Einstein as Historian

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Abstract

Einstein was so fascinated by the rapid change in the theoretical nature of physics that he couldn't resist writing essay after essay on the subject, which he would often refer to as the 'evolution of physics.' But in the process of his so doing, he had become an amateur historian.

Keep an open mind – that's the secret!
— Doctor Who

1 Guessing at a chronology

Einstein was apparently often asked how he came to the theory of relativity. In answer to that, he had to himself recollect on the important events and their proper chronology.

My intention in this work is to try to reverse-engineer some of the thoughts that I believe Einstein was thinking about as he tried to make sense of the ether just prior to his setting forth special relativity (SR). I will provide some of the clues that Einstein left us, which he placed here and there throughout his writings from 1905 to the time of his death in 1955. I believe that it is these thoughts, and not the exact history of his mathematical computations, that is the real important aspects to look at in my search for the meaning of relativity and how to develop a logic of theory invention. The first question to answer is, Why bother? Well, I think there is a lot to learn from the techniques employed by successful theorists.

This is what Einstein said about gaining a foothold in the realm of new ideas:

> Fundamental ideas play the most essential role in forming a physical theory. Books on physics are full of mathematical formulae. But thought and ideas, not formulae, are the beginning of every physical theory.
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> — *The Evolution of Physics*, Einstein & Infeld, Touchstone, 1938, p. 277.

I imagine that Einstein was referring in part to his thoughts that led him to invent special relativity. Let's look at a statement he made about those thoughts in a lecture he gave in Japan in 1922:

> It was more than seventeen years ago that I had an idea of developing the theory of relativity for the first time. While I cannot say exactly where that thought came from, I am certain that it was contained in the problem of the optical properties of moving bodies. Light propagates through the sea of ether, in which the Earth is moving. In other words, the ether is moving with respect to the Earth. I tried to find I clear experimental evidence for the flow of the ether in the literature of physics, but in vain.
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> Then I myself wanted to verify the flow of the ether with respect to the Earth, in other words, the motion of the Earth. When I first thought about this problem, I did not doubt the existence of the ether or the motion of the Earth through it....
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> While I was thinking of this problem in my student years, I came to know the strange result of Michelson's experiment. Soon I came to the conclusion that our idea about the motion of the Earth with respect to the ether is incorrect, if we admit Michelson's null result as a fact. This was the first path which led me to the special theory of relativity. Since then I have come to believe that the motion of the Earth cannot be detected by any optical experiment, though the Earth is revolving around the Sun.
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> I had a chance to read Lorentz's monograph of 1895.... At that time I firmly believed that the electrodynamic equations of Maxwell and Lorentz were correct. Furthermore, the assumption that these equations should hold in the reference frame of the moving body leads to the concept of the invariance of the velocity of light, which, however, contradicts the addition rule of velocities used in mechanics.
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> —First few paragraphs from the transcribed speech given by Einstein in when he was in Japan in 1922. ("How I created the theory of relativity," translated by Yoshimasa A. Ono, *Physics Today*, Aug. 1982, pp. 45–47.)

Then, he went on to say, that with the help of his friend Michele Besso, he was able to come to the astounding conclusion that 'time cannot be absolutely defined' — a conclusion which to this day confounds and irritates the Einstein debunkers and conspiracy promoters.

Before we go back to the beginning of this quoted passage and point out some important features, let's first lay a contextual foundation Einstein was working within. He was working within the context of the Maxwell-Lorentz ether concepts. This ether was originally invented freely by Maxwell to explain how light, which seems to be a wave-like thing, can propagate through so-called empty space. This ether had presumed mechanical properties, in fact, the idea of a mechanical ether was natural in view of the prominent research program which had won the day after Newton's death. Einstein would later call it the "Mechanical Program" in the book he co-authored with Infeld called *The Evolution of Physics*.

Einstein described it this way:

> According to Newton's system, physical reality is characterized by the concepts of space, time, material point, and force (reciprocal action of material points). Physical events, in Newton's view, are to be regarded as the motions, governed by fixed laws, of material points in space. The material point is our only mode of representing reality when dealing with changes taking place in it, the solitary representative of the real, in so far as the real is capable of change. ... All happenings were to be treated purely mechanically—that is to say, simply as motions of material points according to Newton's law of motion. [reference below]

Einstein goes on to complain about the arbitrary and kludgy way that different kinds of "material" particles are introduced to account for ordinary matter, light, and charged matter

> Moreover, it is unsatisfactory in any case to introduce into the discussion material points of quite a different sort, which had to be postulated for the purpose of representing ponderable matter and light respectively. Later on, electrical corpuscles were added to these, making a third kind, again with completely different characteristics. It was, further, a fundamental weakness that the forces of reciprocal action, by which events can be determined, had to be assumed hypothetically in a perfectly arbitrary way. Yet this conception of the real accomplished much: how came it that people felt compelled to forsake it?
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> — Found in: "Maxwell's influence on the evolution of the idea of physical reality," Einstein, *Ideas and Opinions*, Three Rivers Press, pp. 266–267.

I don't have the time to go into all the wonderful things Einstein had to say about the concept of the field, but I will mention the following quote and the reader can take it from there:

> . . .before Maxwell people conceived of physical reality—in so far as it is supposed to represent events in nature—as material points whose changes consist exclusively as motions, which are subject to total differential equations. After Maxwell they conceived physical reality as represented by continuous fields, not mechanically explicable, which are subject to partial differential equations. This change in the conception of reality is the most profound and fruitful one that has come to physics since Newton; but it has at the same time to be admitted that the program has by no means be completely carried out

> yet. The successful systems of physics which have been evolved since rather represent compromises between these two schemes which for that very reason bear a provisional, logically incomplete character, although they may have achieved great advances in certain particulars.
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> — Found in: "Maxwell's influence on the evolution of the idea of physical reality," Einstein, *Ideas and Opinions*, Three Rivers Press, p. 269.

I believe what Einstein means by "logically incomplete character" of the program (i.e., the research program that mixes them together) is that these "material points" don't "logically" mix well with principles, which is the constructive mode of theory building, to use Einstein's own term. One can always reconstruct a principle theory as a constructive theory and vice versa, by use of some creative interpretations. In particular, SR consists of the point mass particles of Newton's program and two additional principles of SR, the Light Principle and the (Special) Principle of Relativity.

So, how does Einstein justify calling SR a principled theory even though it contains a constructive Newtonian theory at its core? I can fix this myself with two reasonable design principles: First, what we do is to reduce the Newtonian theory to a trusted body of trusted Newtonian knowledge. Second, that we can define a theory which is a generalization of a constructive theory to be a principle theory if it adds only principles to the constructive theory. Why not? In the end, however, Einstein's goal was to make classifying distinctions that each physicist can employ personally in a practical way to guide his or her thinking in physics theorizing. Call it a 'principle' or 'constructive' theory.

> We must not be surprised therefore, that, so to speak, all physicists of the last century classical mechanics a firm and final foundation for all physics, yes, indeed, for all natural science, and that they never grew tired in their attempts to base Maxwell's theory of electromagnetism, which, in the meantime, was slowly beginning to win out, upon mechanics as well.
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> — Found in: "Autobiographical Notes," *Albert Einstein: Philosopher-Scientist*, Vol. 1, Open Court Classics, 1949, p. 21.

In other words, this was the mechanical mindset Einstein was up against, though, as he admits, it was somewhat being eroded by the field-theoretical approach to Maxwell's equations. Einstein, however, did get tired of that old way of thinking, and had to reject it in the end to make progress, ending in the invention of what came to be known as special relativity.

If we accept that the misgivings of the mechanical program were Einstein's prior to his invention of SR, which I do, and that he accomplished a sort of analysis of the weaknesses of the mechanical program during the gestation period of forming SR prior to 1905, then it is also clear that the clarity of analysis that Einstein was able to bring to the discussion, which apparently his then peers, were not able to do (except perhaps Poincare), was simply because to Einstein, the intersection of what the theorists can talk about and what the experimentalists can talk about centers around the concept of the event, and a 'measurement' being a mapping of event pairs into the reals or a set of reals (components). Thus, it is the duty of the theorist to invent theories that account for how measurements will be made of event pairs in all inertial reference frames.[1]

The switch of the formal point of view that dethroned the preeminence of the point particle model and elevated the "event" in its place is the beginning of the relativistic research program, and was the key to building a principle theory that deals with the notions of metrical phenomena, reference frame, and "relativistic law of physics." It is on the subtlety of the concept of event that the invention of special relativity hung. Sure, the notion of event was already there in Newton's mechanics, undergirded by the Galilean transformation equations, but Galilean relativity – if we may call it that – trivialized the notion of event because it held space and time to be absolute in themselves; that is, independent of each other in all reference frames.

The classical physicist, doing routine mechanics, hardly had a reason to compare events in different reference frames. But when Einstein analyzed the expansion of a spherical wave front emitted from a point source, constrained by the Lorentz transformation, he had to come to terms with how to map measurements of event pairs into two different inertial reference frames at the same time. This inevitably led to his conclusion that time cannot be absolutely defined (or put another way, the lack of distance simultaneity, or the lack of universal simultaneity).

So, here we've arrived at an important philosophical conclusion that is hated by many people who don't understand the need for relativity (which I'll put in my own words):

> Physics cannot invent theories of the physical realm that are logically independent of the instrumentalities it uses to measure the observables of its theories. Why? Because the instrumentalities we use to make measurements with are either physical devices which are extended in space or extended in time or both, requiring us to deal with events pairs and how they transform in different reference frames. Furthermore, if we are to posit the equation of a law that regulates observable quantities over some equivalent set of reference frames, then we need to also specify the transformation rule that leaves this law invariant in form when the coordinates are transformed between these equivalent frames.

[1] An event pair is required to make any measurement. If you want to measure the length of a moving rigid rod, say, you must use either a simultaneous location of its ends in a system of synchronized clocks, or else use one location in space and two different 'locations' in time (as its ends pass by). Even the taking of a temperature by an ordinary thermometer requires that the instrument was previously calibrated before its use in the field.

2 The disunity between mechanics and optics in the early 20th century

For starters we have three problems between what Newtonian mechanics allows and what Maxwell's theory of light allows:

1) Newton's mechanics allows for arbitrarily large speeds, but Einstein concluded on the basis of his thought experiment about watching a standing light wave (at age sixteen) that no reference frame can travel at the speed of light.

2) Yet another problem between Maxwell and Newton which we read above (page 2) on the invariance of the velocity of light:

> At that time I firmly believed that the electrodynamic equations of Maxwell and Lorentz were correct. Furthermore, the assumption that these equations should hold in the reference frame of the moving body leads to the concept of the invariance of the velocity of light, which, however, contradicts the addition rule of velocities used in mechanics.
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> Why do these two concepts contradict each other? I realized that this difficulty was really hard to resolve. I spent almost a year in vain trying to modify the idea of Lorentz in the hope of resolving this problem.
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> — Found in: The transcribed speech given by Einstein in when he was in Japan in 1922. ("How I created the theory of relativity," translated by Yoshimasa A. Ono, *Physics Today*, Aug. 1982, pp. 46.)

3) This one takes a little thought. Newtonian mechanics can be characterized by laws covariant under Galilean transformations; but Maxwell's electrodynamics by laws covariant under Lorentz transformations. So, if we posit that all phenomena is describable by laws covariant under some transformation, what transformation would that be that characterizes the interaction of light with a mechanical particle, such as occurs in the photo-electric effect or Compton scattering? Would it be the Galilean, Lorentzian, or some other covariance transformation?

How can the phenomena of two different kinds interact yet have different characterizing covariances. It doesn't make sense. If there are laws that describe the interaction, these laws should, by use of induction on the meaning of general law of physics gleaned from mechanics (Galilean covariance) and optics (Lorentz covariance) should also be guided in its construction by the heuristic of some covariance. We should also remember that any experiment that would measure any property of light would require the use of macroscopic matter to build the measuring instruments to do so. And such an instrument is already a Newtonian mechanical device.

In each of the three cases above we get either a direct "contradiction," implying a condition of non-unity to Einstein, or we get, as in the last case, an indication of how to unify by finding some appropriate covariance to describe the interaction phenomena. The motivation to Einstein to deal with this combined phenomena of mechanics and optics (electromagnetism) was to resolve apparent contradictions in our human description of Nature. In the end he unified the two by his invention of a new meaning to a "law of nature," which combines the two according to how their respective laws transform, rather than on trying to model the two phenomena as being "the same thing." In other words, the unification Einstein eventually found for mechanics and electrodynamics came from the similarity of form their governing equations would have, that being Lorentz invariant. A particularly good example of this is the relativistic Lorentz force law

$$F^{\alpha} = qF^{\alpha\beta}U_{\beta} \,, \tag{1}$$

which describes the force on a charged particle under the influence of electromagnetic fields. If the force is known is a particular inertial reference frame, it can be calculated for any other inertial reference frame. A force in one frame that appears as purely electric, can appear in some other frame as both electric and magnetic.

So, Einstein was pondering these things and playing around with the math and eventually stumbled upon that fact the only two postulates, added on to Newtonian mechanics (as a limiting case) and Maxwell's equations, could reproduce the electrodynamics of moving bodies. But this is not the end of the story. Something is left out of the explanation so far, at least as far as Einstein was concerned. He made a fuss over the difference in kind of theory that he produced compared to those of the previous attempts to deal with optics and mechanics. The previous mindset (formal point of view) was to build upon the successes of the Newtonian mechanics, which was the use of mechanical models of interacting point masses, and attempt to extend this program to include optical phenomena as well. This is at first a very reasonable thing to do. Generally speaking, one should always try to take a research paradigm to its limits, and the so-called Mechanical Program, as Einstein termed it, was just this attempt to place all phenomena under the heading: "Interacting particles and elastic mediums rule here over everything."[2]

At the bottom of this formal point of view was the notion of the speculative model of matter, meaning that models of matter are introduced that are not obviously "true" by naked-eye observation. In other words, models of matter, such as the rigid body, that are obvious to the naked-eye are not "speculative," though such a model its clearly approximate. But models of matter that cannot be confirmed by naked-eye observation are "speculative." Now, Einstein did not provide us with a definition of "speculative." He just introduced the speculative-nonspeculative distinction and apparently thought that its meaning would be obvious to the readers. There was no question that the mechanical program employed speculative models by this definition. The entire program was justified by its success, speculative models notwithstanding.

[2]Lorentz assumed that rigid rods elastically contract in the direction of their absolute motion.

Now, it seems quite apparent to me that Einstein bothered to make this distinction between speculative-nonspeculative modes, because he realized that the obvious new path to take was not about finding a common speculative model shared by mechanical and optical phenomena because he had a ready-made unification by the artifice of the covariance of the laws dealing with these phenomena, as I already indicated above. Einstein said that his guiding example for a new way to think about theories rested in the classical theory of thermodynamics.

> We can distinguish various kinds of theories in physics. Most of them are constructive. They attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start out. Thus the kinetic theory of gases seeks to reduce mechanical, thermal, and diffusional processes to movements of molecules – i.e., to build them up out of the hypothesis of molecular motion. When we say that 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.
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> — Found in: " What is the Theory of Relativity?" A. Einstein, *Ideas and Opinions*, Three Rivers Press, p. 228.

Thus, when the Einstein debunkers complain that Einstein had created in SR a "math theory" that "explains nothing" (such as, **how** light moves from point A to point B in space), they are at least partly correct, as Einstein himself explained in the above paragraph. Let's continue.

> Along with this most important class of theories there exists a second, which I will call "principle-theories." These employ the analytic, not the synthetic, method. The elements which form their bases and starting-point are not hypothetically constructed but empirically discovered ones, general characteristics of natural processes, principles that give rise to mathematically formulated criteria which these separate processes or the theoretical representations of them have to satisfy. Thus the science of thermodynamics seeks by analytical means to deduce necessary conditions, which separate events have to satisfy, from the universally experienced fact that perpetual motion is impossible. [same as the last reference]

What Einstein was referring to in SR is the principle of the constancy of the speed of light in a vacuum as measured in any inertial frame,[3] which was consistent with the null result of the Michelson-Morley experiment. (It was also consistent with the Lorentz transformation equations of Maxwell's equations.) To Einstein, it didn't need to be explained; it just was an empirical fact! The only question for him to resolve was how he would make use of this empirical fact? Let's continue.

[3]See the appendix for the controversy this 'innocent' principle can engender.

> The advantages of the constructive theory are completeness, adaptability, and clearness, those of the principle theory are logical perfection and security of the foundations.
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> The theory of relativity belongs to the latter class. In order to grasp its nature, one needs first of all to become acquainted with the principles on which it is based. Before I go into these, however, I must observe that the theory of relativity resembles a building consisting of two separate stories, the special theory and the general theory. The special theory, on which the general theory rests, applies to all physical phenomena with the exception of gravitation; the general theory provides the law of gravitation and its relations to the other forces of nature.
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> — Found in: "What is the Theory of Relativity?", Einstein, *Ideas and Opinions*, Three Rivers Press, p. 228-9.

Let's go further about this notion of "logical perfection and security of the foundations." In his autobiography, Einstein made a point to talk about this occurrence in his life at age twelve that greatly influenced his patterns of thought that set the stage for him to see beyond the constructive mode of theorizing, popular since Newton's time:

> At the age of 12 I experienced a second wonder of a totally different nature: in a little book dealing with Euclidean plane geometry, which came into my hands at the beginning of the school year. Here were assertions, as for example the intersection of the three altitudes of a triangle in one point, which—though by no means evident—could nevertheless be proved with such certainty that any doubt appeared to be out of the question. The lucidity and certainty made an indescribable impression upon me. In any case it was quite sufficient for me if I could peg proofs upon propositions the validity of which did not seem to me to be dubious.
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> — Found in: "Autobiographical Notes," *Albert Einstein: Philosopher-Scientist*, Vol. 1, Open Court Classics, 1949, p. 9.

For me, this passage of his autobiography indicates Einstein's profound attachment to the methods of pure mathematics. This cannot be helped to a large extent, and Einstein admits this himself. Einstein seems to connect the lucidity and certainty of Euclidean geometry with the logical perfection and security of the foundations of his principle theories. He was primed from an early age to seek the clarity of what his principle theories when he could find them. In fact, I believe that Einstein harbored a secret regret that the foundations of physics were not more like the logical foundations of pure mathematics.

Generally speaking: Principle theories are best for inspiring broad research programs, and models get built on top of them (or better expressed as: shoehorned into them). Constructive theories go deep at the expense of (not) going broad. Constructive theories are founded on some notion of primary thingness, be that the point mass particle or the mechanical ether of Maxwell, but Nature seems to bridge the diverse kinds of phenomena not by thingness in common but by behavior in common (i.e., set down by empirically derived mathematical 'principles'). Behavior is determined by macroscopic measuring instruments.

Abstractly, that behavior is formalized by 'physical laws' that are constrained by the covariances of transformations of the laws that describe the phenomena. The use of this knowledge is twofold. First, we can use covariances as a natural means of classification of kinds of phenomena, and second, that we can use covariances as a heuristic in the search for the "general laws of physics" within a given theory.

> Since, however, sense perception only gives information of this external world or of "physical reality" indirectly, we can only grasp the latter by speculative means. It follows from this that our notions of physical reality can never be final. We must always be ready to change these notions — that is to say, the axiomatic sub-structure of physics — in order to do justice to perceived facts in the most logically perfect way.[4]
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> — Found in: "Maxwell's influence on the evolution of the idea of physical reality," Einstein, *Ideas and Opinions*, Three Rivers Press, p. 266.

Comments on discovery of special relativity in autobiographical notes:

> By and by I despaired of the possibility of discovering the true laws by means of constructive efforts based on known facts. 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 theorem: 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? After ten years of reflection such a principle resulted from a paradox upon which I had already hit at the age of sixteen: If I pursue a beam of light with the velocity c (velocity of light in a vacuum), I should observe such a beam of light as a spatially oscillatory electromagnetic field at rest. However, there seems to be no such thing, whether on the basis of experience or according to Maxwell's equations. From the very beginning it appeared intuitively clear to me that, judged from the standpoint of an observer, everything would have to happen according to the same laws for an observer who, relative to the earth, was at rest. For how, otherwise, should the first observer know, i.e., be able to determine that he is in a state of fast uniform motion?

[4]Perhaps the Apostle Paul foresaw this long ago, when he claimed 'we see through a glass, darkly'.

> One sees that in this paradox the germs of the special relativity theory is already contained. Today everyone knows, of course, that all attempts to clarify this paradox satisfactorily were condemned to failure as long as the axiom of the absolute character of time, viz., of simultaneity, unrecognizedly was anchored in the unconscious. Clearly to recognize this axiom and its arbitrary character really implies already the solution of the problem. The type of critical reasoning which was required for the discovery of this central point was decisively furthered, in my case, especially by the reading of David Hume's and Ernst Mach's philosophical writings.
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> — Found in: "Autobiographical Notes," *Albert Einstein: Philosopher-Scientist*, Vol. 1, Open Court Classics, 1949, p. 53.

In the phrase, "The general principle was there given in the theorem: the laws of nature are such that it is impossible to construct a perpetuum mobile," Einstein referred to a "theorem" but he could have also employed direct empirical observation that everyone already knows who ever wound-up machine only to find that it will eventually wind down; that is, it can't run forever doing useful work.

This is proof to me that Einstein here claimed that the linchpin of the invention of special relativity was the formal point of view he adopted in the negative principle (what he called a universal formal principle) of the impossibility of any reference frame to move at the speed of light. However, an alternative formulation of this negative principle could be: It is impossible by use of any optical experiment performed in a contained laboratory in any inertial reference frame to detect that frame's so-called 'absolute velocity'; i.e., its velocity relative to some 'absolute rest frame'.

What this implies is that in any theory that employs such an absolute rest frame, such as the rest frame of the luminiferous ether, that rest frame has no physical content. Sure, one is free to invent a theory that hypothesizes an absolute rest frame for light propagation. And sure enough, such an hypothesis is part of the logical content of theory, but it's not part of the physical content of the theory. Why? Because the Lorentz transformation with regard to optical phenomena makes all inertial reference frames equivalent. That is, any inertial frame could equally well serve as this 'absolute frame of reference' and the observable behavior of objects according to the equations of electrodynamics would stay the same.

Now, I equate 'hypothetically constructed' and 'speculative' as the same thing. The advantage of the principle theory is its security of foundation, Einstein tells us, but at the price of incompleteness of description afforded by speculating about models of things in the micro-world.

The easy thing to overlook here is that the disunity Einstein believed existed was resolved by him by generalizing what is meant by a "law of physics." First, let's define what we mean by a "law of physics": it is an invariable relationship between the variables of physics, put very simply. But this doesn't get us very far in Einstein's mind, because phenomena is partitioned "naturally" into categories according as its covariance goes. I'm now going to speculate a bit: In other words, at the heart of physical law is reference frame and how measurements are made within them. To Einstein it was an empirical "fact" that phenomena are described in terms of human equations in the form of "general laws of physics," that is, in terms of laws that manifest some covariance. In fact, it is implicitly defined by Einstein that the "general" in the "general laws of physics" is covariance. To make a law of physics meaningful in this formal point of view, one has to convert them into generally covariant form, meaning that the "general" law is not just these invariable relationships, but it is also invariable relationships that are also covariant under some transformation group, to account for the infinite variety of reference frames that the 'general law' must hold good within.

3 The General Laws of Physics

Do not fear that special relativity has eliminated Newtonian physics. Instead, it retains Newtonian physics as the low-velocity limit of SR. For in the limit as velocities of particles go much less than the speed of light, the dynamical equations of SR to go the dynamical equations of Newton, and the Lorentz transformation equations go to the Galilean transformation equations.

The following was Einstein's view in 1938 on his frame of mind in 1904–5 regarding the mechanical (understandable) ether as the medium of light propagation:

> Science did not succeed in carrying out the mechanical programs convincingly, and today no physicist believes in the possibility of its fulfillment.
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> — *The Evolution of Physics*, Einstein & Infeld, Touchstone, 1938, p. 121.

This is what I think happened to Einstein: He was embroiled in these Lorentz-like computations, duplicitously treating the electric and magnetic fields as irreducible (i.e., not bothering to think of them a states of an ether) or, at other times treating them as reducible to mechanical states of this ether, when the thought occurred to him that if he were ever to succeed, he must formally accept that the electric and magnetic fields are not mechanically reducible, and as a result make the mechanical ether concept superfluous. And as a result of this, came the inference that the Mechanical Program had run out of steam, and could no longer be trusted as a foundation for the advancement of physics.

In the case of special relativity, Einstein told us the intuition he relied on to bring order out of chaos: It was the

> . . .universal formal principle [that] could lead us to assured results. . . .. From the very beginning it appeared intuitively clear to me that, judged from the standpoint of an observer, everything would have

> to happen according to the same laws for an observer who, relative to the earth, was at rest. [quoted above]

That is, if the observer is at 'rest' on the earth's surface, then he is not 'moving with respect to the presumed absolute rest frame of the mechanical ether'.[5] In other words, Einstein was claiming that the physicist is free to consider the earth's surface as a 'rest frame' for all experiments sufficiently localized in space and time, regardless of whatever motion one envisions the earth to have in the universe. So, if one is always allowed to think of one's frame as (quasi) inertial over small enough space-time regions, then what purpose is served by supposing the existence of some absolute space that assigns this reference frame an absolute velocity?

In other words, it was the principle of relativity. And that was Einstein's genius! That genius manifested itself as a feeling of concinnity that acts as a selection rule to tell him what formal points of view were setting things up according to his sense of inner harmony, and which ones were not.

As Einstein labored long to resolve the mystery of the Lorentz ether, he found himself repeatedly falling back on his intuitions of unity and simplicity of Nature to help him see his way through the fog. Regarding unity, Hans Reichenbach recounts this of Einstein:

> When I, on a certain occasion, asked Professor Einstein how he found his theory of relativity, he answered that he found it because he was so strongly convinced of the harmony of the universe.
>
> — from *Albert Einstein Philosopher–Scientist*. Autobiographical Notes: Philosophical Significance of Relativity, by Hans Reichenbach (p. 292).

As for simplicity:

> The second point of view is not concerned with the relation to the material of observation but with the premises of the theory itself, with what may briefly but vaguely be characterized as the "naturalness" or "logical simplicity" of the premises (of the basic concepts and of the relations between these which are taken as a basis). This point of view, in exact formulation of which meets with great difficulties, has played an important role in the selection and evaluation of theories since time immemorial. The problem here is not simply one of a kind of enumeration of the logically independent premises (if anything like this were at all unequivocally possible), but that of a kind of reciprocal weighing of incommensurable qualities. Furthermore, among theories of equally "simple" foundation that one is to be taken as superior which most sharply delimits the qualities

[5] No, I'm *not* discounting the rotation of the earth, nor its 'motion' through the galaxy. All I'm claiming, with Einstein, is that for the purpose of, say, of performing a Michelson-Morley experiment, that the distances and times involved are so short as to render these motions irrelevant to the results of the experiment.

of systems in the abstract (i.e., contains the most definite claims). Of the "realm" of theories I need not speak here, in as much as we are confining ourselves to such theories whose object is the totality of all physical appearances. The second point of view may briefly be characterized as concerning itself with the "inner perfection" of the theory, whereas the first point of view refers to the "external confirmation." The following I reckon as also belonging "inner perfection" of a theory: we prize a theory more highly if, from the logical standpoint, it is not the result of an arbitrary choice among theories which, among themselves, are of equal value and analogously constructed.

> — Found in: "Autobiographical Notes," *Albert Einstein: Philosopher-Scientist*, Vol. 1, Open Court Classics, 1949, p. 23.

Perhaps a good way to sum up this view, we could claim that 'good' theories are those that can predict the most using the fewest hypotheses.

And then there's this quote that combines them:

> What, then, impels us to devise theory after theory? Why do we devise theories at all? The answer to the latter question is simply: because we enjoy "comprehending," i.e., reducing phenomena by the process of logic to something already known or (apparently) evident. New theories are first of all necessary when we encounter new facts which cannot be "explained" by existing theories. But this motivation for setting up new theories is, so to speak, trivial, imposed from without. There is another, more subtle motivation of no less importance. This is the striving toward unification and simplification of the premises of the theory as a whole (i.e., Mach's principle of economy, interpreted as a logical principle).
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> — Found in: *Ideas and Opinions*, "On the generalized theory of gravitation," p. 342.

And,

> This incorporation of optics into the theory of electromagnetism represents one of the greatest triumphs in the striving toward unification of the foundations of physics; Maxwell achieved this unification by purely theoretical arguments, long before it was corroborated by Hertz's experimental work.
>
> — Found in: *Ideas and Opinions*, "On the generalized theory of gravitation," p. 344–5.

And,

> The purpose of any physical theory is to explain as wide a range of phenomena as possible. It is justified in so far as it does make events understandable.
>
> — Found in: *The Evolution of Physics*, Einstein & Infeld, Touchstone, 1938, p. 40.

However, what constitutes 'understanding' to one person is sheer malarkey to another. Lorentz understood the Fitzgerald contraction as a real mechanical effect in which the moving rod contracts along the direction of its 'motion'; whereas, Einstein understood this effect as explainable by the lack of distance simultaneity, and not mechanical at all.

So, what Einstein had accomplished single-handedly was to finally put the Mechanical Program out of its misery after its long lingering death throes, and institute a brand new research program, the relativistic research program, founded on new principles and a new definition of the "general laws of physics." This is not, however, to say that Newtonian mechanics died. Rather, only to declare that the domain of validity of accurate prediction of Newtonian mechanics is when it's restricted to low velocities ($v << c$) as measured in near-inertial reference frames.

A final thought on the thinking that was in Einstein's mind after the special theory of relativity had gained some measure of acceptance among physicists. Einstein said:

> What has nature to do with our coordinate systems and their state of motion? If it is necessary for the purpose of describing nature, to make use of a coordinate system arbitrarily introduced by us, then the choice of its state of motion ought to be subject to no restriction; the laws ought to be entirely independent of this choice (general principle of relativity).
>
> — Found in: " What is the Theory of Relativity?" A. Einstein, *Ideas and Opinions*, Three Rivers Press, p. 230.

The following is one of Einstein's most profound conclusions (made in 1940):

> In order to construct a theory, it is not enough to have a clear conception of the goal. One must also have a **formal point of view** which will sufficiently restrict the unlimited variety of possibilities. [emphasis mine]
>
> — Found in: *Ideas and Opinions*, The fundaments of theoretical physics, p. 328.

4 Conclusion

Thus, this last quote leaves us at the beginning of general relativity, which removes from the inertial frame any claim to logical superiority among all possible frames of reference.[6] But this is not the end of the insight we can glean from this point.

[6]However, the inertial reference frame retains a prominence for practical reasons, because, if you can find one, it will be the frame that the predictions of general relativity must reduce to those of special relativity.

One key point of consternation that Einstein commented on, while he was trying to coalesce all aspects of electrodynamics of moving bodies prior to his formulation of special relativity, was his learning of the strange result of the Michelson experiment. This experiment used an optical interferometer to detect differential motion of light speed along one arm than the other. The null result was that the speed of light appeared not to depend on the 'motion' of the experimental apparatus with respect to the hypothetical ether of Maxwell.

One conclusion one can draw from this is that it is impossible to perform any optical experiment that is capable of detecting the earth's absolute motion through the ether. But wait. There's more.

Whatever laws we are to invent from then on, it's clear that they are constrained, not only by Nature itself, but also by the measuring instruments humans invent to make measurements. This principle would show itself much stronger in the Copenhagen interpretation of quantum mechanics, in which the nature of the measuring instruments used in all aspects of the theory are taken as a priori to the theory itself, and need not be explained by the theory.

Perhaps we should acknowledge our collective tacit assumption that : There exists measuring instruments.

5 Appendix

He that answereth a matter before he heareth it,
it is folly and shame unto him.
– Proverbs 18:13 (KJV)

It has been, by my reckoning, over fourteen years since I last contributed to a certain physics forum. As I look back at my posts, I am not always proud of how I reacted to criticism from other posters. But for the moment, I want to lay aside the issue of my bad behavior back then and deal right now with just one issue: The Light Principle (LP) of Einstein and how it was critically received — or better put — outright 'critically' rejected, even by physicists.

Looking back on those days, it strikes me that just maybe I could have reduced so much of the confusion as to what I trying to accomplish with my posts on Einstein's relativity, in particular, my purpose being to present only a historical review of the subject, specializing in how Einstein viewed it, and it was certainly not any attempt to systematically present the current state of the art of special or general relativity at the time, either in how it was taught in university or used in practice by physicists.

I want to emphasize that this article is not to teach the reader physics, per se. It is, rather, to teach a limited amount of the history of physics concerning how Einstein claimed he came to derive the special theory of relativity. This entails a brief discussion of the LP.

First, let's make an accurate statement of the Light Principle as it was known to Einstein:

> The measured speed of light made within an inertial reference frame in a vacuum is the invariant number *c*.

Now, to be honest, I know of no reference of Einstein's I can give that presents the LP this clearly, but it must be so. Why? Because Einstein claimed that the LP was empirically derived and provided security of foundation to his theory of special relativity. For it to be secure (reliable), it must be just a measurement of the speed of light as it moves from source point to terminus point, i.e., from point A to point B, say, calculated as though it were an average. It cannot be a vague claim about what invisible light does while in transit from point A to point B. You can't talk about the speed of light between points A and B, unless you make a measurement at some point B′ between those points, and in doing so, you've created a new terminus point B′.

So, what does this word 'invariant' mean? Well, it doesn't mean constant. It refers to a Lorentz-invariant quantity, in this case, the speed of light as measured in an inertial reference frame is the same for all inertial reference frames.

Warning: Back in those early decades of the twentieth century, Einstein often used the term 'velocity' instead of 'speed.' (Or at least, his German writing was interpreted this way.) This is admittedly confusing. Today, we rightly make a clear distinction between the velocity vector and the scalar speed.

The LP is a historical claim of Einstein and thus it cannot be 'updated'. It can, however, be invalidated, though I've not heard of any physicist who claims that. It's a semantic and historical issue. A revised 'version' of the LP is no longer *the* Einstein LP. It's something else. I'm not even claiming that the LP is true, though I personally think it is. I am claiming that Einstein held it to be true.

I think the most important source of confusion about the LP is what people imagine it claims about the behavior of light while it's in transit between points A and B. The point is that the LP claims absolutely nothing about what light does while it's in transit.

Richard Feynman invented a beautiful theory of quantum electrodynamics that claims that light does all kinds of weird things while in transit. Fine. But I've never heard that that invalidates the LP.

Let's now take a look at how Werner Heisenberg regarded the LP as adding to physics a "measurement constant":

> Already a few years after Planck's discovery, the significance of a second "measurement constant" was understood. Einstein's special theory of relativity made it clear to physicists that the velocity of light did not, as had previously been supposed in electrodynamics, describe the property of a special substance—"ether"—that supported the propagation of light, but that a property of space and time was involved, that is, a general property of nature not related in any way to particular objects or things in nature. Thus, the velocity of light can also be considered as a measurement constant of nature.

Our intuitive concepts of space and time can be applied only to those phenomena in which small velocities with respect to the velocities of light are involved. Conversely, the well-known paradoxes of the theory of relativity are based on the fact that phenomena involving velocities near that of light cannot be properly interpreted with our normal concept of space and time. May I remind you of the well-known paradox of the clocks — that for a rapidly moving observer time apparently moves more slowly than for a stationary one. After the mathematical structure of the special theory of relativity had been made clear, it very soon became possible in the first decade of this century to analyze the physical significance of these mathematical relationships. This was done so thoroughly that is was possible to understand completely the aspects of nature connected with the velocity of light as a measurement constant. The many discussions on the theory of relativity clearly show that our deep-rooted concepts impeded the understanding of the theory, but the objections were rapidly overcome.

— Found in: *On Modern Physics*, "Planck's discovery and the philosophical problems of atomic physics," Werner Heisenberg, Werner Heisenberg et al, Clarkson N. Potter, Inc./Publisher, New York c. 1961. pp. 7–8.

Now for David Bohm's viewpoint on the Light Principle.

Moreover, as we shall see later, Einstein's theory of relativity, which is based on the assumption that all observers will obtain the same measured velocity of light, has been found to be correct in so many different kinds of experiments that one can regard this fundamental assumption as very well confirmed indeed.

— Found in: *The Special Theory of Relativity*, David Bohm, 1965, 2002, p. 41, Routledge, New York.

I want to finish this section with a quote from Heisenberg on what amounts to 'operationalism' in physics; i.e., that the meaning of variables comes only from the procedure by which they are measured. This is the famous conversation between Heisenberg and Einstein in which Einstein told Heisenberg that it's the theory that tells us what we can observe, but I will stop before that to make a point relevant to this essay.

. . . I shall report my talk with Albert Einstein following a lecture on the new quantum mechanics in Berlin.

At the time, the University of Berlin was considered the stronghold of physics in Germany, with such renowned figures as Planck, Einstein, von Laue and Nernst. It was here that Planck had discovered quantum theory and that Rubens had confirmed it by special measurements of thermal radiation; it was here that Einstein had formulated his general theory of relativity and his theory of gravitation in 1916. At the center of scientific life was the so-called physics colloquium, which probably went back to the time of Helmholtz and which was generally attended by the entire staff of the physics department. In the spring of 1926, I was invited to address this distinguished body on the new quantum mechanics, and since this was my first chance to meet so many famous men, I took good care to give a clear account of the concepts and mathematical foundations of what was then a most unconventional theory. I apparently managed to arouse Einstein's interest, for he invited me to walk home with him so that we might discuss the new ideas at greater length.

On the way, he asked about my studies and previous research. As soon as we were indoors, he opened the conversation with a question that bore on the philosophical background of my recent work. "What you have told us sounds extremely strange. You assume the existence of electrons inside the atom, and you are probably quite right to do so. But you refuse to consider their orbits, even though we can observe electron tracks in a cloud chamber. I should very much like to hear more about your reasons for making such strange assumptions."

"We cannot observe electron orbits inside the atom," I must have replied, "but the radiation which an atom emits during discharges enables us to deduce the frequencies and corresponding amplitudes of its electrons. After all, even in the older physics wave numbers and amplitudes could be considered substitutes for electron orbits. Now, since a good theory must be based on directly observable magnitudes, I thought it more fitting to restrict myself to these, treating them, as it were, as representatives of the electron orbits."

"But you don't seriously believe," Einstein protested, "that none but observable magnitudes must go into a physical theory?"

"Isn't that precisely what you have done with relativity?" I asked in some surprise. "After all, you did stress the fact that it is impermissible to speak of absolute time, simply because absolute time cannot be observed; that only clock readings, be it in the moving reference system or the system at rest, are relevant to the determination of time."

— Found in: *Physics and Beyond, Encounters and Conversations*, Werner Heisenberg, 1972, pp. 62–63.

This phrase 'that only clock readings' can go into the theory is at the heart of a principle theory as Einstein had defined it. What Heisenberg is here promoting is well beyond operationalism, and is referred to as 'positivism'.

So, are we allowed to speak of electron orbits in an atom? Well, yes, if you're referring to the theory originally proposed by Bohr in 1913, referred to as the

‘Bohr Model’. However, you are not allowed to speak of literal electron orbits in the Copenhagen interpretation of quantum mechanics. At best, the phrase ‘electron orbit’ can be retained in Copenhagenism as a vague metaphor for a ‘bound state of an electron to an atom’.

Bohr explained this disconnect between human language and the goings-on in the atom as the failure of natural language to adequately deal with the quantum world of the atom. Hence, we need a ‘dictionary’ that allows us to go between natural language and the quantum world, so to speak. An interpretation of quantum mechanics gives us that dictionary. Copenhagenism affords us one interpretation.

And in the sense of ‘interpretation’ just given, I think it absolutely crucial that quantum mechanics — be it in the form of matrix mechanics, Schrödinger theory, Bohmian mechanics, or whatever — must have an interpretation, or you can’t even explain the theory to someone else. Without an interpretation, how does the experimentalist have any meaning to the procedures used in the experiment?