configurations ought to include some fully antisymmetrical orbital factors built up of two relative coordinates $\vec{r} = \vec{r}_1 - \vec{r}_2$ and $\vec{\varrho} = \vec{r}_3 - \frac{1}{2}(\vec{r}_1 + \vec{r}_2)$. In the particular case of the spin-0 $\phi\phi\phi$ configuration such a factor is a scalar of the form

$$f(\vec{r}_1, \vec{r}_2, \vec{r}_3) = P_l(\hat{r} \cdot \hat{\varrho}) R(r, \varrho)$$

$$+ \text{ two cyclic permutations of } \vec{r}_1, \vec{r}_2, \vec{r}_3, \tag{3}$$

where $\hat{r} = \vec{r}/r$ and $\hat{\varrho} = \vec{\varrho}/\varrho$, while $P_l(x)$ is the Legendre polynomial with an *odd* l. Here, $R(r, \varrho)$ is the radial wave function to be determined from the wave equation. For the lowest states, $l = 1$. The angular variable $\hat{r} \cdot \hat{\varrho}$ can be written as

$$\hat{r} \cdot \hat{\varrho} = \frac{4\pi}{3} [Y_{1,0}(\hat{r}) Y_{1,0}(\hat{\varrho}) - Y_{1,1}(\hat{r}) Y_{1,-1}(\hat{\varrho}) - Y_{1,-1}(\hat{r}) Y_{1,1}(\hat{\varrho})], \tag{4}$$

with $Y_{l,m}(\hat{r})$ and $Y_{l,m}(\hat{\varrho})$ denoting the spherical harmonics related to $\vec{L}^{(r)} = \vec{r} \times \vec{p}$ and $\vec{L}^{(\varrho)} = \vec{\varrho} \times \vec{\pi}$, respectively, where $\vec{p} = -i\partial/\partial\vec{r}$ and $\vec{\pi} = -i\partial/\partial\vec{\varrho}$. In the centre-of-mass frame $\vec{L} = \sum_i \vec{L}^{(i)} = \vec{L}^{(r)} + \vec{L}^{(\varrho)}$. Note that

$$\vec{L} P_l(\hat{r} \cdot \hat{\varrho}) = 0, \tag{5}$$

but

$$\vec{L}^{(r,\varrho)2} P_l(\hat{r} \cdot \hat{\varrho}) = l(l+1) P_l(\hat{r} \cdot \hat{\varrho}), \tag{6}$$

whilst for $L_z^{(r)} = (\vec{r} \times \vec{p})_z = -i\partial/\partial\varphi^{(r)}$ and $L_z^{(\varrho)} = (\vec{\varrho} \times \vec{\pi})_z = -i\partial/\partial\varphi^{(\varrho)}$ one gets

$$\int_0^{2\pi} d\varphi^{(r,\varrho)} P_l(\hat{r} \cdot \hat{\varrho}) L_z^{(r,\varrho)} P_l(\hat{r} \cdot \hat{\varrho}) = 0. \tag{7}$$

Note also that two cyclic permutations in Eq. (3) give

$$\vec{r} \to -\vec{\varrho} - \tfrac{1}{2}\vec{r} \to \vec{\varrho} - \tfrac{1}{2}\vec{r},$$

$$\vec{\varrho} \to -\tfrac{1}{2}\vec{\varrho} + \tfrac{3}{4}\vec{r} \to -\tfrac{1}{2}\vec{\varrho} - \tfrac{3}{4}\vec{r}. \tag{8}$$

Nevertheless, $\vec{L} f(\vec{r}_1, \vec{r}_2, \vec{r}_3) = 0$.

A fully antisymmetrical factor of the form (3) should appear both for the $\phi\phi\phi$ boson and for the $\phi\phi\phi$ configuration within the proton and neutron. In the second case, since

ϕ scalars are tightly bound to superleptons U and D resulting into quarks $u = \phi U$ and $d = \phi D$, the UUD and DDU configurations within the proton and neutron, respectively, get in the limit of pointlike quarks the same orbital factor as in the $\phi\phi\phi$ configuration. Thus, in this limit, the proton and neutron wave functions should include a fully symmetrical orbital factor that after reduction with respect to $P_l(\hat{r}\cdot\hat{\varrho})$'s is, in the lowest state, a constant multiplied by a radial wave function dependent on r and ϱ plus two cyclic permutations (subject to relativistic modifications introducing "small" P-wave components). Then, the noncolor part of each of these wave functions is either fully symmetrical or symmetrical with respect to two identical quarks only (viz. 1 and 2) [5].

Denote by $w^{\uparrow\uparrow\downarrow}_{p,n}$, $w^{\uparrow\downarrow\uparrow}_{p,n}$ and $w^{\downarrow\uparrow\uparrow}_{p,n}$ the probabilities of finding in the proton p = uud or neutron n = ddu with spin $\uparrow$ the indicated quark spins (evidently, $w^{\uparrow\uparrow\downarrow}_{p,n}+w^{\uparrow\downarrow\uparrow}_{p,n}+w^{\downarrow\uparrow\uparrow}_{p,n} = 1$). Then, we can write the following formulae for the proton and neutron magnetic moments (in units of $e/2m_p$) defined as $\mu_{p,n} = N_3\langle\sum_i(\mu_i\sigma^{(i)}_z+Q_iL^{(i)}_z)\rangle^{\max}_{p,n}$ (where $\langle\;\rangle^{\max}$ corresponds to maximal magnetic quantum numbers and $N_3 > 0$ denotes a normalization constant):

$$\frac{1}{N_3}\mu_p = (2\mu_u-\mu_d)w^{\uparrow\uparrow\downarrow}_p+\mu_d(w^{\uparrow\downarrow\uparrow}_p+w^{\downarrow\uparrow\uparrow}_p)$$

$$+Q_u\langle L^{(r)}_z\rangle^{\max}_p+(\tfrac{1}{3}Q_u+\tfrac{2}{3}Q_d)\langle L^{(\varrho)}_z\rangle^{\max}_p$$

$$= 2(\mu_u-\mu_d)w^{\uparrow\uparrow\downarrow}_p+\mu_d+\tfrac{2}{3}\langle L^{(r)}_z\rangle^{\max}_p \tag{9}$$

and

$$\frac{1}{N_3}\mu_n = (2\mu_d-\mu_u)w^{\uparrow\uparrow\downarrow}_n+\mu_u(w^{\uparrow\downarrow\uparrow}_n+w^{\downarrow\uparrow\uparrow}_n)$$

$$+Q_d\langle L^{(r)}_z\rangle^{\max}_n+(\tfrac{1}{3}Q_d+\tfrac{2}{2}Q_u)\langle L^{(\varrho)}_z\rangle^{\max}_n$$

$$= -2(\mu_u-\mu_d)w^{\uparrow\uparrow\downarrow}_n+\mu_u-\tfrac{1}{3}\langle L^{(r)}_z-L^{(\varrho)}_z\rangle^{\max}_n. \tag{10}$$

Here, $Q_u = 2/3$ and $Q_d = -1/3$. Since in Eqs (9) and (10) two spins are up and one is down, we put $\langle L_z\rangle^{\max}_{p,n} = 0$, where $\vec{L} = \vec{L}^{(r)}+\vec{L}^{(\varrho)}$. Then using the experimental value $\mu_p = 2.8$ and $\mu_n = -1.9$ we can see from these equations that $0.9 = \mu_p+\mu_n = N_3(\mu_u+\mu_d)$ and $4.7 = \mu_p-\mu_n = N_3[(4w-1)(\mu_u-\mu_d)+\frac{4}{3}\langle L^{(r)}_z\rangle^{\max}_{p,n}]$ if $w^{\uparrow\uparrow\downarrow}_p = w^{\uparrow\uparrow\downarrow}_n (\equiv w)$ and also $\langle L^{(r)}_z\rangle^{\max}_{p,n}$ are equal. When we tentatively apply to $u = \phi U$ and $d = \phi D$ the potential model discussed in Section 5, we get $\langle\psi_0|\sigma_z|\psi_0\rangle^{\max}\to 1/3$ and $\langle\psi_0|L_z|\psi_0\rangle^{\max}\to 1/3$ with $\alpha_{SEM}\to 2$, where $\vec{L} = \vec{r}\times\vec{p}$ and ψ_0 is the Dirac-type Coulombic ground state (of course, $\langle\psi_0|\frac{1}{2}\sigma_z+L_z|\psi_0\rangle^{\max} = 1/2$). Then

$$\mu_u = N_2\langle\psi_0|\sigma_z+(1-\tfrac{1}{3})\tfrac{1}{2}L_z|\psi_0\rangle^{\max}\to\tfrac{4}{9}N_2, \tag{11}$$

and

$$\mu_d = N_2\langle\psi_0|(-\tfrac{1}{3})\tfrac{1}{2}L_z|\psi_0\rangle^{\max}\to -\tfrac{1}{18}N_2, \tag{12}$$

where N_2 is a normalization constant. Hence, $N_2N_3 = 0.9(18/7)$ and $N_3\langle L_z^{(r)}\rangle_{\mathrm{p,n}}^{\max} = \frac{3}{4}[4.7-\frac{1}{2}N_2N_3(4w-1)]$, giving $\langle L_z^{(r)}\rangle_{\mathrm{p,n}}^{\max} = 1.1$ or 0.31 if we take e.g. $w = 1/3$ and $N_3 = 3$ or $w = 1$ and $N_3 = 3$, respectively.

This result seems to suggest that a nonzero orbital angular momentum is involved in the quark structure of the proton and neutron. It may be of the relativistic origin, corresponding to the "small" P-wave components of the quark wave function of the nucleon.

3. *The standard model and supermagnetic moments*

The vertical group structure of our model is given by

$$\mathrm{SU_L}(2) \otimes \mathrm{U_Y}(1) \otimes \mathrm{SU_C}(3) \otimes \mathrm{U_{SEM}}(1), \tag{13}$$

where $\mathrm{U_{SEM}}$ (1) is the Abelian vectorlike gauge group of superelectromagnetic interactions. So, if we assume that there are elementary gluons and electroweak intermediate bosons coupled to our elementary Dirac and scalar particles (viz. leptons, superleptons and the supercharged scalar ϕ) according to the standard-model gauge group $\mathrm{SU_L}(2)\otimes\mathrm{U_Y}(1)\otimes\mathrm{SU_C}(3)$ we achieve the consistency with the standard model. Moreover, restricting ourselves to supercharge-neutral states we get effectively the standard-model gauge group *if* the internal structure of supercharge-neutral composites (first of all, of quarks) can be neglected.

However, *not* all remnants of the internal structure of composite quarks can be really neglected, even in the realm of low energies. In fact, superleptons U and D being supercharged Dirac particles carry *supermagnetic moments* (of a magnitude larger than their magnetic moments). Thus, also quarks $\mathrm{u} = \phi\mathrm{U}$ and $\mathrm{d} = \phi\mathrm{D}$ possess supermagnetic moments (larger than their magnetic moments). These moments cannot, of course, be neutralized within spin-1/2 nucleons p = uud and n = ddu. In this way we are led to the conclusion that the proton and neutron, if built up of our composite quarks, would have supermagnetic moments (whose magnitudes are expected to be larger than the magnitudes of their ordinary magnetic moments by factors of the order of $(\alpha_{\mathrm{SEM}}/\alpha)^{1/2} \leqslant 16.6$ if the superelectromagnetic coupling constant $\alpha_{\mathrm{SEM}} \leqslant 2$). So, a system of polarized protons or neutrons should produce a *supermagnetic field* (stronger than its magnetic field). To detect this field another system of polarized nucleons is needed. Note, however, that the supermagnetic field from a nucleon (though stronger than its magnetic field by a factor of the order of $(\alpha_{\mathrm{SEM}}/\alpha)^{1/2} \leqslant 16.6$ if $\alpha_{\mathrm{SEM}} \leqslant 2$) should be considerably weaker than the magnetic field from an electron, since the ratio of magnitudes of the nucleon supermagnetic moment and the electron magnetic moment is expected to be of the order of $(m_e/m_p) \times(\alpha_{\mathrm{SEM}}/\alpha)^{1/2} \leqslant 0.0085$ if $\alpha_{\mathrm{SEM}} \leqslant 2$. Nevertheless, nuclear-polarized macroscopic bodies, the *supermagnets*, can be thought of to produce and detect the supermagnetic field. Note also that a pointlike nucleon cannot produce in its orbital motion any supermagnetic field because its supercharge is zero (the same is true for a pointlike quark also).

We can see that two nucleons should develop (in addition to their QCD-originated strong interactions) mutual *supermagnetic interactions* of the spin-spin type but none of the spin-orbit type. The absence of the latter coupling (at least on the tree-approximation level) persists even at the considerably high momentum transfers when quark structures of colliding nucleons overlap, but preonic structures of the corresponding quarks are still separated. Just at the very high momentum transfers when the preonic structures of quarks can overlap, the supermagnetic spin-orbit coupling should appear. It is possible, however, that before such very high momentum transfers are reached the quark structure of one of the colliding nucleons, $p = (\phi U)(\phi U)(\phi D)$ or $n = (\phi D)(\phi D)(\phi U)$, may transit into the atomic-like isomeric structure $p^* = (\phi\phi\phi)UUD$ or $n^* = (\phi\phi\phi)DDU$ where all clusters, viz. the extended "nucleus" $\phi\phi\phi$ and the pointlike "electrons" U and D, carry nonzero supercharges (3 and -1, respectively) producing in their orbital motion a supermagnetic field. It leads to an effective supermagnetic spin-orbit coupling for the colliding nucleons that switches on above the excitation threshold for p^* or n^*. Above this threshold also other superelectromagnetic interactions between two colliding nucleons as well as their mutual QCD-originated strong interactions are expected to change. For instance, in the excited nucleon isomer p^* or n^*, only its "nucleus" $\phi\phi\phi$ participates in the QCD-originated strong interactions. One should also stress that inside the atomic-like excited nucleon isomer p^* or n^* its "nucleus" $\phi\phi\phi$ as well as its "electrons" U and D, being bound through the Abelian supermagnetic interactions, are not asymptotically free nor confined. Thus, in the deep inelastic electron-nucleon scattering, considered above the excitation threshold for p^* or n^*, the usual parton language seems to be not so adequate as below the threshold.

We wonder (cf. Appendix), if the quark compositeness and/or the supermagnetic interactions could contribute to the surprizingly big spin effects observed by Krisch and his collaborators in pp elastic collisions with polarized beams and/or targets at $p_\perp^2 > 3.5$ GeV and $\theta_{CM} \simeq 90°$[6] (though in these experiments energies involved are relatively not very high). These effects are not explained yet by the conventional perturbative QCD [7].

4. *Superionization*

Due to the Abelian character of superelectromagnetic interactions, superleptons (like leptons) are not confined (nor are asymptotically free) in any of their bound states, although their superelectromagnetic binding within e.g. $u^{(n)} = \phi U^{(n)}$ and $d^{(n)} = \phi D^{(n)}$ should be really strong. In contrast, the supercharged scalars ϕ are confined in their color-singlet bound states e.g. $\phi\bar{\phi}$ and $\phi\phi\phi$, irrespectively of their superelectromagnetic interactions, whether attractive or repulsive. Finally, superphotons, being gauge bosons of the Abelian group, once produced, can travel freely (like photons).

Thus, at some high energies, the massive superleptons and massless superphotons might be observed as free spin-1/2 and spin-1 particles, respectively. To set an example for the superlepton production we may consider the process where quark splitting occurs in one of two colliding protons, e.g.

$$p + p \to p + \phi(\phi U)(\phi D) + U. \tag{14}$$

The superlepton U, if decelerated (in particular stopped) in matter, can produce a superphoton Γ in the process that may be called the *superbremsstrahlung*. The superphoton, if energetic enough, may in turn cause quark splitting in a target nucleon, e.g.

$$\Gamma + \mathrm{p} \to \phi(\phi\mathrm{U})\,(\phi\mathrm{D}) + \mathrm{U}. \tag{15}$$

Here, $\phi(\phi\mathrm{U})\,(\phi\mathrm{D})$ is a spin-0 color-singlet bound state with charge 0 and supercharge 1, representing the once *superionized* proton with charge 0. If it is heavy enough, it can decay into p and $\bar{\mathrm{U}}$. If not, it can be pretty stable in a supercharge-neutral substratum. In this case, beside the superleptons U and D, the *superion* $\phi(\phi\mathrm{U})\,(\phi\mathrm{D})$ (and, similarly, $\phi(\phi\mathrm{U})\,(\phi\mathrm{U})$ and $\phi(\phi\mathrm{D})\,(\phi\mathrm{D})$) may be among candidates for new stable particles. An interesting example of superphoton production is also the process:

$$\mathrm{p}+\mathrm{p} \to \mathrm{p}+\mathrm{p}^* \to \mathrm{p}+\mathrm{p}+\Gamma \tag{16}$$

(recall that $\mathrm{p} = (\phi\mathrm{U})\,(\phi\mathrm{U})\,(\phi\mathrm{D})$ and $\mathrm{p}^* = (\phi\phi\phi)\mathrm{UUD}$). Note that in $\mathrm{p}\bar{\mathrm{p}}$ collisions some natural superelectromagnetic channels are $\pi^0\pi^0\mathrm{U}\bar{\mathrm{U}}$ and $\pi^0\pi^0\mathrm{U}\bar{\mathrm{U}}\Gamma\Gamma$.

5. *An estimation of superelectromagnetic coupling*

Unfortunately, neither the superelectromagnetic coupling constant $\alpha_{\mathrm{SEM}} = e^2_{\mathrm{SEM}}/4\pi$ nor the masses of U, D and ϕ as well as of their color-singlet bound states can be estimated at the moment in a reliable way. In order to give, after all, some estimation for α_{SEM} let us try to describe the bound states $\mathrm{u} = \phi\mathrm{U}$ and $\mathrm{d} = \phi\mathrm{D}$ by means of the relativistic two--body wave equation derived on the potential-theory level for a system of one spin-1/2 particle and one spin-0 particle [8]:

$$\left[\tfrac{1}{2}(E-V) - \vec{\alpha}\cdot\vec{p} - \beta m_1 + \tfrac{1}{2}\,\frac{m_1^2 - m_2^2}{E-V}\right]\sqrt{E-V}\;\psi(\vec{r}) = 0. \tag{17}$$

Here, $\vec{p} \equiv \vec{p}_1 = -\vec{p}_2$ (in the centre-of-mass frame) and $\vec{r} \equiv \vec{r}_1 - \vec{r}_2$, while $\vec{\alpha}$ and β are Dirac matrices of the spin-1/2 particle. In our case we can try to use the Coulombic attractive potential $V = -\alpha_{\mathrm{SEM}}/r$.

For the sake of our estimation let us assume that the masses of U, D and ϕ are equal ($\equiv m$). Then, the wave equation (17) gives for the energy spectrum of bound states the Sommerfeld-type formula:

$$E = 2m\left[1 + \left(\frac{\alpha_{\mathrm{SEM}}/2}{n_r + \gamma}\right)^2\right]^{-1/2},$$

$$\gamma = [(j+1/2)^2 - \alpha^2_{\mathrm{SEM}}/4]^{1/2} \tag{18}$$

with $n_r = 0, 1, 2, \ldots$ and $j = 1/2, 3/2, 5/2, \ldots$, whilst the wave-function behaviour at $r \to 0$ and $r \to \infty$ is $r\psi \sim r^{\gamma+1/2}$ and $\psi \sim \exp(-\sqrt{m^2 - E^2/4}\,r)$, respectively. We can see from Eq. (18) that

$$E_0 = 2m\gamma_0, \quad \gamma_0 = (1 - \alpha^2_{\mathrm{SEM}}/4)^{1/2} \tag{19}$$

for the ground state ($n_r = 0$, $j = 1/2$) identified with u or d quark, and

$$E_1 = m[2(1+\gamma_0)]^{1/2} \tag{20}$$

for the first radially excited state ($n_r = 1$, $j = 1/2$). The radially excited states ($n_r \geqslant 1$, $j = 1/2$) of u or d quark cannot, of course, be identified with up and down quarks of higher generations, because the former are highly unstable due to the spontaneous emission of superphotons. So, the energy E_1, as not being observed yet, ought to be large enough (say, $E_1 > 100$ GeV?), unless the level is smeared out too much by its instability. On the other hand, we have $E_0 \simeq 0$ since $m_u \simeq 0$ and $m_d \simeq 0$. Thus, from Eqs (19) and (20) we get

$$\alpha_{SEM} \simeq 2, \quad m \simeq 0.7\,E_1. \tag{21}$$

Hence, the ground state radius $\simeq (0.7E_1)^{-1}$. It must be small enough to be unseen at present, unless another reason could be thought of for that. More precisely, $\alpha_{SEM} \lesssim 2$, as in Eq. (19) α_{SEM} is upperbounded by its critical value 2 (note that here the critical value 2 is accessible since the wave-function regularity condition $r\psi = 0$ at $r = 0$ is still satisfied for $\alpha_{SEM} = 2$). So, if our estimation (21) is correct, the superelectromagnetic interactions are at least so strong as the QCD strong interactions.

6. *Outlook*

New experimental search is, of course, necessary to say more about the existence of the superleptons U and D and the superphoton Γ (as well as about their coupling constant α_{SEM} and the masses of U, D and ϕ). But, if they exist, they will allow for a really fresh breath in our noble particle physics.

In particular, as we should point out, the considered model, if true, would have a revolutionary influence on the concept of the color quark-gluon plasma [9], since then we should be led in a natural way to a novel colorless plasma consisting of superleptons U and D, superphotons Γ and the nucleon *superions* i.e., (*i*) once, (*ii*) twice and (*iii*) three times superionized protons and neutrons: (*i*) ϕ(ϕU) (ϕU), ϕ(ϕU) (ϕD), ϕ(ϕD) (ϕD), (*ii*) ϕϕ(ϕU), ϕϕ(ϕD) and (*iii*) ϕϕϕ, respectively. All these nucleon superions would display hadron-like strong interactions, but they would differ from hadrons by their nonzero supercharge which could be a source of superbremsstrahlung of Γ's.

APPENDIX

Speculations about the role of pp interaction in pp elastic scattering [10]*

Consider the pp elastic scattering above the excitation threshold for p*. Assume that then the process passes mainly through the intermediate state pp*. In such an intermediate state there is a peculiar configuration where the supercharge-neutral quarks u = ϕU and d = ϕD from p interact with the colorless "nucleus" ϕϕϕ and the colorless "electrons" U and D of p*. Thus, here, the bulk of interaction should go via the supermagnetic field that couples quark spins with orbital angular momenta of the "nucleus" and the "electrons" as well as with spins of the latter. The quark-"nucleus" interaction seems to be more important than the quark-"electron" interactions because the extended "nucleus" $\phi\phi\phi$ carrying supercharge 3 and surrounded by the pointlike "electrons" U and D of supercharge -1 is a central and dense part of p*. There is in addition a QCD-originated quark-"nucleus" interaction caused by the exchange of a twisted $\phi\bar{\phi}$ pair but, as corresponding to a non-planar diagram, it is expected to be weaker than the supermagnetic interaction (and also the antiquark-"nucleus" QCD-originated interaction mediated by the $\phi\bar{\phi}$ boson that may appear in the πp elastic scattering).

In this way one is led to the conjecture that above the excitation threshold for p* the effective pp interaction is dominated in the centre-of-mass frame by the spin-orbit coupling proportional to $(\vec{\sigma}_1+\vec{\sigma}_2)\cdot\vec{L}$ where $\vec{L} = \vec{L}_1+\vec{L}_2 = \vec{r}\times\vec{p}$. Then, above this threshold, the spin-parallel pp elastic cross-section $\sigma(p^{\uparrow}p^{\uparrow})$ overwhelms the spin-antiparallel pp elastic cross-section $\sigma(p^{\uparrow}p^{\downarrow})$ when spins are polarized perpendicularly to the scattering plane.

In contrast, below the excitation threshold for p* (but above the region where low energy resonances are important) the effective pp interaction stems from quark-quark interactions. Assume the naive quark model, where quarks inside the colliding protons scatter independently with the same spin-parallel and spin-antiparallel elastic cross-sections $\sigma^{\uparrow\uparrow}$ and $\sigma^{\uparrow\downarrow}$. Then, the ratio R of the double-polarized pp elastic cross-sections $\sigma(p^{\uparrow}p^{\uparrow})$ and $\sigma(p^{\uparrow}p^{\downarrow})$ is given by the formula

$$R = \frac{5\sigma^{\uparrow\uparrow}+4\sigma^{\uparrow\downarrow}}{4\sigma^{\uparrow\uparrow}+5\sigma^{\uparrow\downarrow}}, \tag{A.1}$$

independent of details of the proton spin structure expressed by the probabilities $w_p^{\uparrow\uparrow\downarrow}$, $w_p^{\uparrow\downarrow\uparrow}$ and $w_p^{\downarrow\uparrow\uparrow}$. Thus, it is restricted to the narrow range $4/5 \leq R \leq 5/4$, where the lower or upper limit corresponds to $\sigma^{\uparrow\uparrow} = 0$ or $\sigma^{\uparrow\downarrow} = 0$, respectively.

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[2] For some examples of composite models cf.: H. Harari, N. Seiberg, *Phys. Lett.* **98B**, 269 (1981); O. W. Greenberg, J. Sucher, *Phys. Lett.* **99B**, 339 (1981); L. P. Abbott, E. Farhi, *Phys. Lett.* **101B**, 69 (1981); *Nucl. Phys.* **B189**, 319 (1981); H. Fritzsch, G. Mandelbaum, *Phys. Lett.* **102B**, 547 (1981); R. Casalbuoni, R. Gatto, *Phys. Lett.* **103B**, 113 (1981); R. Barbieri, R. N. Mohapatra, A. Masiero, *Phys. Lett.* **105B**, 369 (1981); W. Królikowski, *Phys. Lett.* **90B**, 241 (1980); *Phys. Rev. Lett.* **54**, 974 (1985).

[3] Cf. W. Królikowski, Superleptons and Composite Quarks, Warsaw University report IFT-10-86, July 1986 (unpublished); there $u^{(n)} = \phi N^{(n)}$ and $d^{(n)} = \phi E^{(n)}$, where $N^{(n)}$ and $E^{(n)}$ are true replicas of $e^{(n)}$ and $\nu^{(n)}$ but carrying additionally the supercharge -1, while the scalar ϕ gets the charge 2/3 beside the supercharge 1 (correct there a misprint for ϕ on p. 3: $Y = 0$ should read $Y = 4/3$). That version, in contrast to the present one, is not anomaly free. Note that the anomaly freedom requirement excludes

the composite model of leptons, where beside quarks they would be bound states of the superleptons $U^{(n)}$ and $D^{(n)}$ and a scalar.

[4] The idea of factorization of quarks into two constituents carrying separately flavor and color was put forward long ago in: W. Królikowski, CERN report TH-1313 (1971); *Bull. Acad. Pol. Sci. Ser. Math. Astron. Phys.* **20**, 487 (1972). There the flavored constituents were like the original noncolor Gell-Mann — Zweig quarks, but obeying "wrong" Bose statistics compensated by "wrong" Fermi statistics of colored scalar constituents. Such a "wrong" statistics was conjectured to be responsible for confining both constituents. In the present paper "correct" statistics is used, while the supercharge is responsible for binding (not confining) two constituents.

[5] Of this second kind is the realistic model of the nucleon wave function in the infinite-momentum frame, extracted recently from QCD sum rules in: V. L. Chernyak, J. R. Zhitnisky, *Nucl. Phys.* **B246**, 52 (1984).

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[7] Cf., however, G. F. Farrar, *Phys. Rev. Lett.* **56**, 1943 (1986); cf. also H. J. Lipkin, *Phys. Lett.* **181B**, 164 (1986); for a criticism of the Lipkin's paper cf. M. Anselmino, E. Leader, *Phys. Lett.* **184B** 261 (1987).

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[9] For a recent discussion cf. L. van Hove, Opening lecture at 5th Inter. Conf. on Ultra-Relativistic Nucleus-Nucleus Collisions, Quark Matter '86, Asilomar Pacific Grove, April 1986, CERN report TH. 4450/86, May 1986.

[10] W. Królikowski, Composite quarks and nucleon isomers Warsaw University report IFT-17-87, March 1987 (unpublished).