Title: Symmetry Principles in Physics - Lecture 2

Date: Apr 21, 2008 11:00 AM

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Abstract:

2. Should SR be a template for a fundamental reformulation of QM?

H.R.B. and Christopher G. Timpson. 'Why special relativity should not be a template for a fundamental reformulation of quantum mechanics'. in *Physical Theory and Its Interpretation: Essays in Honor of Jeffrey Bub*. W. Demopoulos, I. Pitowsky (eds.). Springer. 2006: pp. 29–41.

arXiv:quant-ph/0601182

the role of the relativity principle, isotropy

Einstein 1905

Relativity principle
Light postulate
Poincaré-Einstein synchrony convention

invariance of light-speed
k-Lorentz transformations
(see Bogoslovsky-Budden transformations)

Relativity principle
spatial isotropy

$k = 1$
Lorentz transformations

Ignatowski 1910-11

Relativity principle
Synchrony convention
Isotropy
Reciprocity

Existence of invariant speed
Ignatowski transformations

$$x' = (1 - Kv^2)^{-1/2}(x - vt)$$
$$y' = y$$
$$z' = z$$
$$t' = (1 - Kv^2)^{-1/2}(t - Kvx)$$

H.R.B. *Physical Relativity* (2005), Chs. 5,6

Lesson for QM?

Clifton, Bub and Halvorson (2002): considered three principles:

no superluminal information transmission between two systems
no broadcasting of information contained in an unknown physical state
no unconditionally secure bit-commitment

A theory formulated in C*-algebraic terms so constrained incorporates a non-commuting algebra of observables for individual systems, kinematic independence for the algebras of space-like separated systems and the possibility of entanglement between space-like separated systems.

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"The fact that one can characterize quantum theory ... in terms of just a few simple information-theoretic principles ... lends credence to the idea that an information-theoretic point of view is the right perspective to adopt in relation to quantum theory. ...[W]e are suggesting that quantum theory be viewed, not as first and foremost a mechanical theory of waves and particles ... but as a theory about the possibilities and impossibilities of information transfer."

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"The foundational significance of our derivation, as we see it, is that quantum mechanics should be interpreted as a *principle theory*, where the principles at issue are information-theoretic. The distinction between *principle* and *constructive* theories is introduced by Einstein in his discussion of the significance of the transition from Newtonian to relativistic physics."

Einstein's misgivings

Einstein's misgivings

- limitations of thermodynamic template (1907, 1908)
  SR only a "(half) salvation" to the "predicament" posed by the MM experiment

- treatment of rods and clocks as primitive bodies, and not "moving atomic configurations" (1921, 1949)

- the special role of light (1935, 1949)

"The special theory of relativity grew out of the Maxwell electromagnetic equations. But ... the Lorentz transformation, the real basis of special-relativity theory, in itself has nothing to do with the Maxwell theory." (1935) "... the Lorentz transformation transcended its connection with Maxwell's equations and had to do with the nature of space and time in general." (1955)

Einstein vs pre-Einstein

the trail-blazers

1905: *annus mirabilis*

vs

Einstein vs pre-Einstein

the trail-blazers

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1905: *annus mirabilis*

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1850s: *anni mirabili*

motion-induced shape deformation:

an answer to the 1887 MM conundrum

G F FitzGerald (following Heaviside) 1889

H A Lorentz 1892, 1895

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" ...the length of material bodies changes, according as they are moving through the ether or across it, by an amount depending on the square of the ratio of their velocities to that of light."

"The suggestion bore the impress of truth from the first."
Oliver Lodge (1909)

'Happy are those who are gifted with that immediate feeling for "truth"'. Silberstein (1914)

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$1 + \delta$ (longitudinal); $1 + \varepsilon$ (transverse)

$$\varepsilon - \delta \sim v^2/2c^2$$

The ratio of the deformation factors was "the source of all our troubles".

dynamics to the rescue!

"We know that electric forces are affected by the motion of electrified bodies relative to the ether [HEAVISIDE] and it seems a not improbable supposition that the molecular forces are affected by the motion and that the size of the body alters consequently." (1889)

"... [deformation] is by no means far-fetched, as soon as we assume that molecular forces are also transmitted through the ether, like the electric and magnetic forces... Now, since the form and dimension of a solid body are ultimately conditioned by the intensity of molecular actions, there cannot fail to be a change of dimensions as well. (1895)

" ... the interpretation given by me and FitzGerald was not artificial ... one arrives at the [deformation] hypothesis if one extends to other forces what one could already say about the influence of a translation on electrostatic forces. Had I emphasized this more, the hypothesis would have created less of an impression of being invented *ad hoc*." (1915)

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What is the role of the ether?


TORBAY CIVIC SOCIETY
OLIVER HEAVISIDE F.R.S.
1850-1925
MATHEMATICIAN AND SCIENTIST
RENOWNED WORLDWIDE FOR HIS
CONTRIBUTION TO ELECTROMAGNETIC
THEORY AND PREDICTION OF THE
HEAVISIDE LAYER OFF WHICH
RADIO SIGNALS ARE REFLECTED
LIVED HERE
1859-1897


OLIVER
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Premonitions of time dilation

Joseph Larmor (1857–1942)

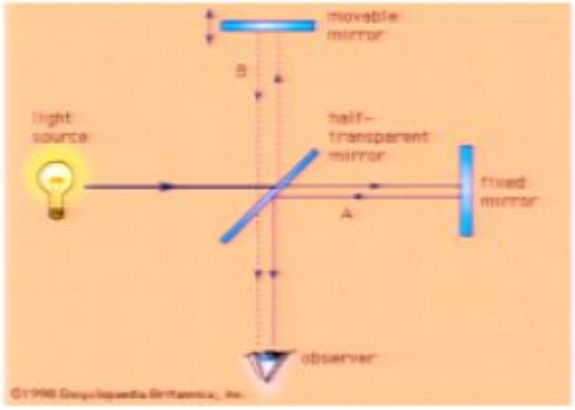
In 1897, predicted time dilation for a moving system of orbiting charged particles (inspiration for Bell 1976?)

Ives (1937), Kittel (1974), Bell (1976), vs Rindler (1970)

Hendrik Antoon Lorentz (1853–1928)

In 1899, independently predicted time dilation for a moving source of monochromatic light.

Janssen (1995)



1888 Liénard version: implies FitzGerald-Lorentz deformation, and (*k*-dependent) time dilation for light source

Henri Poincaré (1854-1912)

- c. 1900 understood the conventionality of distant simultaneity, and the meaning of Lorentz' "local time" (and hence the relativity of simultaneity)

- first to claim that the relativity principle applies to electrodynamics exactly; argued for $k = 1$ on similar grounds to Einstein; ambivalent about the role of the ether; c. 1905 anticipated aspects of Minkowskian space-time geometry

- overlooked the dynamical plausibility arguments of FitzGerald and Lorentz for length contraction (a "*coup de pouce*"); did not see contraction as a consequence of the Lorentz transformations; possibly overlooked time dilation before Einstein's 1905 paper

Early Einstein

Einstein's problem: the light quantum

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"Reflections of this type [on the dual wave-particle nature of radiation] made it clear to me as long ago as shortly after 1900, i.e. shortly after Planck's trailblazing work, that neither mechanics nor electrodynamics could (except in limiting cases) claim exact validity. By and by I despaired of the possibility of discovering the true laws by means of constructive efforts based on known facts." Einstein (1949)

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Einstein's policy of despair: using the template of thermodynamics

"The longer and more despairingly I tried, the more I came to the conviction that only the discovery of a universal formal principle could lead us to assured results. The example I saw before me was thermodynamics. The general principle was there given in the statement: the laws of nature are such that it is impossible to construct a perpetuum mobile (of the first and second kind). How, then, could such a universal principle be found?" Einstein (1949)

Albert Einstein 1905

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- abandonment of a constructive approach; used template of thermo-dynamics
- emphasis on operational analysis of coordinate systems and their transformations: first to read length contraction and time dilation directly off the transformations; first to understand dilation as a universal phenomenon
- rediscovered (?) Poincaré's analysis of conventionality of distant simultaneity, allowing for the understanding of relativity of simultaneity factor.
- independently of Poincaré, understood role of spatial isotropy in deriving the correct scale factor ($k = 1$) in the conformal ("k-Lorentz") transformations
- rejected ether, not as impossible or self-contradictory, but merely as redundant (partly anticipated by Poincaré)

Einstein's misgivings

Einstein on Special Relativity

1907 reply to Paul Ehrenfest:

"The principle of relativity, or, more exactly, the principle of relativity together with the principle of the constancy of velocity of light, is not to be conceived as a "complete system", in fact, not as a system at all, but merely as a heuristic principle which, when considered by itself, contains only statements about rigid bodies, clocks, and light signals. . . . . we are ... dealing here ... only with a principle that (similar to the second law of the theory of heat) permits the reduction of certain laws to others."

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1908 letter to Arnold Sommerfeld:

"So, first to the question of whether I consider the relativistic treatment of, e.g., the mechanics of electrons as definitive. No, certainly not. It seems to me too that a physical theory can be satisfactory only when it builds up its structures from elementary foundations. The theory of relativity is not more conclusively and absolutely satisfactory than, for example, classical thermodynamics was before Boltzmann had interpreted entropy as probability. If the Michelson–Morley experiment had not put us in the worst predicament, no one would have perceived the relativity theory as a (half) salvation. Besides, I believe that we are still far from having satisfactory elementary foundations for electrical and mechanical processes."

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In both cases, Einstein was emphasizing the limitations of SR, not its strengths.

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BUT:

"It seems to me ... that a physical theory can be satisfactory only when it builds up its structures from elementary foundations." (1908)

"... when we say we have succeeded in understanding a group of natural processes, we invariably mean that a constructive theory has been found which covers the processes in question." (1919)

Einstein's "sin"

1921 "It is . . . clear that the solid body and the clock do not in the conceptual edifice of physics play the part of irreducible elements, but that of composite structures, which must not play any independent part in theoretical physics. But it is my conviction that in the present stage of development of theoretical physics these concepts must still be employed as independent concepts; for we are still far from possessing such certain knowledge of the theoretical principles of atomic structure as to be able to construct solid bodies and clocks theoretically from elementary concepts." *Geometry and experience*

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1949 "One is struck [by the fact] that the theory [of special relativity] . . . introduces two kinds of physical things, i.e. (1) measuring rods and clocks, (2) all other things, e.g., the electromagnetic field, the material point, etc. This, in a certain sense, is inconsistent; strictly speaking measuring rods and clocks would have to be represented as solutions of the basic equations (objects consisting of moving atomic configurations), not, as it were, as theoretically self-sufficient entities. However, the procedure justifies itself because it was clear from the very beginning that the postulates of the theory are not strong enough to deduce from them sufficiently complete equations . . . in order to base upon such a foundation a theory of measuring rods and clocks. . . . But one must not legalize the mentioned sin so far as to imagine that intervals are physical entities of a special type, intrinsically different from other variables ('reducing physics to geometry', etc.)." *Autobiographical Notes*

"Should one, then, completely abandon any attempt to explain the Lorentz contraction atomistically? We think that the answer to this question should be No. The contraction of a measuring rod is not an elementary but a very complicated process. It would not take place except for the covariance with respect to the Lorentz group of the basic equations of electron theory, as well as of those laws, as yet unknown to us, which determine the cohesion of the electron itself."

Pauli 1921

"There is really nothing mysterious about the FitzGerald contraction. It would be an unnatural property of a rod pictured in the old way as continuous substance occupying space in virtue of its substantiality; but it is an entirely natural property of a swarm of particles held in delicate balance by electromagnetic forces, and occupying space by buffeting away anything that tries to enter."

Eddington 1928

Dynamical underpinning of kinematics

H. Weyl 1918, W. Pauli 1921, A.S. Eddington 1928,
W.F.G. Swann 1941, L. Jánossy 1971, J.S. Bell 1976, 1992,
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Bell 1992 "If you are, for example, quite convinced of the second law of thermodynamics, of the increase of entropy, there are many things that you can get directly from the second law which are very difficult to get directly from a detailed study of the kinetic theory of gases, but you have no excuse for not looking at the kinetic theory of gases to see how the increase of entropy actually comes about. In the same way, although Einstein's theory of special relativity would lead you to expect the FitzGerald contraction, you are not excused from seeing how the detailed dynamics of the system also leads to the FitzGerald contraction."

Special relativity, like thermodynamics, is not a fundamental theory. It is a "restricting principle" on fundamental theories of the non-gravitational interactions (theory of matter).