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ABSTRACT

The theory of magnetic monopoles and its importance for Big Bang Cosmology and Grand Unification Theory are reviewed. Although indications existed that Blas Cabrera detected evidence of magnetic monopoles at Stanford in 1982, all efforts to replicate his research have so far failed. Currently no valid explanation exists as to why this important plank in Big Bang Cosmology has not been experimentally verified in spite of over a decade of sophisticated experiments. This area is a major "missing link" which argues against the evolution of matter and the four forces, and also the current big bang world view. The history of the efforts to detect magnetic monopoles are reviewed, and the reasons behind their need for big bang cosmology was discussed.

INTRODUCTION

The origin of life is postulated by the modern science establishment to have occurred by evolutionary naturalism from hypothetical "simple" one organelle animals to the complex 100-trillion-celled human beings in about 3.5 billion years. Likewise in physics, naturalism postulates that a single force and very few or even one elementary particle have developed into all of the enormous complexity existing all around us [25]. The four forces which are observed today-gravity, the strong and weak nuclear forces, and electromagnetism--are all hypothesized to have developed from one single force due to the dissipation of the heat and pressure caused by the big bang expansion. This theory is called the *grand unification theory* (GUT).

A super heavy magnetic monopole is inextricably linked to the GUT theory and thus "any true GUT necessarily implies magnetic monopoles that formed very early in the universe's history" [14, p.84]. In Taubes words, the GUT theory "positively demanded the existence of monopoles" [32, p.48]. Von Baeyer puts it as follows: "GUTs have unequivocally predicted the existence of monopoles" [33, p.3]. For this reason:

> Most hypothetical particles, such as quarks, wimps, winos and technipions, may be loved by their mothers but are easy for the rest of us to shrug off. Given that magnetic monopoles *must* exist according to theories unifying the four fundamental forces--grand unified theories, or GUTS--they are less easy to ignore [12, p.706, emphasis mine].

The GUT theory postulates that when the symmetry of the original unified force was lost, it was broken into at least four separate, disparate forces:

In the late 1970s, the Soviet theorist Sasha Polyakov (now at Princeton) proved that creation of these exotic particles *must* occur whenever any unified force breaks down to the electromagnetic force (as well as other forces). Just as the GUTs breakdown was producing baryons and generating a tiny excess of matter, therefore, it should also have created a comparable number of these ultraheavy particles, over a million billion times more massive than a proton, which possess the magnetic characteristics of a single north or south pole [27, p.162].

For this reason, although "physicists have been intrigued by magnetic monopoles for more than a century, interest in them has risen to new heights in the past decade" [33, p.2]. Their confirmation would "be the discovery of the century" because the "quest has high theoretical stakes for particle physics and cosmologists" [30; 31, p.625; 1; 2; 26; 8, p.118; 9]. Since magnetic monopoles are hypothesized to be a stable particle, if big bang evolution occurred, many would still be existing today. The number of magnetic monopoles estimated to exist varies, depending on the theory. In Krauss' words, when the "GUT symmetry breaks down into the separate strong and 'electro weak' theories, many monopoles should be produced. So many, in fact, that they would easily close the universe today [by gravity collapse]. The problem becomes not one of how to produce a single monopole, but rather how to get rid of so many" [22, p.246]. Preskill argued in 1979 that in the universe there should be one per proton, others conclude that as few as one per 10^{15} protons exist [8, p.116]. At one time huge numbers were postulated by many researchers -- as many as to account for "most of the mass of the universe--but now that no evidence of them has been produced, estimates have been drastically lowered [33, p.3].

Much of the work on magnetic monopoles is connected with the development of grand unification theories. The big bang theory hypothesizes that, although the strong and weak forces and electromagnetism all have very different strengths and properties at cold temperatures, they converge as temperatures and pressures approach the enormous levels hypothesized to have existed in the early micro-seconds of the big bang. All three were melted together as a single force in the intense heat that existed then until cooling separated them. Grard 't Hooft of the University of Utrecht and Alexander M. Polyakov of the Landau Institute for Theoretical Physics near Moscow, "demonstrated not only that a monopole solution of the classical equations governing these theories existed, but that any unified theory that breaks down to the standard model at low energies must result in magnetic monopoles" [22, p.245]. Their theory "demands" heavy monopoles to describe three of the four known forces of nature.

A super heavy monopole ($>10^{16}$ GeV/c^2) is crucial to the GUT theory because events that have been confirmed to occur in particle accelerators reveal some of the details that must have occurred in early big bang evolution had it occurred [3, p.839]. Magnetic monopoles themselves probably cannot be produced in a particle accelerator because about ten-trillion times the energy released from the current most powerful accelerators is required--the now defunct superconducting super collider would have produced only 10^4 GeV Although it is now estimated that, given the validity of GUT theory, pressure levels speculated to exist in a black hole provide enough force.

The theory received an enormous boost when Sheldon Glashow, Stephen Weinberg, and Abdus Salam reportedly achieved "unification" of the weak nuclear and electromagnetic force (called electroweak force), a feat for which they shared the Nobel Prize in physics. The next step in proving the GUT theory is a unification theory that includes the electroweak and the nuclear or color force [5].

The Theory of Magnetic Monopoles

A magnetic monopole is a particle with a charge system that has only one magnetic pole as opposed to the normal two, often called north and south poles. The theory requires that they have a large charge and therefore a rapidly moving monopole would ionize atoms far more rapidly than electrons. This property is the basis of many detectors set up to measure them. The magnetic field poles are the source of the magnetic field just as electrons and protons are the source of the electrical field [15]. A magnetic monopole is comparable to an electron which has only one unit of charge (a negative charge) or a proton which carries the other charge (a positive unit), each which is 1.6 x 10^{-19} coulomb. The isolation of "electric poles but not magnetic ones is a fundamental distinction between electricity and magnetism" [8, p.106]. Monopoles are theorized to be a concentrated point of enormous mass, about a million-billion times more massive than a proton and about one ten-trillionth of its size [27, p.162]. Krauss estimates that monopoles weigh as much as 10^{16} times the proton, or about one-billionth of a gram [22, p.245]. The heaviest particles so far discovered, the W^+, W^- and Z^0 particles, are only about thirty to one-hundred times more massive than a proton (and a proton is about 1,800 times more massive than an electron). A large mass is predicted because particles produced in the early big bang would come from the enormous energy existing then, and the more energy used to produce a particle, the more massive it becomes [12].

The original speculation about the existence of magnetic monopoles is based on our understanding of electricity, specifically electric dipoles [33]. If a metal bar that is positively charged on one half and negatively charged on the other was cut in half, one half would have an excess of positive charges and the other half a negative charge excess. At the atomic level, protons carry the positive charge, electrons the negative. Observation reveals that if a magnet is cut in half, each of the two new magnets always has both a north and a south pole. This process can continue until the magnet is separated into its elementary spins consisting of the protons, neutrons and electrons--and each *complete* atom functions as a magnetic dipole. A magnetic monopole is where a single particle functions as either a north or south pole.

In classical and later in quantum electrodynamics, "magnetism has been described as a byproduct of the motion of an electric charge" [15, p.674]. A magnetic field can, the monopole theory predicts, arise not only from an electric current, but also from the presence of a magnetic monopole. In 1931, physicist Paul Adrien Maurice Dirac noted that the theory of quantum mechanics indicated that the existence of a single magnetic monopole would both restore complete symmetry between electric and magnetic charges as required in Maxwell's equation, and would also help explain how electric charges existed in integer multiples of a fundamental charge [11; 22, p.245]. In his words, "the mathematics led inexorably to the monopole" [25, p.287]. The electric charge of an electron is exactly equal and opposite to that of a proton--and this consistency persuasively argues that all electrical charges exist as separate units (thus excluding quarks which exist as ±1/3, ±2/3) and are integer multiples of the basic electron charge.

Quantum mechanics and relativity also predict the magnetic monopole force [26]. Since every particle of matter, including the magnetic monopole, must have an antimatter counterpart," an antimonopole could be *either* north or south polarity in contrast to a dipole magnet, which has both north and south in a single unit [8, p.108]. When a monopole collides with a dipole of the opposite pole, an estimated one megawatt is released--an incredible amount of energy for such a small particle. Because of its huge mass, though, magnetic monopole cosmic rays would normally travel right through the earth because "its interactions with light atoms would not be sufficiently strong to impede its motion" [22, p.245]. It would, in Krauss' words, "be like trying to stop a Mack truck by throwing popcorn at it."

Detection Systems

To detect monopoles, Cabrera used a superconducting quantum interference device (SQUBD) ring connected to a low noise sensor which monitors the persistent current in the ring [20, p.835]. Magnetic monopoles must effect electric fields as they pass by them and if a monopole passes through the SQUIID loop, a DC surge of current will occur. The minimal Dirac charge monopole passing through the loop is determined by Gauss's theorem, or $4\pi g/L$ which is $4.4.\text{xlO}^{-15}/L$ for each monopole [17]. The signature of a monopole's passage through an isolate loop should be a current change of an integral multiple of $2\phi_0$ where ϕ_0 = hc/2e [17, p.338]. Cabrera's monopole signature was expected to produce a current transition equivalent to a flux change of $8\phi_0$ [17, p.339]. This produces a small magnetic field that is difficult to detect partly because of interference, thus a magnetic sensitivity one million times above the earth's one gauss (10^{-4} tesla) magnetic field is necessary. After the monopole has left the ring region, the current change is sustained in a SQUID system [20, p.835].

If a substance that could harbor magnetic monopoles is repeatedly passed through the SQUDD loop, the current it induces would increase incrementally, allowing detection of even single monopoles. This principle, discovered by Michael Faraday, forms the basis of all generators and alternators when a magnet is moved up or down inside a coil of wire, it induces an electric field in it. The same effect would also occur if cosmic ray monopoles passed through the detector. A SQUID unit is incredibly sensitive to magnetic fields, and can detect the hypothesized magnetic molecules moving at a wide variety of velocifies--a necessary feature since the velocity that cosmic ray monopoles travel is estimated at one-one-thousandth of the speed of light [12, p.706]. Superconductivity detectors also must incorporate superconducting shields to attenuate ambient magnetic fields [20, p.835]. Cabrera's newer shield is a lead sheeting 0.8 mm thick which surrounds the detector at a radius of 25 cm, with yet another shield around it [4; 20, p.835].

The IBM detector has "six independent planar detector coils, each connected to its own SQUID to differentiate between true and spurious signals" [3, p.839]. A magnetic monopole, according to the theory, will excite two and only two of the six coils, but other cosmic ray types will excite all six coils. Cabrera's unit functions as follows: an electric current injected into the ring can circle "forever" due to its superconductivity, thus an electrical surge caused by a monopole would persist and can easily be detected [4]. Measuring the magnitute of the current can "enable us to deduce the strength of the monopole long after the particle had disappeared into the laboratory floor" [33, p.4]. Usually niobium-titanium ribbon is used because it Kold Welds very effectively, reducing the likelihood of weld flaws, a major problem in making super-conducting magnets. When a cosmic ray or other magnetic monopole source travels through the loop, its field will interact with the loop current, creating a turbulence that effects the total superconductor loop current level.

Another detection method is the use of a photographic emulsion plate which chemically changes in response to electrically charged particles. A monopole would in theory be easy to detect because it ionizes atoms 10,000 times more effectively than electrons, thus would produce a track thousands of times darker [8, p.108]. On the Earth, they are theorized to have been pulled toward the Earth's center due to their density, the north monopoles collecting near the south geomagnetic pole, and the south near the north geomagnetic pole. The reversal of the earth's magnetic field would cause them to migrate to opposite poles, causing annihilation of those that come too close together during their migration. Research has also indicated other detectors are feasible [13].

The History of the Search

The half-century search for magnetic monopoles has involved evaluating virtually every conceivable possible source, including moon rock, the bottom of sea beds, the upper atmosphere, iron ore, flakes of mica, and the debris from high-energy particle collisions. All of these efforts have failed to find any confirming evidence [31, p.625]. On St. Valentine's Day in 1982, Blas Cabrera of Stanford in a carefully designed experiment produced the best candidate yet-but in spite of "an enormous increase in collection time and area for such detectors," his experiment has never been successfully duplicated and was later formally retracted [15, p.675; 33; 4; 5]. Cabrera concluded that his monopole coordinates were due to "mutual interference between SQUID'S, coupled through adjacent pick-up coils" and "none have occurred since we carefully adjusted the rf excitation frequency for each SQUID to avoid mutual resonances" [20, p.836-837]. All of the other putative candidates have now been ruled out [7, p.463; 18, p.463].

The Stanford detector had, as of 1990, 6,482 hours with "no candidate events" and would have seen 2,000 events by now had Cabrera's single event been real [12, p.706]. The IBM-BNL detector has as of 1990 logged 13,410 hours without experiencing a single candidate event. Researchers have also attempted to detect evidence for monopoles among both terrestrial and extraterrestrial iron atoms and the byproduct of collisions between cosmic rays atmospheric atoms, especially nitrogen, oxygen and carbon.

The most recent effort to find monopoles have not been small. One of the most ambitious projects is the Monopole, Astrophysics and Cosmic Ray Observatory (MACRO) at Italy's Gran Sasso National Laboratory, about sixty miles east of Rome [34, p.219). This huge 20-million dollar monopole detector is 2,000 times larger than Cabrera's unit--it stretches nearly the length of a football field--and lies beneath the Apennine mountain range [30, p.625]. The approximately 15,00OM^2 5m thick detector consists of alternating layers of concrete and iron to screen out unwanted particles, plus tons of clear mineral oil. In the mineral oil are fluorescent compounds which, if struck by passing monopoles, causes a trail of decaying protons which produce photons, and these discernible flashes of light are picked up by liquid scintillation counters [25, p.297]. Two other detectors are also used, one in which the monopoles cause a burst of ionized helium in plastic streamer tubes, and another which consists of a trail of cracks in plastic called a *track etch detector* [31, p.625]. The redundancy is designed to insure that spurious detections can be factored out of the data. If magnetic monopoles exist, the researchers feel that this project they has an excellent chance of finding them within five years. So far, none have been detected, prompting Von Baeyer to state the search has produced "overwhelming negative evidence" for monopoles [33, p.3].

Many physicists today are now pesimistic that evidence will ever be found because, in spite of the best designed experiments and over sixty years of searching, no clear evidence that the hypothesized super heavy monopoles exist has ever been uncovered. Even if they consisted of a relatively small percent of the particles in the universe, they would still play a significant part in physics, ranging from influencing the galaxy's magnetic fields to the interior of neutron stars. Under certain conditions, monopoles are theorized to destroy protons, releasing much energy. Consequently, they are hypothesized to play a pivotal role in detemiining the temperature of both stellar and planetary cores.

Monopoles and the Big Bang

Monopoles are theorized to have formed specifically during the second stage of the big bang, at about 10^{-35} seconds after the start of the cosmic egg's expansion [3, p.839]. The first stage produced the original cosmic egg that is theorized to have came into existence then, or had already existed. This atom sized super hot microcosmos then cooled from its high of 10^{27}K, forming monopoles at the time of the GUT spontaneous-symmetry breaking [3, p.839]. Continued expansion caused continued cooling, reaching a critical value which resulted in a second explosion that occurred as a result of a phase change from gas to liquid, a process which releases enormous energy. Specifically, the space-time fabric is hypothesized to have liquefied at this time, releasing energy which caused the reheating phase, and consequently "inflated" the universe by about 10^{50} times. Called the **inflationary model**, this view concludes that this expansion stage is still occurring. The inflationary model is a modified big bang theory, and certain aspects of it compete with the standard big bang scenario. The theory's leading proponent and inspiration was NUT's Allen Guth.

According to this model, the early phase transitions that occurred with symmetry breaking produced a number of effects, "foremost among them the *magnetic nonopole*" [29, p.123-124]. A third expansion was then produced from a second phase change, this time from liquid to solid, again releasing enormous amounts of energy. This energy is theorized to have produced the range of subatomic particles existing today. This model predicts that the number of monopoles produced depends exponentially on the reheating energy existing at this time [20].

Since monopoles are hypothesized to be very massive, they could be produced only at extremely high energies. It was during the grand-unification phase of the big bang, shortly after Planck time, about 10^{-35} seconds after the big bang began, that their development is theorized to have occur-red. Topological defects concluded to have formed between different regions of spacetime would produce the magnetic monopoles [32]. Specifically, the energy in the universe per unit area dropped after the symmetry broke and the monopoles and anti-monopoles would have annihilated each other, leaving behind those monopoles that "failed to find a partner" [29, p.124].

The magnetic monopoles are also theorized to account for "anywhere between three percent and one-hundred percent of the dark matter in the universe, depending upon how many we find and how heavy they are" [31, p.625]. This should help explain the "large" amount of "invisible and so far inexplicable-mass" [31, p.625]. Magnetic monopoles would be a perfect candidate-they contain a huge amount of mass, and it is theorized that huge numbers of them existed, at least early in the universe's evolution. Cabrera noted that the missing mass density estimate of 0.05 solar masses per cubic parsec "is in good agreement with the halo mass estimates extrapolated back to our local galactic radius" and assuming the entire hidden mass "is made up of monopoles of mass 10^{16} GeV/C^2 with isotropic velocities of over 3OOkm/sec, as suggested from grand unification theories, the number passing through the earth's surface would be 4×10^{-10} cm^{-2} sec^{-1} sr^{-1} which would result in 1.5 events per year" through Cabrera's relatively small detector loop.

CONCLUSIONS: THE IMPLICATIONS OF THE LACK OF MAGNETIC MONOPOLES

The theory has major implications for both big bang cosmology and the theories of how elementary particles came into existence. Huge numbers of magnetic monopoles must exist, but there must be far fewer magnetic monopoles than baryons, otherwise they would have dominated the universe's mass, triggering its collapse eons ago [27, p.162]. Both the inflationary universe and the GUT theory postulates magnetic molecules existing "in great profusion" and that "the universe should have been *swarming* with them, in fact, but not a single one had every been observed. Not one" [27, p.1-2]. The fact that these massive particles which "could help cosmologists out of their own theoretical bind" have not been discovered is a major missing link in the hypothetical evolution of both forces and particles and also of the universe [31, p.625]. This has forced a drastic revision of our cosmological theories, and has not been an easy task since many theories depended heavily on their existence:

> The great appeal of magnetic monopoles is that their existence would both explain why electric charge is quantized and provide clues about the structure of the Universe moments after the Big Bang. Furthermore, whole classes of theories in particle physics work only if they exist. All of which explains why two groups, one from Stanford and the other a collaboration between IBM and Brookhaven national Laboratory, have spent the past three years searching for these elusive objects--without success--and look forward to doing so for years to come [12, p.706].

The debate is to the extent that many cosmologists are now reworking their theories to account for the nonexistence of monopoles. This development illustrates the major problems in existing cosmological theories and illustrates how much is pure speculation:

> The big bang of creation would have been the only event hot enough (almost 10^{10} degrees Kelvin) to generate such particles. Both north and south magnetic monopoles would have been formed, and a small fraction of them would have recombined, annihilating each other. Most of the superheavy monopoles would have escaped an early death, however, and there is no reason to think they would not have survived to the present. It is unclear where the monopoles would have collected as the universe evolved, but then it is also unclear how the universe evolved from the big bang into the galactic structures we see today [8, p.115].

A common response to the lack of monopoles is to modify the inflationary hypothesis to conclude that "only a few monopoles can be created" and consequently the grand total is relatively small so that "unless we happen to be incredibly lucky, we can never expect to see one, no matter how long we search" [27, p.170]. Although they are now hypothesized to be rare--partly because of the negative experimental results has forced reevaluation of existing theory--they are so critical that theory cannot now account for their nonexistence today. Postulating fewer of them is speculation, as presently no evidence whatsoever exists for them even though many researchers have concluded magnetic monopoles must exist for our cosmological and GUT theories to be valid [10, p.472]. The number is a secondary issue; only one monopole need be proved to confirm the basic theory and their existence, a step we have not yet achieved [33, p.31]. Some physics have even began to develop new theories about "the nature of charged particles [which] may be used to interpret the apparent absence of magnetic monopoles" [35, p.414]. Unfortunately, the nondiscovery of magnetic monopoles is not solved so easily, especially since "the theory of inflation [itself is] ... still a hypothesis" [27, p.179]. Furthermore, disconfirmation of one aspect of the theory is generally not sufficient in order to produce a scientific revolution and the debate still involves the most basic aspects of magnetic monopole theory [6, 19, 10, 16, 17].

The theory of inflation also requires the "existence of dark matter" a view which is also not confirmed yet [23, 28]. Ironically, magnetic monopoles "were probably the first exotic cold dark matter candidates to be directly sought in a laboratory, although, "the possibility that monopoles actually make up the dark matter of the universe has subsided somewhat since the development of inflationary cosmologies" [22, p.274]. The GUT theory also has not been supported by other research such as the lack of evidence for proton decay [21]. The lack of monopoles and other problems has caused some researchers to question the validity of the GUT theory. The magnetic monopole research may turn out to be a major hole that contributes to the collapse of evolutionary naturalism. It is part of the growing evidence that the whole universe cannot be understood from the naturalism world view [24]. In conclusion, we believe we cannot improve on Groom's words:

> Over the past three years, in a search of unprecedented scale and intensity, theoretical and experimental physicists from many specialties have quested for the legendary relic magnetic monopole, a particle required in the context of a very general class of grand unified theories. Occasional rumors to the contrary, there is at this point not one shred of evidence for its existence.... We must regretfully conclude that the massive magnetic monopole is not only endangered, but very likely extinct. We hope for nothing more than to be proven wrong by future experiments [17, p.368-364].

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