Magnetic Monopole Decay and Its Consequences

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(May 28, 1999)

Abstract

We return to further examination of the need for the existence of magnetic monopoles based on the decades old derivation [Sherman Frankel, Amer. Jour. of Physics, 44 7 683-6 1976], of both the monopole-charge force, \( \vec{F} = eg(\vec{r} \times \vec{v}/c)/r^3 \), as well as the Dirac angular momentum, \( \vec{l}_f = eg\hat{r} \), from \( P \) and \( T \) conservation alone, without any recourse whatsoever to Maxwell’s Equations. The \( eg \) product also appeared in the charge conserving equation, \( deg/dt = 0 = edg/dt + gde/dt \), and this paper examines the second possible solution, \( dg/dt = -de/dt \), namely monopole decay, accounting for the non-observance of stable monopoles. It treats astrophysics and neutrino physics consequences and suggestions for experimental searches.
I. Introduction

Over two decades have passed since I published the paper entitled “Pseudoscalar and Scalar Charges” which is the basis for this present work [1]. In that paper I showed that imposition of parity conservation and time reversal invariance allowed one to derive the fundamental relations dealing with monopoles (charge = g) and electric charges (charge = e) without the slightest knowledge of any of the laws of electromagnetism. This was accomplished by requiring that charges are scalars, even under T, and monopole charges are pseudoscalars, odd under T [2].

The proof was carried out for spinless particles by writing down the most general force and angular momentum in terms of the relative velocities, \( \vec{v} \), and separations, \( \vec{r} \), the charges \( e \) and \( g \), and demanding \( P, T \), angular momentum, linear momentum, and charge conservation. As we showed in reference [1], the expressions for the most general force and most general angular momentum each contain a number of possible terms consistent with the symmetry assumptions for \( e \) and \( g \).

The only possible term that did not vanish was the well known force [3], falling off exactly as \( 1/r^2 \), namely:

\[
\vec{F} = e g (\vec{r} \times \vec{v}/c)/r^3
\] (1)

However, what was most revealing was that, in addition to the orbital angular momentum \( \vec{r} \times \vec{p} \), one automatically found that a new term, which can be called the “field angular momentum”, needed to be included to conserve overall angular momentum. (This came about because the charge-monopole force of Equation [1] is not a central force and therefore the orbital angular momentum alone could not be a constant of the motion.) It was found that the surviving term that was needed for angular momentum conservation was just

\[
\vec{l}_f = e g \hat{r}
\] (2)

where \( \hat{r} \) was the unit vector separating the charges.
This is the expression $|\vec{l}_f| = eg = nh$ which Dirac used as the basis for his argument that existence of a single monopole would result in a quantized electric charge. A classical derivation was given by H. A. Wilson [5]. Yet our derivation of Equation 2 made no use of Equation 1 or any part of electromagnetic theory.

The quantization of the angular momentum by the expression

$$|\vec{l}_f| = eg = nh$$  \hspace{2cm} (3)

with $n = a$ ratio of integers, proved that the product of the charges was quantized, not that they were separately quantized \[6\].

Equations 1 and 2 depend on the product of the charges and it is useful to note that their derivation also required that the product of the charges be conserved, namely:

$$d(ge)/dt = 0 = gde/dt + edg/dt$$  \hspace{2cm} (4)

As described more fully in ref. 1, this came about naturally since it was necessary to include every possible term having the dimensions and $P$ and $T$ properties in a total angular momentum and require that the torque be given by $\vec{T} = d\vec{L}_{total}/dt$. Further, the derivation had to include charge conservation and not add it in as an ad hoc assumption in order to obtain eqs. 1) and 2).

There are two possible solutions to this generalized equation:

a) $de/dt$ and $dg/dt$ separately vanish, which is the usual conventional assumption that yields stable charges.

b) the sum vanishes and one charge, presumably the monopole, $g$, can decay into an ordinary charge \[7\].

This present paper returns to examine the consequences of this “generalized charge conservation”, bringing to bear considerations of the neutrality and isotropy of the universe and, also, the consideration of whether there exists a preferred direction in space. It proposes a set of experimental consequences relating to the existence of a possible fourth neutrino, the possibility of a new neutral current contribution to the weak breakup of deuterium in
the SNO experiment, and the possibility of the observance of large photon jets in the universe, in one scenario accompanied by neutrinos. It also examines unique ways to search for monopole production at accelerators.

II. Magnetic Monopole Decay

The first point I shall address is the astrophysical constraint on the “classical” derivation of charge quantization. Two approaches, one based on the angular momentum in the electromagnetic field, \( \int \mathbf{r} \times (\mathbf{E} \times \mathbf{B})dV \) and the other, based on the angular momentum acquired in the impulse approximation for the scattering of a charge by a fixed monopole are well known to lead to Equation 2, with its unique unit vector relationship.

However the classical charge quantization argument assumes that a monopole and charge exist but that the rest of the universe is isotropic and uncharged. For example, if there were only one other unpaired electron somewhere in space, the angular momentum would now be \( \mathbf{l}_f = ge_1 \mathbf{r}_1 + ge_2 \mathbf{r}_2 \), which is not a unit vector. Thus the semi-quantum mechanical derivation of charge quantization would not be independent of particle position and would fail. However it is possible to restore the charge quantization by assuming an isotropic and uncharged universe and then creating an electric-monopole pair from the vacuum, which is allowed by generalized charge conservation. This would result in the existence of a single \( eg \) pair plus an isotropic and uncharged remaining universe and the semi-quantum mechanical derivation could then proceed. Full quantum-mechanical treatments of the \( eg \) quantization have been given by several authors.

III. Monopole Production

It is crucial to recognize that both the production and decay of magnetically charged particles will be accompanied by jets of photons. Unlike ordinary radiative interactions, (both production and decay), determined by the electric fine structure constant, \( e^2/\hbar c \), such production or decay of magnetically charged particles would be dominated by the
huge monopole fine structure constant, \( g^2/\hbar c \), which would be at least \((137)^2\) times larger than \( e^2/\hbar c \). These would make interesting and dramatic signatures independent of whether monopoles decayed. It will be convenient to think that a monopole charge particle would recoil against the momentum of the radiated photons so that the photon distribution will not be isotropic but directed in a jet-like cone.

In order not to violate any known conservation laws, the most likely reactions would involve simultaneously producing a magnetically charged particle and its antiparticle, e.g.,

\[
p + \bar{p} \rightarrow M + \bar{M} + \text{photon jet} \\
\]

\[
e + \bar{e} \rightarrow M + \bar{M} + \text{photon jet} \\
\]

\[
\gamma + \text{nucleon} \rightarrow M + \bar{M} + \text{nucleon} + \text{photon jet} \\
\]

Here \(M\) designates either a magnetically charged baryoM or leptoM.

a) First, we consider a most interesting possibility, the leptoM, \(l^M\), undergoing leptonic decay.

The production mechanism could be that of Equation 5 with \(M\) being a leptoM.

A most interesting decay possibility would then be the conventional weak decay:

\[
l^M \rightarrow l + \nu_l + \nu_M + \text{photon jet} \\
\]

where \(l\) denotes electron, muon, or tau and \(\nu_M\) is the monopole neutrino.

a) We next consider monopole charged baryons, (baryoMs)

If the the baryoMs were to have the same baryon number as the proton, they could decay by either strong or weak interactions. The strong interaction would dominate so the decay reaction could be:

\[
M \rightarrow p + x + \text{photon jet} \\
\]

Each \(M\) or \(\bar{M}\) would decay, producing protons or antiprotons plus their jets of photons.
The decays of the baryoMs would then appear to be oppositely directed hadrons and photon jets. Thus the final state would have four jets plus a proton and antiproton and probably some additional bosons.

Another possibility is the production of single monopole charged bosons (bosoMs) using a high energy pion beam, in a fixed target accelerator. The production process would not conserve ordinary charge, following the inverse transformation, $e \rightarrow g$, for example in the reaction

$$\pi^+ + p \rightarrow bosoM + p + x + \text{photon jet}$$

(10)

That bosoM (perhaps a $\pi^M$) could then decay back by the reaction:

$$\pi^M \rightarrow \pi^- + x + \text{photon jet}$$

(11)

where $x$ could be neutral boson configurations.

IV. Astrophysical Consequences

A. The Missing Mass of the Universe

If very heavy monopole pairs were created in the early universe, there would now be a background of monopole neutrinos and antineutrinos arising from the leptonic monopole decay. From studies of the Z vector boson decays, such a fourth neutrino would have to have a mass greater than 45 Gev, but only if the leptom were coupled to the Z in the same way as ordinary leptons. But if this were not the coupling, there would be no constraint on the monopole neutrino mass.

Since we have no *a priori* knowledge of the mass of the monopole we cannot estimate the number of such neutrinos in the present universe, nor can we estimate the contribution of this source of mass to the “missing mass” of the universe if the monopole neutrino were not massless. If one assumed that the monopole leptonic decay was governed by the strength of the usual weak coupling constant and one knew the missing mass, one could calculate what pairing of monopole mass and monopole neutrino mass could account for the missing mass.
B. Neutral Monopole Neutrino Currents

Monopole decays would produce monopole neutrinos which could interact in neutrino detectors by the reaction $\nu_g + \text{nucleon} \rightarrow \nu_g + \text{nucleon}$, raising the neutral current rate so that neutrino disintegration of deuterium would be enhanced. Thus the reaction:

6) $\nu_m + d \rightarrow n + p + \nu_m$ might be observed in the SNO experiment and be mistaken for an ordinary neutral current anomaly. Such events would also come from the ordinary neutrinos from the monopole decays.

C. Photon Bursts

If somewhere in the universe monopoles and antimonopoles are being created and decay there will be regions from which large, high energy, photon bursts would be observed. If these monopoles were leptoMs they would be accompanied by neutrinos, both standard neutrinos and monopole neutrinos. This correlation, if observed, would suggest the production of $g$ and $\bar{g}$ lepton pairs. Thus one would look in neutrino detectors for coincidences with photon bursts.

D. A Preferred Direction in Space?

Imagine an electron and positron approaching each other in their cm system and annihilating to produce a monopole boson and a charged boson in accordance with generalized charge conservation and producing the field angular momentum $ge$ times their unit vector separation. It is of course possible that the universe is not exactly spatially isotropic. If it came into being from a state of zero angular momentum, the universe at that instant would have a field angular momentum $\sum g_i e_j \vec{r}_{ij}/r_{ij}$. To conserve overall angular momentum, the universe would then have to possess an orbital angular momentum to compensate for the field angular momentum. Thus one might wish to attempt to refine measurements searching for an orbital angular momentum of the universe.
V. Accelerator Experiments

We cannot reliably predict the monopole masses. But, if monopoles were not too massive, they could be made at Fermilab by the allowed reaction \( q + \bar{q} \rightarrow M + \bar{M} \). Because of the huge monopole coupling constant, one would expect photon jets at opposite \( \phi \) as the \( M \) and \( \bar{M} \) recede. In addition, one would get photon jets from each of the monopole decays. Unfortunately, in the case of monopole leptoMs, there would be four undetected neutrinos and a large missing mass in the event, making reconstruction difficult. If the jet energies were very large, the monopoles might have very low energies before their decay, somewhat simplifying the analysis.

However, the production of a single bosoM would be a simpler event to look for and reconstruct. The reaction might be \( p + \bar{p} \rightarrow \text{bosom} + \text{photon jet} + \text{singly charged pion} \), the jet possibly radiated in the bosoM direction. The bosoM could then decay back by: \( \text{bosom} \rightarrow \pi + \text{photon jet} \). Thus, in this case, one would expect to see a jet roughly in the bosoM direction opposite to a pion and then another jet opposite the bosoM decay pion. In addition the pions would have opposite sign charges. In this simple case there would be no missing energy and a unique spatial configuration of two pion-jet pairs.

VI. Discussion

Derivation of the fundamental laws of electrical interactions from the \( P, T \) invariance properties of electric and magnetic charges alone has allowed for the possibility for monopole decay. This would account for the non-observance of stable magnetic monopoles in over a half-century of energetic search. Including such generalized charge conservation and monopole decay in a full theory cannot be accomplished by merely inserting monopoles into the classical Maxwell Equations which were constructed to account for a world containing electric charges and no experimental evidence for monopoles. It will require a quantum-mechanical theory, perhaps an electro-weak theory including new \( W \)'s and \( Z \)'s, but we simply cannot predict its structure. Nor can electromagnetic theory, based on ob-
served electromagnetic effects in a monopole-free world, be trivially modified to incorporate monopole decay. In this paper we have examined the decays of possible monopole charged particles, leptons and baryons, without discussing how they are related, the size of the families, the possible quark constituents, etc. This is an interesting area for speculation even if monopoles existed and monopole decay did not exist. Further, we are well aware that this is a classical theory and that it is not obvious how one will have to modify present theories to include monopole decay just as one cannot now make new theories that include monopoles without accounting for their absence as stable particles. Our thought is that this paper might stimulate such efforts. Finally, we propose experimental searches for effects of monopole photon bursts, monopole neutrinos, monopole production at Fermilab, and a possible asymmetry in space that could be carried out with existing detectors.

Acknowledgements: We wish to thank many theoretical and experimental colleagues for their incisive comments on this work.
REFERENCES

[1] Sherman Frankel, Amer. Jour. of Physics, 44 7 683-6 1976, can be accessed on www.physics.upenn.edu/facultyinfo/frankel.html

[2] The choice of name is arbitrary but in agreement with Maxwell’s Equation: $\text{div } \vec{E} = \rho_e$.

[3] A finite photon mass could include a term in the force proportional to $e^{-kr}$ and be introduced as the Proca modification of Maxwell’s Equation, but our analysis did not allow such a term. Further, defining the electric (E) and magnetic (B) fields in the usual way allowed one to derive, from eq. 1 which involved monopoles, the usual expressions for the experimentally observed forces between both static and moving electric charges.

[4] P.A.M. Dirac, Proc. Roy. Soc. London A33 60 (1931)

[5] H. A. Wilson, Phys. Rev. 75 309 (1949)

[6] Of course if one assumed that only a single monopole existed in the universe, it would follow that electric charges were quantized, but then one would be faced with wondering why nature bothered to produce only a single monopole.

[7] This assumption automatically yields exponential time decay, consistent with the requirement of probability conservation in quantum mechanics.

[8] A. S. Goldhaber, Phys. Rev. 140B 1407 (1965)

[9] See, for example, T.T. Wu and C. N. Yang, Phys. Rev. D 14 437-445 (1976)