Time Asymmetry in the Universe

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"The moving finger writes, and having writ, moves on." - Rubaiyat of Omar Khayam

Abstract

The Universe is time asymmetric in a number of fundamental processes and phenomena. We grow older. The Universe is expanding. Radioactive nuclei emit particles. In closed systems, entropy is constant or increasing. All these processes have one fundamental all-encompassing element: the governing space-time metric changes irreversibly along the world-line of the process. The arrow of time has only one direction: forward. Yet the traditional equations of space-time physics are symmetrical in time, being equally applicable in one direction as the other. We shall prove that a simple and necessary extension of general relativity brings irreversibility to the fundamental equation governing the space-time metric and a direction to time.

Introduction

From Newton's laws to Einstein's general relativity, all of the traditional governing differential equations are time reversible. But irreversibility manifests even in non-relativistic systems, which implies that the traditional equations governing the physics of everyday phenomena are incomplete. Electromagnetic, weak and velocity fields govern the atomic structure of these material phenomena. Thus, intuitively, we would expect changes in these fundamental fields to be related to time irreversibility. For example, highly-ordered life-forms decay into low-order systems after death with corresponding changes in their electromagnetic field structure. Radioactive particles decay in time with accompanying changes in their weak fields. Rotating planets slow down. All such phenomena are geometrically represented by space-time metric structures moving and changing irreversibly along their world-lines.

Einstein, in his original derivation of the theory of general relativity, restricted the space-time under consideration to possess only a symmetric metric and a symmetric curvature field. Under these restrictions, Einstein intuitively produced a field equation relating the tensors of energy-momentum and symmetric curvature. Weinberg (1972) has shown how to derive this fundamental relation based on the fundamental tenet that the weak static non-relativistic limit of Einstein's field equation must yield Newton's Law relating gravitational potential to mass density. Weinberg's further assumption is that Einstein's curvature tensor is dependent solely on terms of quadratic order in derivatives of the metric structure. Together with conservation of energy-momentum and, therefore, symmetric curvature, Weinberg derives Einstein's field equation. Simultaneously, he shows that Einstein's curvature tensor is governed by quadratic derivatives of the symmetric metric tensor.

Einstein, later in life, realized that, in order to represent physical reality as a field, a generalized relativity must incorporate a non-symmetric metric (Appendix V, 1952). In the same exposition, by examining a spinning disk, he deftly demonstrates, using clocks and measuring rods, that general relativity has an intrinsic problem with angular velocity. Changes in the angular momentum of a body are caused by torques, which are moments of forces. Everyday phenomena are dependent on torques, inherent in such human actions as turning around or breaking bread. Torques in space and time are represented in space-time by torsion fields, which must be included in any generalized relativity.

Generalized Relativity

A space-time that incorporates torsion fields as well as non-symmetric curvature has been termed a Riemann-Cartan U_4 space-time (Schouten, 1954) in which $g_{\mu\nu}$ is the completely general non-symmetric metric tensor. We examine the case of sufficiently small fields such that linearization is valid and only terms of lowest order are incorporated. In this linear approximation, the non-symmetric curvature $L_{\alpha\beta\mu\nu}$ is antisymmetric between the pair of indices $(\alpha\beta)$, as well as

$(\mu\nu)$. Thus it suffices to consider, in this linear approximation, the related non-symmetric second-order curvature tensor:

$$(1)\quad L_{\delta}{}^{\gamma} = -1/4\ \varepsilon^{\chi\gamma\alpha\beta}\ \varepsilon_{\chi\delta\mu\nu}\ L_{\alpha\beta}{}^{\mu\nu}$$

whose symmetric part is the usual Einstein tensor, and ε is the usual alternating tensor.

Torsion Q is the antisymmetric part of the connection, where the antisymmetry occurs only in two of the indices:

$$(2)\quad Q_{\alpha\beta\gamma} = 1/2\,[L_{\alpha\beta\gamma} - L_{\alpha\gamma\beta}]$$

Davies (1988) has defined the modified dual of the torsion as

$$(3)\quad A_{\alpha\chi\mu} = L_{\alpha}{}^{\beta\gamma}\ \varepsilon_{\chi\beta\gamma\mu}$$

or, alternatively,

$$(4)\quad A_{\alpha\chi\mu} = Q_{\alpha}{}^{\beta\gamma}\ \varepsilon_{\chi\beta\gamma\mu}$$

as the alternating tensor only operates on the two antisymmetry indices. In space and time, A is also known as the translational defect density tensor in the theory of defect-containing media, such defects being produced by torques. Consequently the torsion and its dual A tensor are equivalent quantities in that each determines the other.

Bianchi Identities

An original form of the first Bianchi Identity was obtained by extending the 3 dimensional case and incorporating covariant differentiation in the linearized continuity equation (Davies, 1988):

$$(5)\quad L_{\alpha\beta\gamma\delta} = L_{\alpha\beta\delta;\gamma} - L_{\alpha\beta\gamma;\delta}$$

where the fundamental relation used is

$$(6)\quad L_{\alpha\beta\gamma} = 1/2\,[g_{\gamma\alpha,\beta}+g_{\beta\alpha,\gamma}-g_{\beta\gamma,\alpha}] + Q_{\alpha\beta\gamma}+Q_{\beta\gamma\alpha}-Q_{\gamma\alpha\beta}$$

On substitution of these equations (5),(6) into the definition of the second order curvature tensor (1) and after some manipulation, Davies (1988) obtained the Bianchi-Davies First Identity in the limit of small fields and in terms of the second-order curvature and modified torsion tensors:

$$(7)\quad L_{\gamma}{}^{\delta} = \varepsilon^{\mu\delta\alpha\beta} A_{\mu\beta\gamma;\alpha} - 1/2\, \varepsilon^{\mu\chi\delta\alpha} g_{\chi\gamma} A^{\beta}{}_{\mu\beta;\alpha} - 1/2\, \varepsilon_{\mu\gamma\tau\sigma} \varepsilon^{\mu\delta\alpha\beta} g_{\beta,\alpha}{}^{\sigma,\tau}$$

where the semi-colon implies covariant differentiation. The usual Second Bianchi Identity now applies:

$$(8)\quad L^{\gamma\delta}{}_{;\delta} = 0$$

where, however, $L^{\gamma\delta}$ is non-symmetric in this more general approach.

We use 2nd order tensors as they can be uniquely decomposed into symmetric and anti-symmetric independent components. Davies (1988) thus uniquely split the second order curvature tensor into its symmetric Einstein curvature tensor $G_{\alpha\beta}$ and the anti-symmetric Davies curvature tensor $D_{\alpha\beta}$:

$$(9)\quad L_{\alpha\beta} = G_{\alpha\beta} + D_{\alpha\beta}$$

From the First Bianchi-Davies Identity,(7), Davies (1988) obtained the original relation governing the gradients of the space-time metric in terms of the symmetric curvature and torsion components:

$$(10)\quad 1/2\, \varepsilon_{\chi\alpha\gamma\delta} \varepsilon^{\chi\beta\mu\nu} g_{\nu,\mu}{}^{\delta,\gamma} = -G_{\alpha}{}^{\beta} + [\, \varepsilon^{\chi\beta\mu\nu} A_{\chi\nu\alpha;\mu} \,]_{s}$$

where s indicates that the symmetric component of these torsion gradients is taken. This equation, apart from the torsion gradient terms, is identical to Einstein's field equation as derived by Weinberg (1972).

Removing (10) from (1) and multiplying the first Bianchi-Davies Identity, (7), with the alternating tensor, results in the original equation:

(11) $$A^{\alpha\gamma}{}_{\mu;\gamma} = -\varepsilon_{\mu\gamma\delta\chi} D^{\gamma\delta} g^{\chi\alpha}$$

implying that these torsion-dual gradients produce antisymmetric component of curvatures (Davies, 1988).

The usual second Bianchi Identity applies to symmetric curvature conservation, namely:

(12) $$G^{\gamma\delta}{}_{;\delta} = 0$$

so that we also have conservation of antisymmetric curvature, namely:

(13) $$D^{\gamma\delta}{}_{;\delta} = 0$$

Torsion Fields Identification

Torsion in space and time is related to spin and angular velocity produced by torques on solid media, and to the production of translational and rotational defects in more general media. The concept of mass energy-momentum being represented by angular defects has previously been used in Regge calculus where curvature is related to the angular defect in a skeleton space-time (Misner, Thorne and Wheeler, 1973). This discrete space-time has been used by Davies (1997) in quantization of the Action of the fundamental particles and explanation of their properties.

Einstein (1956) originally argued that torsion should be related to the electromagnetic field. Davies (1988) used a model of particle-antiparticle pair production to identify torsion-dual tensor components with electromagnetic and weak fields. Using equations (11) and (13), he derived Maxwell's equations and similar relations for the weak currents, which were shown to be non-conserved, one of their fundamental properties (Taylor, 1976).

Gogala (1980) has demonstrated that the electromagnetic field may be related to a time-like modification of the torsion. Also, Borschenius (1976a,b) has identified a modified torsion tensor with electroweak fields using Lagrangian and gauge methods. Similar techniques have been used by Rumpf (1979) to show that a step-gradient in torsion produces fermion currents through a pair production example. Edelen (1980) has examined the gauge properties of the linear Bianchi

Identities and argues for a complete identification with those of electromagnetism. Other researchers have also shown the similarity between torsion and the weak field (Kaempffer, 1976).

Time Asymmetry

The fundamental relation (10), namely:

$$1/2\ \varepsilon_{\chi\alpha\gamma\delta}\, \varepsilon^{\chi\beta\mu\nu}\, g_{\nu,\mu}{}^{\delta,\gamma} = -G_{\alpha}{}^{\beta} + [\ \varepsilon^{\chi\beta\mu\nu} A_{\chi\nu\alpha;\mu}\ ]_{s}$$

implies that torsion gradients contribute to the non-symmetric metric in this generalized space-time. Einstein (1952) believed that such generalizations would allow physical reality to be described by fields, but was unable, in his allotted time on earth, to prove this hypothesis against the facts of experience. However, one of these most fundamental facts is the direction of time. As Penrose (1989) has remarked: "it seems to be clearly the case that whatever physics is operating, it must have an essentially time-asymmetrical ingredient, i.e. it must make a distinction between past and future".

If a partial differential equation contains either single or second-order derivatives in time, but not both, its solutions manifest only reversibility. A partial differential equation incorporating both types of time derivatives has solutions that are time irreversible. Thus, the above equation, with second-order derivatives of the metric and first-order time derivatives of torsion has that essential time-asymmetric ingredient.

Newton's and Einstein's equations without this torsion-gradient term are symmetric in positive and negative time. Radioactive decay implies weak field gradients. Entropy increase implies the generation of heat, which is the production of thermal electromagnetic field gradients. The slowing down of rotating solid bodies by frictional forces produces heat, eventually emitted as electromagnetic radiation.

Thus, time asymmetry in the Universe is due to the effect of torsion gradients on the non-symmetric metric in a generalized four-dimensional space-time. Yet, as Einstein commented: "People like us, who believe in physics, know that the distinction between past, present, and future is only a stubbornly persistent illusion".

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