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LIBERATED QUARKS AND GLUONS IN e^-e^+ JETS AND BEAM-DUMP EXPERIMENTS *

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ABSTRACT

The implication of the rates of $(\bar{\mu}e)$ and $(e\rho)$ events observed at SLAC and DORIS on a choice between two alternative quark decay patterns are noted. If jets produced in e^-e^+ annihilation contain liberated quarks, decaying predominantly into neutrinos + mesons, we would expect some 20-30% of energy to be carried away by neutrinos in calorimetric measurements, compared with $\approx$ 12% in case the quarks are confined. Pair production of quarks and gluons by hadrons could provide an abundant source of prompt neutrinos. Whether such a source, unavailable within confined QCD, is needed to account for the recently reported beam-dump results can be decided unambiguously once measurements of charm production are carried out adequately.

I. INTRODUCTION

The discovery of jet phenomenon 1) in e^+e^- annihilation displaying a predominant $(1 + \cos^2\theta)$ distribution offers credence to the hypothesis of a production of point-like spin-1/2 naive quark partons. But it also raises an important question: are these quarks liberated - decaying as physical particles into leptons and hadrons (with a violation of baryon number 2)) or are they confined 3)? An appraisal of this question is also motivated by the recent results of the beam-dump experiments 4) reportedly exhibiting a production of neutrinos from a new source at a rate perhaps an order of magnitude higher than expected.

It has been stressed within the context of a unified gauge theory that depending upon the pattern of spontaneous symmetry breaking, the theory in general permits 2),5) of two possible solutions for quark charges: integral and fractional. For the former, colour SU(3) as a local symmetry is softly broken, and the octet of gluons acquire physical masses (in the favoured model $\sim$ 1 to 10 GeV). Also baryon 6) (B) and lepton numbers (L) and possibly also the fermion numbers (F = B + L) are violated, the quarks thereby becoming unstable against decays into leptons 2). For instance, with fermion-number conservation $(\Delta F = 0)$, but baryon and lepton-number violation $(\Delta B = -\Delta L \neq 0)$, quarks acquire decay modes 7) as

$$q \to \nu + \text{mesons} \quad . \tag{1}$$

The associated lifetimes are in the range $\sim 10^{-11}$ to 10^{-12} sec for $m_q \approx$ 2-3 GeV and decrease as m_q^{-3} for larger masses. Real pair production of such unstable spin-1/2 integer-charge quarks followed by their decays into missing neutrinos plus normal hadrons (π's, K's and η's) provide the simplest explanation 8) of the observed hadronic jets and simultaneously of the fact that only integer but no fractional charges are seen in the jets. There is, in short, no need 9) in this picture of absolute confinement of quarks and gluons.

For the alternative fractional quark charges, colour SU(3) as a local symmetry remains unbroken and the octet of gluons remains massless. Since no fractional charges or massless gluons are seen, it must be assumed that if the primary production is that of quark partons, these partons quickly lose their energy by shedding π's, K's, η's etc. and then without any disturbance to the jet-like tendency, themselves, recombine into coloursinglet hadrons, through the long-range confining force which they experience. The two theories mentioned above (integer versus fractional charge quarks with spin-one gluons) both rely on quantum chromodynamics (QCD) to generate the effective strong interactions. Both enjoy asymptotic freedom at least in the temporary sense [10]. They differ from each other primarily in respect of the question of liberation or confinement; hence we refer to the two theories as "liberated QCD" and "confined QCD", respectively.

It is important to distinguish experimentally between these two alternatives. With this end in view, we first review in this paper the alternative decay patterns allowed for quark decays within the flavour-colour symmetric unified theory of quarks and leptons [2]. We remark that depending upon the masses of red versus yellow and blue quarks and the masses of quarks versus gluons, there are essentially two alternative patterns for quark decays [11]

I) Either all twelve quarks [12] (p,n,λ,c with red, yellow and blue colours) decay primarily (directly or sequentially) into neutrinos plus mesons ($\pi,K,\eta,\ldots$etc) without emitting charged leptons (see (1)),

or

II) the eight yellow and blue quarks as well as the two neutral red quarks (p^0_{red} and c^0_{red}) decay as in I , but the two charged red quarks (n^-_{red} and λ^-_{red}) can decay into charged gluons plus neutrinos; the charged gluons in turn decay into $(e\nu)$, $(\mu\nu)$ or hadrons

$$\begin{array}{l}(n^- , \lambda^-)_{red} \to V^- + \nu \\ \qquad\qquad\quad \hookrightarrow (e\nu),(\mu\nu),\text{hadrons}\end{array} \tag{2}$$

Needless to say, the *second decay pattern could arise only provided the charged* red quarks are heavier than the charged gluons.

Now, subject to the assumptions that i) the liberated (p and n) quarks have a physical mass [13] $m_q \approx 1.8$-2 GeV, ii) their electromagnetic form factors [14] in the SPEAR energy range is of order unity,and iii) they are slowly varying, the decay pattern II could lead [8] to $(e\mu)$ events ($e^-e^+ \to e^{\pm}\mu^{\mp}$ + missing momentum) of the type observed at SLAC and Doris [15] through real pair production and subsequent decay of charged red quarks. We remark that this particular interpretation of the $(e\mu)$ events,though consistent with the observed lepton-momentum-spectrum [16] and the energy dependence of the $(e\mu)$ cross-section, appears to be in conflict with the recently reported rates of $(e\rho)$ events together with those of $(e\mu)$ events.

This in turn has the following implications for the hypothesis of liberted QCD:

Either a) liberated quarks and gluons are relatively light (i.e. $m_q \sim 2$ to 3 GeV for p,n,λ,c flavours), but the decay pattern I rather than II holds. In this case all twelve quarks are decaying primarily into neutrinos + mesons [17].

Alternatively,

b) liberated quarks are relatively heavy ($m_q \sim 4$ to 10 GeV). In this case either decay pattern I or II is permissible. Such medium heavy quarks as well as gluons would be pair produced at PETRA and PEP and by high-energy pp and $\bar{p}p$ machines which are being planned.

Using either quark decay pattern I or II, we spell out a distinct signature of liberated QCD for high-energy e^-e^+ experiments involving calorimetric measurements. Such measurements should show an excessive energy loss of order 24-30% for liberated QCD(assuming quark electromagnetic form factors are nearly unity). Such a loss owes its origin primarily to energy being carried away by neutrinos arising from pair production and decays of liberated quarks. Confined QCD would give rise to an energy loss of only about 12%.

At the end we remark briefly on the role which liberated quarks and gluons may conceivably play in providing an explanation of the perhaps excess neutrinos observed in beam-dump experiments.

II. *QUARK DECAY PATTERNS*

Quark decay modes as predicted in the framework of a unified gauge theory have been presented earlier [8],[11]. Here we list these and draw attention to some of their salient features. Basically the following patterns emerge [18] subject to the assumption of fermion-number conservation ($\Delta F = 0$):

$$\left.\begin{array}{ll} q_{\rm yellow,blue} & \to \nu_e + (\pi,\eta,\rho,\omega) \\ & \to \nu_\mu + (K,K^*,\cdots) \end{array}\right\} \; q = p,n$$

$$\begin{array}{ll} \lambda^0_{\rm yellow,blue} & \to \nu_\mu + (\eta,\phi,\cdots) \\ & \to \nu_e + (\bar{K},\bar{K}^*) \end{array}$$

$$\begin{aligned} c^{+}_{\text{yellow,blue}} &\to \nu_e + (D, D^{*}, \dots) \\ &\to \nu_\mu + (F, F^{*}, \dots) \\ &\to \lambda^{0}_{\text{yellow,blue}} + \pi^{+} \text{ (perhaps dominant)} \\ &\qquad \hookrightarrow \nu_e \text{ or } \nu_\mu + \text{(mesons)} \end{aligned} \tag{3}$$

$$n^{0}_{\text{yellow,blue}} \to p^{0}_{\text{red}} + \gamma \left\{ \text{if } m(n^{0}_{\text{yellow,blue}}) > m(p^{0}_{\text{red}}) \text{ ; dominant} \right\} . \tag{4}$$

(In all decays above strangeness is to be conserved, with either ν_e or ν_μ being strange 18).)

Neutral red quark decays

$$\begin{aligned} & & &\underline{\text{Allowed if}} \\ p^{0}_{\text{red}} &\to n^{0}_{\text{yellow,blue}} + \gamma & &(m(p^{0}_{\text{red}}) > m(n^{0}_{\text{yellow,blue}}) \text{ ; dominant}) \\ &\to \nu_\mu + \pi & &(*) \\ c^{0}_{\text{red}} &\to \lambda^{0}_{\text{yellow,blue}} + \gamma & & \\ &\qquad \hookrightarrow \nu + \text{mesons} & & \end{aligned} \tag{5}$$

(In the decays above strangeness is not conserved.)

Charged red quark decays

i) $\underline{m_{\text{red}} - m_{\text{yellow}} < m_\pi}$

$$\begin{aligned} (n^{-}, \lambda^{-})_{\text{red}} &\to V^{-} + \nu & &(m(q^{-}_{\text{red}}) > m_{V^{-}}) \\ &\qquad \hookrightarrow e\nu,\ \mu\nu,\ \text{hadrons} & & \\ n^{-}_{\text{red}} &\to (A_1 \text{ or } \rho \text{ or } \pi) + \nu_\mu & &(*) \\ \lambda^{-}_{\text{red}} &\to (K^{-}, K^{*-}) + \nu_\mu & &(*) \end{aligned} \tag{6}$$

(In these decays strangeness is conserved.)

ii) $\underline{m_{\text{red}} - m_{\text{yellow}} > m_\pi}$

$$\begin{aligned} q^{-}_{\text{red}} &\to q^{0}_{\text{yellow,blue}} + \pi^{-} \text{ (dominant)} \\ &\qquad \hookrightarrow \nu + \text{mesons} \quad . \end{aligned} \tag{7}$$

(*) Allowed for $[SU(4)]^4$ theory 19), but not for the basic model based on $SU(2)_L \times SU(2)_R \times SU(4)'_{L+R}$.

We thus see that under all circumstances the eight yellow and blue quarks as well as the two neutral red quarks decay into neutrinos + mesons. The two charged red quarks would decay sequentially into charged leptons if $m(q^{-}_{\text{red}}) > m_{V^-}$ and simultaneously $m(q^{-}_{\text{red}}) - m(q_{\text{yellow}}) < m_\pi$. <u>If either of these two conditions are not satisfied, even the two charged red quarks would decay into neutrinos + mesons.</u> Their lifetime in all cases would still lie in the range of about 10^{-11} to 10^{-12} sec (if $m_q \sim 2$-3 GeV). It would be about an order of magnitude shorter (10^{-12} - 10^{-13} secs) if quarks are about twice as heavy.

Thus quark decay modes, for practical considerations, may be classified into two basic alternative patterns as mentioned in the introduction:

I) $\underline{\text{Either } m(q^{-}_{\text{red}}) < m_{V^-} \text{ or } m(q^{-}_{\text{red}}) - m(q_{\text{yellow,blue}}) > m_\pi}$

In this case all quarks decay directly or sequentially into (neutrinos + mesons) without emitting charged leptons

$$q \to \nu + \text{mesons} \quad , \tag{8}$$

II) $\underline{\text{Alternatively, } m(q^{-}_{\text{red}}) > m_{V^-} \text{ and } m(q^{-}_{\text{red}}) - m(q_{\text{yellow,blue}}) < m_\pi}$

In this case all except the two charged red quarks decay as above. The charged red quarks can decay sequentially into charged leptons

$$\begin{aligned} q^{-}_{\text{red}} &\to V^{-} + \nu \\ &\qquad \hookrightarrow e\nu,\ \mu\nu \text{ or hadrons} \quad . \end{aligned} \tag{9a}$$

In addition they may also decay (assuming that the underlying symmetry is at least as big as $[SU(4)]^4$) into (neutrinos + mesons) (see (6)),

$$q^{-}_{\text{red}} \to \nu + (\rho,\ A_1 \text{ or } \pi \text{ etc.}) \quad . \tag{9b}$$

The following features are now worth noting:

a) First observe that quark decays yield <u>neutrinos</u> but not anti-neutrinos. This is a consequence of fermion-number conservation 20) ($\Delta F = 0$).

b) Preferential emission of neutrinos rather than charged leptons:

The most characteristic feature of quark decays is that they predominantly emit neutral leptons, i.e. neutrinos (ν_e and ν_μ) rather than the charged leptons. At best, only two out of the twelve quarks $(p,n,\lambda,c)_{\text{red,yellow,blue}}$, i.e. n^-_{red} and λ^-_{red}, may decay via a two-step process emitting charged leptons (e^- and μ^-), if the decay pattern II materializes. In other words, all twelve quarks (for decay pattern I)and ten out of twelve quarks (for decay pattern II) decay into neutrinos plus mesons without emitting accompanying charged leptons. Thus pair production of quarks by hadronic collisions would contribute (for either decay pattern) to prompt neutrinos without at the same time contributing to prompt electrons and muons. This unique property of quark decay, we stress, can be used to signal quark-pair production via beam-dump experiments (see remarks later). To our knowledge no other "hadron" exhibits this strong preference for emitting neutrinos rather than charged leptons.

c) ν_e/ν_μ - Ratio in hadronic collisions: Following decay pattern I (or II), we see that the sum of branching ratios for quarks to decay into ν_e and ν_μ is unity: $B(q \rightarrow \nu_e) + B(q \rightarrow \nu_\mu) = 1$. The ratio $[B(q \rightarrow \nu_e)/B(q \rightarrow \nu_\mu)]$ averaged over all quarks is in general expected to differ from unity. This is partly due to the fact that ν_e's may be emitted in association with (π,ρ) particles and ν_μ's in association with heavier (K,K^*) particles for the case of (ν_e,e) being non-strange (see list of quark decay modes). Even within the decay pattern I, the ratio $B(\nu_e)/B(\nu_\mu)$ depends quite sensitively, however, on the relative masses of red versus yellow versus blue quarks. After examining different alternatives we find that the ratio may vary quite easily between ≈ 2.5 to $1/2.5$. To see this, assume that quarks of (p,n,λ) flavours of all three colours are produced equally (in pairs) in hadronic collisions and that charm-quark production in comparison is negligible due to their heavier masses. Now consider the following three cases: Case 1: $m(p^0_{\text{red}}) > m(n^0_{\text{yellow}})$ and $[m(n^-_{\text{red}}) - m(n^0_{\text{yellow}})] > m_\pi$; Case 2: $m(p^0_{\text{red}}) > m(n^0_{\text{yellow}})$; but $[m(n^-_{\text{red}}) - m(n^0_{\text{yellow}})] < m_\pi$ with $m(q^-_{\text{red}}) < m_{V^-}$; and Case 3: $m(q_{\text{yellow,blue}}) > m(q_{\text{red}})$; but $[m(q_{\text{yellow,blue}}) - m(q_{\text{red}})] < m_\pi$ with $m(q^-_{\text{red}}) < m_{V^-}$.

The major differences between the decay patterns for these three cases may be seen by using the list given above. For example, consider Case 1 versus Case 3. For Case 1, p^0_{red} would decay into $(n^0_{\text{yellow}} + \gamma)$ with n^0_{yellow}

decaying into ($\nu_e + \pi$ etc) or ($\nu_\mu + K$ etc). For Case 3, on the other hand, p^0_{red} would decay (see list) into $\nu_\mu + \pi$'s, so also would n^-_{red}, while λ^-_{red} would decay into $(\nu_\mu + K)$.

Taking this sort of differences into account and also allowing for some phase space difference between (π,ρ) versus (K,K^*) associated modes, we estimate

$$B(\nu_e)/B(\nu_\mu) \approx (2 \text{ to } 2.5),\ 1 \quad \text{and} \quad (1/2 \text{ to } 1/2.5)$$

for Cases 1,2 and 3, respectively. The above numbers correspond to averages over (p,n,λ) flavours of all three colours. Thus we see that $B(\nu_e)$ may have a value roughly between 70 to 30% and correspondingly $B(\nu_\mu)$ between 30 to 70%. The important remark is that any significant asymmetry between prompt ν_e's versus ν_μ's, to our knowledge, can only be ascribed to production of decaying quarks.

d) The rates of SLAC-DESY $(\bar{\mu}e)$ and $(e\rho)$ events and a choice between the decay patterns I and II (for light liberated quarks): It has been remarked before [8),11)] that both $(\bar{\mu}e)$ and $(e\rho)$ events of the type discovered at SLAC and DESY [15)] may have their origin in the pair production and subsequent decay of light [21)] liberated charged red quarks provided that the quarks decay via pattern II rather than I. The sequence of events in this case would be as follows:

$$\begin{array}{llll} e^-e^+ \rightarrow q^-_{\text{red}} \;\; + & q^+_{\text{red}} & & (q = n \text{ and } \lambda) \\ \quad\;\; \downarrow & \;\downarrow & & \\ \quad\;\; V^-\nu & V^+\bar{\nu} & & \\ \quad\;\; \lfloor\!\rightarrow e^-\bar{\nu}_e & \lfloor\!\rightarrow \mu^+\nu_\mu & . & \end{array} \qquad (10)$$

$$\begin{array}{llll} e^-e^+ \rightarrow q^-_{\text{red}} \;\; + & q^+_{\text{red}} & & (q = n \text{ and } \lambda) \\ \quad\;\; \downarrow & \;\downarrow & & \\ \quad\;\; V^-\nu & \rho^+\nu & & \\ \quad\;\; \lfloor\!\rightarrow e^-\bar{\nu}_e & & . & \end{array} \qquad (11)$$

To date,with improved measurements,[15)] the above interpretation of the $(e\mu)$ events still appears to be consistent with a) the lepton-momentum spectrum [22),23)], b) the rate and energy dependence of the $(\bar{\mu}e)$ events by themselves, and c) the lack of significant semileptonic ($\bar{\mu}e$) events. We now argue that the recently reported rate of ($e\rho$) events (and in general of (e + hadron) events) together with the rate of leptonic ($e\mu$) events, however, seems to be incompatible with the quark interpretation for these events. This may be seen as follows.

The rates of ($e^-\mu^+$) and ($e^-\rho^+$) events arising through (10) and (11) may be represented by the corresponding R parameters. These are given by:

$$R(e^-\mu^+)_{q\bar{q}} = (R_{q\bar{q}})\ [B_{V\nu}]^2\ [B(V \to e\nu)]\ [B(V \to \mu\nu)] \quad , \qquad (12)$$

$$R(e^-\rho^+)_{q\bar{q}} = (R_{q\bar{q}})\ [B_{V\nu}]\ [B(V \to e\nu)]\ [B_{\rho\nu}] \quad . \qquad (13)$$

Here $R_{q\bar{q}}$ denotes the contribution of the sum of ($n^-_{red} + n^+_{red}$) and ($\lambda^-_{red} + \lambda^+_{red}$) pair productions to the R parameter. Within the gauge theory approach [24] $R_{q\bar{q}} \approx (\frac{2}{9})|f_{qq\gamma}(s)|^2$, where $f_{qq\gamma}(s)$ is the quark electromagnetic form factor. $B_{V\nu}$ and $B_{\rho\nu}$ denote the branching ratios for charged red quarks to decay into (charged gluons + neutrinos) and ($\rho^+ + \nu$), respectively, while $B(V \to e\nu)$ is the branching ratio for charged gluons to decay into electrons plus neutrinos. From (12) and (13)

$$\frac{R(e^-\rho^+)_{q\bar{q}}}{R(e^-\mu^+)_{q\bar{q}}} = \frac{B_{\rho\nu}}{(B_{V\nu})\ B(V \to \mu\nu)} \quad . \qquad (14)$$

A fraction ($\lesssim$ one third) of the $e^-\mu^+$ events could also arise [8] from the pair production and subsequent decay of charged gluons [25]. Inclusion of this contribution does not in any way alter our conclusion [26]. For simplicity of writing let us therefore ignore this contribution. We may then evaluate the right side of (14) by equating the same with the observed ratio of ($e^-\rho^+$) versus ($e^-\mu^+$) events. The latter may be deduced from the quoted experimental branching ratios for the presumed heavy lepton origin for the events. Using [15] $B(\tau^- \to e^-\bar{\nu}_e\nu_\tau) = 0.18 \pm 0.02$ and [27] $B(\tau^+ \to \rho^+\nu_\tau) = 0.24 \pm 0.09$, we obtain

$$\left.\frac{R(e^-\rho^+)}{R(e^-\mu^+)}\right|_{obs} \approx \frac{0.24 \pm 0.09}{0.18 \pm 0.02} \approx (1.3 \pm 0.7) \quad . \qquad (15)$$

Equating the right sides of (14) and (15) and using $B(V \to \mu\nu) \approx \frac{1}{3}$ (see Refs.8 and 11), we obtain

$$[B_{\rho\nu}/B_{V\nu}] \approx 0.43 \pm 0.23 \quad . \qquad (16)$$

Including other semileptonic decay modes of charged red quarks, i.e. ($A_1\nu$), $(3\pi)^+\nu$, ($\pi^+\nu$) modes in accordance with the observed rates [15),27)] of $e^-A_1^+$, $e^-(3\pi)^+$, $e^-\pi^+$ events, one may conservatively deduce that the total semileptonic branching ratio of charged red quarks

$$B_{h\nu} \equiv \sum_{h^+ = \rho, A_1, \pi^+, (3\pi)^+, \ldots} B(q^+_{red} \to h^+\nu)$$

(where h does not include the gluon), is at least 30% higher than $B_{\rho\nu}$. Using $B_{h\nu} \gtrsim (1.3)B_{\rho\nu}$, Eq.(16) and the sum rule $B_{h\nu} + B_{\rho\nu} = 1$, we may now deduce

$$B_{V\nu} \lesssim 0.7 \quad . \qquad (17)$$

Thus, in order to account for the observed rate of (e^-h^+) events (where $h^+ = \rho^+, (3\pi)^+, A_1, \pi^+$ etc) relative to that of the ($e^-\mu^+$) events, we need to assume that the gluonic branching ratio $B_{V\nu}$ of charged red quarks must be less than about 70%. On the other hand, using $R_{q\bar{q}} \approx (\frac{2}{9})$ (with $|f_{qq\gamma}(s)|^2 \approx 1$), it is easy to see (see Ref.8) that one needs the gluonic branching ratio $B_{V\nu}$ to exceed by about 90% in order that the bulk ($\gtrsim 2/3$) of the $e^-\mu^+$ events may be attributed to pair production and subsequent decay of charged red quarks. This is the incompatibility which we referred to earlier. From this we may draw two important inferences:

i) A large fraction of the ($\bar{\mu}e$) and the ($e\rho$) events, which cannot be attributed to charm-particle decays, are in all likelihood due to pair production and decays of heavy leptons. So far, this conclusion had been drawn by several authors without, however, adequate reasons.

ii) If quarks and gluons carrying integer charges are liberated and have relatively light physical masses (m_q, $m_V \lesssim$ 2 to 3 GeV), then all twelve of them, including the charged red quarks (n^-_{red} and λ^-_{red}), must be decaying into neutrinos plus mesons (π, ρ, K, K^*, η, etc.) without emitting charged leptons. In short, decay pattern I rather than II must apply if quarks are liberated and are relatively light. This would be the case, as noted before, as long as at least one of the two conditions: a) $m(q_{red}) - m(q_{yellow}) > m_\pi$ and 28) b) $m(\bar{q}_{red}) < m(V^-)$ is satisfied. In the subsequent discussion we shall discard decay pattern II and assume decay pattern I for the case of light liberated quarks. 29)

There is of course the alternative that liberated quarks and gluons are medium heavy with their physical masses in the range of 4 to 10 GeV for quarks and perhaps 8 to 10 GeV for gluons. These would be produced only at PETRA and PEP energies.

III. CALORIMETRIC MEASUREMENTS FOR $e^-e^+ \to$ HADRONS

With liberated QCD, assuming that liberated quarks have physical masses ~ 2 to 3 GeV, we would expect a significant fraction $\rho_q(s)$ $(\gtrsim \frac{1}{2})$ of the total e^-e^+ hadronic annihilation at SPEAR energies to involve real $q\bar{q}$ production. Here $\rho_q(s)$ denotes the square of the quark electromagnetic form factor 14). Since light liberated quarks decay entirely into neutrinos plus mesons (see Sec.II), we would therefore expect that a sizeable fraction κ of the total centre-of-mass energy will be carried away by neutrinos. Now, making the plausible assumption that quark decays into ν + mesons occur primarily via two-, three-and four-body channels with roughly equal probabilities (so that on the average nearly one third of the quark energy is carried away by neutrinos), we estimate that sufficiently above the threshold for quark-pair production a fraction

$$\kappa^{\text{quarks}} \approx [\rho_q(s) \quad (\tfrac{10}{3}) \quad (\tfrac{1}{3})]/R_{\text{total}} \quad ,$$

$$\approx \rho_q(s) \quad (\tfrac{10}{9}) \; /(4.5) \approx \rho_q(s) \; (25\%) \; , \qquad (18)$$

of the total e^-e^+ centre-of-mass energy going into the so-called hadronic channel 30) would be carried away by missing neutrinos arising from just quark decays. Here (10/3) $\rho_q(s)$ represents the total contribution of (p,n,λ,c) quark pair production to R, $\rho_q(s)$ being the square of the quark electromagnetic form factor. We have set $R_{\text{total}} \approx 4.5$.

There would in addition be missing energy due to

a) pair production and decays of charged gluons (V^+V^-), which contribute (1/8) $\rho_V(s)$ to R where $\rho_V(s)$ denotes the square of the gluon electromagnetic form factor;

b) pair production and decays of charmed mesons; these would contribute $(1-\rho(s))$ (4/3) to R, corresponding to nearly a fraction $(1-\rho(s))$ of charmed quark-parton pairs recombining to form charmed mesons, and

c) pair production and decays of heavy leptons, which contribute one unit to R.

Since charged gluons decay into $(e\nu)$ and $(\mu\nu)$ with nearly 30% (or 1/3) branching ratio for each mode and that neutrinos from two-body decays would carry nearly 50% of parent energy, we expect

$$\kappa^{\text{gluon}} = \rho_V(s) \; (\tfrac{1}{8}) \; (\tfrac{2}{3}) \; (\tfrac{1}{2})/R_{\text{total}} \approx \rho_V(s) \; (1\%) \quad . \qquad (19)$$

For charmed particles, taking a $(e+\mu)$ leptonic branching ratio $\approx 20\%$ and the fraction of charmed particle energy carried away on the average by neutrinos to be nearly (30%), we estimate

$$\kappa^{\text{charm}} = (1-\rho_q(s)) \; (\tfrac{4}{3}) \; (20\%) \; (30\%)/R_{\text{total}}$$

$$\approx (1-\rho_q(s)) \; (2\%) \qquad . \qquad (20)$$

Likewise, taking into account the known 15) as well as some theoretically calculated 31) branching ratios for $(\nu_\tau e^- \bar{\nu}_e)$, $(\nu_\tau \mu^- \bar{\nu}_\mu)$, $(\nu_\tau \rho)$, $(\nu_\tau A_1)$, $(\nu_\tau \pi)$ and $(\nu_\tau$ + multimeson) modes for heavy lepton decays, we estimate that the fraction of heavy lepton energy carried away on the average by ν_τ and $(\nu_e$ or $\nu_\mu)$ is nearly 40-50%. From this we estimate

$$\kappa^{\text{heavy lepton}} \approx (1) \; (40\text{-}50\%)/R_{\text{total}}$$

$$\approx 10\% \qquad . \qquad (21)$$

Adding (18), (19), (20) and (21), the net fraction of e^-e^+ centre-of-mass energy going into channels other than e^-e^+ and $\mu^-\mu^+$, which would be carried away by missing neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$, for liberated QCD, is estimated to be

$$\kappa_{\text{liberated}} = \kappa^{\text{quarks}} + \kappa^{\text{gluons}} + \kappa^{\text{charm}} + \kappa^{\text{heavy lepton}}$$
$$\approx \rho_q(s)\ (25\%) + \rho_V(s)\ (1\%) + (1-\rho_q(s))\ (2\%)$$
$$+ (10\%) \quad . \qquad (22)$$

Taking[14] $\rho_{q,V}(s) \approx$ (1/2 to 4/5) at SPEAR energies we estimate

$$\kappa_{\text{liberated}} \approx (24\text{–}30\%) \quad . \qquad (23)$$

For confined QCD, the corresponding fraction may be estimated from above by simply setting $\rho_{q,V}(s) = 0$ (this amounts to saying that for confined QCD quark pair partons recombine one hundred percent of the time to form normal hadrons and are never liberated as physical particles). Thus we estimate

$$\kappa_{\text{confined}} \approx 12\% \quad . \qquad (24)$$

In other words, liberated QCD is expected to yield missing energy, which is about twice as large as that expected of confined QCD. A measurement of total missing energy (and momentum) through calorimetric measurements involving detectors covering as much of the 4π solid angle as possible should thus help provide a clear distinction between confined and liberated QCD. Such a test at SPEAR energies would help establish or eliminate the hypothesis of light liberated quarks, while such measurements at PETRA and PEP energies would do the same for medium heavy or heavy liberated quarks ($m_q \approx$ 4-10 GeV).

IV. BEAM-DUMP EXPERIMENTS

Finally we comment on the possible role which liberated quarks and gluons may play in accounting for the recently reported[4] apparently excess neutrinos (ν_e, ν_μ, $\bar{\nu}_e$,$\bar{\nu}_\mu$'s) being produced in the 400 GeV proton induced beam-dump experiments.

First of all the neutrinos produced in the dump appear to be in excess of those expected from π and K, which would decay in the dump. This excess translated into a total cross-section σ_{new} for production of a new particle "N" in p+p multiplied by the branching ratio $B(\nu_e)$ of N to decay into ν_e appears to yield[4] (subject to certain assumptions about x_F dependence and average p_T for the production of N)

$$\sigma_{\text{new}} \times B(\nu_e) \approx (3\text{–}20)\mu b \quad . \qquad (25)$$

The lower value is given by the CDHS and the higher by the bubble chamber groups[32]. If the new particle is charm, taking $B(\nu_e) \approx 10\%$ for charm particle decays, it appears that one would need

$$\sigma_{\text{charm}} \approx (30\text{–}200)\mu b \qquad (26)$$

to account for the observed data. This is at least a factor of 20 higher than the upper limit of 1.5μb given by emulsion experiments[33] for the production of charm particles by the 300 GeV proton beam under the assumption that charm particles have lifetimes in the range $10^{-12} - 10^{-14}$ sec.

Until the experimental numbers involving charm production measurements (especially their sensitivity towards different lifetime assumptions) as well as beam-dump measurements settle, it appears premature to conclude that charm production cannot account for the excess beam-dump neutrinos. However, if the discrepancy turns out to be real, we wish to stress that it would be a strong signature for a source of neutrinos unexpected within confined QCD[34].

We now remark that the excess neutrinos of the sort observed can in fact quite naturally be ascribed to pair production and subsequent decays of either light liberated quarks or light liberated gluons or both.

Since light liberated quarks have almost a 100% branching ratio to decay into either ν_e or ν_μ plus mesons, one needs pair production of quarks of the same order (within roughly a factor[35] of 2) as that given by Eq.(25), i.e. (say)

$$\sum_q \sigma_{q\bar{q}} \approx (6\text{–}20)\mu b \quad , \qquad (27)$$

to account for the beam-dump data on the basis of quark production only. Such a cross-section is incidentally about a factor of 5 lower than that which would be needed for charm production to account for the data. It is not in conflict with the emulsion measurements, since quarks with masses of order 2 to 2.5 GeV are expected to have lifetimes in the range of $10^{-11} - 10^{-12}$ sec, which is outside the range of sensitivity of the emulsion measurements. (Quarks, as mentioned before, are an abundant source of prompt neutrinos. They do not contribute (under decay pattern II) to prompt charged leptons;[36] even under decay pattern I only two out of twelve quarks can give rise to prompt charged leptons in association with neutrinos.)

Pair production of charged colour gluons $V_\rho^+V_\rho^-$ and $V_{K*}^+V_{K*}^-$ may also at least partly or entirely be responsible for the excess beam-dump neutrinos. Since the charged colour gluons each have about a 30% branching ratio to decay into two-body $(e\nu_e)$ and the same branching ratio to decay into two-body $(\mu\nu_\mu)$ mode, one would need pair production cross-section of charged colour gluons of $\sigma(pp \to V^+V^-)_{\rho,K*} \approx 10\mu b$ to account for the CDHS signal on the basis of just charged colour gluon production.

Assuming that liberated charged gluons have masses exceeding about 1.5 GeV, such a cross-section for charged colour-gluon production is also not in conflict with the emulsion measurements, since charged colour gluons with masses $\gtrsim 1.5$ GeV are expected to have lifetimes 37) shorter than 10^{-14} secs.

If charged gluons $(V_\rho^+V_\rho^- + V_{K*}^+V_{K*}^-)$ are being pair produced with a cross-section $\sim 10\mu b$, one would expect to observe, taking Clebsch-Gordan coefficients and symmetrization into account, pair production of neutral colour gluons $\sigma(pp \to \tilde{U}+\tilde{U} + \text{hadrons})$ to be about $2.5\mu b$, which could be seen through a measurement 38) of $\sigma(pp \to (e^-e^+)$ or $(\mu^-\mu^+) + X)$. (The expected branching ratio 37) of $\tilde{U} \to e^-e^+$ or $\mu^-\mu^+$ is about 10^{-3}.)

As a general remark we observe that pair production of quarks and/or charged gluons would inevitably generate an equal number of neutrinos and antineutrinos $(\sigma(\nu_e,\nu_\mu) = \sigma(\bar{\nu}_e,\bar{\nu}_\mu))$. (In the forward direction, there may still be a preference for neutrinos over antineutrinos, since the incoming protons bring in fast quarks rather than antiquarks.) By contrast, nucleon dissociation into three quarks, when it occurs, would in general lead (within the $\Delta F = 0$ transitions) to an excess of neutrinos over antineutrinos.

As an additional remark, it is important to note that should liberated quarks and gluons be needed to account for the observed beam-dump signal, it would be more than likely that they are relatively light with masses perhaps $\lesssim 2$ to 3 GeV, rather than heavy. As mentioned before, liberated quarks and gluons with heavier masses $\gtrsim 4$ GeV are, of course, logically feasible. They would be pair produced at PETRA and PEP; but assuming the familiar theoretical models 39) for particle production, it appears that pair production of such heavy objects by hadronic collisions at ISR and Fermilab energies would be too low ($<<$ 1μb) to explain the observed signal.

To conclude, light liberated quarks with lifetimes in the range $10^{-11} - 10^{-12}$ secs and charged gluons with lifetimes 37) $\lesssim 10^{-14}$ secs with production cross-sections at ISR and Fermilab energies perhaps at the level of the beam-dump signal ($\sigma_{q\bar{q}}$ and $\sigma_{V\bar{V}} \gtrsim 1\mu b$, say) should be visible in a combined emulsion bubble chamber experiment. Calorimetric measurements for e^-e^+ annihilation at SLAC-DORIS as well as at PETRA and PEP should show an excess of missing energy and momentum ($\sim$ 25-30%) if quark and gluon pairs are liberated rather than confined. Last, but not least, the neutral gluon $(\tilde{U})$ should show itself in $pp \to e^-e^+ + X$ measurements, photoproduction experiments 37) as well as in e^-e^+ annihilation as a relatively narrow resonance. If $\tilde{U}$ is relatively light 37) ($m_U \sim 1.1$ to 1.8 GeV), it should be seen in a scanning search at Frascati, Novosibirsk and Orsay laboratories. Decay modes for $\tilde{U}$ are given in Refs. 37 and 40.

These measurements as well as improvements in the beam-dump measurements and especially in the charm production measurements should help establish or exclude the hypothesis of light liberated quarks and gluons. If there is a distinction between prompt ν_e's versus ν_μ's, to our knowledge it can only be ascribed to quark decays irrespective of whether quarks are produced in $q\bar{q}$ pairs or by dissociation. (Dissociation of nucleon into three quarks would have the added signature that it would lead to excess of neutrinos over antineutrinos within $\Delta F = 0$ transitions.) Measurements at PETRA and PEP involving the search for $\tilde{U}$ as well as missing energy would be especially suitable to test the hypothesis of heavy liberated quarks and gluons.

At the end, a clear experimental choice between the two alternatives - liberation be it with light ($m_{q,V} \lesssim 2$ to 3 GeV) or relatively heavy ($m_q \sim 4$ to 10 GeV and $m_V \sim 10$ GeV) quarks and gluons versus confinement - is of fundamental importance. Both appear to arise as allowed alternatives within the more fundamental postulate 2) of unification of quarks and leptons and of their forces.

We thank Professors D.C. Cundy, F. Dydak, E. Fiorini, G. Myatt and G.A. Snow for several helpful discussions.

REFERENCES AND FOOTNOTES

1) G. Hanson et al., Phys. Rev. Letters 35, 1489 (1975).

2) J.C. Pati and Abdus Salam, Phys. Rev. Letters 31, 661 (1973); ibid. Phys. Rev. D10, 275 (1974); Phys. Letters 58B, 333 (1975).

3) H. Fritzsch, M. Gell-Mann and H. Leutwyler, Phys. Letters B47, 365 (1973); S. Weinberg, Phys. Rev. Letters 31, 494 (1973) and D.J. Gross and F. Wilczek, Phys. Rev. D8, 3633 (1973). See also C. Itoh et al., preprint (1973), unpublished.

4) P. Alibran et al. (Gargamelle Collaboration), CERN preprint (1978); T. Hansl et al. (CDHS Collaboration), CERN preprint (1978); P.C. Bosetti et al. (BEBC Collaboration), CERN preprint (1978).

5) R.N. Mohapatra, J.C. Pati and Abdus Salam, Phys. Rev. D13, 1733 (1976); R.N. Mohapatra and J.C. Pati, Phys. Letters 63B, 204 (1976).

6) By convention we choose $B = 1$ for quarks.

7) With fermion-number violation ($\Delta F = 2,4,\ldots$), quarks could decay into anti-leptons + mesons or into nucleons + mesons ($q \to qqq$, $F = 2$). In a gauge theory context $\Delta F \neq 0$ transitions can occur in a spontaneously broken gauge theory where fermions and anti-fermions are placed in the same multiplet. Typically one may expect that such transitions occur at a rate an order of magnitude slower than $\Delta F = 0$ transitions, on which we shall concentrate in this note. For remarks on $\Delta F = 2,4$ transitions within a gauge theory context, see J.C. Pati, Abdus Salam and J. Strathdee, Il Nuovo Cimento 26A, 76 (1975), and J.C. Pati, Proceedings of Second Orbis Scientiae, Coral Gables, Florida, January 1975, pp.253-256. For phenomenological considerations see Y. Nambu and M. Han, Phys. Rev. D10, 674 (1974).

8) J.C. Pati, Abdus Salam and S. Sakakibara, Phys. Rev. Letters 36, 1229 (1976).

9) Proton stability up to about 10^{30} years is guaranteed in this picture through the proton being a three-quark composite and its decay being a triple B decay (see Ref.2).

10) Abdus Salam and J. Strathdee (ICTP, Trieste, preprint IC/78/44) show that if the Higgs fields are introduced into the Lagrangian without bare self-couplings and the gauge Lagrangian is based on a non-abelian local symmetry, the quartic self-couplings of the scalar fields are induced with finite strength and are therefore "natural". This in turn induces spontaneous breakdown of the symmetry and the resulting theory is asymptotically free. It remains to examine whether such a theory with only induced Higgs self-couplings can generate the physically observed pattern of vacuum expectation values for a realistic theory. Even if bare self-couplings of Higgs fields are permitted (note that Higgs mechanism is needed for both alternatives of quark charges to generate masses for the weak gauge bosons), the resulting theory based on non-abelian local symmetry is still at least temporarily asymptotically free. See some general remarks in this regard, for example, in H.D. Politzer, Phys. Rep. 14C, No.4 (1974).

11) For a detailed listing of such decay modes see Ref.8. In addition, see especially, J.C. Pati and Abdus Salam, "Lepton-hadron unification", Proceedings of the International Neutrino Conference, Aachen 1976, pp.589-629, Eds. H. Faissner, H. Reithler and P. Zerwas; J.C. Pati and Abdus Salam, "Design of future experiments", ICTP, Trieste, preprint IC/77/65 (unpublished).

12) To be specific, we shall discuss quark decay patterns within the unifying symmetry $[SU(4)]^4$, which requires twelve "basic" and twelve mirror quarks plus four "basic" and four mirror leptons; the total number of quark flavours is in this case eight. In the absence of mixing between basic and mirror fermions the baryon number violating decays of mirror quarks would be analogous to those of the basic quarks with basic leptons being substituted by mirror leptons. The qualitative aspects of our considerations here would not be altered even if we extend the symmetry structure to $[SU(n)]^4$ with $n > 4$, which would possess n^2 basic plus n^2 mirror four component fermions. For an introduction to the mirror theory, see J.C. Pati and Abdus Salam, Phys. Letters 58B, 333 (1975) and J.C. Pati, "An introduction to unification", University of Maryland, Tech. Rep. 78-065, to appear in the Proceedings of GIFT VIII International Seminar on Theoretical Physics, held at Salamanca, Spain (June 1977).

13) The physical masses of liberated quarks must be distinguished from their effective lighter "Archimedes" masses, which they would seem to possess when they are inside a hadronic "bag".

14) Calculations of quark electromagnetic form factor have been carried out in the framework of QCD permitting a mass for the gluon, by J. Carrazone, E. Poggio and H. Quinn, Phys. Rev. D11, 2286 (1975). Using these results for timelike region we estimate quark electromagnetic form factor to be ≈ 0.7 to 0.9 in the SPEAR energy range. (Note that for the case of liberated QCD, quark pair as well as two- and three-gluon intermediate states would contribute to quark electromagnetic form factor.) We emphasise that the estimate of quark electromagnetic form factor is a crucial factor for most of the conclusions (including the interpretation of the $\bar{\mu}e$ events) drawn in this paper. Any substantial deviation from this estimate for yet unexpected circumstances would naturally alter the conclusions.

15) M.L. Perl et al., Phys. Rev. Letters 35, 1489 (1975). For a good review of the experimental status covering SPEAR and DORIS experiments see M.L. Perl, Proceedings of the 1977 Photon-Lepton Symposium held at Hamburg, Fed. Rep. Germany (p.159).

16) See remarks later.

17) Or else, the quark electromagnetic form factor is substantially lower than unity in the SPEAR range (see Ref.14).

18) The decay modes exhibited in the text correspond to the choice that μ is the strange lepton. If e and μ are interchanged, ν_e and ν_μ would also be interchanged. If e and μ represent two distinct colours, the distinction between ν_e versus ν_μ in quark decay modes would in general disappear.

19) J.C. Pati and Abdus Salam, third paper in Ref.2.

20) With fermion number violation ($\Delta F = 2, 4$), anti-neutrinos would arise from quark decays as well in addition to a proportion of decays $q \to qqq$, where the quark turns into a hadron. We are not taking these into account in this note.

21) By "light liberated quarks" we shall mean liberated quarks with physical masses ≈ 2 to 3 GeV (for p and n flavours).

22) Lepton-momentum spectrum for ($\bar{\mu}e$) events arising from quark decay (see (10)) has been calculated by B. Kayser, J.C. Pati, S. Sakakibara and G. Zorn (unpublished). The spectrum coincides with heavy lepton spectrum for lepton momentum $\gtrsim 800$ MeV/c for a mass of the gluon $\lesssim 1.3$ GeV at $E_{CM} = 4.8$ GeV.

23) The most recent measurement of the spectrum is by the DELCO Collaboration. This was reported by L.J. Nodulman at the third International Conference at Vanderbilt, on New Results in High-Energy Physics, Nashville, Tennessee, 6-8 March 1978 (SLAC-PUB-2104, 1978). We thank Professors L.J. Nodulman and S. Wojcicki for kind communications of their results.

24) See Ref.8 and J.C. Pati and Abdus Salam, Phys. Rev. Letters 36, 11 (1976); G. Rajasekharan and P. Roy, Pramana 6, 303 (1975).

25) Note that the contribution of real charged gluon pair production to R parameter is (1/8) (see Ref.24) to be compared with charged red quark pair production contribution of 2/9. One may also deduce from the empirical lepton-momentum spectrum that the gluonic contribution, which would lead to two-body decay spectrum, should not be much more than 50% of quark contribution, leading to two-step three-body decay spectrum.

26) In fact such an inclusion would only go towards strengthening the incompatibility noted above.

27) See results of DASP and PLUTO measurements reported in Proceedings of 1977 Photon-Lepton Symposium, held at Hamburg, Fed. Rep. Germany (pages 89, 109 and 113).

28) If the mass of charged red quarks exceeds that of charged gluons only by 50-100 MeV (say), then the decay mode $q^-_{red} \to V^-\nu \to (e^-\bar{\nu}_e) + \nu$ or $(\mu^-\bar{\nu}_\mu) + \nu$, though allowed, would be suppressed by limited phase space relative to, e.g., $q^-_{red} \to \rho^- + \nu_\mu$ mode.

29) We should stress that the conclusion depends crucially on the fact that we use, following Ref.24, that the net contribution of charged red quark pair production to R is $(2/9)\,\rho(s)$ (where $\rho(s) \lesssim 1$).

30) These include all channels including heavy lepton production but excluding $e^-e^+ \to \mu^-\mu^+$ and $e^-e^+ \to e^-e^+$.

31) Y.S. Tsai, Phys. Rev. D4, 2821 (1971).

32) Gargamelle results seem to allow even higher than 20μb for $\sigma_{new}\,B(\nu_e)$.

33) C. Coremans-Bertrand et al., Phys. Letters 65B, 480 (1976).

34) Needless to say, pair production of heavy leptons would have too low a cross-section to account for the data. Pair production of new flavour particles (for example, involving bottom flavours), which are significantly heavier than charm particles, would presumably be much lower than charm pair production and thus would not be relevant to the beam-dump data.

35) In Sec.II, we have discussed that $B(\nu_e)$ may vary between (70-30)% with $B(\nu_e) + B(\nu_\mu) = 1$. Thus for guidance, we take $B(\nu_e) \sim B(\nu_\mu) \sim$ ~ 50%.

36) This is, of course, not in conflict with the fact that prompt charged lepton production is comparable (within a factor ~3) to prompt neutrino production (as revealed by beam-dump data), since the former may arise from sources such as $(\rho^0, \omega^0, \phi^0, J/\psi)$, which do not contribute to prompt neutrinos.

37) See J.C. Pati, J. Sucher and C.H. Woo, Phys. Rev. D15, 147 (1977) for these calculations. To be precise, one obtains:

$$\Gamma(V_\rho^+, V_{K*}^+) = [\cos^2(\theta+\phi), \sin^2(\theta+\phi)]\ (f^2/4\pi)^{-1}\ (3 \times 10^{13}\ \mathrm{sec}^{-1})\ (m_V/\ 1\ \mathrm{GeV})^5,$$

where θ and ϕ denote Cabibbo-like rotations in (p,n) and (c,λ) spaces, respectively, with $(\theta-\phi)$ being the observed Cabibbo angle. The quantity $(f^2/4\pi)$ is the "strong" colour gluon coupling constant at the colour gluon mass (thus $(f^2/4\pi) \approx \frac{1}{2}$ to 1). Here m_V denotes gluon mass. Thus for $\sin^2(\theta+\phi) \approx \cos^2(\theta+\phi) \approx \frac{1}{2}$, $(f^2/4\pi) \approx 1$ and $m_V = 1.5$ GeV, we obtain $\Gamma(V_\rho^+, V_{K*}^+) \approx (1.2) \times 10^{14}$ sec. Note the rapid decrease in lifetime with increase in m_V. Note also the intriguing possibility; if $\sin^2(\theta+\phi) \lesssim 10^{-2}$ with $\cos^2(\theta+\phi) \approx 1$, one of the charged colour gluons (V_{K*}^+) will have a "long" lifetime $\gtrsim 10^{-12}$ sec, while the other (V_ρ^+) will have "short" lifetime $< 10^{-14}$ sec. Both V_ρ^+ and V_{K*}^+ would, even in this case, have been missed by the emulsion measurements.

38) An existing measurement by K.J. Anderson et al. (Phys. Rev. Letters 37, 799 (1976)), involving 150 GeV protons, does not appear to exclude production cross-section of (1-2)μb of neutral colour gluons (especially for the mass region around 1.5 GeV). Note that production of $\tilde{U}$ can be somewhat higher for 400 GeV protons (relevant for beam-dump experiments) than for 150 GeV protons. If quarks as well as charged colour gluons are responsible for the observed signal in beam-dump experiments, then $\tilde{U}$ gluon production need not be as large as 2.5 μb.

39) See a recent review by N. Craigie, Imperial College, London, preprint (1978), to be published in Phys. Reps.

40) J.C. Pati and Abdus Salam, "Design of future experiments", ICTP, Trieste, preprint IC/77/65 (unpublished).

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