MAGNETIC MONOPOLE BIBLIOGRAPHY

1973-1976

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INTRODUCTION

The last four years have seen an explosive development of the literature that relates to the magnetic-monopole conjecture. More articles have been written in this period than had been published altogether prior to 1973. Two excellent monopole bibliographies were assembled in the early seventies by D. M. Stevens (R73.S) and V. I. Strazhev and L. M. Tomil'chik (R73.ST). This bibliography is intended as a supplement for these works to cover the later period.

Recent interest in magnetic monopoles has been stimulated by several major developments. Perhaps the most exciting was the announcement of the experimental discovery of a monopole candidate by Price, Shirk, Osborne, and Pinsky (K75.P, henceforth designated PSOP). Subsequently this event has been widely critiqued and the authors have adopted a more conservative position. Meanwhile a series of searches at the new high energy facilities have not found magnetic monopoles so that additional constraints are placed on the conjecture.

On the theoretical side 't Hooft (G74.T) and Polyakov (G74.P) have found a magnetic-monopole solution to a classical non-abelian gauge theory. Polyakov has given this solution the appealingly descriptive name hedgehog. Unfortunately this name has not caught on. The 't Hooft - Polyakov solution has a very heavy mass, 5 to 10 TeV, for plausible assumptions. Interest in this solution has stimulated a great deal of the recent work in monopole theory. Parallel developments include "magnetic" confinement as a technique for generating the dual-string model and the classical theory of Wu and Yang (A76.W1) that treats monopoles without the need for Dirac strings (A76.D) by using fiber bundle or homotopy theory.

A word is in order about nomenclature and its effect on this bibliography. One man's magnetic monopole may be another person's analogue. I have taken a fair degree of lattitude here and include articles wherever the word monopole was used even if the authors went to some pains to say that they were only adapting the trappings of monopole theory without implying physical magnetic monopoles - that is magnetic monopoles that accelerate in a conventional magnetic field. A helpful convention is sometimes used by having the word "monopole" appears in quotations when it is an analogue. Dirac magnetic monopoles constitute a subclass of physical magnetic monopoles carrying a singularity called a Dirac string. Hedgehogs or 't Hooft monopoles are not Dirac monopoles. Dual strings should not be lightly confused with Dirac strings.

To put the bulky literature in some perspective I have included schematic reviews of the experimental and theoretical developments along with a compendium of some of the physical effects attributed to magnetic monopoles.

EXPERIMENTAL DEVELOPMENTS

In 1975 Price, Shirk, Osborne, and Pinsky (K75.P or PSOP) announced evidence for the detection of a magnetic monopole. The event was detected in a balloon-borne stack of plastic foils, nuclear emulsions, and a Cherenkov detector utilizing fast film. The candidate was moving relatively slowly and had a mass greater than 200 m_p. Measurements indicated that the ionization loss corresponded to a magnetic charge of two Dirac charges. The area-time factor for the experiment was more than one hundred thousand times less than that obtained earlier in null searches so that the event was somewhat anomalous.

There have been many critical reviews of this event. One general area of criticism put forward by Hungerford (M75.H), Wilson (M75.W), Cornwall et al. (M76.C) and Badhword et al. (M76.B) concerns kinematics. Monopoles coming in from outside the earth gain a great deal of energy from the magnetic field so it is very difficult to have them moving slowly. On the other hand, heavy monopoles produced in the atmosphere also have a minimum velocity. These constraints make it difficult to incorporate the PSOP event in a plausible kinematic picture. A second criticism concentrates on the apparent constant energy loss - a trait that is expected for monopoles. Alvarez (M75.A, M75.A1), Friedlander (M75.FR), Fleischer (M75.F), and Fowler (M75.FO) have suggested that the event was faked by a heavy ion which underwent spallation. They have pointed out that each spallation would have reduced the charge of the main fragment and consequently caused an instantaneous decrease in ionization loss.

The resulting sawtooth pattern could mock a constant ionization loss. Finally Carrigan et al. (L76.C), observe that the candidate was not trapped and it and its relatives should be loose in some unexpected place since other searches have not found monopoles. They searched air and seawater, the materials lying between the stack and other normal monopole collectors and found no monopoles. This, in concert with earlier searches, indicate that ambient monopole densities are everywhere substantially less than PSOP would indicate.

Price et al. (K76.P, K76.P1), have since critically reviewed this information. They have also performed additional calibrations and checks on the stack. They now take a more conservative position, stating that the event produced effects inconsistent with a positively charged nucleus, and that a magnetic monopole cannot be ruled out. Hagstrom (M77.H) has recently examined the possibility that the event is an antinucleus. He suggests a critical test on the emulsion.

Meanwhile a series of searches have been carried out at Fermilab and the CERN ISR. Eberhard et al. (L75.E) have searched dumps exposed to 2.5×10^{18} 300 GeV protons at Fermilab using an elegant superconducting electromagnetic detector. They find no monopoles. They have also found no monopoles in a lunar search (L73.R). Carrigan et al. (L73.C, L74.C), have set cross section upper limits for monopoles at 300 and 400 GeV production energies on the order of 5×10^{-42} cm^2 at Fermilab. They use a high field solonoid to extract monopoles from a target and scintillation counters to record any monopole that is accelerated. Note that these experiments imply some limits on production by all relatively short-lived, reasonably strongly interacting particles including gamma rays because they employ thick dumps as production targets. Searches have also been made at the CERN ISR by Giacomelli et al. (L75.G), Eberhard et al. (L75.E) and Carrigan et al. (to be published). No monopoles have been detected, establishing a cross section upper limit on the order of 10^{-37} cm^2. None of these experiments demonstrates that monopoles do not exist. Rather they show that monopoles with masses within the limits accessible at these machines are difficult to find.

There have also been a series of searches at both these machines for the de-excitation and annihilation radiation from pole-antipole pairs. These searches were stimultated in part by the suggestion of Ruderman and Zwanziger (Q69.R) that some old cosmic-ray events, for example see Collins et al. (Q73.C), could be due to such a process. The experiments were performed by Burke et al. (Q75.B) and Stevens et al. (Q76.S) at Fermilab and Yuan et al. (Q73.Y, Q76.D) at the ISR. While some of the experiments find anomalous signals, these are at cross-section limits many factors of ten below the cosmic-ray levels. Multiphoton events of this sort remain quite difficult to interpret; however, events at the frequency suggested by the cosmic-ray results do not seem to occur.

THEORETICAL DEVELOPMENTS

Although many of the theoretical developments concerning the monopole conjecture in the last several years have been in the area of gauge theories and confinement there still remain fundamental questions concerning the validity of the concept. Recently some of these concerns have been lucidly expressed in the letter columns of Physics Today (C76.Bl). Hagen (C76.H) states that magnetic-monopole theory has not been shown to be covariant. Both Schwinger and Zwanziger have answered this criticism. Zwanziger admits that no satisfactory proof of consistency exists for the relatitivistic quantum theory but points out that this is also true for ordinary quantum electrodynamics. Rosenbaum, however, notes that he has shown that there is no action principle for the classical relativistic electromagnetic field containing electric and magnetic charges. Goldhaber (A76.G), suggests that there has still not been a fundamental reconciliation between monopoles and relativity. These serious questions should not be overlooked in any consideration of the monopole conjecture.

As mentioned earlier, Wu and Yang (A76.W1) have now answered another long-standing question: are Dirac strings necessary? They have found a fiber bundle theory which obviates the need for strings. They use a section, in effect a pair of potentials, to describe a monopole. In essence each potential describes an incomplete region of space but with some overlap region between the two. They (G75.W) give a helpful table of identifications of fiber-bundle terms with gauge-theory language. Coleman (G75.CO) contains a good review of the uses of homotopy theory for soliton problems.

Recent theoretical interest in monopoles harks back to the recognition several years ago by Nielsen and Olesen (H73.N) of the similarity of the static limit of the Higgs model of broken gauge invariance to the Ginzburg-Landau phenomenological field theory of a type II superconductor. In a type II superconductor, magnetic flux is confined to a tight bundle (Abrikosov flux lines) with a finite energy per unit length. The only way to terminate the bundle is with a magnetic monopole. The energy of the vortex-monopole system will still be infinite unless the other end is terminated by an oppositely charged monopole. This system gives a quark-confinement model since the flux bundle cannot be broken and separating the two poles to infinity produces infinite energy. See, for example, Creutz (H74.C). Nielsen and Olesen use these analog vortex solutions in the Higg's Lagrangian for an Abelian gauge field coupled to a charged scalar field to obtain the Nambu dual string. It should be emphasized that they do not identify the solution with a coupled monopole-antimonopole pair. Nambu (H74.N) and Parisi (H75.P) have developed these ideas as magnetic confinement models. While Nambu uses Dirac monopoles buried in an Abelian superconducting vacuum he explicitly states that this is done as an analogue.

The solid-state theory and the implications of some of these analogies have been succinctly reviewed by P. W. Anderson (A76.AN) one of the father's of the relevant theory. Blaha (A76.BL) has now turned the problem around to show that pointlike singularities may exist in He^3 in analogy to magnetic monopoles in gauge theory.

The Nielsen-Olesen model of confinement in terms of magnetic monopoles has undergone substantial development. For example, Mandelstam, (H75.M) working in an SU(3) non-Abelian field, shows that monopoles are confined in multiples of three by the equivalent of the Meissner effect. (Weak magnetic fields are completely shielded by a superconductor while strong fields destroy the superconductivity). Frampton (G756.F) suggests that this paper shows a non-Abelian monopole can't terminate a dual string. Ezawa and Tze (H75.E) have extended Mandelstam's work to show how baryonic confinement models can be made (three quark bolas). Brout et al. (H76.BR) incorporate the solutions discussed below to get confinement.

Even more interesting than the confinement models has been the scheme put forward independently by 't Hooft (G74.T) and Polyakov (G74.P). Using a classical, non-Abelian field theory they find a magnetic-monopole solution with finite, but very heavy mass. 't Hooft calculates the mass as $M = 4\pi M_W/e^2$ or roughly M_W/α. For reasonable values of M_W this is 5 to 10 TeV. There are no strings attached to this monopole, unlike the Dirac case. 't Hooft essentially obtains the Schwinger quantization condition. 't Hooft uses an SU(2) gauge theory containing a triplet of scalar mesons that is spontaneously broken by the Higgs mechanism. In this approach U(1), the electromagnetic group, is a subgroup of some compact covering group such as SO(3) Bludman and Ruderman (P76.B) point out that the covering group needs to be non-Abelian so that magnetic-field lines converge onto a point. The need for a compact covering group excludes the Weinberg-Salam model (SU(2) x U(1)) unless that model is embedded in turn in some larger structure with a compact covering group. Note that Weinberg-Salam is the currently favored non-Abelian gauge theory because it includes neutral currents. The 't Hooft model is compatible with the Georgi-Glashow picture, a theory without neutral currents. Interestingly both of these models, Georgi-Glashow and 't Hooft - Polyakov, contain a mechanism for electric-charge quantization. In the case of the 't Hooft model this is because of the presence of the magnetic monopole. Goldhaber (A76.G) and Lee (S76.L) speculate that this mechanism has its roots in SO(3). Sometime earlier Yang had observed that charge quantization required a compact group (T70.Y).

't Hooft chooses a solution that is time independent and spherically symmetric. Weinberg and Guth (G76.W) point out that this results in tremendous simplifications. This solution represents a localized solution of a classical non-linear field equation, that is a soliton. The solution can be thought of as built up from magnetic dipoles pointing radially outward with a singularity at the origin. This graphic picture perhaps led Polyakov to give the solution the name "hedgehog". The effect of the singularity is to give a net monopole moment.

Interestingly an exact solution to this model has been found by Prasad and Sommerfeld (G75.PR). Bogomolny (G76.B01) has obtained a similar result. The solution is for a special limiting, perhaps non-physical, case. Some suggest that this particular solution may be due to a vanishing self coupling of the Higgs scalar.

What are some of the attributes of the 't Hooft-Polyakov model? Julia and Zee (G75.J) have generalized the development to include electric charge, a 't Hooft Dyon, so to speak. This entity is not guaranteed stable. The Dyon can have a continuous range of charge. Frampton (G76.P1) and others have shown the 't Hooft solution for an SU(2) Yang-Mills theory is unique for the spherically symmetric case. In addition, Weinberg and Guth (G76.W) and others show there are no multiple, magnetically charged, spherically symmetric solutions. Coleman and Parke (G76.CO) have looked at non-spherically symmetric cases to see if they are stable. They are able to demonstrate stability using the Prasad-Sommerfeld solution. Friedman and Kaku (G76.FR) have found a time-dependent solution which reduces to a 't Hooft monopole in the stationary case.

Several authors have shown how to quantize classical theories like those of 't Hooft and Polyakov. These include Goldstone and Jackiw (G76.J2) and others.

The 't Hooft picture requires spontaneous symmetry breaking via the Higgs mechanism and the embedding of U(1) in a larger group. How necessary are these conditions for a solution? Troost and Vinciarelli (G76.TR) have examined this question. They submit that a much wider class of possibilities are allowed. They state that the necessary conditions for a monopole-type solution to exist are the presence of a matter field with an intrinsic spin and positive anomalous magnetic moment along with U(1) gauge invariance.

An interesting possibility would be to generalize the 't Hooft picture to an SU(3) gauge theory. Marciano and Pagels (G75.M) have offered a topologically stable solution without Higgs scalars. The monopole has infinite energy and no strings. There is no direct charge quantization. Goldhaber (A76.G) states that these monopoles are only topological, - not physically magnetic.

Gursey (G76.GU) with Swank have considered the SU(3) case with Higgs scalars. This theory leads to 't Hooft-type magnetic monopoles that carry quark-like (2/3 e, -1/3 e) electrical charges. Corrigan et al., (G76.COR) and Dereli and Swank (G76.D) have pursued similar models and obtained the same result. Sinha (G76.SI) maps out a more general plan that includes these results as particular cases. He finds some monopoles with an extended structure.

It has already been pointed out that in the 't Hooft picture the need for a compact covering group excludes a simple approach to Weinberg-Salam theory. This theory can be included by embedding in a larger group. Monastyrskii and Perelomov (G75.MO) use homotopic arguments to find a necessary condition for the existence of solutions in gauge-invariant theories with arbitrary compact groups. They use this approach to show that there is no solution in the simple Weinberg model. Hsu (G76.HS) has approached the problem of accommodating the Weinberg model by using a local unit isovector to substitute for the role of the Higgs scalars. He states that this relieves the requirement for a compact covering group and thus admits a Weinberg model. Hsu's model gives $\sin^2\theta_w = 1/2$. It should be noted that this model has been emphatically criticized by Cervero (G76.C).

More than 80 years ago, J. J. Thompson (for example, see A76.A) and perhaps others realized that monopole-charge systems contain angular momentum in the electromagnetic field. One of the most curious developments to grow out of the interest in the 't Hooft monopole has been the realization that it may be possible to construct fermions out of bosons. This concept, while not completely new, is still a most striking development. An earlier non-monopole example devised by S. Coleman (T75.C) employs a two-dimensional boson theory using the massive sine-Gordon equation. Coleman's theory obeys Fermi-Dirac statistics. Some earlier approaches to classical gauge theories, such as one put forward by Wu and Yang, (T69.W) mix spatial and internal degrees of freedom. This is the key to the arguments employed by Jackiw and Rebbi (G76.J) and Hasenfratz and 't Hooft (G76.H). Jackiw and Rebbi use as an example a quantum SU(2) theory where isospin degrees of freedom are converted into spin in the field of a magnetic monopole. They suggest that in general spin will always emerge from isospin when there is an isospin-degenerate, classical solution in the field of a monopole. Hasenfratz and 't Hooft use the same model but a somewhat different approach. They state that the theory is expected to be fully Lorentz invariant and unitary. They do indicate that it will be difficult to derive a realistic Dirac equation for the composite particle. Huang and Stump (G76.HUA) have generalized this approach while

Hasenfratz and Ross (G76.H1) have determined the second quantization. Goldhaber (A76.G1) has gone on to analyze the relative motion of two boson-composite dyons with half-integer spins to show that the conventional spin-1/2 Fermi-Dirac statistics hold. Criticisms have been leveled at the idea that isospin is converted to spin. Troost and Vinciarelli (G76.TR1) examine spinless bosons and magnetic monopoles to see how they acquire spin in SU(2). They conclude that isospin is not converted to spin. The arguments depend to some extent on the fact that the same situation occurs classically but is actually a spin degeneracy. Acharya and Nigam (C76.A) find difficulties with Poincare invariance. A succinct review of these developments appears in Physics News in 1976 (G76.P).

There have been several other developments related to the interests generated by 't Hooft-Polyakov monopoles. Several authors including Kim (A76.KI), and Horvath and Palla (G76.HO3) have investigated grand unification schemes along the lines of Pati-Salam to try to incorporate both baryons and leptons in one picture. Many others have generalized the 't Hooft model or similar pictures to gravitating or curved-space schemes. For example, see Bias and Russell (G75.B), Cho and Freund (G75.CO), Kibble (G76.KI), Marciano and Pagels (G76.M1), etc. Finally a number of articles have now begun to appear on the scattering of magnetic charge including articles by Boulware et al. (J76.B), Milton and DeRaad (A76.M), Kazama et al. (J76.K) and Schwinger et al. (J76.S).

PHYSICAL EFFECTS ATTRIBUTED TO MAGNETIC MONOPOLES

Experimental work up to now indicates that free magnetic monopoles are difficult to find. Therefore, if there are theoretical reasons that suggest the existence of monopoles it is important to cast the experimental net widely, looking not only for direct effects of monopoles but indirect effects as well. Unfortunately the less direct the effect, the less likely it is that it can be uniquely ascribed to a magnetic monopole. Many of the effects that have been predicted are noted below along with citations on some articles, usually current, that discuss them. An attempt has been made to order the effects sequentially from the most definitive on.

Intrinsinc Effects

1) Magnetic charge: Simply put, a magnetic charge will be accelerated by the presence of a magnetic field. This constitutes the basis for many, but not all, magnetic-monopole detection schemes. Price et al., (PSOP, K75.P) is an example of a technique that does not use this property. Carrigan and Nezrick (L71.C) and Winterberg (A75.W) make the point that conjectural magnetic quark systems could be stripped apart by large enough magnetic fields.

2) Charge quantization: Dirac theory fixes a relation between electric charge and magnetic charge. Many other theories reproduce a fixed relation but often with different effective magnetic charges. Examples include Schwinger (B75.S), Horvath and Palla (G76.H02),

and Gursey (G76.GU). Note that in some theories magnetic charge is not quantized. An example is the classical theory of Wu and Yang (A76.W1).

3) Time reversal violation: This characteristic of magnetic monopole-electric charge systems has been recognized for many years. The violation is maximal, an embarassment of riches. This system is not the only time-reversal violating mechanism but it may be the most straightforward.

4) Mass: Until recently there were no definite predictions on this point, only a general sense that a monopole would be heavy because its self energy was large. 't Hooft (G74.T) gives a concrete prediction for his brand of monopole, 5 to 10 TeV, for a plausible intermediate boson mass. Tombolis and Woo (G76.T) and Polyakov (G74.P) also discuss mass questions.

5) Size and structure: Goebel (A69.G) has considered the size of magnetic monopoles. Barut (A71.B) often discusses monopole sizes in terms of the equivalents of the classical electron radius. Hietarinta et al. (G76.HI) contains a discussion of magnetic monopole form factors, while Schechter (G76.SC) suggests a small distance behavior difference between 't Hooft and Dirac magnetic monopoles. Shaposnik (G76.S) uses a power series development to calculate form factors.

6) Decay modes: In essentially all models magnetic charge is conserved. Julia-Zee (G75.J) illustrates a dyon that could decay to a monopole. Jackiw (G76.J2) discusses a case where an electrically charged monopole is stable.

7) Capture modes: Often theories suggest monopoles and dyons can capture other particles. For instance Julia-Zee (G75.J) suggest that a dyon can capture a fermion to become a fermionic dyon.

8) Relation to tachyons: Recami and Mignani (E74.M) have considered the possibility that tachyons would be magnetic monopoles.

9) Need for superposition of states: Barut (e.g., B73.B) has suggested that magnetic charges occur as the coherent superposition of states of opposite magnetic charge in analogy with the superposition of states of opposite hypercharge. This idea has been extended by Tomil'chik (C76.TO).

Direct Magnetic Effects

1) Atomic spectra: If magnetic charge appears on the nuclear or electronic constituents of atoms there could be observable spectroscopic effects. Biza and Tomil'chik (N75.B) have examined these possibilities. Opat (N76.O) has looked at the limits placed on magnetic charge in the proton by the ground state hyperfine splitting in hydrogen. Barut (N76.B) argues that the Opat approach is incorrect.

2) Muon g-2 effect: The virtual production of monopole pairs could contribute to the muon magnetic moment. This effect has been estimated by Amaldi et al. (R63.A).

3) Modulation of neutral kaon mass difference: Carrigan and Nezrick (L71.C) have suggested that neutral kaons constructed from dyons and moving in a magnetic field might exhibit an effect in analogy to the first order Start effect. A possible theoretical format for calculating this is Hsu (T74.H).

Detector Related Effects

1) Binding: There seems to be relatively little question that magnetic monopoles will bind to ferromagnetic materials. Eberhard and Ross (N75.E) and Kittel and Manoliu (N76.K) have recently re-examined this question. There is not a concensus on the question of binding to nuclei.

2) Cherenkov radiation: The polarization of the Cherenkov radiation from a moving magnetic charge is rotated ninety degrees from that of an electric charge. A soviet group (L74.Z) has used this to search for moving magnetic monopoles at Serpukhov. Recently Hagstrom (N75.H) pointed out that this effect offers a potentially practical way to discriminate between heavy ions and magnetic monopoles in emulsion packets.

3) Delta rays and their effect on track character: Katz (e.g., N65.K) pointed out that the radial grain density in an emulsion for a monopole track should be distinctive because of the large effective z. This characteristic was used in the PSOP experiment. Price (K76.P)

reviews this question in some detail. It is amusing to note that understanding of the energy-loss mechanisms of heavy ions, a process that is now significant for heavy ion pellet fusion, is in some sense a spin-off from interest in the monopole conjecture. See for instance, Katz, et al., (T72.K).

4) High Energy Loss: The ionization loss of a moving magnetic monopole should be extremely high and approximately constant. For a simple derivation see Snyder (N76.S). Ahlen (N76.A) has recently included the density effect in the energy loss calculation and shown that it produces a lowering of dE/dx at low β.

5) Difference of energy loss effects - dyons vs. monopoles: Schwinger (R76.S) has reviewed some aspects of this question.

Magnetic-Monopole Production

1) Production Energy: One possible cause for the failure to detect magnetic monopoles is that they are massive. For proton collisions with a fixed target proton the maximum monopole mass that can be produced in a pair is $(mE/2)^{1/2}$ or about 15 GeV/c^2 for E = 500 GeV. At a given energy (related to some upper monopole mass) fixed target experiments overwhelm cosmic-ray experiments, characteristically by several factors of ten. On the other hand, storage rings can produce much higher masses (M = E) but with a substantially lower

production rate. Cosmic rays offer a spectrum of particles going to very high energy, roughly as $1/E^3$. Based on this, storage-ring experiments become competitive with cosmic-ray experiments at about Isabelle energies. Note that if the proposed VBA is built with provision for colliding beams that the mass range of the 't Hooft monopole becomes accessible.

2) Production models: Unfortunately little work has been done on this, in part because of the super strong interactions of magnetic monopoles. Newmeyer and Trefil (I72.N1) have considered this question fairly recently. Campbell (I77.C) has discussed monopole production by pair annihilation. Note that cross sections for all sorts of incident particles would be useful for comparison to experiments. Experimenters have little guidance on what type of particle is most likely to produce a monopole.

Gauge Theory Effects

1) Neutron electric dipole moment: Characteristically theories that incorporate time-reversal violation give rise to a neutron electric dipole moment. So far no such effect has been found. Acharya and Horvath (G73.A) consider an electron electric dipole moment for a special monopole theory.

2) Proton stability: Many gauge theories predict an unstable proton. Kim (A76.KI) gets a lifetime of 10^{29} years using a color model.

3) Weinberg angle: Weinberg theory is something of a forbidden preserve for monopole enthusiasts. However Hsu (G76.HS) predicts $\sin^2\theta_w = 1/2$ in one model.

Particle Model Effects

1) De-excitation-annihilation model: Some time ago Ruderman and Zwanziger (Q69.R) explored the de-excitation and ultimate annihilation of a pole-anti-monopole pair. De-excitation consists of a large number of relatively soft photons from de-acceleration of the monopoles followed by hard photon emission on annihilation. Ruderman and Zwanziger suggest that this scenario might account for a number of rather peculiar photon shower events summarized recently by Collins et al. (Q73.C). Troost and Vinciarelli (G76.TR) have also studied this, noting that copious pair production could also occur. Budnev et al. (A75.B) examine this process and discuss cross sections. Experimental interpretation of large photon showers as monopole annihilation events is fraught with difficulties. There is no manifest magnetic handle on the events and it is easy to offer alternate interpretations. The presence of any finite thickness of radiator leads to further development of a single photon shower.

2) Particle spectral models: Schwinger's dyon model (a recent reference is A75.5) is the pioneering work in building a quark-like model out of magnetic monopoles. Han and Biedenharn (A70.H) extended this to

a three-triplet model. Barut (e.g., A71.B) has discussed an "atomic" model in which the proton is made out of a pole-antipole pair.

3) Dual resonance models: Magnetic-confinement models along the lines of Nielsen - Olesen (H73.N) and Mansouri - Nambu (H72.M) can produce the dual-resonance model. Nambu and many others are always careful to point out that this is an analogue. Others, such as Barut (H73.B), have explored a more direct connection. Balachandran et al.(H75.B), can give insights into charm-particle spectra.

4) Regge theory: A number of authors have extracted Regge slopes from monopole models. See, for example, Balachandran, et al. (H75.B) and Coon and Suura (A74.C).

5) Form of nuclear force: Sawada (e.g. A73.5) reasons that a magnetic-monopole model of the nucleon should give rise to a nucleon-nucleon force with unique characteristics. He finds an attractive Van der Waals force with a repulsive inner potential. He suggests that the Van der Waals force gives rise to tangible effects for small angle elastic scattering.

External Effects

1) Large scale magnetic field destruction: The presence of free magnetic monopoles in the universe would act to damp out galactic and stellar magnetic fields. This can be used to set fairly stringent limits on the presence of free magnetic poles in the cosmos.

Recent discussions include Badhwar et al. (M76.B) and Kalman and D. Ter Haar (P76.K).

2) Large-scale deviations from Maxwell's equations: Gaffney (E74.G) discusses a model incorporating monopoles at one stage which contains large length scale deviations from Maxwell's equations.

3) Monopole density from the big bang: Kibble (G76.KI) has discussed symmetry breaking on a cosmic scale. He suggests how the cosmic density of 't Hooft poles can be estimated.

4) Production by high field lasers: Yueh (A74.Y) and Winterberg (A75.W) have looked at high-field laser production. Yueh concludes that it is not feasible.

THE NATURE OF THE BIBLIOGRAPHY

Activity on subjects related to monopoles in the last several years has been intense. As an example, 't Hooft's original monopole paper has been cited in several percent of all theory papers written since, leading to several hundred citations. In the face of this mass of literature I have aimed for a wide coverage, possibly at the expense of thoroughness in encapsulating, classifying and finding articles in obscure places. This possible sacrifice was deemed worthwhile in light of maintaining timeliness.

The bibliography search included Nuclear Science Abstracts and the INIS Atom index for the period of 1973 to 1976. SLAC preprints from 1974 to 1976 were searched using SPIRES. This included a search for citations of 't Hooft's article. In addition Physical Review and Physical Review Letters, Nuclear Physics, and several other journals were searched title by title for 1976 to cover recently published preprints. In most cases when the article was available citations were back-checked to make sure they were included.

I have listed a few citations earlier than 1973 either because they were not in Steven's excellent bibliography or because they were necessary for textual clarification.

The bibliography has been organized by major topics. Articles have not been cross-filed under several topics even if they touch in a major way on several points, so the reader should exersize some discretion in using the information. Within major topics articles are listed by year and then alphabetically by author. An asterisk by an article indicates that only an abstract was available, a dagger indicates that only a title was seen. For many of the escapsulations I have drawn freely from the original text.

I would appreciate being notified of errors including escapsulation or classification. I would like to thank M. Luba and R. Donaldson for help in assembling the bibliography.

The bibliography was closed for practical purposes in January of 1977.

BIBLIOGRAPHY MAJOR SUBJECTS

A. Theory - General

B. Theory - Charge Quantization

C. Theory - Invariance

D. Theory - Electrodynamics

E. Theory - Relativity

F. Theory - Gravity

G. Theory - Gauge

H. Theory - Strings, Dual Models

I. Theory - Production

J. Theory - Scattering

K. Experiment - Detection

L. Experiment - Searches

M. Experiment - Critiques

N. Experiment - Detection Schemes

P. Experiment - Large Scale Effects

Q. Experiment - Gamma Ray Events

R. Monopole Reviews

S. General Reviews - Hypothetical Particles

T. Related Topics

A. THEORY - GENERAL

A69.G The Spatial Extent of Magnetic Monopoles

C. J. Goebel

Wisconsin preprint (69)

Discusses monopole sizes

Prediction

Monopole sizes

A70.H Dyon Three-Triplet Model of Hadrons

M. Y. Han and L. C. Biedenharn

Phys. Rev. Lett. 24, 118 (70)

Schwinger Dyon picture formulated in terms of the Han-Nambu three-triplet model.

A71.B Atoms with Magnetic Charges as Models of Hadrons

A. O. Barut

Topics in Modern Physics (71), p. 15.

General review of Barut's magnetic pole model of hadrons.

A72.0 S. Ozaki

Ozaki has discussed a Dyon model in a series of unpublished preprints and communications in Soryushiron-Kenkyu from 1972 to 1976. These notes are difficult to abstract satisfactorily.

A73.B Magnetic Charges and Strings as Building Blocks of Hadrons-Connection Between Electromagnetic and Dual Strings

A. O. Barut

Int. Cent. for Theo. Phys. 73/74 (73)

Suggests that magnetic charge occurs in parity eigenstates rather than in eigenstates of magnetic charge. Discusses string excitations.

A73.C The Classical Problem of Charge and Pole

E. F. Carter and H. A. Cohen

Am. J. Phys. 41, 994 (73)

Straightforward discussion of classical dynamics. Nice review of early history of monopoles from Maxwell on.

A73.S Proposal to Observe the "Van der Waals Force" in Hadron-Hadron Scattering

T. Sawada

Phys. Lett. 43B, 517 (73).

(See also A74.S1).

Considers long-range singularities near t = 0. Sees effect in terms of slope paramter.

Prediction

Van der Waals force from Dyons can be measured via small- angle pp elastic scattering.

A74.C Regge Trajectories and the Quark-Gluon Coupling Constant

D. D. Coon and H. Suura

Phys. Rev. D10, 348 (74)

Relates Regge trajectories to gluon coupling constant. Gives a model in terms of magnetic charges. Suggests gluon: photon, quark: magnetic monopole analogy.

A74.S Semi-Empirical Detecion of the Dirac's Magnetic Monopoles

T. Sawada

Phys. Lett. B52, 67 (74)

Van der Waal model of proton used to abstract magnetic monopole potential. Model fits - but paper closes with a "next task" of doing nucleon-nucleon potential problem.

Prediction

Observable nuclear potential.

A74.S1 Nuclear Force and a Magnetic Monopole Model of Hadrons

T. Sawada

Nucl. Phys. B71, 82 (74)

Models 2π exchange potential from phase shifts of low energy πN and $\pi\pi$ scattering. Finds difference from other potentials. Difference has the form of an attractive Van der Waals potential and inner repulsive core. Existence of Van der Waals force discussed in connection with a magnetic monopole model of hadrons.

*A74.Y <u>Pair Production Processes and Final-State Interaction</u>

W. R. Yueh

Columbia Univ., New York 1974 (Thesis)

Principally a discussion of general radiative processes - but also considers case of magnetic monopole.

Prediction

Discussion of laboratory production of pole pairs with a laser. Concludes it is not feasible.

A75.B <u>The Two-Photon Particle Production Mechanism. Physical Problems. Applications. Equivalent Photon Approximation</u>

V. M. Budnev, I. F. Ginzburg, G. V. Meledin, V. G. Serbo

Phys. Rep. <u>15</u>, 181 (75)

Reviews how photon spectrum from virtual excitations of monopole pairs should go.

Prediction

Cross section and distributions from virtual excitation of $M\bar{M}$.

†A75.C <u>Dirac Monopoles, The Aharanov - Bohm Effect and Flux Quantization in Superconductors</u>

W. B. Campbell, P. Finkler, C. E. Jones, and M. N. Misheloff

Print-75-1005 (Nebraska) (75)

A75.G Minimal Coupling and Complex Line Bundles

W. Greub and H. R. Petry

J. Math. Phys. 16, 1347 (75)

An early development of the monopole-charge system without strings using fiber bundles and sections.

A75.S Psi Particles and Dyons

J. Schwinger

Science 188, 1300 (75)

Discusses the ψ particles in terms of the dyon model.

A75.T Dynamical Model of Spin-1 and Spin-0 Particles

R. V. Tevikian

Nucl. Phys. B93, 74 (75)

Contains a classification of fundamental interactions. Concludes from table that strong interactions are based on magnetic monopoles.

A75.W Quarks, Magnetic Monopoles, and Negative Mass

F. Winterberg

Nuovo Cimento Lett. 13, 697 (75)

Using Parker's result suggests monopoles have negative mass. Goes on to discuss possibilities of idea.

Predictions

Monopoles have negative mass.

Magnetic quarks set free in strong magnetic fields.

†A75.W1 Quarks Possibly are Negative Mass Magnetic Monopoles

F. Winterberg

Atomkernergie 26, 43 (75)

A75.Y Comments on Vacuum Polarizations of Magnetic Monopoles

W. R. Yueh

Phys. Rev. D12, 3221 (75)

Suggests there is charge renormalization for magnetic monopoles. Also points out that there are no induced vacuum currents.

A76.A Thomson's Monopoles

I. Adawi

Am. J. Phys. 44, 762 (76)

Contains several derivations of angular momentum in a classical pole - electric charge system.

A76.AN <u>Uses of Solid State Analogies in Elementary Particle Theory in Gauge Theory and Modern Field Theory</u>

P. W. Anderson

Proceedings of a Conference on Gauge Theories and Modern Field Theory, held Sept. 19, 75 at MIT-Cambridge

MIT Press (76)

Not a monopole paper.

Review of solid state theory analogy to monopole gauge theory.

†A76.B <u>De Rham Currents, Extended singularities of Fields and Magnetic Monopoles</u>

A. O. Barut

76-1019 (Colorado) (76)

Presented at Symposium on Methods of Differential Geometry in Physics and Mechanics, Warsaw, Poland, June 14-19, 1976.

A76.B1 <u>Quantization Rules for Point Singularities in Superfluid ^{3}HE and Liquid Crystals</u>

S. Blaha

Phys. Rev. Lett. <u>36</u>, 874 (76)

Not a monopole paper.

Shows that pointlike singularities can exist in ^{3}He superfluid. Is an analog to monopoles in a gauge theory.

A76.B11 An Experimentally Accessible Analog of the Magnetic Monopole in He-A

S. Blaha

Syracuse SU-4208-69 (76)

Not a monopole paper.

Discusses point singularities called vortons in fluids. These are analogous to magnetic monopoles. Strings in an abelian Higgs model are analogs to vortices.

A76.D Theory of Magnetic Monopoles

P. M. Dirac

"Magnetic Charge and Other Fundamental Approaches", A. Perlmutter, Ed., Plenum, N.Y. (76). p. 1.

Review of basic Dirac scheme. No extensive comments on other developments.

A76.G Electric Charge in Composite Magnetic Monopole Theories

A. S. Goldhaber

"Magnetic Charge and Other Fundamental Apprаches", A. Perlmutter, Ed., Plenum, N.Y. (76). p. 121.

Reviews spin in monopole systems. Also gives a more stringent limit than 't Hooft on theories to produce a 't Hooft monopole.

A76.G1 Connection of Spin and Statistics for Charge-Monopole Composites

A. S. Goldhaber

Phys. Rev. Lett. 36, 1122 (76)

An object composed of a spinless electrically charged particle and a spinless magnetically charged particle may have half interger spin. Careful study shows proper relation under spin and statistics. Fermion can be made out of bosons.

A76.K Existence of Bound States for a Charged Spin 1/2 Particle with an Extra Magnetic Moment in the Field of a Fixed Magnetic Monopole

Y. Kazama and C. N. Yang

SUNY-Stony Brook ITP/SB 76-65(76)

(submitted to Phys. Rev. D)

Shows monopole can bind to an electron. Speculates that it is possible to bind to two electrons. The analysis is not suitable for the proton case.

Predictions

Monopole could bind to an electron.
Indicate it might be possible to bind more than one electron.

A76.KI Color and Magnetic Charge

B. R. Kim

Phys. Rev. D13, 3156 (76)

Following Schwinger extends color to leptons. (Leptons are quarks with zero magnetic charge.) Replaces baryon number and lepton number with fermion number and magnetic charge.

Prediction

Proton is not stable

A76.KY Monopole--Antimonopole Bound State

E. Kyriakopoulos and R. Ramachandran

Nuovo Cimento Lett. 15, 161 (76).

Uses classical monopole-antimonopole states to get a mass spectrum. Ground state is $M/\mu = \frac{2}{3} g^2 \sim 90$ where M = pole mass, μ = bound state mass (a la Goebel, use of classical magnetic radius). Develops case with form factor folded in. Some comments about decay from excited state.

Predictions

Ground state bound mass

Mass spectrum

A76.M Strings and Gauge Invariance

K. A. Milton and L. L. DeRaad, Jr.

UCLA/76/TEP/16 (76)

Studies charge quantization by solving two-body Schrodinger equation with arbitrarily oriented string. Some results on dyon-dyon scattering.

A76.P Some Remarks on the U(1)-Axial Problem of Quantum Chromodynamics

H. Pagels

Phys. Rev. D13, 343 (76)

Discusses $U_A(1)$ problem, conservation of the "ninth axial-vector current" in quantum chromodynamics.

A76.S Theory of Magnetic Monopoles and the Dirac--Schwinger Quantization Condition without Strings

V. Sokolov

Yad. Fiz. 23, 628 (76)

Sov. J. Nucl. Phys. 23, 330 (76) (Eng. Trans.)

Find a rotationally invariant theory. Some comments on original Goldhaber angular momentum article.

A76.SE Path Integral Formulation of Field Theories with Second-Class Constraints

P. I. Senjanovic

Ann. Phys. 100, 227 (76)

Uses path integral method to quantize a local field theory of magnetic monopoles.

A76.ST Spontaneous Breaking of Electric-Magnetic Charge Symmetry in Local Quantum Field Theory

F. Strocchi

Phys. Lett. 65B, 447 (76)

It is shown that in local quantum field theory with electric and magnetic currents, duality transformations are always spontaneously broken.

Prediction

Model for why magnetic charge not observed.

A76.V Hamiltonian Formulations Without and With Strings for Electric and Magnetic Charges

D. Villarroel

Phys. Rev. D14, 3350 (76)

Noncanonical (without string) and canonical (with string) Hamiltonian formulations for a system of classical electric and magnetic charges. The quantum theory associated with the canonical description is the Schwinger field theory.

A76.W Dirac Monopole without Strings: Monopole Harmonics

T. T. Wu and C. N. Yang

Nucl. Phys. B107, 365 (76)

Uses fiber bundles to show wave function of a particle of charge Ze around pole g should be regarded as a section.

A76.W1 Dirac's Monopole without Strings: Classical Lagrangian Theory

T. T. Wu and C. N. Yang

Phys. Rev. D14, 437 (76)

Studies non-quantum mechanical interaction of Dirac pole and point charge through electromagnetic field.

Prediction

Since $\hbar$ not introduced $Zeg/\hbar c \neq$ integer is possible.

A76.Y New Weakly Decaying Particles and Subnucleons

P. C. M. Yock

Phys. Rev. D13, 1316 (76)

Not a monopole paper.

Discusses a model with very large electrical charges.

Prediction

Explanation of PSOP

*A77.B Avoiding "Dirac's Veto" in Monopole Theory

R. A. Brandt and J. R. Primack

To be published, Phys. Rev. D (Mar. 15, 77)

Extension of Wu-Yang work to Dirac's original formulation.

B. THEORY - CHARGE QUANTIZATION

*B72.E Magnetic Poles and Charge Quantization

H. J. Efinger

From Symposium on the Structure of Matter (1972), p. 158. Portland, Oregon International Scholarly Book Services, Inc.

Model for interaction between electric and magnetic charges. Interaction takes place in a uniform magnetic field. Motion of electrically charged particles is then subject to a simple quantization condition.

B72.J Flux Quantization and Particle Physics

H. Jehle

George Washington University Preprint (72)

Not a monopole paper.

Suggests that a quark be considered as a closed quantized flux loop if interlinked with other flux loops.

B73.B The Impossibility of Splitting the Superposition of States of Opposite Magnetic Charges in External Electromagnetic Fields. An Anti-Superselection Rule

A. O. Barut

Phys. Lett. 46B, 81 (73)

Shows that a Stern-Gerlach type splitting of an unpolarized magnetic charge beam is not possible in a parity-conserving theory.

Prediction

Can't separate unpolarized magnetic charge beam via a Stern-Gerlach experiment.

B73.U Is there a Theorem for the Quantization of Magnetic Charge?

Y. D. Usachev

Sov. J. Particles Nucl. 4, 94 (73)

Contains a critique of the Dirac charge quantization condition. Doesn't say it is wrong - but rather that it can be critized.

B74.A Electric Charge of Elementary Particles

A. I. Akhiezer and M. P. Rekalo

Usp. Fiz. Nauk 114, 487 (74)

Soviet Physics - Uspekhi 17, 864 (75)

Nice review of electric charges and electric dipole moments. On elementary particles cites magnetic monopole as a possible reason for quantization.

*B74.C Is There a Quantization Condition for the Classical Problem of Charge and Pole?

H. A. Cohen

Found. Phys. 4, 115 (74)

Shows that there is not a classical "quantization" condition.

B74.P Ramifications of Flux Quantization

E. J. Post

Phys. Rev. D9, 3379 (74)

If one assumes absence of magnetic charges then a law of magnetic flux conservation is needed. That is, it must be put on an equal level with charge quantization.

*B74.R Path Independence and Charge Quantization

D. K. Ross

J. Phys., A (London) 7, 705 (74)

It is shown that if quantum electrodynamics is assumed to be manifestly gauge independent and path independent, then electric charge must be quantized.

B75.S Magnetic Charge and the Charge Quantization Condition

J. Schwinger

Phys. Rev. D12, 3105 (75)

Description of Schwinger charge quantization.

B75.ST <u>Possibility of Theory of Magnetic Charge without Charge Quantization Conditions</u>

V. I. Strazhev, L. M. Tomil'chik

Vestsi Akad. Navuk BSSR, Ser. Fiz.- Mat. Navuk 51, (75).

Looks at non-quantized theories and concludes there is no basis for disregarding charge quantization.

†B76.B <u>Charge Quantization Condition with N Strings. A New Internal Quantum Number of Charge - Monopole Systems</u>

A.O. Barut

76-0749 (76)

B76.T <u>Magnetic Charge Quantization and Fractionally Charged Quarks</u>

G. 't Hooft

Nucl. Phys. <u>B105</u>, 538 (76)

Suggests his model probably excluded because it contains no neutral currents. Good discussion of color magnetic monopoles.

Prediction

Some discussion of Weinberg angle.

C. THEORY - INVARIANCE

C73.B Galilean Invariance and Magnetic Monopoles

H. Bacry and J. Kubar-Andre

Int. J. Theor. Phys. 7, 39 (73)

Shows existence of magnetic monopoles is incompatible with Galilean invariance.

*C73.C Minimal Coupling and Magnetic Charge

P. Combe and J. L. Richard

CNRS-CPT--73-P-539 (73)

For certain conditions it is shown that principal of minimal coupling breaks down if invariance under space reflection is required.

*C75.L Rotational Invariance and the Magnetic Monopole Field

J. M. Leinaas

Phys. Norv. 8, 41 (75)

A general expression is found for the generator of rotations for a spinless particle. It is shown to correspond to the total angular momentum of the system of a charged particle in a magnetic monopole field.

C76.A Poincare Invariance of Charge - Monopole Composites and Parity Violation

R. Acharya and B. P. Nigam

Nuovo Cimento Lett. 17, 351 (76)

In reviewing angular momentum suggestions find Poincare invariance violated unless parity violation introduced.

C76.AN <u>Rotational Covariance and the Yang-Mills Monopole</u>

M. M. Ansorian

Phys. Rev. <u>D14</u>, 2732 (76)

Rotational covariance is examined in the monopole sector of the SU(2) Yang-Mills model with a triplet of Higgs scalars and the possible additions of fermions.

†C76.B <u>Rotationally Invariant Approximation to Charge - Monopole Scattering</u>

A. P. Balachandran, S. Borchardt, R. Cahalan, S. S. Chang, R. Ramachandran, H. Rupertsberger and A. Stern, Goteborg-76-15, (76).

†C76.BA <u>Covariant Field Theory of the Magnetic Monopole</u>

A. O. Barut, 76-0750 (Munich) (76).

†C76.BA1 <u>Covariance of the Field Theory of the Magnetic Monopole</u>

A. O. Barut

76-0274 (Colorado) (76).

C76.C <u>Covariant Problem of the Magnetic Monopole Theory</u>

C. C. Chiang

Nuovo Cimento <u>33A</u>, 73 (76).

Shows how to introduce a shadow electromagnetic field quantized with "wrong sign" so that locality is retained and equations of motion become covariant.

C76.F Invariance Properties of the Dirac Monopole

A. Frenkel and P. Hrasko

Hung. Acad. of Sci. KFKI-75-82 (76)

Shows, in part, that one gets rotational invariance and correct space reflection for e, g system with Dirac quantization.

C76.H Noncovariance of the Schwinger Monopole

C. R. Hagen

"Magnetic Charge and other Fundamental Approaches".

A. Pertmutter Ed., Plenum, N.Y. (76), p. 135.

Shows canonical formulation of magnetic monopole cannot be covariant if only couplings which are manifestly invariant under three dimensional rotations are allowed. Shows Lorentz invariance violated in Schwinger theory. Says there is no consistent field theory of monopole at the present time.

C76.H1 Lorentz Invariance Question

C. R. Hagen, J. Schwinger and D. Zwanziger

Phys. Today, Apr. (76), p. 15 (see also December (76) p. 46; D. Rosenbaum, A. O. Barut.)

Hagen states he showed non-covariance of monopole and that Schwinger is incorrect. Good review of fundamental problems concerning monopoles.

C76.O <u>Lorentz Invariance of Charge--Monopole Scattering</u>

F. Ore, Jr.

Phys. Rev. <u>D13</u>, 2295 (76)

Eikonal approximation applied to Schwinger theory for e, g interaction. Scattering amplitude is Lorentz-invariant if Schwinger quantization holds.

C76.T <u>Non-Abelian Magnetic Charge and Lorentz Invariance</u>

L. R. Thebaud

Phys. Rev. <u>D14</u>, 1673 (76)

Shows why Mandelstam formulation does not allow a generalization of magnetic charge theory to non-Abelian case. Considers a fully generalized, quantized field theory. Concludes nonlocality is probably incompatible with Lorentz invariance.

C76.TO <u>Space Reflection Symmetry and the Pseudo-Scalar Magnetic Charge</u>

L. M. Tomil'chik

Phys. Lett. <u>B61</u>, 50 (76)

Extension of Barut approach to pseudo-scalar charge.

D. THEORY - ELECTRODYNAMICS

*D71.T Electrodynamics of Dual-Charged Particles

R. G. Tarkhanyan

Dokl. Akad. Nauk Arm. SSR 53, 156 (71)

Develops a dual-charged electrodynamics in contrast to Dirac.

D72.S Dual Symmetry of Quantum Electrodynamics

V. I. Strazhev

Teor. Mat. Fiz. 13, 200 (72)

Theoretical and Mathematical Physics 13, 1083 (72) (Eng. Trans.)

Discusses dual-charge symmetry. Argues that dual charge is necessary. Requires a universal ratio of g/e.

*D73.R Impossibility of Reduction of Generalized Electromagnetic Fields for Non-Zero Mass System in Free Space

B. S. Rajput and O. Prakash

Indian J. Phys. 47, 641 (73)

Theoretical treatment of monopoles using complex charge.

D73.W Complex Symmetries of Electrodynamics

D. Weingarten

Ann. Phys. 76, 510 (73)

In this development of electrodynamics magnetic charges and sources moving faster than light occur in a natural and unavoidable manner.

Prediction

Some interconnection between monopoles and tachyons.

*D74.P Existence of Magnetic Monopoles

O. Parkash and B. S. Rajput

Indian J. Phys. 48, 152 (74)

Theoretical treatment of monopoles using a complex charge. Continues earlier work.

†D74.Y Spontaneous Duality Symmetry Breaking, Non-Classical Monopole Theory and Finite Quantum Electrodynamics

W. R. Yueh

Print-74-0344 (Columbia) (74)

D75.M Complex Electromagnetic Four-Potential and the Cabibbo-Ferrari Relation for Magnetic Monopoles

R. Mignani and E. Recami

Nuovo Cimento 30A, 533 (75)

Generalization to an extended relativity to include tachyons. Suggestion in earlier articles was that monopoles were only tachyons.

Prediction

Monopoles are tachyons (stated in a slightly more sophisticated way).

D75.T <u>Direct Action Electrodynamics and Magnetic Monopoles</u>

F. J. Tipler

Nuovo Cimento <u>28B</u>, 446 (75)

Direct Action electrodynamics cannot be generalized to magnetic charges. Note that Direct Action avoids some self energy problems of field theory.

D76.M <u>Symmetries of Electrodynamics with Magnetic Monopoles and the Hertz Tensor</u>

R. Mignani

Phys. Rev. <u>D13</u>, 2437 (76)

Shows that parity and time-reversal violations only occur for a system without electric charges.

D76.MA <u>Quaternionic Form of Maxwell's Equations with Sources</u>

V. Majernik and M. Nagy

Lett. Nuovo Cim. <u>16</u>, 265 (76)

Treatment of Maxwell's equations with sources including magnetic monopoles. This attack is supposed to offer an easier approach to curved spaces.

D76.V A New Two-Potential Approach for Electric and Magnetic Charge

D. Villarroel

Nuovo Cimento Lett. 15, 507 (76)

Similar approach to Zwanziger of directly integrating Maxwell's equation, but uses a different particular solution of the inhomogenous Maxwell's equations.

D77.C Quantum Electrodynamics with Charges and Monopoles: A Covariant Perturbation Theory

W. B. Campbell

Univ. of Nebraska Preprint - Apr. (77)

Derives manifestly covariant Feynman rules for a QED with magnetic and electric charges. Needs two component spinors for this. Approach does not include Dirac quantization.

D77.M Some Geometrical Aspects of Monopole Theories

D. Maison and S. J. Orfanidis

NYU Pth 31/76

To be published in Phys. Rev. D. (March 15, 77).

Connects Kaluza's theory of electromagnetism and its non-Abelian generalizations to a geometrical formulation in terms of fiber bundles.

E. THEORY - RELATIVITY

E74.C Imaginary Quantities in Superluminal Lorentz Transformations

H. C. Corben

Nuovo Cimento Lett. 11, 533 (74).

Originally contested ideas of Recami and Mignani about superluminal charges being viewed as magnetic monopoles.

E74.G Electric and Magnetic Charge in Einstein's Unified Field Theory

G. W. Gaffney

Phys. Rev. D10, 374 (74)

Solution incorporating a length scale.

Prediction

Gross astronomical scale differences from normal electromagnetic fields.

E74.M Magnetic Monopoles and Tachyons

R. Mignani and E. Recami

Nuovo Cimento Lett. 9, 367 (74)

The connection between magnetic monopoles and tachyons is shown in the framework of extended special relativity theory by generalizing Maxwell's equations to superluminal sources.

E74.M1 <u>Possible Experimental Behavior of Tachyon Monopoles</u>

R. Mignani and E. Recami

Nuovo Cimento Lett. <u>11</u>, 417 (74)

Superluminal particles behave as monopoles expected to do except for velocity.

Predictions

Low magnetic charge

Superluminal velocities

*E74.M2 <u>Classical Theory of Tachyons (Special Relativity Extended to Superluminal Frames and Objects).</u>

E. Recami and R. Mignani

Rivista del Nuovo Cimento <u>4</u>, 209 (74)

Review of superluminal theories - similar to later articles.

E74.R <u>Do Magnetic Monopoles Exist? Considerations for Theory and Experiments.</u>

E. Recami and R. Mignani

Nuovo Cimento Lett. <u>9</u>, 479 (74)

Review of superluminal relativity. In part contains a critique of Bartlett-Lahana search because of hypothesis on Cherenkov radiation.

*E74.R1 <u>About Search for Magnetic Monopoles.</u>

E. Recami and R. Mignani

Catania Univ. (74)

Reviews superluminal relativity theory. (Similar to later article on predictions.)

E75.C <u>Behavior of Electromagnetic Charges under Superluminal Lorentz Transformations</u>
H. C. Corben and E. Honig
Nuovo Cimento Lett. <u>13</u>, 586 (75)
Critique of Recami and Mignani point-of-view.

E75.F <u>Elementary Particles in a Curved Space. IV. Massless Particles.</u>
C. Fronsdal
Phys. Rev. <u>D12</u>, 3819 (75)
Demonstrates that monopoles can't exist if physics is stable to a class of perturbations of the space-time metric.

E75.M <u>Some Magnetic and Electric Monopole One-Body Solutions of the Maxwell--Einstein Equations</u>
P. McGuire and R. Ruffini
Phys. Rev. D<u>12</u>, 3019 (75)
General relativity solution.

E75.R <u>Connection between Magnetic Monopoles and Faster-than-Light Speeds</u>
E. Recami and R. Mignani
ICTP, Trieste, IC/75/83, (75).

†E76.A <u>Magnetic Charge in General Relativity</u>
R. J. Adler
Phys. Rev. <u>D14</u>, 392 (76)
Can generalize Schwinger result to general relativity. Curvature of space plays no role.

E76.R <u>Magnetic Monopoles and Tachyons in Special Relativity</u>

E. Recami and R. Mignani

Phys. Lett. <u>62B</u>, 41 (76)

Extended relativity predicts one charge; electric below c, magnetic above. The magnetic charge is much smaller than the Dirac charge.

Predictions

Tachyonic monopoles

Monopole charge much smaller than normal.

F. THEORY - GRAVITY

F74.K Gravitation and Magnetic Charge

B. Kursunoglu

Phys. Rev. D9, 2723 (74)

Theory explaining elementary particles on the basis of general relativity using alternating layers of magnetic charge. No net magnetic charge.

F75.B Physical Consequences of a Solution of the Non-Symmetric Unified Field Theory

D. H. Boal and J. W. Moffat

Phys. Rev. D11, 2026 (75)

Have a gravitational theory of electricity and magnetism, gravity. Find that magnetic monopoles are not allowed in their theory.

†F75.I Gravitational Strings in Elementary Particle Models

D. D. Ivanenko and A. Ya. Burinskii

Izv. Vyssh. Uchebn. Zaved., Fiz. 5, 135 (75)

F75.K Electromagnetic Theory Treated in Analogy to the Theory of Gravitation

O. Klein

Nucl. Phys. B92 541 (75)

Five dimensional representation of electricity and magnetism shows a generalization that could accept magnetic charge.

F75.P Non-Linear Gravitational Effects and Magnetic Monopoles

L. Parker

Phys. Rev. Lett. 34, 412 (75)

Does Einstein-Maxwell equation with e, g.

*F75.T Monopoles-Gravity: A Symmetry Approach

M. J. Trinkala

Albany-State Univ. of - Dissertation (75)

Electromagnetism with monopoles combined with gravity. Some comments on possible application to elementary particle models.

†F76.C Gauge Field Model of Combined Gravitational, Electromagnetic and Magnetic Monopole Fields

M. Carmeli and M. Kaye

Ben Gurion preprint (76)

F76.H Schwarzschild Black Hole in an Asymptotically Uniform Magnetic Field

R. S. Hanni and R. Ruffini

Nuovo Cimento Lett. 15, 189 (76)

Not a magnetic monopole article in normal sense. Monopole is used as a construct to solve black hole in external field.

F76.K Consequences of Non-Linearity in the Generalized Theory of Gravitation

B. Kursunoglu

Phys. Rev. D13, 1538 (76)

Magnetic charge in no way related to Dirac or Schwinger charge. Model has shells of magnetic charge of alternating signs. Monopoles don't exist in theory.

F76.M A General Static Spherically Symmetric Solution in a Unified Theory of Gravitation and Electromagnetism

J. W. Moffat

Toronto preprint (76)

A generalization of the work of Boal and Moffat (F75.B).

†F76.N Electric and Magnetic Gravitational Monopoles.

I. The Equation of Motion of Poles

M. Novello, C. A. P. Galvao, I. D. Soares and J. M. Salim

J. Phys., A. (London) 9, 547 (76)

F76.W Magnetic Monopole, Quark Confinement and Gravitational Effects

M. Y. Wang

Nuovo Cimento Lett. 15, 505 (76)

Note considers that a magnetic monopole type of quark might be confined by gravitation.

G. THEORY - GAUGE

G73.A Taylor's Nonclassical Theory of Magnetic Monopoles as a Spontaneously Broken $U_{L1} \times U_{R1}$ Model

R. Acharya and Z. Horvath

Nuovo Cimento Lett. 8, 513 (73)

Monopole in static limit has no charge and is not an inverse square field. Get $C_\gamma P_\gamma (T_\gamma)$ violation.

Predictions

Electron mass

Electron electric dipole moment

Zero magnetic charge in static limit

G73.K Dirac Monopoles for General Gauge Theories

P. Klimo and J. S. Dowker

Int. J. Theo. Phys. 8, 409 (73)

Different approach than Dirac to obtain quantization condition.

G73.V Prototype Non-Abelian Gauge Field Theory, Monopoles and Strings

G. Venturi

Nuovo Cimento Lett. 12, 257 (73)

Examines the effect of the introduction of two magnetic charges of opposite sign in a prototype non-Abelian gauge field theory.

G74.H Non-Abelian Magnetic Charges

A. Hosoya and J. Ishida

Osaka University preprint OU-HET-6 (74)

Investigates the classical equation of the Yang-Mills fields together with the non-Abelian analog of the Dirac monopole.

G74.P Particle Spectrum in Quantum Field Theory

A. M. Polyakov

ZhETF Pis. Red. 20, 430 (74)

JETP Letters 20, 194 (74)

Development of extremon and hedgehog picture. Spirit is similar to 't Hooft.

G74.T Magnetic Monopoles in Unified Gauge Theories

G. 't Hooft

Nucl. Phys. B79, 276 (74)

Starts from Nielsen-Olesen model - needs a model with compact covering group and a group in which U(1) is a subgroup. Classical theory with no strings.

Predictions

Georgi-Glashow: $M_m = \frac{4\pi}{e^2} M_W \, c(\beta) \approx 137 \, M_W$

Weinberg: substantially higher mass

G75.A Topology of Higgs Fields

J. Arafune, P. G. O. Freund and C. J. Goebel

J. Math. Phys. 16, 433 (75)

It is shown that the conserved magnetic charge discovered by 't Hooft in non-Abelian gauge theories with spontaneous symmetry breaking is a topological characteristic of an isotriplet of Higgs fields in a three-dimensional space.

G75.B Magnetic-Monopole Solution of Non-Abelian Gauge Theory in Curved Spacetime

F. A. Bais and R. J. Russell

Phys. Rev. D11, 2692 (75)

't Hooft approach in curved space-time.

G75.BA Monopole Theories with Massless and Massive Gauge Fields

A. P. Balachandran, H. Rupertsberger, and J. Schechter

Phys. Rev. D11, 2260 (75)

Gauge theory. Recover known results for zero mass, Nambu for some cases of non-zero mass. There are some difficulties with rotational invariance.

G75.C Gravitating 't Hooft Monopoles

Y. M. Cho and P. G. O. Freund

Phys. Rev. D12, 1588 (75)

Study 't Hooft, Wu-Yang type solution for SO(3) coupled to gravity. At large distance get Reissner-Nordstrom. Higgs field can contribute a scalar cosmological term. Get solutions.

G75.CH Theory of Magnetic Monopoles with Non-Abelian Gauge Symmetry

N. H. Christ

Phys. Rev. Lett. 34, 355 (75)

Classical non-Abelian gauge theory.

G75.CO Classical Lumps and their Quantum Descendents

S. Coleman

Lectures at the 1975 Int. School of Subnuclear Phys-Ettore Majorana (Harv. preprint).

Serious topological review of "solitons". Touches on 't Hooft monopoles.

G75.E Colored Magnetic Monopoles

T. Eguchi

Phys. Lett. B59, 73 (75)

Takes Dirac theory to a non-Abelian color, gauge symmetry.

G75.H <u>Exact Magnetic Monopole Solutions in Yang-Mills and Unified Gauge Theories</u>

J. P. Hsu

ORO-3992-223 (1975)

The exact static spherically symmetric solutions of the magnetic monopoles in both Yang-Mills and unified gauge theories are obtained.

Prediction

Production and decay coupling goes as e rather than g.

G75.H1 <u>Magnetic Monopoles and Distorted Gauge Symmetry</u>

J. P. Hsu

Nuovo Cimento Lett. <u>14</u>, 189 (75)

Magnetic monopoles exist in vector-boson theories with intrinsic symmetry break down rather than spontaneously broken symmetry.

Prediction

Possibly mass = M/e^2 (M = vector boson mass)

No strings

†G75.H2 <u>Radial Excitations of the 't Hooft Monopole</u>

P. H. Hampton

UCLA/75/TEP/22 Dec (75)

G75.J <u>Pole with Both Magnetic and Electric Charges in Non-Abelian Gauge Theory</u>

B. Julia and A. Zee

Phys. Rev. <u>D11</u>, 2227 (75)

Generalizes 't Hooft to electric charges to get dyons.

Predictions

Dyon can't decay to monopole plus massive vector meson.

Dyons can capture fermions to become fermionic dyons.

Dyons not much heavier than 't Hooft poles.

G75.K <u>Generalized Magnetic Monopole for the Yang-Mills Field</u>

R. Kerner

Int. J. Theor. Phys. <u>12</u>, 177 (75)

Quantizes charge and hypercharge. Does this by looking at SU(3) after solution and identifying certain quantum numbers with hypercharge.

G75.M <u>Classical SU(3) Gauge Theory and Magnetic Monopoles</u>

W. J. Marciano and Heinz Pagels

Phys. Rev. <u>D12</u>, 1093 (75)

Get a topologically stable solution to pure Yang-Mills SU(3) gauge field equations which corresponds to a point magnetic monopole.

Prediction

M = strength of monopole

$= \frac{\sqrt{3}}{g}$ (g = universal coupling const. of theory)

G75.MO <u>Some Remarks on Monopoles in Gauge Field Theories</u>

M. I. Monastrykti and A. M. Perelemov

ZhETP Pis. Red. <u>21</u>, 94 (74)

JETP Lett. <u>21</u>, 43 (75)

Find a simple necessary condition for the existence of 't Hooft-type solutions in gauge-invariant theories with arbitrary compact group G.

G75.P <u>Extended Particles and Magnetic Charges</u>

A. Patrascioiu

Phys. Rev. <u>D12</u>, 523 (75)

In any gauge theory in three space magnetic charge is shown to have an intrinsic topological nature.

Prediction

A gauge theory based upon SU(n) can have n-1 magnetic charges.

G75.PO <u>Compact Gauge Fields and the Infrared Catastrophe</u>

A. M. Polyakov

Phys. Lett. <u>B59</u>, 82 (75)

Mainly infrared catastrophe rather than monopoles. Draws upon quasi-particle solutions of Maxwell's equation which simply coincide with the Dirac monopole solution.

G75.PR <u>Exact Classical Solution for the 't Hooft Monopole and the Julia-Zee Dyon</u>

M. K. Prasad and C. M. Sommerfield

Phys. Rev. Lett. <u>35</u>, 760 (75)

Gives an exact analytical solution to SU(2) 't Hooft model.

Prediction

Monopole mass is slightly less than 't Hooft estimate. Note that this is a special solution.

†G75.T <u>Gauge Fields with Unified Weak, Electromagnetic, and Strong Interactions</u>

G. 't Hooft

Rapporteur's talk given at Int. Conf. on High Energy Physics, Palermo (75)

G75.TY <u>Existence of Heavy Particles in Gauge Field Theories</u>

Yu. S. Tyupking, V. A. Fateev and A. S.Schwarz

ZhETP Pis. Red. <u>21</u>, 91 (75)

JETP Lett. <u>21</u>, 42 (75).

Sufficient condition for existence of heavy particles in gauge theories with arbitrary, singly connected compact group G.

G75.V <u>Monopoles in a Non-Abelian Gauge Field Theory</u>

G. Venturi

Nuovo Cimento Lett. 14, 233 (75)

Shows that introduction of "magnetic" monopoles in non-Abelian case can proceed in same manner as Abelian case.

G75.W <u>Concept of Non-Integrable Phase Factors and Global Formulation of Gauge Fields</u>

T. T. Wu and C. N. Yang

Phys. Rev. D12, 3845 (75)

This is a generalization of electromagnetism. Dirac monopole case is considered as an example. Monopole types are quite different for SU(2), SO(3) and for electromagnetism.

G76.B <u>Integral Equations for Extended Solutions in Field Theory: Monopoles and Dyons</u>

F. A. Bais and J. R. Primack

Phys. Rev. D13, 819 (76)

Uses integral equations to get solution of nonlinear classical field theories.

G76.B1 <u>Configurations of SO(3) Monopoles with Multiple Magnetic Charge</u>

F. A. Bais

Phys. Lett. 64B, 465 (76)

String singularities discussed in some detail.

G76.BO <u>Calculations of the Monopole Mass in Gauge Theory</u>

E. B. Bogomolny and M. Marinov

Yad. Fiz. <u>23</u>, 676 (76)

Sov. J. Nucl. Phys. <u>23</u>, 355 (76)

Numerically solves for mass and field distribution inside monopole for 't Hooft-Polyakov case using a system of nonlinear differential equations.

G76.B01 <u>Stability of Classical Solutions</u>

E. E. Bogomolny

Landau Institute preprint (76)

Submitted to Yadernaya Fizika (Nov. 75)

(may be Sov. J. Nucl. Phys. <u>24</u>, 861 (76))

Obtains an analytic value for the mass of a monopole based on a stability criterion. Similar in character to Prasad-Sommerfield.

†G76.BOL <u>On the Gauge Field of Magnetic Monopoles</u>

C. G. Bollini and J. J. Giambiagi

Rio De Janeiro, RO—PUC-16 (76)

*G76.BR <u>Dirac Monopole Theory With or Without Strings</u>

R. A. Brandt and J. R. Primack

To be published in Phys. Rev. (Jan '77 expected)

Examines Dirac theory under gauge transformations and shows strings not observable.

G76.C <u>No Monopoles in Weinberg-Salam Theory</u>

J. Cervero

Harvard Theo 76/A175 (76)

A critique of Hsu, Phys. Rev. Lett. <u>36</u>, 646 (76)

Says his conclusion about finding a monopole solution to Weinberg theory is wrong.

*G76.CH <u>Classical Solutions for SU(4) Gauge Fields: Interacting Monopoles</u>

A. Chakrabarti and J. Dipoko

To be published in Phys. Rev. A. (Jan '77 expected).

Review of SU(4) classical gauge solutions.

G76.CHR <u>Canonical Formalism for Gauge Theories with Application to Monopole Solutions</u>

N. H. Christ, A. H. Guth, E. J. Weinberg

Nucl. Phys. <u>B114</u>, 61 (76)

Discusses use of axial gauge for solving classical Yang-Mills theories with 't Hooft type monopole solutions.

G76.CO <u>Can One Dent a Dyon?</u>

S. Coleman and S. Parke

Yale Report COO-30750144 (May '76)

(to be published in Phys. Rev. D - Dec. (76) expected)

Studies non-spherically symmetric solutions a la Julia and Zee to see if they are stable. Proves stability for Prasad-Sommerfield.

G76.COR <u>Magnetic Monopoles in SU(3) Gauge Theories</u>

E. Corrigan, D. I. Olive, D. B. Fairlie, and
J. Nuyts

Nucl. Phys. <u>B106</u>, 475 (76)

An SU(3) gauge theory broken down to U(2) by an octet Higgs vector is considered and two finite-mass stable solutions corresponding to the two ways of embedding SU(2) in SU(3) are found.

Prediction

1, 1/2 Dirac charges appearing

G76.COR1 <u>Color and Magnetic Monopoles</u>

E. Corrigan and D. Olive

Nucl. Phys. <u>B110</u>, 237 (76)

The existence of nontrivial solutions to a condition they set out means that there must be fractionally charged colored particles and magnetic monopoles emanating color magnetic flux.

G76.CR <u>Uniqueness of the 't Hooft-Polyakov Magnetic Monopole Solution</u>

E. Cremmer, F. Schaposnik and J. Scherk

Phys. Lett. <u>65B</u>, 78 (76)

For O(3) gauge theory with a triplet of scalar mesons, show uniqueness of the 't Hooft solution if it is static, finite energy solution and there is separability of radial and angular variables.

G76.D <u>SU(3)/SO(3) Magnetic Monopoles</u>

T. Dereli and L. J. Swank

Yale COO-3075-137 (76)

Introduce SU(3) monopoles.

Find they give Schwinger quantization.

Prediction

$M_{I,II} \approx 3\ M_W/\alpha$

$M_{III} \approx 6\ M_W/\alpha$

G76.E <u>Quantization Condition for 't Hooft Monopoles in Compact Simple Lie Groups</u>

F. Englert and P. Windey

Phys. Rev. D14, 2728 (76)

The quantization conditions for 't Hooft monopoles and for related conserved topological charges are obtained for all compact simple Lie groups. In addition, all possible Dirac monopoles are classified.

G76.EZ <u>Monopoles, Vortices and the Geometry of the Yang-Mills Bundles</u>

Z. F. Ezawa and H. C. Tze

J. Math. Phys. 17, 2228 (76)

A topological classification of monopoles and vortices is formulated in terms of fiber bundles.

Predictions

Some comments about the difference between Dirac and 't Hooft monopoles.

*G76.EZ1 A Theory of Dirac Monopoles with a Non-Abelian Symmetry

Z. F. Ezawa, H. C. Tze

SLAC-PUB-1798 (76)

To be published, Phys. Rev. D (Mar 15, '77)

Lagrangian theory of non-Abelian classical Dirac monopoles that is free of such problems as the "Dirac veto".

G76.F 't Hooft Monopoles and Singular Gauge Transformations

P. H. Frampton

UCLA preprint TEP/12 (76)

States non-Abelian monopoles are not sources and have no attached strings. Also non-Abelian monopoles may terminate dual strings of magnetic flux, but it seems unlikely.

G76.F1 Uniqueness of S-Wave Non-Abelian Magnetic Monopole

P. H. Frampton

Phys. Rev. D14, 528 (76)

Shows the 't Hooft solution for SU(2) is only spherically symmetric solution.

G76.FR Time-Dependent Generalizations of 't Hooft Type Monopoles

K. A. Friedman and M. Kaku

Phys. Rev. D14, 2023 (76)

Gets exact time-dependent solution to Yang-Mills with particle properties. Reduce to monopole solution a la 't Hooft, Julia-Zee when particles at rest.

G76.G The Surface Term in Gauge Theories

J. L. Gervais, B. Sakita and S. Wadia

Phys. Lett. 63B, 55 (76)

Further consideration of 't Hooft-Polyakov model. Obtains Schwinger quantization condition for dyon.

G76.GU Supersymmetric Ansatz for Spontaneously Broken Gauge Field

F. Gürsey

"Gauge Theories and Modern Field Theories", p. 369

Ed. R. Arnowitt and P. Nath (MIT Press, Cambridge, 76)

(in collaboration with L. J. Swank)

Shows that spinors in a gauge theory with Higgs fields based on SU(3) leads to 't Hooft type monopoles which carry fractional electric charge.

G76.H Fermion-Boson Puzzle in a Gauge Theory

P. Hasenfratz and G. 't Hooft

Phys. Rev. Lett. 36, 1119 (1976)

It is argued that magnetic monopoles in an SU(2) gauge theory may bind with an ordinary boson with isospin to give bound states with spin.

G76.HA1 Anomalous Angular Momenta in a Quantized Theory of Monopoles

P. Hasenfratz and D. A. Ross

Nucl. Phys. B108, 462 (76)

Second quantization applied to 't Hooft-Hasenfratz model.

G76.HI <u>Magnetic Monopole Solution in Non-Abelian Gauge Theory</u>

J. Hietarinta, E. Takasugi, and K. Tanaka

C00-1545-185 (76)

Purpose is to get an approximate analytic solution to 't Hooft monopole.

Predictions

Mass of 't Hooft monopole

Form factor of monopole

G76.HO <u>Dyons in Classical SU(3) Gauge Theory and a New Topologically Conserved Quantity</u>

Z. Horvath and L. Palla

Phys. Rev. <u>D14</u>, 1711 (76)

Gets solutions which describe point-like dyons that are the SU(3) generalization of Julia-Lee dyons by extending work of Marciano and Pagels.

G76.HO1 <u>Monopoles, Dyons and Other Topologically Stable Solutions in Gauge Theories</u>

Z. Horvath and L. Palla

ITP 361 March 76

Looks at SU(3) monopoles and dyons in the presence of Higgs scalars.

G76.H02 <u>On the Structure of Generalized Monopole Solutions in Gauge Theories</u>

Z. Horvâth and L. Palla

Roland Eötvös Univ. ITP 362 (76)

Present a method for constructing generalized 't Hooft monopole solutions in a gauge theory with an arbitrary gauge group.

Prediction

Charge quantization spans $g_o \leq kg_o \leq (N-1)g_o$ in SU(N) gauge theories.

G76.H03 <u>Monopoles and Grand Unification Theories</u>

Z. Horvâth and L. Palla

Roland Eötvös University preprint ITP 364 (76)

Shows a method for constructing static extended monopole solutions in grand unification theories.

G76.HS <u>Mixing Angle Theta and Magnetic Monopole in Weinberg's Unified Gauge Theory</u>

J. P. Hsu

Phys. Rev. Lett. <u>36</u>, 646 (76)

Magnetic monopole had been shown to exist in certain gauge theories excluding Weinberg. To circumvent introduces a local unit isovector to substitute for role of 3 Higgs scalars.

Prediction

Value for mixing angle $\sin^2\theta = 1/2$ (Dirac Case).

G76.HS1 <u>Forms of Gauge Fields and Non-integrable Phase Factors</u>

J. P. Hsu

Phys. Rev. Lett. <u>36</u>, 1515 (76)

Shows a connection between magnetic monopoles with quantized strengths and the form of solutions of gauge fields.

G76.HUA <u>Mixing of Internal and Space Time Symmetries</u>

K. Huang and D. R. Stump

Phys. Rev. Lett. <u>37</u>, 545 (76)

Further discussion of angular momentum in systems containing charges and monopoles and a general Yang-Mills system.

G76.I <u>Extended Objects in Gauge Theories</u>

K. Ishikawa

Tohoku Univ. TU/76/141 (76)

Relativistic covariant collective coordinates are applied to gauge theories. Some discussion of an extension of 't Hooft-Julia-Zee, Sommerfield-Prasad models.

Prediction

Some poles in a function that could correspond to monopole-antimonopole bound states.

G76.J Spin from Isospin in a Gauge Theory

R. Jackiw and C. Rebbi

Phys. Rev. Lett. 36, 1116 (76)

In an SU(2) quantum field theory with isospin symmetry broken spontaneously by a triplet of scalar mesons, isospinor degrees of freedom are converted into spin degrees of freedom in the field of a magnetic monopole.

Prediction

Spin from isospin whenever there is an isospin-degenerate classical solution in the field of a monopole.

G76.J1 Solitons with Fermion Number 1/2

R. Jackiw and C. Rebbi

Phys. Rev. D13, 3398 (76)

Adds fermions to the 't Hooft-Polyakov model.

G76.J2 Charge and Mass Spectrum of Quantum Solitons

R. Jackiw

"Gauge Theories and Modern Field Theories"

Ed. R. Arnowitt and P. Nath (MIT Press, Cambridge, 76)

p. 377

After describing one spatial dimension solitons goes on to explore quantum theory associated with Yang-Mills monopole.

Prediction

Charged monopoles are stable.

G76.JA <u>SU(3) Theory of Fermion-Monopole Systems</u>

L. Jacobs

Phys. Rev. <u>D14</u>, 2739 (76)

Extends work of Jackiw and Rebbi. Dirac equations possess an isolated, normalizable solution at exactly zero energy.

G76.K <u>SU(4) and a New Class of Exact, Time-Dependent, Classical Solutions to Gauge Theories</u>

M. Kaku

Phys. Rev. <u>D13</u>, 2881 (76)

Opens a door to new class of SU(4) solutions including 't Hooft monopoles. Related to Wu-Yang solutions.

G76.KI <u>Topology of Cosmic Domains and Strings</u>

T. W. B. Kibble

Imperial College ICTP/75/5 (76)

Principally concerned with symmetry breaking on a cosmic scale.

Prediction

Suggest how density of 't Hooft monopoles in universe could be estimated.

G76.L The Strict Equivalence of the Abelian Monopole and its Non-Abelian Stringless Counterpart by Use of Sections

V. A. Lugo

UCLA/76/TEP/25 (76)

In an SO(3) theory shows Dirac monopole under certain conditions can be properly transformed to global, nonsingular gauge field. For Dirac monopole means 't Hooft solution is equivalent to Abelian monopole.

G76.M Chiral-Charge Conservation and Gauge Fields

W. Marciano and H. Pagels

Phys. Rev. D14, 531 (76)

An example is presented of a gauge field theory with classical dyon solutions which violates anomalous chiral-charge conservation.

G76.M1 Multiply Charged Magnetic Monopoles, SU(3) Pseudoparticles and Gravitational Pseudoparticles

W. Marciano, H. Pagels and Z. Parsa

Rockefeller COO-22323-108 (76)

To be published in Phys. Rev. D (Feb. 15, '77)

Demonstrate how finite energy, unit magnetic monopole of an SU(2) gauge theory generalizes to configurations with multiple magnetic charge when properly embedded in higher rank gauge theories.

G76.MI Static Finite-Energy Solutions of Gauge Fields with Separated, Radial Variable

L. Michel, L. O'Raifeartaigh and K. C. Wali

Syracuse SU - 4210-83 (76)

Examines gauge problem for an arbitrary compact gauge group. Find 't Hooft type solution with unit charge. Higgs fields may belong to an integer representation of this SO(3).

G76.0 Angular Momentum, Magnetic Monopoles and Gauge Theories

D. I. Olive

Nucl. Phys. B113, 413 (76)

Discusses angular momentum of gauge group monopole solutions. Some remarks on possible relation to color.

†G76.OR Gauge and Representation Independent Proof of the Guth-Weinberg Theorem

L. O'Raifeartaigh

Dublin Inst. DIAS-TP-76-36 (76)

G76.P Fermions Made of Bosons-A Surprising Theoretical Construct

Physics News in 1976, p. 38

Jackiw and Rebbi and Hasenfratz and 't Hooft get 1/2 integer spin from integral spin. Goldhaber then showed composite had proper statistics.

G76.PR <u>Solutions of Classical Gauge-Field Theories with Spin and Internal Symmetry</u>

M. K. Prasad and C. M. Sommerfield

Nucl. Phys. <u>B110</u>, 153 (76)

Find for spherical case with degrees of freedom corresponding to spin 1/2 and isospin 1/2 that the solitons are monopoles with eg = 1/2.

G76.S <u>A Power Series Solution of the 't Hooft-Polyakov Monopole</u>

F. A. Schaposnik

Nuovo Cimento Lett. <u>17</u>, 245 (76)

Uses his development to study form factors and mass.

Prediction

Form factors

G76.SC <u>Yang-Mills Particle in 't Hooft's Field</u>

J. Schechter

Phys. Rev. <u>D14</u>, 524 (76)

Looks at Yang-Mills test particle in external field given by 't Hooft's monopole solution.

Prediction

Difference at small distance between 't Hooft monopole and Dirac pole.

G76.SCH <u>Magnetic Monopoles in Gauge Theories</u>

A. S. Schwarz

Nucl. Phys. <u>B112</u>, 358 (76)

The existence of magnetic monopoles is proved in the case of a gauge group with a compact covering group while the covering group of the group of symmetries, not spontaneously broken, is noncompact.

G76.SH <u>The SO(3) Monopole Catalog</u>

R. Shankar

Harvard Preprint (76)

Exploration of monopoly, the study of topologically stable solutions like the 't Hooft-Polyakov monopole.

G76.SH1 <u>More SO(3) Monopoles</u>

R. Shankar

Phys. Rev. <u>D14</u>, 1107 (76)

Enlarges 't Hooft to arbitrary 2n + 1 dimensional irreducible representation of gauge group SO(3).

G76.SI <u>SU(3) Magnetic Monopoles</u>

A. Sinha

Phys. Rev. <u>D14</u>, 2016 (76)

Carries 't Hooft analysis to SU(3)

Predictions

Some monopoles are extended.

Some are 25% lighter than 't Hooft monopole.

Variety of charge quantization conditions.

G76.T <u>Soliton Quantization in Gauge Theories</u>

E. Tombolis and G. Woo

Nucl. Phys. <u>B107</u>, 221 (76)

Study of quantization of an SU(2) Yang-Mills model with a triplet of Higgs scalars. Finds spectrum of charged monopole states.

†G76.TO <u>'t Hooft Monopoles in Larger Gauge Groups</u>

D. Toussaint and F. Wilczek

Print-76-0989 Princeton (76)

G76.TR <u>Monopoles from Dipoles</u>

W. Troost and P. Vinciarelli

CERN preprint TH. 2195 (76)

Monopole-solitons exist in a wide class of theories of vector or spinor fields in interaction with the e.m. field. Non-Abelian gauge theories are only a specific example

Predictions

Spinors give $E \leq (\sqrt{2\pi}/\alpha^2)m_e \approx 43$ GeV.

Vector meson gives $E \approx 10^4$ GeV.

G76.TR1 <u>Spin and Isospin in a Gauge Theory with Monopoles</u>

W. Troost and P. Vinciarelli

Phys. Lett. <u>63B</u>, 453 (76)

Looks at systems of spinless bosons with isospin and spinless magnetic monopoles to see how they acquire spin in SU(2). Find isospin not converted to spin.

G76.TZ <u>Global Signatures of Gauge Invariance: Vortices and Monopoles</u>

H. C. Tze and Z. F. Ezawa

Phys. Rev. <u>D14</u>, 1006 (76)

Gauge theory with an arbitrary compact Lie group.

G76.V Regular Solution of 't Hooft's Magnetic Monopole Model in Curved Space

P. Van Nieuwenhuizen, D. Wilkinson and and M. J. Perry

Phys. Rev. D13, 778 (76)

A regular solution of 't Hooft's magnetic monopole model in curved space is presented.

G76.VE Monopoles and the Higgs Model

G. Venturi

Nuovo Cimento 31A, 79 (76)

Discusses case with very massive gauge fields. Higgs scalar field then confined to the string.

G76.VI Monopoles

P. Vinciarelli

CERN Th. 2246 (76)

Review of paper "Monopoles From Dipoles" in more detail.

Prediction

Several mass predictions including

$E \approx (\sqrt{2}\pi / \alpha^2)\, m_e = 43$ GeV.

G76.W <u>Non-Existence of Spherically Symmetric Monopoles with Multiple Magnetic Charge</u>

E. J. Weinberg and A. H. Guth

Phys. Rev. <u>D14</u>, 1660 (76)

Show that in a spontaneously broken SU(2) gauge theory there are no field configurations with magnetic charge > 1 which are spherically symmetric and of finite energy.

Predictions

Multiple charge probably has higher mass.

Richer spectrum in quantum theory than unit monopole.

G77.C <u>SU(3) Monopoles Saturating the Bogomolny Bound</u>

A. Czechowski

Th. 2282-CERN (77)

Uses Bogomolny approach to show that for each isospin embedding in SU(3) there is only one maximum-symmetry solution saturating the absolute lower bound for monopole energy.

G77.Y <u>Topology of Euclidean Yang-Mills Fields: Instantons and Monopoles</u>

T. Yoneya

CCNY-HEP-77/1 Jan (77)

Generalizes the topology of instantons and monopoles to higher dimensional space. Some of the work parallels R75.Y.

H. THEORY - STRINGS, DUAL MODELS

H72.M Gauge Conditions in Dual Resonance Models

F. Mansouri and Y. Nambu

Phys. Lett. 39B, 375 (72)

The article contains a remark on how magnetic charges might relate to dual resonance picture.

*H73.B Magnetic Charges and Strings as Building Blocks of Hadrons-Connection Between Electromagnetic and Dual Strings

A. O. Barut

Trieste (73)

Starting from a very simple physical model involving magnetic charges, it is shown how one can obtain the internal dynamical properties of hadrons.

H73.N Vortex-Line Models for Dual Strings

H. B. Nielsen and P. Olesen

Nucl. Phys. B61, 45 (73).

Not a monopole paper. Higgs type Lagrangian allows for vortex line solutions in analogy with the vortex lines in a type II superconductor.

H74.B The Electromagnetic String with Spin

A. O. Barut and G. L. Bornzin

Nucl. Phys. B81, 477 (74)

Discusses connection between dual strings and monopole string.

H74.C Higgs Mechanism and Quark Confinement

M. Creutz

Phys. Rev. D10, 2696 (74)

Discuss a recently proposed mechanism for quark confinement obtained by combining the Higgs mechanism for producing massive gauge mesons with the theory of magnetic monopoles.

H74.K Vortex-Line Models for Dual Strings and Magnetic Monopoles

M. Kobayashi

Prog. Theor. Phys. 51, 1636 (74)

Following Nielsen and Olesen uses "magnetic" charges to terminate strings.

H74.N <u>Strings, Monopoles and Gauge Fields</u>

Y. Nambu

Phys. Rev. <u>D10</u>, 4262 (74)

The Nielsen-Olesen interpretation of dual strings as Abrikosov flux lines is extended to the case of open-ended strings by adapting Dirac's description of magnetic monopoles to a London-type theory.

Predictions

No isolated magnetic charges - because of infinite energy.

Relates dual resonance models to Regge trajectories.

H74.T <u>Lines of Quantized Magnetic Flux and the Relativistic String of the Dual Resonance Model of Hadrons</u>

L. J. Tassie

Int. J. Theor. Phys. <u>9</u>, 167 (74)

Identifies relativistic string of the dual resonance model with a line of quantized magnetic flux. Quarks have magnetic charge.

H75.A <u>String Model with Baryons: Topology; Classical Motion</u>

X. Artru

Nucl. Phys. <u>B85</u>, 442 (75)

Mostly a dual-string model but contains a speculation on how to incorporate magnetic monopoles.

Prediction

Some discussion of Regge slopes.

H75.B Monopole Strings and Charmonium

A. P. Balachandran, R. Ramachandran, J. Schechter, K. C. Wali and and H. Rupertsberger

"Theories and Experiments in High Energy Physics" - -Plenum (75)

Model has a force between two monopoles with a vector field acquiring mass.

Gets connection between dual string and Dirac string.

Predictions

Relate potential to Regge slope.

Agreement with charmonium analysis.

H75.D Fermions in Yang-Mills Electric and Magnetic Pole Potentials

T. Dereli, J. H. Swank and L. J. Swank

Phys. Rev. D11, 3541 (75)

Solutions are given for the Dirac equation, with a Yang-Mills magnetic potential and with combined Yang-Mills electric and magnetic pole potentials.

H75.E Triality Monopoles, Hadronic Vortices and the Yang-Mills Connection

Z. F. Ezawa and H. C. Tze

Nucl. Phys B100, 1 (75)

Uses Mandelstam picture which is a non-Abelian extension of Nambu. Idea is to get bolas for hadrons.

H75.F String Approaches to Hadron Structure

P. H. Frampton

Phys. Rev. D12, 538 (75)

Points out some problems with Nambu approach.

H75.H Quantization for Regge Slopes and Psi Particles

A. Hosoya and T. Saito

Prog. Theor. Phys. 54, 237 (75)

Principally a dual string model-monopole involvement only peripheral in sense of Nambu.

H75.J String-like Solution of Higgs Model with Magnetic Monopoles

A. Jevicki and P. I. Senjanovic

Phys. Rev. D11, 860 (75)

Derives a static solution of the equations of motion following from a Higgs-type Lagrangian containing, in addition, static magnetic monopoles representing quarks.

H75.M Vortices and Quark Confinement in Non-Abelian Gauge Theories

S. Mandelstam

Phys. Lett. B53, 476 (75)

Considers Nielsen-Olsen vortices.
Monopoles confined in units of three by Meissner effect.

H75.P Quark Imprisonment and Vacuum Repulsion

G. Parisi

Phys. Rev. D11, 970 (75)

Notes a Lagrangian density with the same features as Higgs equation.

H75.PA On the Landau-Ginzburg Type of Quark Confinement

A. Patkós

Nucl. Phys. B97, 352 (75)

Basically a development of Nambu-like model with "magnetic" monopoles.

H75.S Fermions in Yang-Mills Potentials

J. H. Swank, L. J. Swank and T. Dereli

Phys. Rev. D12, 1096 (75)

't Hooft, Julia-Zee monopoles do not bind to isospinor magnetic monopoles. Shows an infinite energy Yang-Mills solution that does confine wave function.

H75.V Prototype Non-Abelian Gauge Field Theory, Monopoles and Strings

G. Venturi

Nuovo Cimento Lett. 12, 257 (75)

Looks at a string model for two oppositely charged monopoles in a prototype non-Abelian gauge field theory.

†H76.A Monopoles, Duality, Triality

X. Artru (CERN)

CERN-TH-2221 (76).

H76.B Hamiltonian Formulation of Monopole Theories with Strings

A. P. Balachandran, R. Ramachandran, J. Schechter, K. C. Wali and H. Rupertsberger

Phys. Rev. D13, 354 (76)

Considers the Hamiltonian formulation of the theory resulting from Dirac's monopole action supplemented by a mass term for the gauge field.

H76.B1 Strings, Monopoles, and Meson States

A. P. Balachandran, R. Ramachandran, J. Schechter, K. C. Wali and H. Rupertsberger

Phys. Rev. D13, 361 (76)

Dirac's model plus mass term for gauge field to get meson states.

Prediction

Some detail on a magnetic charmonium model.

H76.BR Magnetic Confinement in Non-Abelian-Gauge Field Theory

R. Brout, F. Englert and W. Fischler

Phys. Rev. Lett. 36, 649 (76)

Get a form for Nambu confinement using a classical finite-energy solutions of non-Abelian gauge field theory. They use 't Hooft's result.

†H76.BR1 <u>Flux Line and Monopole Mechanisms of Confinement</u>

R. Brout

76-0913 - Brussels (76)

H76.M <u>Vortices and Quark Confinement in Non-Abelian Gauge Theories</u>

S. Mandelstam

Phys. Reports <u>23C</u>, 245 (76)

Discussion somewhat following Physics Letters article. Suggests an alternate color confinement model.

*H76.MA <u>A Detailed Study of Relativistic Strings</u>

H. Matsumoto, H. Umezawa and N. J. Papastamatiou

Phys. Rev. <u>D14</u>, 3536 (76)

Relativistic vortex analysis. Includes possibility of attaching Dirac monopoles at end of string.

H76.N <u>Magnetic and Electric Confinement of Quarks</u>

Y. Nambu

Phys. Reports <u>23C</u>, 250 (76)

Says faced with two problems in looking at Nielsen-Olsesen model; (1) to get a non-Abelian generalization, (2) quantization. Discusses some problems with magnetic confinement.

H76.P <u>Semistrong Coupling in the Higgs Model</u>

A. Patkós

Nucl. Phys. <u>B112</u>, 333 (76)

Curved flux-tube confinement model using "magnetic" monopoles.

H76.Pl <u>Non-Abelian Vortex-Bond Model of Hadrons</u>

A. Patkós

ITP-Budapest Report 366 (76)

Points out problems of extending magnetic quark confinement to non-Abelian theories.

H76.S <u>Theory of Quark Confinement Based on Analogy with Magnetic Monopole</u>

H. Sugawa

Phys. Rev. <u>D14</u>, 2764 (76)

Nonlocal theory of quark confinement. Theory can be constructed either from confined quarks or magnetic monopoles.

Prediction

Static limit gives potential used by Eichen et al., for charmonium.

H76.W <u>Flux Tubes, Monopoles and the Magnetic Confinement of Quarks</u>

H. W. Wyld and R. T. Cutler

Phys. Rev. <u>D14</u>, 1648 (76)

Numerical study of gauge field model of magnetic confinement.

Prediction

Gives "force" between two monopoles.

I. THEORY - PRODUCTION

*I72.N Topics in High Energy Physics-Approximations in Multiple Scattering Theory and Magnetic Monopole Production

J. L. Newmeyer

Univ. of Virginia, Thesis (72)

Second part of thesis covers magnetic monopole production.

Prediction

Monopole production cross sections for nucleons and photons.

I72.N1 Magnetic Monopole Production by Virtual Photons

J. L. Newmeyer and J. S. Trefil

Phys. Lett. 38B, 524 (72)

Estimates magnetic monopole pair production cross section from virtual internal photons in pp collisions. Based on lunar search set $M_p >$ 100 GeV.

I77.C Field Spin in Charge - Monopole Interactions

W. B. Campbell

Univ. of Nebraska preprint - Apr. (77)

Using D77.C studies charge monopole scattering and pair annihilation into magnetic poles. Suggests he can find regions where perturbation theory holds even though g is large.

Predictions

Elastic scattering amplitudes.

Annihilation cross sections into monopoles with angular distributions.

J. THEORY - SCATTERING

J76.B Scattering on Magnetic Charge

D. G. Boulware, L. S. Brown, R. N. Cahn, S. D. Ellis and C. Lee

Phys. Rev. D14, 2708 (76)

Monopoles in an SO(3) gauge are used to scatter charged particles.

†J76.C Charge-Monopole Scattering: A Covariant Perturbation Theory

W. B. Campbell

76-0354 - Nebraska (76)

J76.K Scattering of a Dirac Particle with Charge Ze by a Fixed Magnetic Monopole

Y. Kazama, C. N. Yang and A. S. Goldhaber

Stony Brook 76/73 (76)

(To be published in Phys. Rev., Apr. '77)

Adds an infinitesimal extra magnetic moment to charged particle. Find helicity flip and helicity non-flip amplitudes.

J76.S Non-Relativistic Dyon-Dyon Scattering

J. Schwinger, K. A. Milton, W-y Tsai,

L. L. Deraad, Jr., and D. C. Clark

Ann. Phys. 101, 451 (76)

Get effects in cross section corresponding to optical effect of the "glory" and rainbows. Gives some consideration to difference of delta rays from monopoles and dyons.

K. EXPERIMENT - DETECTION

K75.P Evidence for Detection of a Moving Magnetic Monopole

P. B. Price, E. K. Shirk, W. Z. Osborne and L. S. Pinsky

Phys. Rev. Lett. 35, 487 (75)

(Designated as PSOP)

Report a monopole candidate with $\beta = 0.5$, $g = 137e$ and mass $> 200m_p$. Flux is 10^{-13} cm^{-2} sec sr - based on all flights.

K76.P Status of the Evidence for a Magnetic Monopole

P. B. Price

"Magnetic Charges and other Fundamental Approaches", A. Perlmutter, Ed., Plenum, N.Y. (76), p. 167

Very thorough review of PSOP in light of critics comments and later experimental data.

K76.P1 Further Studies of the Monopole Candidate

P. B. Price, E. K. Shirk, R. Hagstrom, and W. Z. Osborne

LBL-5355 (76)

Calibration with cosmic rays suggests $\beta > 0.7$ in Lexan but $0.35 \leq \beta \leq 0.58$ in emulsion. Suggest event is monopole, highly charged particle or highly charged anti-particle.

L. EXPERIMENT - SEARCHES

L71.C Upper Limit for Magnetic-Monopole Production by Neutrinos

R. A. Carrigan, Jr. and F. A. Nezrick

Phys. Rev. D3, 56 (71)

Re-evaluation of existing cosmic ray monopole searches to establish neutrino production cross sections. Some discussion of neutral kaon mass difference if kaon is formed from dyons.

L72.B Search for Tachyon Monopoles

D. F. Bartlett and M. D. Lahana

Phys. Rev. D6, 1817 (72)

No tachyon monopoles seen from Co^{60} source. Maximum cross section of 0.6×10^{-36} cm^2 from 1 MeV γ.

L72.BA Search for Magnetic Monopoles at the 70 GeV IPHE Proton Synchrotron

L. M. Barkov, I. I. Gurevich, M. S. Zolotarev, L. A. Makar'ina, V. P. Martem'yanov, A. P. Mishakova, V. V. Ogurtsov, V. S. Okhapkin, M. N. Tarakanov, V. G. Tarasenkov, S. Kh. Khakimov, and L. A. Chernysheva

Proceedings of the XVI International Conference on High Energy Physics. (72), V. 2, p. 336.

$\sigma(95\%) < 1.4 \times 10^{-43}$ at Serpukhov using a ferromagnetic tape.

L72.Z <u>Preliminary Experimental Results on a Search for the Dirac Monopole at the 70 GeV IHEP Synchrotron Using Vavilov--Cherenkov Radiation</u>

V. P. Zrelov, L. Kollarova, D. Kollar, V. P. Lupil'tsev, P. Pavlovic, J. Ruzicka, V. I. Sidorova, M. F. Shabanov, P. Sulek, and R. Janik.

J. D. Jackson, A. Roberts, and R. Donaldson - Ed. Proceedings of the XVI International Conference on High Energy Physics. (72), V. 2, p. 340

See 1974 paper for details

L73.C <u>Search for Magnetic-Monopole Production by 300-GeV Protons</u>

R. A. Carrigan, Jr., F. A. Nezrick, and B. P. Strauss

Phys. Rev. <u>D8</u>, 3717 (73)

Fermilab search.

$\sigma_n(95\%) < 6 \times 10^{-42}$ cm^2 for 1/6 nucleon → 24 Dirac charges.

L73.R <u>Search for Magnetic Monopoles in Lunar Material Using an Electromagnetic Detector</u>

R. R. Ross, P. H. Eberhard, L. W. Alvarez, and R. D. Watt

Phys. Rev. <u>D8</u>, 698 (73)

Set upper limit of 1.7×10^{-4} monopoles/gm in lunar material. Searched about 20 Kg. Used electromagnetic detector.

*L73.Z Preliminary Experimental Results on a Search for the Dirac Monopole at the 70 GeV IHEP Synchrotron Using Vavilov--Cherenkov Radiation

V. P. Zrelov, L. Kollarova, D. Kollar, V. P. Lupil'tsev, P. Pavlovic, J. Ruzicka, V. I. Sidorova, M. F. Shabanov, P. Sulek and R. Janik.

JINR - E1 - 6946 (73)

See 1974 paper

L74.C Extension of Fermi National Accelerator Laboratory Magnetic Monopole Search to 400 GeV

R. A. Carrigan, Jr., F. A. Nezrick, and B. P. Strauss

Phys. Rev. D10, 3867 (74)

$\sigma_{nucleon}$ (95%) = 5×10^{-42} cm^2 on aluminum.

Charge region is 1/30 → 24 Dirac charges.

*L74.Z Search for the Dirac Monopole over the Vavilov-Cherenkov Radiation using the 70 GeV IHEP Proton Synchrotron

V. P. Zrelov, L. Kollarova, D. Kollar, V. P. Lupil'tsev, P. Pavlovich, Ya. Ruzhichka, and V. I. Sidorova

JINR--P1-7996 (74)

Uses special Cherenkov counters.

$\sigma(95\%) < 10^{-40}$ cm^2, $2/3\ g_D < g < 2\ g_D$, $3 < m_g < 5.5 m_p$.

L75.C. Search for Neutrino-Produced Magnetic Monopoles in a Bubble Chamber Exposure

R. A. Carrigan, Jr. and F. A. Nezrick

Nucl. Phys. B91, 279 (75)

No monopole candidates found in rescan of CERN neutrino bubble chamber photographs. Also ruled out photon showers.

L75.E Evidence at the 10^{-18} Probability Level Against the Production of Magnetic Monopoles in Proton Interactions at 300 GeV/c

P. H. Eberhard, R. R. Ross, J. D. Taylor, L. W. Alvarez, and H. Oberlack

Phys. Rev. D11, 3099 (75)

Superconducting electromagnetic detector. 2.5×10^{18} protons on aluminum. Also report ISR (5×10^{10} interactions) and SLAC electron beam exposure. Wide range of magnetic charge covered.

L75.G Search for Magnetic Monopoles at the CERN--ISR with Plastic Detectors

G. Giacomelli, A. M. Rossi, G. Vannini, A. Bussiere, G. Baroni, S. Di Liberto, S. Petrera, and G. Romano

Nuovo Cim. 28A, 21 (75)

Production limit of $\sigma(95\%) < 2 \times 10^{-36}$ cm^2, $m_g < 30$ GeV, $.4\ g_D < g < 2.5\ g_D$.

L76.C <u>Search for Misplaced Magnetic Monopoles</u>

R. A. Carrigan, Jr., P. A. Nezrick, and B. P. Strauss

Phys. Rev. <u>D13</u>, 1823 (76)

Search of air and water to see if PSOP "monopole" might have been trapped in an unlikely place. Get area time factors substantially larger than PSOP.

L76.Q <u>Abundances of Z > 52 Nuclei in Galactic Cosmic Rays: Long-Term Averages Based on Studies of Pallasites</u>

O. Otgonsuren, V. P. Perelygin, S. G. Stetsenko, N. N. Gavrilova, C. Fieeni, P. Pellas

Astrophys. J. <u>210</u>, 258 (76)

Principally a heavy ion experiment. Get an upper limit of 10^{-18} cm^{-2}s sr for flux of monopoles with g $\geq$ 4 in interstellar space.

M. EXPERIMENT - CRITIQUES

M75.A Analysis of a Reported Magnetic Monopole

L. W. Alvarez

LBL--4260 (75)

Criticism of PSOP suggesting event may be a heavy ion undergoing several interactions. Points out that thickness above Cherenkov detector was 0.3 gm/cm^2 lexan equivalent rather than reported 0.7 gm/cm^2.

*M75.A1 Analysis of a Reported Magnetic Monopole

L. W. Alvarez

International Symposium on Lepton and Photon Interactions at High Energies, Stanford (75)

Criticism of PSOP suggesting event may be a heavy ion undergoing several interactions.

M75.F Probabilities for an Alternative Explanation of the Moving Magnetic Monopole

R. L. Fleischer and R. M. Walker

Phys. Rev. Lett. 35, 1412 (75)

Criticism of PSOP. Alternate suggestion of two nuclear interactions. Requires a $\beta \approx 0.7$ to satisfy.

+M75.FO P. H. Fowler

Proc. 14th Inter. Cosmic Ray Conf. - Munich 12, 4049 (75)

An analysis of PSOP event along the lines of Alvarez.

M75.FR Comments on the Reported Observation of a Monopole

M. W. Friedlander

Phys. Rev. Lett. 35, 1167 (75)

Criticism of PSOP. Suggests an interacting nucleus of $Z = 96$ with $\beta \approx 0.7$.

M75.H Comment on the Observation of a Moving Magnetic Monopole

E. V. Hungerford

Phys. Rev. Lett. 35, 1303 (75)

Criticism of PSOP. Shows that kinematically production of pole in atmosphere is not allowed. Further, for pole incident from outside particle must have mass less than 6.6×10^3 GeV/c^2 and be south seeking.

M75.W Kinematic Constraints on the Production of Magnetic Monopoles

L. W. Wilson

Phys. Rev. Lett. 35, 1126 (75)

Criticism of PSOP. Gets a lower limit to laboratory energy for a monopole produced in atmosphere. This energy cannot be reconciled with PSOP.

M76.B <u>Kinematical Constraints on the Observation of Slow Monopoles at the Top of the Atmosphere</u>.

G. D. Badhwar, R. L. Golden, J. L. Lacy, S. A. Stephens, and T. Cleghorn

Phys. Rev. Lett. <u>36</u>, 120 (76)

Shows that kinematically PSOP event could not have resulted from nuclear production and that extraterrestrial origin is unlikely. Also has some comments about galactic field being destroyed if flux this large.

M76.C <u>Relation between Monopole Mass and Primary Monopole Flux</u>

J. M. Cornwall and H. H. Hilton

Phys. Rev. Lett. <u>36</u>, 900 (76)

Points out earth's field is 8,000 GeV - so monopole of less mass would be extremely relativistic.

M77.H <u>Have We Seen a Heavy Antinucleus?</u>

R. Hagstrom

Phys. Rev. Lett. <u>38</u>, 729 (77)

Points out that negative particles are more penetrating. Differences arise mainly because of close collisions. Lexan mainly sensitive to far collisions. He suggests looking for depleted halos in the PSOP event. Says PSOP event is not out of line with other antimatter searches.

N. EXPERIMENT - DETECTION SCHEMES

N65.K Width of Ion and Monopole Tracks in Emulsion

R. Katz and J. J. Butts

Phys. Rev. 137B, 198 (65)

Theory of track widths in emulsion.

N72.S Dispersion Relation for Čerenkov Radiation of Moving Test Particles in a Magnetoplasma

P. K. Suh and W. Erickson

Plasma Phys. 14, 981 (72)

Discusses several different kinds of test particles including magnetic monopoles.

*N73.H Thomas Precession and Motion of Charged Particles

E. Honig

New York Univ., Thesis (73)

Not principally a magnetic monopole paper but does review case for magnetic monopoles.

N74.K Magnetic Monopole Detector

L. Karlsson

Nucl. Instrum. Methods 116, 275 (74)

Reports the design and operation of a real-time electromagnetic monopole detector. Reports one event.

*N75.B <u>Effect of the Non-universality of the Ratio g/e on the Spectrum of a Hydrogen-Like System and Evaluation of the Magnetic Charge</u>

Yu. S. Biza and L. M. Tomil'chik

Vestsi Akad. Navuk BSSR, Ser. Fiz.-Mat. Navuk <u>2</u>, 110 (75)

Examines how much magnetic charge can be added to hydrogen atom within experimental spectroscopy limits.

+N75.C <u>Generating Ultra-low Magnetic Field Regions with Superconducting Shields and their Use with a Sensitive Magnetic Charge Detector</u>

B. Cabera

Low Temperature Physics, Vol. IV, M. Krusins and M. Vurio, Ed. (North-Holland- 1975).

N75.E <u>Are Monopoles Trapped by Ferromagnetic Material</u>?

P. H. Eberhard and R. R. Ross

LBL-4614 (75) (Sub. to Nucl. Phys. B)

Reviews arguments of binding of monopoles to ferromagnetic material and concludes they are plausible.

N75.E1 <u>Improvements of a Magnetic Monopole Detector</u>

P. H. Eberhard, R. R. Ross and J. D. Taylor

Rev. Sci. Instrum. <u>46</u>, 362 (75)

Describes addition of SQUID magnetometer to Berkeley electromagnetic monopole detector.

N75.G <u>Monopole Searches at Isabelle</u>

G. Giacomelli and A. Thorndike

Proceedings of the 1975 Isabelle Summer Study, July 14-25, 1975. Volume II.

Contains a discussion of possible monopole search experiments that could be carried out at the Isabelle storage rings.

N75.H <u>Practicable Discrimination of Rapidly Moving Electric and Magnetic Charges</u>

R. Hagstrom

Phys. Rev. Lett. <u>35</u>, 1677 (75)

Suggests that magnetic monopoles can be distinguished from large electric charges in emulsion stacks by incorporating a polarizing layer to distinguish the relatively different polarizations of the Čerenkov light.

+N76.A <u>Monopole Track Characteristics in Plastic Detectors</u>

S. P. Ahlen

Phys. Rev. <u>D14</u>, 2935 (76)

Review of energy loss mechanism for monopoles.

N76.B <u>Magnetic Charge and Hyperfine Splitting in Hydrogen</u>

A. O. Barut

Phys. Lett. <u>63B</u>, 73 (76)

Critique of article by Opat. Points out that spatial extent of Dyon is much larger than Bohr radius of dyonium.

Prediction

No hyperfine splitting and/or too small to be observable.

N76.K <u>Interaction of a Magnetic Monopole with a Ferromagnetic Domain</u>

C. Kittel and A. Manoliu

Phys. Rev. <u>B15</u>, 333 (77)

Uses ferromagnetic exchange interaction. Gets binding energies of 35 eV in magnetite at 400 Å, 50 eV in iron at 300 Å.

N76.O <u>Limits Placed on the Existence of Magnetic Charge in the Proton by the Ground State Hyperfine Splitting of Hydrogen</u>

G. I. Opat

Phys. Lett. <u>60B</u>, 205 (76)

Gives an experimental prediction about magnetic hyperfine splitting. If nucleus contains magnetic constituents shows that hyperfine splitting is consistent with zero magnetic dipole (dipole separation $< 4 \times 10^{-9}$ Fermi)

Prediction

$$E = \frac{2}{3} (1 - \frac{3}{2} \delta) \vec{\mu}_I \cdot \vec{\mu}_J |\psi(o)|^2$$

= fraction of proton magnetic moment due to separated magnetic charges.

N76.S Magnetic Monopole and Charged Particle Ionization Cross Sections

R. Snyder

Am. J. Phys. 44, 1181 (76)

Simple derivation to show why magnetic monopole ionization cross sections are constant independent of energy.

*N76.W Occurrence of Ultrastrong Magnetic Fields in Nuclear Shock Waves

F. Winterberg

Z. Naturforsch A31, 498 (76)

Suggests transient magnetic fields up to 10^{18} gauss may be present in fast heavy nuclei collisions resulting in monopole production.

P. EXPERIMENT - LARGE SCALE EFFECTS

P72.H <u>Accretion Vortices and X-Ray Sources</u>

R. N. Henriksen, and T. T. Chia

Nature- Phys. Sci. <u>240</u>, 133 (72)

Discusses magnetized stars. Does not suggest how proposed monopole strength is introduced.

*P72.W <u>Why Does the Sun Sometimes Look Like a Magnetic Monopole</u>

J. M. Wilcox

Comments Astrophys. Space Phys. <u>4</u>, 141 (72)

Reviews puzzling observation of an apparent solar magnetic monopole in 1965.

*P74.H <u>Studies of Solar Magnetic Fields</u>

<u>I. The Average Field Strengths</u>

R. Howard

Solar Phys. <u>38</u>, 283 (74)

Solar magnetic field study. There is sometimes an apparent solar magnetic monopole but apparently there are many explanations.

*P74.S <u>Magnetic Fine Structure and the Solar Magnetic Monopole</u>

C. Sawyer

Solar Phys. <u>35</u>, 37 (74)

Suggests ways to gain more information on sun's possible monopole field.

*P74.ST On the Solar Magnetic "Monopole"

M. Stix and E. Wiehr

Solar Phys. 37, 493 (74)

Suggests sun's solar magnetic monopole caused by instrumentation effects.

*P75.L Representation of Magnetic Field Lines from Magnetograph Data

R. H. Levine

Sol. Phys. 44, 365 (75)

Information on the Sun's magnetic field.

P75.T Orion-Arm Magnetic Monopoles and Gamma Rays

D. R. Tompkins, Jr. and P. F. Rodney

Phys. Rev., D12, 2610 (75)

Studies interaction of cosmic magnetic monopoles with nearby galactic field.

P76.A Magnetic Monopoles and Cosmology

P. J. Adams, V. Canuto and H. Y. Chiu

Phys. Lett. 61B, 397 (76)

An annihilation rate calculation in terms of a cosmological picture.

P76.B <u>Theoretical Limits on Interstellar Magnetic Poles Set by Nearby Magnetic Fields</u>

S. A. Bludman and M. A. Ruderman

Phys. Rev. Lett. 36, 840 (76)

Discusses limitations on cosmic monopole flux due to interstellar magnetic fields. Also discusses kinematic constraints. Finally proposes that magnetic monopoles attached to dust grains could effectively have large masses.

P76.K <u>Pulsars and Magnetic Monopoles</u>

G. Kalman and D. Ter Haar

Nature 259, 467 (76)

Considers the effect of monopoles on persistence of pulsar fields. Not able to set significant upper limits on flux.

+P76.M <u>Gyro-Synchrotron Radiation in a Magnetic Monopole as a Source of Solar Microwave Bursts</u>

C. Maetzler

Z. Angew. Math. Phys. 27, 137 (76)

Q. EXPERIMENT - GAMMA RAY EVENTS

Q69.R Magnetic Poles and Energetic Photon Showers in Cosmic Rays

M. A. Ruderman and D. Zwanziger

Phys. Rev. Letters 22, 146 (69)

Model of pole-antipole de-excitation and annihilation.

Q73.C Unexplained Multiphoton Phenomenon

G. B. Collins, J. R. Ficenec, D. M. Stevens, W. P. Trower and J. Fischer

Phys. Rev. D8, 982 (73)

Review of some old cosmic-ray emulsion data on photon shower events. Most interesting feature is lack of incident charged particles. Monopoles not mentioned in article but Ruderman-Zwanziger paper is cited.

Q73.Y Search for High Energy Multigamma Events at the ISR

L. C. L. Yuan, G. F. Dell, H. Uto, E. Amaldi, M. Beneventano, B. Borgia, P. Pistilli, I. Sestilli, and J. P. Dooher

Experiments on High Energy Particle Collisons-1973

R. S. Panvini, Ed. AIP Conf. Proc. 12 (73)

ISR experiment searching for multigamma events. States high multiplicity gammas are several orders of magnitude higher than anticipated π^0 background.

Q75.B <u>Search for Anomalous Multiphoton Production at 100-300 GeV</u>

D. L. Burke, H. R. Gustafson, L. W. Jones and M. L. Longo

Phys. Lett. <u>B60</u>, 113 (75)

Cross section of 2.7 μb in neutron collisions for Schein type events or 0.01 of cosmic cross section.

Q76.D <u>An Investigation of High Multiplicity Gamma Events in pp Collisions with C. M. Energies Between 22 and 62 GeV</u>

G. F. Dell, H. Uto, L. C. L. Yuan, E. Amaldi, M. Beneventano, B. Borgia, P. Pistilli, I. Sestili and J. Dooher

Nuovo Cimento Lett. <u>15</u>, 269 (76)

Shows a substantial enhancement of large angle, high multiplicity gammas relative to an uncorrelated model.

Q76.S <u>Search for Multiphoton Events from Proton-Nuclei Interactions at 300 GeV/c</u>

D. M. Stevens, G. B. Collins, J. R. Ficenec, W. P. Trower, J. Fischer and S. Iwata.

Phys. Rev. <u>D14</u>, 2207 (76)

Have attempted to rediscover the old cosmic-ray events independent of interpretation. Some odd multiphoton events found at level of 10^{-7} per proton interaction.

R. Monopole Reviews

R63.A Search for Dirac Magnetic Poles

E. Amaldi, G. Baroni, H. Bradner, H. G. de Carvalho, L. Hoffmann, A. Manfredini, and G. Vanderhaeghe

CERN 63-13 (1963)

One of the best reviews ever made of the monopole conjecture.

*R72.S Aspects of Quantum Theory

E. Amaldi and N. Cabibbo

A. Salam and E. P. Wigner - Ed. Cambridge University Press (72)

A memorial volume to Dirac including some personal reminiscences and a bibliography. One chapter by Amaldi and Cabibbo deals with magnetic monopoles.

R73.S Magnetic Monopoles: An Updated Bibliography

D. M. Stevens

VPI-EPP-73-5 (Oct. 15, 73)

Fine annotated bibliography to 1973 with cross reference on names.

R73.ST Current State of the Dirac Monopole Problem

V. I. Strazhev, and L. M. Tomil'chik

Fiz. El. Chast. Atom. Yad. 4, 187 (73)

Sov. J. Particles Nucl. 4, 78 (73)

Good review, particularly for theory, with extensive bibliography up to 1972.

*R73.V <u>Magnetism of Microparticles</u>

S. V. Vonsovskii

Izdatel'Stvo Nauka Glavnaya Redaktsiya

Fiziko-Matematicheskoi Literatury, 281 (73)

A review of magnetic properties of particles, nuclei, and atoms. Includes discussion of the monopole conjecture.

*R74.W <u>Magnetic Monopoles</u>

R. Wadas

Postepy Fiz. <u>25</u>, 289 (74)

Short review of magnetic monopoles.

*R75.B <u>The Physics of Magnetic Monopoles. A Contribution to the Magnetic Model of Matter</u>

A. O. Barut

Phys. Bl. <u>31</u>, 352 (75)

General review of Barut's position on magnetic monopoles.

R75.C <u>Quest for the Magnetic Monopole</u>

R. A. Carrigan, Jr.

Phys. Teach. <u>13</u>, 391 (75)

A brief review of the properties of the magnetic monopole and of the experimental efforts to detect it.

R75.E Status of Searches for Magnetic Monopoles

P. Eberhard

LBL 4829 (75)

Review of PSOP event and problem of reconciling with existing cosmic searches.

R75.J Classical Electrodynamics

J. D. Jackson

Wiley - N.Y. (75) - Second Edition. Sec. 6.13.

Contains an excellent introduction to the monopole conjecture.

*R75.P The First Magnetic Monopole

P. Perrier

Recherche 6, 965 (75)

Short review of PSOP experiment.

*R75.V Continuing the Monopole Story

V. S. Venkatavaradan

Phys. News 6, 164 (75)

Short note on monopoles.

R75.Y Gauge Fields

C. N. Yang

Proceedings of the Sixth Hawaii Topical Conference in Particle Physics - Dobson et al., Ed.

Hawaii (75), p. 487.

Review of Wu-Yang development of non-quantized gauge fields including developments on magnetic monopoles.

*R76.C The Elusive Monopole

T. Chakraborty

Sci. Rep. 13, 72 (76)

General review of magnetic monopole including PSOP event.

R76.P Magnetic Charges and Other Fundamental Approaches

A. Perlmutter, Ed.

Plenum, New York (76)

The significant monopole articles have been separately listed in this bibliography.

R76.R Experimental Searches for Magnetic Monopoles

R. R. Ross

"Magnetic Charge and Other Fundamental Approaches"

A. Perlumutter - Ed., Plenum (76), p. 151.

A review of the relation of the PSOP event to other cosmic searches.

R76.S Magnetic Charge

J. Schwinger

"Gauge Theory and Modern Field Theory",

R. Arnowitt and P. Nath, Ed. MIT Press (75), p. 388.

Nice review of Schwinger quantization and e, g symmetry. Also includes a rather complete discussion of Dyon energy loss.

S. GENERAL REVIEWS - HYPOTHETICAL PARTICLES

*S72.A Present Position and Future Prospects for the Discovery of New Particles
R. K. Adair
Proceedings of the XVI International Conference on High Energy Physics
Review of particle searches including monopoles.

*S72.R Status Report on Elusive Particles
P. V. Ramana Murthy
Conf-721232--P 187 (72)
Review of particle searches including upper limits as of 1972.

*S73.B Unfound Particles
O. M. Bilaniuk and J. R. Boccio
Recherche 4, 1037 (73)
Short review of unfound particles including monopoles.

*S75.A Missing Particles: Lepton and Hadron Structure
R. K. Adair
International School of Subnuclear Physics, V12
A. Zichichi, Ed, Academic Press Inc., (75)
Review of particle searches in some detail.

S75.G <u>Hypothetical Particles</u>

A. S. Goldhaber and J. Smith

Rep. Prog. Phys. <u>38</u>, 731 (75)

Contains a bibliography of works on dyons. Concise description of monopole problem as of December 1974. Particularly good bird's eye view of theory.

S76.L <u>My Perspectives on Particle Physics Summary of Orbis</u>

Scientiae, 1976

B. W. Lee

New Pathways in High Energy Physics, VII - Plenum (76), p. 359.

A review of contemporary theory touching on magnetic monopoles. Short, but interesting remark on charge quantization.

T. RELATED TOPICS

T69.W Some Solutions of the Classical Isotopic Gauge Field Equations

T. T. Wu and C. N. Yang

"Properties of Matter under Unusual Conditions"

H. Mark and S. Fernbac, Ed - Interscience (69), p. 349.

Not stated to be a monopole picture.

T70.Y Charge Quantization, Compactness of the Gauge Group, and Flux Quantization

C. N. Yang

Phys. Rev. D1, 2360 (70)

Not a monopole paper.

Shows group with quantized charge must be compact.

T72.K Detection of Energetic Heavy Ions

R. Katz, S. C. Sharma and M. Homayoonfar

Nucl. Instrum. Methods 100, 13 (72)

Not a monopole paper.

T74.H Experimental Test for the Origin of CP Non-Invariance and Neutral Kaon Charge

J. P. Hsu

Phys. Rev. D10, 3836 (74)

Not a monopole paper.

Predicts a long-range force between neutral strange hadrons.

T75.C <u>Quantum Sine-Gordon Equation as the Massive Thirring Model</u>

S. Coleman

Phys. Rev. <u>D11</u>, 2088 (75)

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