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Magnetic Charges, Inertia, and Arrow of Time

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The prerelativistic concept of inertial mass (as opposed to gravitational mass) is reconsidered in view of a possible relationship between inertia and magnetic (mass) monopoles. Assuming that such "fictitious" (topological) charges could have developed in the chaotic early cosmology, a physical principle is suggested, based on dissipation of topological charges and decoupling of interactions, which could have governed the onset of inertia and of the arrow of time, and controlled the critical balance between mass density and expansion rate in the FRW universe. In view of the recent accomplishments in the detection of Dirac monopoles, a generalization of the Eötvos experiment is proposed which could shed light on the grand unification regime. A comment is given on the issue of relating the psychological and the cosmological arrows of time.

1. INTRODUCTION

If the big bang cosmology, which developed out of Einstein's ideas and Hubble's observations, has stood the test of time and experimental confirmation, everyone would admit that it is, at best, a first approximation. In fact, the big bang and related initial singularity are commonly acknowledged to be a problem with relativity theory, not with the universe itself; various alternative setups, such as, e.g., the nonsingular bounce models, have been proposed to cope with this situation.

One of the key points here lies in the explanation of the precise balance between the expansion rate of the universe and the mass density below which matter could not have been created (pair creation process and vacuum quantum fluctuations), and above which it could not have crystallized into inhomogeneities, stars, clusters, and superclusters of galaxies (deviation of homogeneity and isotropy via metric fluctuations), and finally into those structures to which our very origin is to be traced back. This can be

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summarized in the "Hubble formula," which expresses the mean mass density $\rho(t)$ as a function of the expansion rate $a(t)$ of the FRW universe:

$$\left[\frac{\dot{a}(t)}{a(t)}\right]^2 = \tfrac{8}{3}\pi G\rho(t) - \frac{c^2}{R^2a^2(t)}$$

where $|R|a(t)$ is the space curvature of a hyperslice of cosmic time $t(R =$ constant).

There is an anthropomorphic viewpoint which consists in trying to set a correlation between this balance and the critical conditions which on one hand led to the phenomena of life and the psychological perception of time and on the other hand to the cosmological arrow of time.

In this note, I shall rather propose to set a correlation between the delicately tuned "Hubble expansion law" and a physical principle motivated by recent results in the detection of magnetic monopoles (Akers, 1986, 1987, 1988; Mikhailov, 1983; Mikhailov and Mikhailova, 1987, 1988*a*,*b*) and the related understanding of the grand unification regime.

2. INERTIAL MASS AND MAGNETIC MASS

Clearly, Einstein's work was inspired by this very basic physical principle, namely the proportionality of weight and mass, i.e., the equality of the accelerations of different bodies when submitted to the gravitational field. This is already expressed in Newton's (dynamical) law of gravitation:

$$F = -Gm_1m_2/r^2$$

One of the tasks of experimental physics has been to check the principle of equal accelerations via accurate measurements of accelerations imparted to different bodies. This led to the principle of proportionality between inertial mass m_i and (passive) gravitational mass m_g, and to a reformulation of Newton's law:

$$m_i(d^2r/dt^2) = m_g\nabla U$$

where the force appears as the gradient of a Newtonian potential. If all bodies satisfy

$$m_i/m_g = \alpha$$

where α is a universal constant, then the principle of equal accelerations is satisfied. As is known, this was checked with great accuracy in 1890 by Eõtvõs, and further confirmed with still greater accuracy by Dicke in 1961 and by Roll, Krotkov, and Dicke in 1964.

The Coulomb law of electrostatics

$$F = e_1e_2/r^2$$

displays a striking analogy with Newton's law, and it has been one of the tasks of general relativity to find similarities between gravity and electromagnetism, and to pave the way toward grand unification theories.

In this section, I shall investigate further similarities. The treatment is within the context of chaotic cosmology (near the initial singularity), where topological (magnetic) charges are expected (gravitational and Maxwellian monopoles). This makes it possible to introduce universal constants (expressing the proportionality of magnetic and electric charges) which are natural candidates to govern the gravitational and the electromagnetic coupling strengths.

I summarize the main results (Magnon, 1987, 1988*b*-*d*). The expansion of a Friedman universe is conveniently described, at least locally, by a conformal isometry ($\xi^a = \partial/\partial t$):

$$\mathscr{L}_\xi g_{ab} = k g_{ab}$$

where k is the expansion field and g_{ab} the space-time metric. I have shown that, in the presence of monopoles (nontrivial second de Rham cohomology class), asymptotic gravitational degrees of freedom are encompassed by conserved stress-tensor fields K^{ab} and $^*K^{ab}$ emerging from the electric and magnetic components of the rescaled Weyl (curvature) tensor

$$K_{abcd} = \Omega^{-1} C_{abcd} \sim \frac{1}{r^2} C_{abcd}$$

with respect to the asymptotic null directions $n^a = \partial/\partial u$, both expressed by $f(u) n^a n^b$. Since charges are given by integrals of these tensor fields over noncontractible 2-spheres surrounding the "fictitious" monopole source, it is natural to identify $f(u)$ with a density field. The same holds true for electromagnetism, provided F_{ab} (or $^*F_{ab}$) is substituted for K_{abcd} (or $^*K_{abcd}$ respectively). An asymptotic expansion law can be derived, which expresses the density as a function of the expansion rate:

$$\frac{\dot{f}}{f} = -\tfrac{1}{2}[k + 3(k + 2\Omega^{-1}\mathscr{L}_\xi \Omega)] = -\tfrac{1}{2}[k + 3\chi]$$

The finiteness and proportionality of electric to magnetic charges is obtained from

$$f(u) = f(0) \exp\left[-\tfrac{1}{2} k u - \tfrac{3}{2} \int_0^u \chi(\tilde{u})\, d\tilde{u} \right]$$

and from the global space-time structure in the presence of Dirac or gravitational monopoles: the nontrivial $U(1)$ gauge bundle over noncontractible 3-dimensional base space (the $\partial/\partial u$ orbits are compact).

The experimental results obtained by Akers (1986, 1987, 1988) and Mikhailov (1983; Mikhailov and Mikhailova, 1987, 1988*a*,*b*) confirm that

for Dirac monopoles, the universal proportionality constant is an integer multiple of the fine structure constant α_f. The theoretical results in Magnon (1988*c*,*d*) suggest that, for gravitational monopoles, the proportionality constant α_g is a multiple of the integer number (first Chern class) of twists of the space-time bundle around its $U(1)$ fiber. Acausality (closed ξ orbits) is thus a feature of the (possibly) primordial monopole geometry. In this setup which enables nonvanishing magnetic charge G and magnetic mass M^*, the equality of coupling constants is not *a priori* excluded:

$$M/M^* = \alpha_g = q/G = \alpha_f$$

where q, the electric charge, is a multiple of the electron charge.

This raises the question of the grand unification regime.

3. EQUIVALENCE PRINCIPLE AND COSMOLOGICAL EXPANSION

A dissipation of the chaotic phase and related space-time noncontractibility ought to go with a process of evaporation of topological charges, and, in the case of magnetic charges, with the opening of the $\xi[U(1)$-gauge] orbits, which means the onset of an arrow of time. One can speculate whether a decoupling of the gravitational and electromagnetic interactions ($\alpha_g \neq \alpha_f$) could have taken place at this stage. Since α_f and α_g both appear as constants of motion, i.e., of the (local) expansion law induced by ξ, one might further conjecture the existence of a conservation principle by which charges tunnel through the dissipation process. For instance, an actualization of the "fictitious" (topological) sources with charge M^* into "real" sources with inertial mass m_i would lead to the conservation law

$$M^* = m_i$$

which expresses inertial mass (and inertia) as the magnetic lag of the breaking of the space-time $U(1)$ (gauge-) bundle structure, and dissipation of topological curvature into metric curvature. In this setup, the equivalence principle appears as the remnant of a more primitive principle based on the proportionality of mass (metric concept) and magnetic mass (topological concept) after decoupling of interactions. Such a principle should be sufficiently compelling to adjust the balance between expansion rate and mean mass density.

Since the experimental detection of Dirac monopoles is presently venturing into the grand unification regime, I suggest that this pre-equivalence principle be checked via an Eötvos-type (zero-torque) experiment where inertial effects induced by the orbital motion of the earth in the solar system would be replaced by (laboratory-) manufactured monopoles. The anthropomorphic school of thought might then (possibly)

go into the search for a birth process for our universe, where the magnetic helix-structure might eventually provide life and awareness of an arrow of time.

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