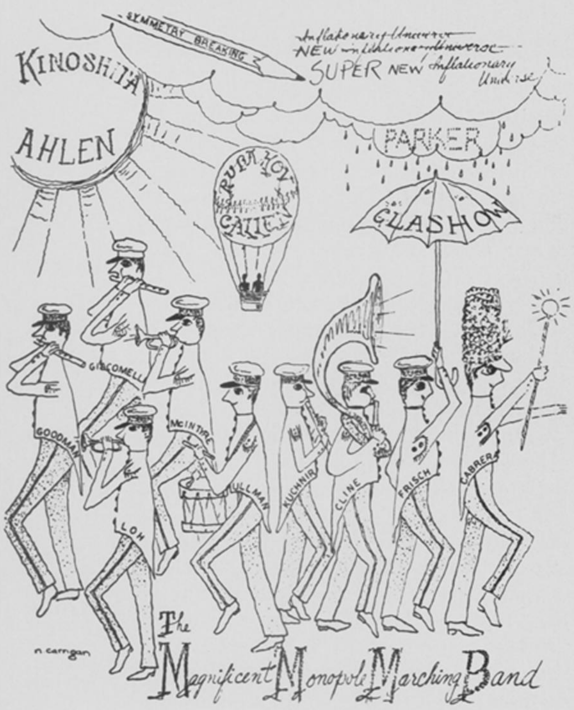
Coming Unstrung Over Monopoles

'The time has come,' the Walrus said, 'to speak of many things,
Of shoes and ships and sealing wax, Of cabbages and kings,
And why the world is boiling hot and monopoles have wings.'
(with apologies to Lewis Carroll)



"The composer Dirac is nowhere to be seen and states the music may be in the wrong key. Arrangers 'tHooft and Polyakov are off the scene leading new bands. Traffic cops Preskill and Shafi are off to the right. Hill is rushing in from the left with a tune for a monopolonium."

Picture and legend: N. Carrigan, R. Carrigan

By DIETRICK E. THOMSEN

First of two articles

To many physicists, not to mention other people, magnetic monopoles seem as weird as the winged pigs of Lewis Carroll's original poem ("...And why the sea is boiling hot/And whether pigs have wings"). They are certainly from the other side of the looking glass — the mirror that reflects every electrical phenomenon into an equal and reciprocal magnetic one. The original reason for believing in magnetic monopoles is that monopolar *electric* charges exist. For reasons of symmetry it has seemed for a long time that *magnetic* ones should be discoverable, too. Lately physicists have an even more compelling reason: The existence of magnetic monopoles is demanded by the new Grand Unification Theories (GUTs) that physicists are developing in the hope of tying up all of physics into one comprehensive, connected theoretical package.

The time had come to talk of monopoles and of many things about and connected to them. Not only was there the theoretical imperative, there was an experimental result too. In a deceptively simple experiment Blas Cabrera, a physicist at Stanford University in Palo Alto, Calif., had made a measurement that he considers a "candidate event" for a monopole (SN: 5/15/82, p. 323). This convergence of impulses brought about 90 physicists to a Magnetic Monopole Workshop at Racine, Wis., in a house called Wingspread, which is maintained as a conference center by the Johnson Foundation. There, under the subtle symmetries and balances of Frank Lloyd Wright's architecture, they discussed the symmetries, asymmetries and antisymmetries of monopoles.

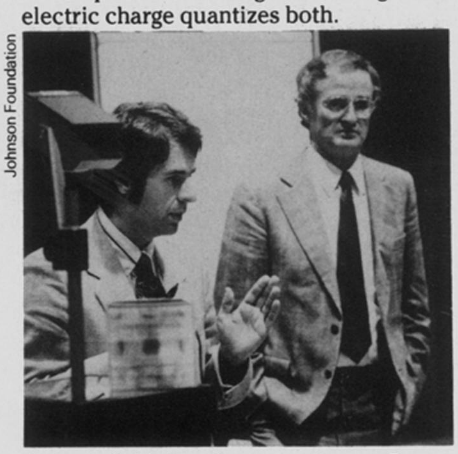
The main thing to emerge from three days of intense conversation is that there is no complete consensus about the details of what a monopole is nor about the best way or even possible ways to hunt them. For example, some speakers assumed that magnetic monopoles have electric charge as well as magnetic charge. Others assumed that they do not. Still others were vague on the point. Faced with the necessity of putting precise properties on such a never-never object so as to give experimenters phenomena to look for, some theorists seemed to grope a little.

The whole question begins with a curious asymmetry of the observed, practical physics of the nineteenth century. Electric charges, the sources of electric fields, are objects. They are microscopic things that sit in space, emanating electric fields and exerting electric forces. They come in positive and negative varieties. Electric field lines, invented by Michael Faraday to describe the phenomenon graphically, start at a positive charge and end at a negative one, or vice versa.

Ordinary observation finds no corresponding magnetic charge. Magnetic fields are generated by electric charges moving in circuits (or rotating on their axes). Magnetic field lines neither start nor end; they are closed loops threading the electric circuit. The convention of speaking of the north and south poles of a solid magnet is a concession to the hardness of such things as the ends of an iron bar. The field lines continue right through, and so would magnetically attracted objects if they could. Cutting a bar magnet in half yields two new magnets; the field-line loops reestablish themselves for each piece. There is no magnetic charge point at which they can stop.

This basic asymmetry in an otherwise symmetric theory — it makes magnetism derivative — was accepted by most physicists. If nature is not symmetrical, nature is not symmetrical, and that's all there is to it. There were some, however, who hankered after an independent status for magnetism and complete reciprocity with electricity. In the early 1930s physicist P. A. M. Dirac found a better reason for the existence of independent magnetic charge than such aesthetic wishfulness: the quantization of electric charge.

Studies of atomic physics had shown that electric charge is quantized, that is, all electric charges in nature were seen to be integral multiples of a basic unit, the charge of the electron (or of the proton, the difference is a matter of sign). Classic electromagnetics as it came from the hands of Faraday and James Clerk Maxwell, and even as modified by Albert Einstein, makes no provision for this quantization. Dirac found that if a magnetic monopole existed (it takes only one in the whole universe), the mathematical relationship between magnetic charge and electric charge quantizes both.



Johnson Foundation

Cabrera (left) describes experiment. Peter Trower (an organizer of the meeting) presides.

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Dirac's mathematical description of a monopole has one serious topological flaw as a description of a real physical particle. The monopole is a point emanating magnetic flux in all directions, but it is a point at the end of a string stretching away to infinity. (No fair to ask what it connects to at infinity.) The topological description of a proper particle is a "knot," something self-contained that can be separated from its surroundings. An object with an infinite umbilical cord cannot be so separated. Theorists strove to get the monopole off the string, while experimentalists looked for it in the hope that there was a reality at least approximate to Dirac's theory.

As Alfred S. Goldhaber of the State University of New York at Stony Brook recounted at the monopole workshop, recourse was first had to the uncertainty principle of quantum mechanics, which had solved an analogous difficulty for the electron. Theoretically the electron is supposed to be a dimensionless geometrical point. However, if the electron's negative charge is concentrated at a point with zero extent in space, that charge repels itself with infinite force, and the electron must explode. (One can also say that the point electron has infinite self-energy, and in the textbooks this dilemma goes down as "the self-energy crisis.") The uncertainty principle comes to the rescue by saying that one can never measure the electron's position exactly, and so it cannot be proved that it really is a point. All physicists know is that the electron is within a small stretch of space. It sits there fluctuating and vibrating, maybe a point, maybe not. Uncertainty gives it room to survive. A similar argument was tried for the monopole, hoping that such uncertainty and fluctuations would cut it off the string. Unfortunately another result came out: The monopole swings back and forth on the end of the string like an ape on a vine.

It was the grand unification theories of particle physics that have developed in the last few years that showed how to get the monopole off the string. Two prominent theoretical physicists, Gerard t'Hooft of the University of Utrecht in the Netherlands and Alexander M. Polyakov of the Landau Institute of Theoretical Physics near Moscow, simultaneously realized how to do it. The GUTs are an attempt to unite ordinary electromagnetic phenomena and those of nuclear and subnuclear physics in a single comprehensive theory. (GUTs leave out gravitational phenomena; theories that bring gravity in also are called supersymmetry theories.) The monopoles that come out of GUTs therefore have connections not only to electromagnetism (like Dirac monopoles) but to a wide variety of phenomena and have a correspondingly greater importance. GUTs yield GUMs (grand unified monopoles), and GUMs are monsters of particle physics. They might be called the creatures that ate the theory.

GUTs are written in the mathematical language of group theory (see box). Polyakov and t'Hooft found that the particular groups used in GUTs, which are technically classed as nonabelian gauge groups (see box), have a topology (see box) different from that of the group that represents electromagnetism alone as formulated by Dirac. In the GUT topology the string disappears and the monopole becomes a knot, that is, a description of a possible real particle. But what a knot!

A GUM is a fantastically heavy thing for a particle. Mass estimates in billions of electron-volts (GeV) range from 10^{16} to 10^{19}. This is the mass of an amoeba or a paramecium. The mass of a proton is slightly less than one billion electron-volts. A GUM is seen as a kind of layered structure related to the stages of the unification of physics.

In current theory the universe was born hot and relatively simple. As it cooled over the ages, many complications crystallized out, so to speak. One of these is the separation of natural forces into four different categories known as gravity, electromagnetism, the weak interaction and the strong interaction or color force. One aspect of the unifying theoretical efforts is to trace the history of these divisions, and to show how they all diverged from a single unity. As one traces backwards, one comes to epochs of higher and higher temperature (or higher energy or higher characteristic mass, as it may also be stated). At a certain level not much above where we are, electromagnetism and the weak interaction are unified. Somewhat higher energy and color force joins the amalgam.

This second level is the grand unification level. If you could dissect a GUM, in the center would be "a big fat core," to use the description of Curtis G. Callen of Princeton University. Around the core appear effects of the color force, and finally, in the outermost layers, ordinary magnetism. The particles characteristically associated with these forces have a virtual existence inside the GUM: in the core a heavy vector meson, further out quarks, gluons, pions, then photons. The GUM, in a sense, recapitulates the whole theory.

As John R. Ellis of the CERN laboratory in Geneva put it in summing up a talk justifying the connection between GUTs and GUMs, "GUMs are an unavoidable feature of GUTs. They'll tell us about the grand unification [energy] scale and the grand unification mixing [the details of how the different forces mix together]."

Goldhaber's talk, cited previously, was an attempt to prove the converse: not only do GUTs imply GUMs, GUMs also imply GUTs. If we find GUMs, says Goldhaber, we'll know that gauge groups are the proper route to unify physics. Goldhaber's suggestion may or may not prove acceptable — Chen-Ning Yang, also of Stony Brook and a very prominent particle theorist, referred to it as "opaque" — but if it does, it will give monopoles a double-barreled importance in particle physics.

GUMs may have a nice cozy relationship with GUTs, but in cosmology they cause serious problems. In the words of Michael S. Turner of the University of Chicago, there are either "too many or too few." GUMs would be made when the universe was much more than boiling hot (temperature on the order of 10^{16} GeV) at a moment 10^{-34} seconds after the big bang. So many of them would have been made, however, that their contribution to the density of the universe would make space more sharply curved than we see it to be. Thermally their cooling power would bring the universe to its present temperature of 3 kelvins in 10,000 years. "That would make creationists happy," Turner says, but it would seriously dismay evolutionary biologists, paleontologists and geologists.

A. H. Guth of Massachusetts Institute of Technology, who estimates 38,400 years for the evolution of the universe to its present state under these conditions, proposes the theory of the "super new inflationary universe" as a cure for the excess number of monopoles. The theory went through previous refinements as "the inflationary universe" and the "new inflationary universe" to reach its present

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Group: Any collection of related objects taken together with a mathematical operation that relates them and satisfying certain rules. An example is the set of all positive real numbers and the operation of ordinary multiplication. By multiplying or dividing the proper factors, one can generate any positive real number out of other positive real numbers. The group theory applications in GUT physics generally concern the ways in which a small number of basic elements called quarks can be combined to make subatomic particles of one kind or another, and so bring some order to the 100 or more known particles.

Abelian, nonabelian: In an abelian group multiplication is commutative. That is, the result of multiplication does not depend on the order in which the factors are combined, a.b = b.a. In a nonabelian group the result depends on order of multiplication, a.b ≠ b.a.

Gauge: A concept rather difficult to define, but having to do with the identities of particles. It helps to determine which processes alter the identities of particles and which do not.

Topology: A group can be represented geometrically as a space in which the points correspond to members of the group. The topology of the space is the rules that tell which elements are neighbors to which elements and how one may draw paths from one element to another.

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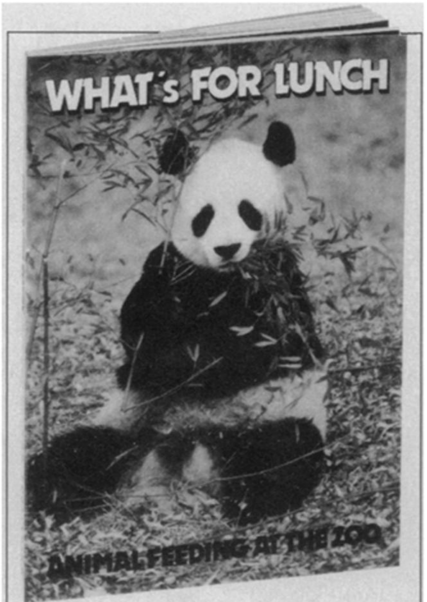
elaboration. It proposes to solve a number of problems relating to causality in the early stages of the universe by having the universe expand much faster (at an exponential rate) in the early moments than it does now or than the ordinary big-bang theory would have it do at any time. The overproduction of monopoles is a question of causality and the exponential expansion would solve it too, but the cure kills the patient. When Guth works it through, he winds up "with zero monopoles."

Contradictions can also arise when old physics mixes with new physics. Cabrera's "candidate event" has the unit of magnetic charge postulated in Dirac's original theory. In general it is all right for a GUM to have that unit, but that unit was calculated to go with electric charges no smaller than the charge of an electron. J. P. Preskill of Harvard University points out that in the same laboratory at Stanford an experiment led by William Fairbank has been finding some kind of object attached to little niobium balls that exhibits electric charge of ⅓ that of an electron. The Dirac magnetic unit is incompatible with that.

Preskill tries and rejects a number of theoretical means for reconciling the inconsistency. He finally suggests a new kind of force, which he calls extraordinary electromagnetism coupled to a new, extraordinary matter. The ordinary matter that we are so far familiar with is neutral with regard to this extraordinary electromagnetism — as Yang interjected, "We won't have seen this in accelerator experiments" — but extraordinary matter carries extraordinary electric and magnetic charge. In this way the monopole that may have been found could carry extraordinary magnetic charge, ordinary magnetic charge and a "magnetic" charge associated with the color force. And so Preskill says the two experimental findings are "not necessarily incompatible, but we need some new physics." It left some in the audience shaking their heads.

Many things are attributed to GUMs. They may be able to catalyze the radioactive decay of protons, neutrons and other particles of the baryon class into things that are not baryons. Such baryon-destroying decays have been forbidden in physics up to now, but GUTs permit them. If GUMs catalyze baryon decay, one possibility is that they may be sitting inside neutron stars, eating neutrons and protons like little Pac-men. GUMs may make or destroy magnetic fields in galaxies and clusters of galaxies, depending on whose theory you follow. They may be trapped in the sun and other stars, in the moon or in rocks on the earth. Monopoles may meet antimonopoles and annihilate each other, giving out puffs of radiation that we might detect. More will be said about these topics in the second chapter of this report: To Catch a Monopole. □



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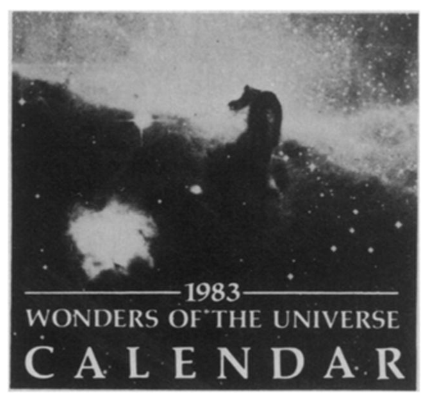

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