Statistical Models of Light with an Example in Relativistic Dynamics

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Abstract:

The propagation of light is well described by Maxwell's field equations of electromagnetism in relativistic space; its emission and absorption by quantum mechanics. However, some open questions remain. For example, is there a means to break gauge symmetry? Do any surprises await us at high energies or unexplored scales? Are there further interactions between fundamental forces? Many authors have suggested that a deeper understanding can be achieved through a statistical model of the continuous electromagnetic media in which light can propagate. In such an approach the electromagnetic fields are of the same nature as more familiar force fields: statistical averages of underlying physical quantities. The goals of this approach are not only to explain why Maxwell's equations of propagation and the quantum theory of emission and absorption apply, but also to explore new predictions as well. Here we briefly review the approach, and demonstrate its utility in allowing a derivation of the Lorentz boost factors of Special Relativity.

Introduction:

Maxwell's equations remain the definitive description of electromagnetic wave propagation and the foundation of coordinate systems and relativity theory after more than a century. Much of the later progress in modern physics has been in describing the quantized absorption and emission of this light from all manner of atomic systems: a broad and successful field known as quantum mechanics. The only addition to the modern corpus of physics that has further affected our understanding of how light propagates (that is, post-emission and pre-absorption) is general relativity. For our purposes in considering advances in understanding the propagation of light, we therefore focus on these two areas of study:

1) Field equations of Electromagnetism
2) Field equations of General Relativity

It is worth noting that these two present a false dichotomy, in that General Relativity is also a set of field equations of electromagnetism. This can be seen by considering that general relativity defines the geodesic which in turn defines the propagation of electromagnetic radiation: it is light which is fundamental to the metric theory of general relativity. Further, GR includes in it's source terms the electromagnetic fields. Together as one, the two subjects aim to define what one might have called a century ago a theory of the aether. Today we might refer to this as a theory of space-time, or a unified fieat fld theory of continuous media.

In this paper we briefly outline our understanding of the propagation of light in the context of statistical models of continuous media. We then consider a single example: using the theory to derive the behavior of clocks and meter sticks in relative motion.

Statistical Electromagnetic Field Theory

The emergence of Lorentz symmetry has seen interesting recent development [Consoli, 2001,2007; Saul, 2003; Kaniadakis, 2006]. According to these authors the field theories and their symmetries emerge from consideration of statistical properties of underlying motions. It appears on the surface that very few people ventured in this direction since the publication of Whittaker's classic overview [1910] or Larmor's overview [1900], though some authors such as Winterburg [1995], Meno [1991], and Marmanis [1998] also pursued these lines of research.

The attractive theoretical framework of these theories is however outside the scope of this paper, and a proper overview would include such geometric examples as Weyl [1918] and others pursuing this approach as described e.g. in O'Raifeartaigh [1997]. Here authors have introduced formalism to include the electromagnetic field in a metric theory or otherwise include its action as part and parcel of a framework including gravity, though not explicitly defining the statistics of the underlying continuous medium which would explain the field equations.

Quantum loop gravity is another pertinent approach [Roveli and Smolin, 1990; Smolin, 1994] which in essence claims our operating thesis: that the field equations of electromagnetism and general relativity emerge from an underlying statistical dynamics of space-time.

Statistical explanations of Special Relativity

We will consider here as a representative of such, an application of the theory. We will give a derivation of length contraction and time dilation, the so-called Lorentz boosts, from basic statistical principles. In deriving these well known equations, the general approach is analogous to the approach taken by much of the above referenced work: we consider empty space (and all space) to be filled with some kind of dynamic system. We make basic assumptions about this system, and from them determine statistical averages which give us field equations describing the macroscopic behavior [Saul, 2005].

The basic consideration known as time dilation is as follows. An atomic clock moving through a continuous electromagnetic medium at some speed *u* will at any moment tick differently than a co-located rest-frame clock. The oscillations which are the tickings of an atomic clock are produced by some electromagnetic forces, for example the interaction of negatively charged electrons with a positive nucleus. Without knowing the exact form of the wave-function or space-time disturbances that are nuclear particles and electrons, or the details of the mechanics of the clock, we can still estimate the effect of motion on the comparative rates of electromagnetic clocks.

We assume first that the velocities of the micro-physical or statistical constituent "particles" of our constituent space-time are in a dynamic equilibrium. That is to say that their statistics are distributed to first order normally as in a Maxwellian gas. The distribution function of these constituents is then given by:

$$f(\vec{v})=N\cdot e^{\frac{-3|\vec{v}-\vec{u}|^2}{2\sigma^2}} \qquad (1)$$

Where $\vec{u}$ is the bulk motion of the laboratory through space (or vice versa), and the velocities of the individual atoms are here labeled $\vec{v}$. Eq. 1 is often proved in thermodynamics as a minimization of energy deviations but here we will simply treat is as an assumption. A normalization factor

$$N=\frac{3}{\sigma^3}\sqrt{\frac{6}{\pi}} \qquad (2)$$

will set the 0^{th} moment (number density) to unity. Even if the statistical distribution of space-time constituents is far more complex than the simple form in Eq. 1, our assumption of the form in Eq. 1 more accurately approximates the dynamics with respect to the linear velocities.

We note in passing that a measurement of the bulk motion of the continuous media $\vec{u}$ of the vacuum or continuous field was a described target of many early physical measurements, most notably the Michelson-Morley experiment and its later follow-ups. Fluid mechanical descriptions of Maxwell's equations as well as gauge geometries lead one to also ascribe this quantity as proportional to the magnetic vector potential. However we don't require these considerations to continue on our derivation of the Lorentz boost factor of time dilation.

The parameter σ has been introduced here as the average 'peculiar' speed so that $\langle|\vec{v}-\vec{u}|\rangle=\sigma$, where the angle brackets denote an average or weighted integral over the distribution function:

$$\langle A(\vec{v})\rangle = \iiint A(\vec{v}) f(\vec{v}) d^3 v \qquad (3)$$

The next important step here is to realize that the parameter σ can be taken as a means to set metric scale. The clock's perturbations in ticking will be linearly correlated to this parameter. If field disturbances in the media move more rapidly as viewed from another frame, as they will if σ is larger as viewed from that frame, then the clock will appear to tick faster. To put it another way: the statistical variations from the mean provide a temporal scale in the medium. One can also view this as a restoring force effect, much as an average peculiar speed in a classical gas is linearly proportional to the pressure force. This average peculiar speed also emerges as the natural wave speed in the medium as viewed in the reference frame in which it was calculated.

We also need to assume that the root-mean-square (RMS) speed of the distribution is given by $\langle|\vec{v}|^2\rangle \equiv c^2$. The assignment of the RMS velocity as the speed of light could be taken here as an assumption, or justified with a wave-equation for light wave propagation based on an underlying micro-physics as in e.g. [Saul, 2003].

We are now ready to explicitly solve the angle bracket integration over the Maxwellian distribution in equation (1) to calculate the speed of light in our assumed distribution. A full integration yields:

$$\langle|\vec{v}|^2\rangle = c^2 = u^2 + \sigma^2 \qquad (4)$$

Thus in a frame moving with respect to the bulk frame, the average ‘peculiar’ speed is found to be

$$\sigma^2 = c^2 - u^2$$

In a reference frame at rest in the kinetic medium, which we can designate with a primed coordinate we have

$$\acute{\sigma}^2 = c^2$$

because in this frame $\vec{u} = 0$.

We now have the controlling factors σ and $\acute{\sigma}$ which control the ticking of the clocks in the primed and unprimed (moving and unmoving) frames. It can be seen here that a clock in motion will tick more slowly, as $\sigma < \acute{\sigma}$. The time dilation factor between the two coordinate frames is given by:

$$\gamma_u = \frac{\acute{\sigma}}{\sigma} = \frac{c}{\sqrt{c^2 - u^2}} = \frac{1}{\sqrt{1 - u^2/c^2}} \tag{5}$$

and we have determined the Lorentz boost factor.
When a clock is at motion with respect to the micro-physical constituents of space-time, its readings no longer match that of a clock at rest, but the two time measurements will be bound by:

$$\acute{t} = t\gamma_u + \alpha \tag{6}$$

The constant α is present here because the tare or offset of the clock has not yet been established. This offset could in theory be different for every clock, and depends on the synchronization procedure of the clocks. γ_u

Because distance scale in a given direction is set by the peculiar speed in that direction, measured distances will also differ when the associated clocks are in motion, according to

$$\acute{d} = d/\gamma_u \tag{7}$$

Distances perpendicular to the motion will be equal in both the real and our assumed micro-physical coordinate systems, as our integration to find the average peculiar velocity in a perpendicular direction is not affected by motion perpendicular to the direction of extension.

The first equations of special relativity are thus explained by the statistical dynamics of space-time constituents, coupled with a choice of using the wave speed, the speed of light, as the local definer of metric.

Discussion and Future Work

Maxwell's equations have defined a century of physics understanding and engineering, enabling untold miracles such as electric power transmission and electronic communications. However underlying theories which explain the existence and geometric connectedness of these fields have encountered difficulties, in part due to the difficulty of probing at the required scales, and gauge invariance required of measuring devices built in and of the continuous media itself. However the utility of an underlying statistical approach in explaining the relevant equations and geometry has not gone unappreciated. Differentiating these theories experimentally to break gauge symmetry also remains a tantalizing goal [e.g. Consoli, 2013; 2015]

We have described here how relativistic time dilation is explained in the statistical theory in reproducing the Lorentz boost factor in Eq. 5 and the spatial dilation in Eq. 7. However, describing relativity using underlying statistical models is not a novel approach. Analog models of gravity [Baceló et al., 2005] show how relativistic geometries appear in well constrained statistical media, and can provide a place to experiment with these ideas, again providing a microscopic understanding of the field equations. It may also be that a deeper understanding of the microphysics will allow further advances in discerning competing theories of general relativity on the very large scale, such as Weyl's conformal gravity, which has been shown to predict galactic rotation curves with great accuracy [Mannheim & O'Brien, 2012; Mannheim, 1993].

References:

Saul, L., “Spin waves as Metric in a Kinetic Space-Time”, Phys.Lett. A314, 472-478 (2003)

Saul, L., “The Dynamic Space of General Relativity in Second Atomization”, General Relativity Research Trends, Horizons in World Physics vol. 249. Albert Reimer, ed.; pp. 153-172, (2005)

Consoli, M., “Newtonian gravity from the Higgs field: the sublimation of aether”, arXiv:hep-ph/0109215, (2001)

Consoli, M., Costanzo, E., “Is the physical vacuum a preferred frame?”, Eur.Phys.J. C54:285-290, (2007)

Consoli, M., Matheson, C., Pluchino, A., “The classical ether-drift experiments: a modern re-interpretation”, Eur. Phys. J. Plus 128: 71, (2013)

Consoli, M., “Probing the Vacuum of Particle Physics with Precise Laser Interfermometry”, Foundations of Physics, Volume 45, Issue 1, pp 22-43, (2015)

F. Meno, “A Plank-Length Atomistic Kinetic Model of Physical Reality”, Phys. Essays, 4, 94, (1991)

Kaniadakis, G.,“Statistical Origin of Quantum Mechanics”, Physica A 307, 172; (2002)

Marmanis, H., “Analogy between the Navier-Stokes and Maxwell's equations: Application to Turbulence”, Phys. Fluids 10 (6), 1428-1437, (1998)

Larmor, J., “Aether and Matter”, Cambridge University Press, Cambridge (1900)

Mannheim, P., O'Brien, J., “Galactic rotation curves in conformal gravity”, arXiv:1211:0188, (2012)

Mannheim, P., “Linear Potentials and Galactic Rotation Curves”, Astrophys.J. 419, 150-154, (1993)

Weyl, H., “Gravitation and Electricity”, Sitzungsber. Preuss. Akad. Berlin (1918)

O'Raifeartaigh, L., “Dawning of Guage Theory”, Princeton Univ. Press, (1997)

F. Winterburg, “Derivation of quantum mechanics from the Boltzmann equation for the Planck aether”, International Journal of Theoretical Physics,34, 2145, (1995) Rovelli, C., Smolin, L., “Loop space representation of quantum general relativity”, Nuclear Physics B331: 80–152, (1990)

Smolin, L "Atoms of Space and Time", Scientific American, January (2004)

Barceló, C., Liberati, S., Visser, M., “Analogue Gravity”, Living Rev. Relativity 8 (2005)