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QUARKS AND MAGNETIC POLES*

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It is argued that if the Dirac magnetic monopole has a finite size R, the consequent quantization of charge applies only to the total charge of all particles within a distance R of each other. Then if quarks carry third-integral charge and R is of order of a classical hadron radius, quarks can move freely within hadrons but cannot escape as individuals.

A number of papers that have appeared recently[1] have shown that many experimental observations on baryons and mesons are in remarkably good agreement with a simple additive quark model. This model assumes that quarks and antiquarks interact with each other within hadrons with much the same freedom that nucleons interact with each other within nuclei. There is, however, the striking difference between the two situations that nucleons are quite easily knocked out of nuclei and observed by themselves, whereas individual quarks have thus far not been observed. As pointed out in a recent note,[2] this can be understood if there is a selection principle that has a range built into it. This selection principle would not only require that the over-all baryon number for any system of quarks and antiquarks be an integer, but that the baryon number for each mutually interacting cluster of quarks be an integer. At the same time, the quarks should be able to move rather freely within each cluster, without being greatly inhibited by the selection principle. A model for such a selection principle in terms of many-particle interactions between quarks was proposed[2] and is now being considered in more detail.

The present paper proposes a completely different mechanism for the selection principle. This mechanism requires that the total electric charge of any cluster of particles within a certain small range of each other be an integral multiple of the electronic charge e, although the individual charges need not be. Thus if quarks have third-integral charge, the baryon number of any cluster will be limited to integer values. This mechanism is based on an idea of Dirac[3,4] which relates the value of e to a hypothetical magnetic pole of strength g. Dirac found that the requirement that the phase of the wave function of a particle of charge e be well defined when the gauge associated with the vector potential of the magnetic pole g is transformed, leads to the condition $eg/\hbar c=\frac{1}{2}n$, where n is an integer. On the other hand, Schwinger[4] found that rotation and Lorentz invariance of a quantum field theory of charges and poles interacting with the electromagnetic field demand that $eg/\hbar c$ be an integer, or possibly an even integer. For definiteness, we shall adopt the value $eg/\hbar c=1$ for the relation between the electronic charge e and the elementary magnetic pole strength g. Then $g=137e$, and the coupling constant of the pole to the electromagnetic field is $g^2/\hbar c=137$, in contrast with the coupling constant of an elementary charge with the electromagnetic field, which is $e^2/\hbar c = 1/137$.

This very large coupling constant suggests that quantum electrodynamics is not likely to be valid when applied to magnetic poles. For the present purpose, a classical, nonrelativistic treatment of a pole should be adequate. This pole is expected to be extended in space, because of its very large magnetostatic self-energy. For example, if the size R is set equal to the "classical electron radius" $e^2/mc^2 = 2.8$ F, the self-energy is of order $g^2/R = 9.5$ BeV. If now the rest mass of the pole were comparable with this, it would not have been observed in recent experiments.[5] That an extended magnetic pole must behave classically can be seen if the angular momentum associated with the electromagnetic field of the pole and a point charge that lies outside it is calculated in the usual way.[4] This angular momentum has the magnitude $(eg/c)[1-(R^2/3r^2)]$ and is directed from e to g, where R is now the rms radius of the pole and r is the charge-pole separation distance. Thus, as a charge moves radially in toward a pole, the field angular momentum decreases, and a corresponding torque is exerted on the pole by the changing electric field of the charge, so that the angular momentum of the pole increases continuously.

With a pole of finite size, Dirac's gauge invariance argument breaks down to some extent. His singularity "string" becomes a "bundle," and the phase of the charged-particle wave function changes continuously by 2π as the path of integration in the phase factor crosses the bundle. The most favorable situation is that in which the bundle is cylindrical, with radius R equal to that of the pole. Then the phase is "almost always" well defined if the particle charge is an integer multiple of e.

In this situation, however, the lack of definition of the phase is not significantly worsened if the integral charge is divided among several particles that are close together. This corresponds to replacing $\psi(\vec{r})$ by $\psi(\vec{r}_1, \vec{r}_2, \cdots)$, where the charge e_i is associated with the particle coordinate $\vec{r}_i$. The transformation of ψ that corresponds to the change of gauge from vector potential $\vec{A}(\vec{r})$ to $\vec{A}'(\vec{r})$ is

$$\psi'(\vec{r}_1, \vec{r}_2, \cdots) = \exp\{i\textstyle\sum_i (e_i/\hbar c)\int_\infty^{\vec{r}_i} d\vec{r}' \times[\vec{A}'(\vec{r}') - \vec{A}(\vec{r}')]\}\psi(\vec{r}_1, \vec{r}_2, \cdots).$$

As with the bundle of singularity strings, the situation here is most favorable if the paths of integration to the points $\vec{r}_1, \vec{r}_2, \cdots$ are parallel. Then, if ψ is chosen so as to vanish when these points are more than a distance R from each other, the phase is "almost always" well defined in the sense used in the preceding paragraph, provided that $\sum e_i$ is an integral multiple of e.

We see then that if we rely on the existence of a magnetic pole of size R to produce the quantization of electric charge, it can only produce quantization of the total charge of all particles that are within a distance R of each other. This is precisely the kind of selection principle envisaged earlier,[2] if it is assumed that quarks carry third-integral charge and that R is of hadronic size.

The foregoing remarks do not provide a description of a dynamical constraint that prevents the fractionally charged particles from separating. A possible mechanism for this constraint consists in replacing the above phase factor exp{ } by its average over paths of integration. If the phase is independent of path, this averaging process does not change anything. On the other hand, if the phase factor is path dependent, averaging will tend to decrease it; the more so, the farther the fractionally charged particles are separated from each other. Such a decrease in the wave function has the same kind of effect on the relative particle motions as the walls of a potential well. But the effect occurs without introducing a restraining potential, so that quark masses and interaction energies may be chosen without affecting the selection principle. This approach presents obvious problems, which are now being explored.

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EVIDENCE AGAINST THE EXISTENCE OF A STRANGENESS +2 MESON RESONANCE AT A MASS OF 1280 MeV*

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Among the many bosons observed to date, the states with spin parity 0^-, 1^-, and 2^+ are composed of nine particles each and have the isospin (I) and hypercharge (Y) properties that can be associated with the constituent states of the representations 1 and 8 of the SU(3) group. Although no representations of larger dimensions have been definitely established, it is of critical importance in the study of strong interactions to determine whether such states actually exist in nature. This question has special relevance with respect to composite quark models, as to whether the presently known bosons are in reality composed of two quarks with increasing angular momentum to account for higher spin states or of multiple quark states, i.e., 4, 6, etc., with zero angular momentum, the higher spin coming from the addition of the individual quark spins. To this end the existence or nonexistence of an $I=1$, $Y=2$ resonance, such as a K^+K^+ state, is highly significant, since the 27 is the smallest representation which can accommodate such a particle and its existence would require the multiple quark approach. In this Letter we wish to report our results as well as present a world compilation concerning this question obtained from a study of the following reactions:

$$K^+ + p \to K^+ + K^+ + \Lambda^0, \qquad (1a)$$

$$\to K^+ + K^+ + \Sigma^0, \qquad (1b)$$

$$\to K^+ + K^0 + \Sigma^+, \qquad (1c)$$

$$\to K^+ + K^+ + \Lambda^0 + \pi^0, \qquad (2a)$$

$$\to K^+ + K^0 + \Lambda^0 + \pi^+. \qquad (2b)$$

The evidence for the possible existence of a K^+K^+ resonance comes from CERN data for the above reactions obtained with K^+'s of momenta of 3.0, 3.5, and 5.0 BeV/c.[1] If one examines each final state individually, one notes that the bulk of the data, as well as the main contribution to the effect, comes from the ΛK^+K^+ at the two lower energies. We have therefore repeated the experiment with K^+'s at 3 BeV/c, essentially doubling the CERN data at this energy, and find no evidence for any K^+K^+ resonance.

The exposure consisted of 120 000 pictures taken in the Brookhaven National Laboratory (BNL) 80-inch hydrogen bubble chamber at the alternating gradient synchrotron (AGS) in the dc separated beam.[2] 4200 τ's were found in a fiducial region whose length was 160 cm. This corresponds to an event rate of 5.75 events/μb. The pictures were scanned for all topologies involving one hyperon decay, either Λ^0 or Σ^+ decay. In the case of V events it was further required that the line of flight of the V be closer to the positive than the negative track. This had the desired effect of eliminating ≈40% of the K^0 decays. It was difficult to detect short decays, and a cutoff of 1 cm was applied, amounting to a ≈5% correction. Similarly, tracks which interacted within 5 cm of their origin were difficult to measure with the necessary precision and were therefore eliminated at the scanning phase, this corresponding to a 2% correction. The events were then measured on an image plane digitizer and analyzed with the TRED-KICK programs. For each event the χ^2 probability and track ionizations were determined. All events which fit hypotheses 1 or 2 were re-examined by a physicist for consistency with ionization. In almost all cases the calculated χ^2 probability for the different hypotheses were widely different, and this coupled with the estimated ionization allowed a selection to be made. The minimum accepted χ^2 probability was 1%. The only pos-