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# Dirac Magnetic Monopoles as Goldstone and Higgs Bosons in the Origin of Mass

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A dyonium model of quarks is incorporated into a theory of the strong QCD and electromagnetic interactions. Dirac magnetic monopoles are introduced as scalar bosons in a triplet of isovector fields within the framework of the QCD theory of colored quarks and gluons. Superheavy vector bosons are predicted to exist with masses of 328 GeV and 11.3 TeV.

## 1. INTRODUCTION

Inspired by the conjectures of Dirac (1931), theorists have regularly investigated the problem of the magnetic monopole. In the years since Dirac, it has been speculated by Schwinger (1969) and Chang (1972) that quarks consist of electric and magnetic charges. In non-Abelian gauge theories, the confinement of quarks is connected with monopoles (Mandelstam, 1975; Nambu, 1974). If magnetic monopoles exist, they are inseparably linked with massive vector bosons as suggested by 't Hooft (1974) and Polyakov (1974).

Recently, the role of magnetic monopoles in quark confinement has been described by the dual superconductor picture of QCD (Zachariasen, 1987). Nair and Rosenzweig (1984) were the first to predict the existence of short-range Yukawa forces in the confinement problem. Dual potential models (Singh *et al.*, 1993) are currently topics in $SU(2)$ lattice gauge theory. Although such topics are important in their own right, we consider the problem of incorporating Schwinger's dyonium model of quarks into a theory of the strong QCD and electromagnetic interactions.

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In this paper, we present theoretical physics beyond the Standard Model. We adopt the suggestion by Chang (1972) that quarks consist of spin-0 magnetic charges and spin-1/2 electric charges. Chang was able to show that mesons and baryons may contain magnetic monopoles, solving the problem of zero electric dipole moments (EDM) in hadrons. In this model, the existence of a spin-0 monopole is incorporated into a modified QCD Lagrangian.

## 2. MODIFIED QCD LAGRANGIAN WITH DIRAC MONOPOLES

The procedure is to first write down a modified QCD Lagrangian in which massless Yang–Mills fields $\mathbf{G}^{a\mu}$ interact with a multiplet of scalar Higgs fields $\phi$, introduce the $U(1)$ gauge fields $A_\mu$ of electromagnetism, choose a renormalized $SU(3)$ gauge theory of real scalar fields, and allow the gauge to be spontaneously broken (Kibble, 1967). Therefore, the Lagrangian is

$$L = -\tfrac{1}{4}F_{\mu\nu}F^{\mu\nu} - \tfrac{1}{4}\mathbf{G}^a_{\mu\nu}\cdot\mathbf{G}^{a\mu\nu} + i\bar{\psi}\gamma^\mu D_\mu\psi + \tfrac{1}{2}(D_\mu\phi)^\dagger(D^\mu\phi) + \tfrac{1}{2}m^2\phi^\dagger\phi - \tfrac{1}{4}f^2(\phi^\dagger\phi)^2 - \alpha_Y\bar{\psi}\phi\phi^\dagger\psi \tag{1}$$

where

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \tag{2}$$

$$\mathbf{G}^a_{\mu\nu} = \partial_\mu\mathbf{G}^a_\nu - \partial_\nu\mathbf{G}^a_\mu + g\mathbf{G}^a_\mu \times \mathbf{G}^a_\nu \tag{3}$$

$$D_\mu = \partial_\mu + ig_eA_\mu - \tfrac{1}{2}ig\boldsymbol{\lambda}^a\cdot\mathbf{G}^a_\mu \tag{4}$$

$g_e$ is the electromagnetic coupling constant and $g$ is the Dirac magnetic charge. $A_\mu$ are the photon fields. $\mathbf{G}^a_\mu$ are the eight gluon fields. $D_\mu$ is the covariant derivative. The space-time indices are $\mu = 0, 1, 2, 3$. The $\boldsymbol{\lambda}^a$ are the Gell-Mann matrices, and $a = 1, \ldots, 8$. The magnetic monopoles are chosen to be represented by the scalar Higgs fields $\phi_1$ and $\phi_2$, where $\phi = \phi_1 + i\phi_2$. The $\psi$ are the four-component Dirac spinors associated with each quark (dyon) field. Substituting equation (4) into equation (1) gives

$$L = L_1 + L_2 + L_3 \tag{5}$$

with

$$L_1 = -\tfrac{1}{4}F_{\mu\nu}F^{\mu\nu} \tag{6}$$

$$L_2 = -\tfrac{1}{4}\mathbf{G}^a_{\mu\nu}\cdot\mathbf{G}^{a\mu\nu} \tag{7}$$

$$L_3 = i\bar{\psi}\gamma^\mu\partial_\mu\psi - J^\mu A_\mu + \tfrac{1}{2}[(\partial_\mu\phi^\dagger)(\partial^\mu\phi) + \mathbf{K}^{a\mu}\cdot\mathbf{G}^a_\mu + \mathbf{C}^{a\mu}\cdot\mathbf{G}^a_\mu + g_e^2\phi^\dagger\phi A_\mu A^\mu + \tfrac{1}{4}g^2\phi^\dagger(\boldsymbol{\lambda}^a\cdot\mathbf{G}^a_\mu)^\dagger(\boldsymbol{\lambda}^a\cdot\mathbf{G}^{a\mu})\phi] + \tfrac{1}{2}m^2\phi^\dagger\phi - \tfrac{1}{4}f^2(\phi^\dagger\phi)^2 - \alpha_Y\bar{\psi}\phi\phi^\dagger\psi \tag{8}$$

We will restrict our attention to equation (8), which connects the observed currents to the photon and gluon fields. In equation (8) we have

$$J^{\mu} = g_e \bar{\psi}\gamma^{\mu}\psi + ig_e[\phi^{\dagger}(\partial^{\mu}\phi) - (\partial_{\mu}\phi^{\dagger})\phi] \tag{9}$$

$$\mathbf{K}^{a\mu} = \tfrac{1}{2}g\bar{\psi}\gamma^{\mu}\boldsymbol{\lambda}^{a}\psi + \tfrac{1}{2}ig[\phi^{\dagger}\boldsymbol{\lambda}^{a}\partial^{\mu}\phi - (\partial_{\mu}\phi^{\dagger})\boldsymbol{\lambda}^{a}\phi] \tag{10}$$

$$\mathbf{C}^{a\mu} = -\tfrac{1}{2}g_e g[(\phi\boldsymbol{\lambda}^{a})^{\dagger}\phi + \phi^{\dagger}\boldsymbol{\lambda}^{a}\phi]A_{\mu} \tag{11}$$

$J^{\mu}$ represents the Maxwell electric current density and a scalar electric current density. From equations (10) and (11), we have eight color magnetic currents $\mathbf{K}^{a\mu}$ and eight color dyonic currents $\mathbf{C}^{a\mu}$.

We now choose a suitable gauge for the two real scalar fields $\phi_1$ and $\phi_2$, each a triplet of isovector fields, to introduce a symmetry-breaking mechanism into equation (8). In our model, the fields $\phi_1$ and $\phi_2$ represent spin-0, isospin-1 magnetic monopole and antimonopole in order to preserve the conservation of magnetic charge, such that the magnetic charge is related to the third component of isospin: $Q_m = I_3$.

The potential energy of the Lagrangian, equation (8), will be minimized by choosing the renormalized triplet of isovector fields

$$\phi_1 = \begin{pmatrix} \phi^{+} \\ \phi^{0} \\ \phi^{-} \end{pmatrix} = \begin{pmatrix} \eta + m/f\sqrt{2} \\ 0 \\ 0 \end{pmatrix}, \qquad \phi_2 = \begin{pmatrix} \phi^{-} \\ \phi^{0} \\ \phi^{+} \end{pmatrix} = \begin{pmatrix} \xi + m/f\sqrt{2} \\ 0 \\ 0 \end{pmatrix} \tag{12}$$

where the monopole–antimonopoles are represented by the fields $\eta$ and $\xi$. Neglecting the spinor terms, we are interested in rewriting the Lagrangian, equation (8), in terms of these new fields:

$$\begin{aligned} &\frac{1}{2}(\partial_{\mu}\phi^{\dagger})(\partial^{\mu}\phi) + \frac{1}{2}m^2\phi^{\dagger}\phi - \frac{1}{4}f^2(\phi^{\dagger}\phi)^2 \\ &\quad = \frac{1}{2}(\partial_{\mu}\eta)(\partial^{\mu}\eta) - \frac{1}{2}m^2\eta^2 + \frac{1}{2}(\partial_{\mu}\xi)(\partial^{\mu}\xi) - \frac{1}{2}m^2\xi^2 \\ &\qquad - \frac{1}{4}f^2(\eta^4 + 2\eta^2\xi^2 + \xi^4) - \frac{mf}{\sqrt{2}}(\eta^3 + \eta^2\xi + \eta\xi^2 + \xi^3) - m^2\eta\xi - \frac{1}{4}\frac{m^4}{f^2} \end{aligned} \tag{13}$$

In equation (13) the three terms have become a massive scalar Higgs particle $\eta$ and a massive Goldstone boson $\xi$, each with Dirac mass $m$ of the magnetic monopole. Neglecting the spinor terms, we are interested in the remaining terms of the Lagrangian, equation (8):

$$-\frac{1}{2}J^{\mu}A_{\mu}=-g_e\left[(\partial_\mu\eta)\xi-(\partial_\mu\xi)\eta+\frac{m}{f\sqrt{2}}\partial_\mu\eta-\frac{m}{f\sqrt{2}}\partial_\mu\xi\right]A_\mu \tag{14}$$

$$\frac{1}{2}\mathbf{K}^a_\mu\cdot\mathbf{G}^a_\mu=\frac{1}{2}g\left[(\partial_\mu\eta)\left(\xi+\frac{m}{f\sqrt{2}}\right)-(\partial_\mu\xi)\left(\eta+\frac{m}{f\sqrt{2}}\right)\right]\left(G^3_\mu+\frac{1}{\sqrt{3}}G^8_\mu\right) \tag{15}$$

$$\frac{1}{2}\mathbf{C}^a_\mu\cdot\mathbf{G}^a_\mu=-\frac{1}{2}g_e g\left[\eta^2+\frac{\sqrt{2}m}{f}\eta+\xi^2+\frac{\sqrt{2}m}{f}\xi+\frac{m^2}{f^2}\right]\times\left(G^3_\mu+\frac{1}{\sqrt{3}}G^8_\mu\right)A_\mu \tag{16}$$

$$\frac{1}{2}g_e^2\phi^\dagger\phi A_\mu A^\mu=\frac{1}{2}g_e^2\left(\eta^2+\frac{\sqrt{2}m}{f}\eta+\xi^2+\frac{\sqrt{2}m}{f}\xi+\frac{m^2}{f^2}\right)A_\mu A^\mu \tag{17}$$

$$\begin{aligned}&\frac{1}{8}g^2\phi^\dagger(\boldsymbol{\lambda}^a\cdot\mathbf{G}^a_\mu)^\dagger(\boldsymbol{\lambda}^a\cdot\mathbf{G}^a_\mu)\phi\\&\quad=\frac{1}{8}g^2\left(\eta^2+\frac{\sqrt{2}m}{f}\eta+\xi^2+\frac{\sqrt{2}m}{f}\xi+\frac{m^2}{f^2}\right)\Big[(G^1_\mu)^2+(G^2_\mu)^2\\&\qquad+(G^3_\mu)^2+(G^4_\mu)^2+(G^5_\mu)^2+\frac{1}{3}(G^8_\mu)^2+\frac{2}{\sqrt{3}}G^3_\mu G^8_\mu\Big]\end{aligned} \tag{18}$$

and

$$-\alpha_Y\bar{\psi}\phi\phi^\dagger\psi=-\alpha_Y\left(\eta^2+\frac{\sqrt{2}m}{f}\eta+\xi^2+\frac{\sqrt{2}m}{f}\xi+\frac{m^2}{f^2}\right)\psi_{\bar{r}}\psi_r \tag{19}$$

In equations (16)–(18), the electric, magnetic, and dyonic currents are recombined to give the coupling between the electromagnetic and strong interactions:

$$\frac{1}{2}\left(\eta^2+\frac{\sqrt{2}m}{f}\eta+\xi^2+\frac{\sqrt{2}m}{f}\xi+\frac{m^2}{f^2}\right)\left[g_eA_\mu-\frac{1}{2}g\left(G^3_\mu+\frac{1}{\sqrt{3}}G^8_\mu\right)\right]^2 \tag{20}$$

We see immediately that the charged spin-1 field is

$$W_\mu=\frac{1}{\sqrt{2}}(A^1_\mu+iA^2_\mu) \tag{21}$$

and has a superheavy mass

$$M_W=g_e\frac{m}{f} \tag{22}$$

$M_W$ is a superheavy vector boson analogous to the electroweak $W^{\pm}$ boson. From equation (18) we have the gluon interactions

$$\frac{1}{8} g^2 \frac{m^2}{f^2} [(G_\mu^1)^2 + (G_\mu^2)^2 + (G_\mu^4)^2 + (G_\mu^5)^2]$$

with superheavy charged vector bosons given by

$$X_\mu = \frac{1}{\sqrt{2}} (G_\mu^1 + iG_\mu^2), \qquad Y_\mu = \frac{1}{\sqrt{2}} (G_\mu^4 + iG_\mu^5) \tag{23}$$

and with masses given by

$$M_X = M_Y = \frac{g}{2} \frac{m}{f} \tag{24}$$

From equation (20) there are neutral spin-1 fields

$$Z_\mu = \left(g_e^2 + \frac{g^2}{4}\right)^{-1/2} \left[g_e A_\mu^3 - \frac{1}{2} g\left(G_\mu^3 + \frac{1}{\sqrt{3}} G_\mu^8\right)\right] \tag{25}$$

and

$$A'_\mu = \left(g_e^2 + \frac{g^2}{4}\right)^{-1/2} \left[\frac{1}{2} g A_\mu^3 + g_e\left(G_\mu^3 + \frac{1}{\sqrt{3}} G_\mu^8\right)\right] \tag{26}$$

Their masses are

$$M_Z = \frac{m}{f} \left(g_e^2 + \frac{1}{4} g^2\right)^{1/2} \tag{27}$$

$$M_{A'} = 0 \tag{28}$$

$A'_\mu$ is to be identified as the photon field.

## 3. CONCLUSION

The masses of the superheavy bosons may be estimated by assuming that the electromagnetic and strong coupling constants $g_e$ and $g$ are approximately equal to their bare charges and that the fine structure constant $\alpha$ characterizes the coupling strength $f$ (Georgi and Glashow, 1974). From the dyonium model (Akers, 1987, 1992), the Dirac mass is $m = 2397$ MeV. If $g_e \simeq e, g \simeq (137/2)e$, and $f \simeq \alpha$, then $M_W = 328.5$ GeV, $M_X = M_Y \simeq 11.25$ TeV, and $M_Z \simeq 11.42$ TeV. Weinberg (1972) also predicted the existence of superheavy vector bosons from a superstrong symmetry-breaking mechanism and suggested large masses ($>200$ GeV) for them. We do not predict the decay modes of the superheavy vector bosons. However, it will be a while before the discovery of superheavy vector bosons—at least until future accelerators like the SSC go online to search for them.

## REFERENCES

Akers, D. (1987). *International Journal of Theoretical Physics*, **26**, 451.
Akers, D. (1992). In *The Vancouver Meeting: Particles & Fields '91*, D. Axen, D. Bryman, and M. Comyn, eds., World Scientific, Singapore, p. 931.
Chang, C. (1972). *Physical Review D*, **5**, 950.
Dirac, P. A. M. (1931). *Proceedings of the Royal Society (London) A*, **133**, 60.
Georgi, H., and Glashow, S. L. (1974). *Physical Review Letters*, **32**, 438.
Kibble, T. W. B. (1967). *Physical Review*, **155**, 1554.
Mandelstam, S. (1975). *Physical Letters*, **53B**, 476.
Nair, V. P., and Rosenzweig, C. (1984). *Physical Letters*, **135B**, 450.
Nambu, Y. (1974). *Physical Review*, **10**, 4262.
Polyakov, A. (1974). *JETP Letters*, **20**, 194.
Schwinger, J. (1969). *Science*, **165**, 757.
Singh, V., Browne, D. A., and Haymaker, R. W. (1993). Louisiana State University preprint LSU-HE-138-1993.
'T Hooft, G. (1974). *Nuclear Physics B*, **79**, 276.
Weinberg, S. (1972). *Physical Review D*, **5**, 1962.
Zachariasen, F. (1987). *Comments on Nuclear and Particle Physics*, **17**, 135.