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Abstract

To make out in what way Einstein's manifold 1905 'annus mirabilis' writings hang together one has to take into consideration Einstein's strive for unity evinced in his persistent attempts to reconcile the basic research traditions of classical physics. Light quanta hypothesis and special theory of relativity turn out to be contours of a more profound design, mere milestones of implementation of maxwellian electrodynamics, statistical mechanics and thermodynamics reconciliation programme. The conception of luminiferous ether was an insurmountable obstacle for Einstein's statistical thermodynamics in which the leading role was played by the light quanta paper. In his critical stand against the entrenched research traditions of classical physics Einstein was apparently influenced by David Hume and Ernst Mach. However, when related to creative momenta, Einstein's 1905 unificationist *modus operandi* was drawn upon Mach's principle of economy of thought taken in the context of his 'instinctive knowledge' principle and with faint inclinations of Kantian epistemology presuming the coincidence of both constructing theory and integrating intuition of Principle.

Keywords (separated by '-'): Annus mirabilis - Light quanta - Special relativity - Instinctive knowledge - Mach - Stevinus - Constructive theory - Kant

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ORIGINAL PAPER

Einstein's 1905 'Annus Mirabilis': Reconciliation of the Basic Research Traditions of Classical Physics

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Abstract
To make out in what way Einstein's manifold 1905 'annus mirabilis' writings hang together one has to take into consideration Einstein's strive for unity evinced in his persistent attempts to reconcile the basic research traditions of classical physics. AQ1 Light quanta hypothesis and special theory of relativity turn out to be contours of a more profound design, mere milestones of implementation of maxwellian electrodynamics, statistical mechanics and thermodynamics reconciliation programme. The conception of luminiferous ether was an insurmountable obstacle for Einstein's statistical thermodynamics in which the leading role was played by the light quanta paper. In his critical stand against the entrenched research traditions of classical physics Einstein was apparently influenced by David Hume and Ernst Mach. However, when related to creative momenta, Einstein's 1905 unificationist *modus operandi* was drawn upon Mach's principle of economy of thought taken in the context of his 'instinctive knowledge' principle and with faint inclinations of Kantian epistemology presuming the coincidence of both constructing theory and integrating intuition of Principle.

Keywords Annus mirabilis · Light quanta · Special relativity · Instinctive knowledge · Mach · Stevinus · Constructive theory · Kant

1 Introduction

It is a commonplace idea that Einstein's scientific contributions were highly motivated by the ideal of unity of physical laws, and this had a considerable influence on the whole theoretical physics community (see, for instance, van Dongen 2010). For example in the 1949 epoch-making Schilpp volume Einstein, reflecting on his

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scientific creativity in general, eagerly acknowledged that "the special aim which I have *constantly* kept before me is *logical unification* in the field of physics" (Einstein 1949a, p. 400; my italics).

And it is well-known that all the scientific career of Einstein after 1915, i.e. after the general relativity had been achieved, was precisely the vehement search for unitary theories, unification of gravitation and electrodynamics, and so on (see, for instance, Vizgin 2011). And it is no wonder that the quest for unity of nature is best illustrated by *these* attempts of Einstein towards unitary theories during almost forty years than by the early works.

Yet, in my innermost conviction, Einstein's mature unification efforts and especially his stupendous general relativity had sprung out of his early writings and first and foremost out of his 1905 obstinate efforts to create special theory of relativity, as well as out of his audacious 1905 light quanta hypothesis. For instance, as Einstein recalled later, his strenuous efforts to set up the basic general relativity tenet—the principle of equivalence—were drawn upon his experience of creating the SRT (special relativity theory):

> At this point, there occurred to me the happiest thought in my life [der glücklichste Gedanke meines Lebens]. *Just as in the case with the electric field* produced by electromagnetic induction, the gravitational field has similarly only a relative existence. For if one considers an observer in free fall, e.g. from the roof of a house, there exists for him during this fall no gravitational field – at least not in his immediate vicinity. Indeed, if the observer drops some bodies, then these remain relative to him in a state of rest or in uniform motion, independent of their particular chemical or physical nature (quoted from Pais 1982, p. 178; my italics).

Likewise, his revolutionary 1905a paper on light quanta starts with unfolding "***a profound formal difference*** between the theoretical conceptions physicists have formed about gases and other ponderable bodies and Maxwell's theory of electromagnetic processes in so-called empty space" (Einstein 1905a, p. 86, my bold italics). The paper as a whole aims at unification of the basic research traditions of classical physics. Moreover, Einstein's 1905d paper on special relativity commences with scrutinizing a "***deep asymmetry***" (Einstein 1905d, p. 140) in the electromagnetic induction description. Furthermore, as Einstein recalled later in his fascinating "*Evolution of Physics*",

> The relativity theory arose from necessity, from ***serious and deep contradictions*** in the old theory from which there seemed no escape. The strength of the new theory lies in the ***consistency*** and ***simplicity*** with which it solves all these difficulties, using only a few convincing assumptions.
>
> Although the theory arose from the field problem, it has to embrace all physical laws. A difficulty seems to appear here. The field laws on the one hand and the mechanical laws on the other are of *quite different kinds*. The equations of electromagnetic field are invariant with respect to Lorentz transformations and the mechanical equations are invariant with respect to the classical transformations (Einstein and Infeld 1938, p. 202; my italics).

Hence *the overall aim of the present paper is to take the next step and to unfold the abiding influence of unification on Einstein's 1905 papers and especially on SRT genesis and advancement*. Accordingly, the next part of this paper deals with the circle of unification problems that brought Einstein to electrodynamics of moving bodies. The aim of the third part is to answer the question: what was the train of thought that provoked Einstein to invent light quanta and SRT. It is argued that the former and the latter turn out to be mere milestones of implementation of maxwellian electrodynamics, statistical mechanics and thermodynamics reconciliation programme. The leading part in the programme was played by Einstein's 1905a light quanta paper, since it was first and foremost the ether conception that put insurmountable obstacles in realization of Einstein's statistical-thermodynamics design. Finally, my ultimate aim will be to exhibit that the pivotal concept necessary to conceive Einstein's relativity creation and all his 1905 papers *as a whole*, as well as the *order* of their arrangement is Mach's principle of Economy of Thought taken in the context of his 'instinctive knowledge' principle and with some faint inclinations of Kantian epistemology presuming the coincidence of both constructing theory and integrating intuition of Principle.

2 Einstein, Helmholtz, Hertz, Poincaré, Hume and Mach

In Germany Maxwell's strenuous efforts to arrive at a reasonable compromise between the research programmes of Young–Fresnél, Faraday and Ampére–Weber (Nugayev 2015) were set forth by Hermann Helmholtz and his star pupil Heinrich Hertz. In Helmholtz's seminal paradigm (Helmholtz 1870) charges and currents were taken as the sources of electrical and magnetic fields. It led directly to H.A. Lorentz's dualistic worldview of the field equations and the equations of motion exhibited in his 1892–1900 papers. Lorentz's theory was an ingenious amalgamation of Maxwell's field theory and Wilhelm Weber's particle theory of electrodynamics.

And it was young Albert Einstein who dared to pick up the problem after Maxwell, Helmholtz, Hertz and Lorentz. In early August 1899 letter to Mileva Marić an ETH (Eidgenossiche Technische Hochschule) student acknowledges that "I admire the original, free mind of Helmholtz more and more"(Doc. № 50 of Einstein 1987, 129). In 10 August 1899 'Paradies' hotel letter he confesses to his fiancée that

> I am more and more convinced that the electrodynamics of moving bodies, as presented today, is not correct, and that it should be possible to present it in a simpler way. The introduction of the term 'ether' into the theories of electricity led to the notion of a medium of whose motion one can speak without being able, I believe, to associate a physical meaning with this statement. I think that the electric forces can be directly defined only for empty space, which is also emphasized by Hertz […]
>
> Electrodynamics would then be the theory of the motion of moving electricities and magnetisms in free space: which of the two conceptions must be chosen will have to be revealed by radiation experiments (Doc. № 52 of Einstein 1987, p. 131).

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It was Hertz's fine 1890 paper "*Uber die Grundgleichungen der Elektrodynamik fur bewegter Körper*" ("*On the Basic Equations of the Electrodynamics of Moving Bodies*") that appeared to be the source of the phrase "*bewegter die Elektrodynamik Körper*" ("Electrodynamics of Moving Bodies") in the heading of Einstein's 1905d STR paper. Einstein used these words in the letter and thereafter to designate the complex of problems that eventually led him to special relativity. Nevertheless, Einstein was not a slavish adherent of Hertz's "*Darstellung*" (representation). From the very beginning of his scientific career Einstein had persistently expressed doubts on the role of 'des Namens Aether' (of the name Aether) in electrodynamics. Yet his skepticism was directed at Hertz's concept of the ether as *a medium with a certain state of motion*, not at the ether concept *itself*. It was because Einstein attributed basic significance to the concept of 'elektrische Massen' (electrical masses) and treated electric currents as real motions of such charges in empty space, and not as the 'Verschwinden elektrische Polarisation in der Zeit' (missing electrical polarisation in space). At the start of Einstein's scientific career his views were drawn upon the lectures on electricity of his ETH physics teacher prof. H.F. Weber, as is indicated by Einstein's lecture notes (see, for instance, Doc. № 37 and salient comments on it in Einstein 1987, pp. 223–225).

The 'substantive' concept of electricity was advanced by Wilhelm Weber and was widely accepted by many German-speaking physicists, including H.F. Weber. Therein, *initially Einstein's views on electrical masses moving in the immobile ether were similar to the dualistic theory of H.A. Lorentz*. Einstein concluded the above-mentioned letter recapitulating that 'Strahlungversuche' (radiation experiment) was necessary for choosing between the two viewpoints he outlined, and his next, 10 September 1899 'Paradise' letter to Marić judiciously mentioned an idea for experimentally investigating the influence of motion relative to the ether on light propagation in transparent bodies.

Though, Einstein's physics professor manifested no enthusiasm for his work, and Albert made no further mention in his correspondence of his activity in the electrodynamics of moving bodies for almost two years. Nevertheless 'die prinzipielle Trennung von Lichtaether und Materie' (the principal separation of light aether and matter), 'Definition absoluter Ruhe' (definition of absolute rest), etc. were among the topics he vividly discussed with his close friend Michele Besso (see Einstein's 4 April 1901 letter to Marić). In March 1901 Einstein informed Miss Marić that he looked forward to the conclusion of "unsere *Arbeit uber die Relativbewegung*" (our work on relative motion). In September 1901 he informed his boon companion Marcel Grossman on inventing a simpler method for the investigation of the motion of matter relative to ether, based 'auf gewonlichen Interferenzversuchen' (on customary interference experiments). By December 1901 he was 'arbeite eifrigst' (working hard) on "*die Elektrodynamik bewegter Körper*" (the electrodynamics of moving bodies), that promised to become "eine kapitale Abhandlung"(a capital treatise) (Einstein's 17 December 1901 letter to Marić). A calculation error had earlier led him to doubt the correctness of his 'Ideen über die Relativbewegung' (ideas on relative motion), but he now believed in these ideas more than ever. He unfolded the motley stuff to prof. Kleiner and the latter even "thought that the experimental method proposed by me is the simplest and most appropriate and conceivable. I was

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very pleased with the success. I shall certainly write the paper in the coming weeks" (Einstein's letter to Marić, 19 December 1901, p. 189). Notwithstanding prof. Kleiner's encouragement and Einstein's youthful enthusiasm, no publication on this subject ensued for over three years—till 21 June 1905.—Why? What was the matter?—Einstein really was working hard on a "capital treatise" on the electrodynamics of moving bodies at the end of 1901. Then he had desisted and retraced to the memoir only in 1905. What did happen in that span, and ***why had Einstein, being initially an adherent of the ether, became its strong enemy?***

To give a sober answer one has first to recall Einstein's derogative evaluation of his early works—'my worthless beginner papers' (Einstein/Marić 1992). All the evidence at hand indicates that the planned "*kapitale Abhandlung*" was a 'far cry' from the 1905d preeminent STR paper. On the other hand, now one knows for sure (Rynasiewicz 2000) that Einstein arrived at the body of results presented in his 1905d relativity paper, in a 'sudden burst of creativity' and only *after* he had completed his first three works in the spring of 1905. *The key insight—the discovery of the relativity of simultaneity—occurred to Einstein only in late May 1905* ***after*** *the completion of the 1905c Brownian motion paper*. For instance, when asked by the biographer Carl Seelig, Einstein enunciated:

> Between the conception of the idea of the special theory of relativity and the completion of the corresponding published paper there passed five or six weeks (Seelig 1960, p. 114).

Maybe Einstein had renounced the ether concept on finding some uncontestable, irrefutable *physical* argument in the writings of those luminaries of science whose influence he readily and publicly admitted? The argument could turn out a final straw for growing aversion to ostensible metaphysical remnant of the obsolete classical research traditions.

To begin with, how important was Poincaré and Mach's proverbial influence?—Indeed, in a letter to Michele Besso on 6 March 1952 Einstein recalled:

> These readings were of considerable influence on my development – along with Poincaré and Mach (Speziali 1972, Doc. 182).

At first, how crucial was Poincaré's pre-eminent 'Relativity Principle', that asserted relativity of time and space? Already in 1902 Henri Poincaré contended that

> *There is no absolute time*. To say two durations are equal is an assertion which has by itself no meaning and which can acquire one only by convention. Not only have we no direct intuition of the equality of two durations, but *we have not even direct intuition of the simultaneity of two events occurring in different places*: this I have explained in an article entitled '*La mesure du temps*' (Poincaré 1902, p. 114; my italics).

Furthermore, one of droll 'Academia Olympia' members—Einstein's close friend Maurice Solovine—took Henri Poincaré's book "*La science et l'hypothese*" (first published in 1902) as one

> that profoundly impressed us and kept us breathless for many weeks (Solovine 1956; quoted from Howard and Stachel 2000, p. 6).

Nevertheless, *the relativity principle, elaborated by Henri Poincaré, did not prevent the latter from believing in luminiferous ether* as in the medium necessary for propagation of electromagnetic disturbances (Darrigol 2001).

And as for Ernst Mach, in a letter of 8 April 1952 to Carl Seelig, Einstein confessed:

> My attention was drawn to Ernst Mach's '*Science of Mechanics*' by my friend Besso while a student, *around the year 1897*. The book exerted a *deep* and *persisting* impression upon me owing to its *physical* orientation toward fundamental concepts and fundamental laws (quoted from Holton 1968, p. 636; my italics).

The apparent influence on Einstein of Mach's critique of Newton's concepts of absolute space and absolute time is a humdrum. For instance, according to Mach's famous dictum

> It is scarcely necessary to remark that in the reflections here presented Newton has again acted contrary to his expressed intention only to investigate *actual facts*. No one is competent to predicate things about absolute space and absolute motion; they are pure things of thought, pure mental constructs, that *cannot be produced in experience*. All our principles of mechanics are, as we have shown in detail, experimental knowledge concerning the *relative* positions and motions of bodies (Mach 1893/1999, p. 229; my italics).

On the other hand, in 1916 Einstein himself asserted:

> I can say ***with certainty*** that the study of Mach and Hume has been directly a *great help* in my work…Mach recognized the weak spots of classical mechanics and was not very far from requiring a general theory of relativity half a century ago… (quoted from Frank 1949, p. 272; my bold italics).

Yet, of course, there is apparently no direct and unambiguous way from elevated philosophical critique of Newtonian mechanics to queer postulates of special relativity (see, for instance, Zahar's startling 1973 account). It should be added that the strongest argument against the inductivist explanation of the STR genesis consists in the following. Let us turn to the so-called "emission theories of light" that contested the light-constancy postulate and exchanged it with the Galilean law (that simply added the velocities of light and of its source). These theories (see Tolman 1912 for details) had *no* problems in explaining the Michelson–Morley result since they were specially conjured up to explain it. And they did. But they should not, if the inductivists were right.

One can, of course, appeal to falsificationist explanation, contending that the Lorentz–Fitzgerald contraction (LFC) hypothesis, aimed at explaining the Michelson–Morley results within the classical physics research tradition, was an "ad hoc" hypothesis. Indeed, presumably following Poincaré's lecture (Rapports du Congres de Physique de 1900, Paris, i, pp. 22–23), Einstein in his 1907 exposition of the

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STR characterized Lorentz's and Fitzgerald's contraction hypothesis as an "ad hoc" one and "only an artificial means of saving the theory" from the negative results of Michelson and Morley 1887 experiment. However, in his subsequent writings Poincaré, starting from his eminent St. Louis lecture (1904), had irrevocably changed his mind. Correspondingly, Einstein did not label the LFC hypothesis as 'ad hoc" anymore.

Yet it is Elie Zahar's (1973) conspicuous account of ad hocness in the context of the Lorentz–Einstein transition that had convincingly exhibited that the Lorentz–Fitzgerald contraction hypothesis was not an ad hoc_i (i = 1,2,3) hypothesis. According to Zahar, the most complete and multifareous account of ad hocness in philosophy of science is provided by Imre Lakatos's methodology of scientific research programmes.

> A theory is said to be ad hoc_1 if it has no novel consequences as compared with its predecessor. It is ad hoc_2 if none of its novel predictions have been actually 'verified'; for one reason or another the experiment in question may not have been carried out, or - much worse - an experiment devised to test a novel prediction may have yielded a negative result. Finally the theory is said to be ad hoc_3 if it is obtained from its predecessor through a modification of the auxiliary hypothesis which does not accord with the spirit of the heuristic of the programme (Zahar 1973, p. 217).

Zahar convincingly exhibited that the Lorentz–Fitzgerald contraction hypothesis was not an ad hoc_1 one evidently because the STR and the LFC predicted *different* results of the Kennedy–Thorndike experiment. Likewise, LFC was not an ad hoc_3 hypothesis too. Lorentz derived the LFC hypothesis from a *deeper* theory—from the Molecular Forces Hypothesis (MFH): "molecular forces transform and behave like electromagnetic ones". It was quite natural for Lorentz to admit that there is no special "molecular" ether to transmit the interactions between the bodies. All the interactions should be transmitted by the common "luminiferous" ether.

It is also necessary to supplement that, while Zahar correctly takes the LFC hypothesis as non ad hoc_2, his sophisticated arguments are rather doubtful since they are grounded on his notorious 'definition of the novel fact'.

> A fact will be considered novel with respect to a given hypothesis if it did not belong to the problem situation which governed the construction of the hypothesis (Zahar 1973, p. 218).

I approve Alan Musgrave (1974, pp. 13–14) in that Zahar's definition is rather dubious since it puts the procedures of empirical justification from the hands of experimentalists to the hands of historians of science. Such a comprehension of the novel fact deviates as a matter of fact from Lakatosian "temporal novelty". On my humble opinion Zahar's redefinition of the novel fact is redundant for the defence of the LFC hypothesis. As a matter of fact LFC is not an ad hoc_2, but due to the other fine reasons. The following quotation is of importance here:

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> This assumption of a shrinkage, although bold and thus far entirely hypothetical, is not impossible and is the only suggestion yet made which is capable of reconciling the negative results of second and third order experiments with a quiescent ether. Poincaré (Rapports du Congres de Physique de 1900, Paris, i, pp. 22–23) has raised objection to the electromagnetic theory for moving bodies, that each time new facts are brought to light a new hypothesis has to be introduced. This criticism seems to have been fairly met by Lorentz in his latest treatment of this subject (Brace 1905, p. 72).

Advancing Lorentz's arguments, Brace skillfully employed the results of Hasenörl (Annalen der Physik, 1903, band 13, p. 367). Reasoning from a cyclic process in a moving radiating system, Hasenörl had elicited that the second law of thermodynamics is blatantly contradicted unless a second order contraction takes place. Hence not only the Michelson–Morley experiment, but *all* the variety of the experiments establishing the second law of thermodynamics support the LFC. This is an outstanding empirical confirmation!

In the upshot, Einstein carefully and zealously perused Mach's "*Science of Mechanics*" already in 1897; yet this did not hamper to him to believe in luminiferous ether up to 1905.

Or maybe it was sage David Hume? For instance, in a letter to Michele Besso in 1948 Einstein again recalled that

> How far [Mach's writings] influenced my own work is, to be honest, not clear to me. In so far as I can be aware, the *immediate* influence of D. Hume on me was great. I read him with Konrad Habicht and Solovine in Bern (quoted from Speziali 1972, p. 153; my italics).

Yet it should be stressed that Hume's and Einstein's conceptions of space and time have *substantial* differences (see Slavov 2016 for details). In Hume's adamant epistemological doctrine, space and time are *direct* abstractions from simple perceptions. On the contrary, Einstein stubbornly and constantly emphasized that the basic concepts of science are ***free creations*** of the human mind (see, for instance, Schilpp's 1949 eminent volume and all the references cited therein).

3 What was the Train of Thought that Brought Einstein to Special Relativity?

To give a reasonable and cogent answer one should first delve into the special relativity paper itself (Einstein 1905d). The paper famously commences with scrutinizing a "*deep asymmetry*" in the description of electromagnetic induction. Experience tells us that the induction current caused in the conductor by the motion of the magnet depends only on *relative* motion of the conductor and the magnet. However the Maxwell–Lorentz theory provides one with *two* qualitatively different accounts of the effect that mysteriously lead to one and the same quantitative result.

But for conceiving the sober reasons of special relativity genesis it is quite important to take into consideration that ***Albert Einstein was by no means the***

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first to note asymmetries in theoretical representation of the induction phenomenon. In 1885 the asymmetries were indicated by Oliver Heaviside, in 1894—by Herman Föppl, and in 1898—by Wielhelm Wien himself (see Darrigol 2001, p. 377 for details). One should especially punctuate Heinrich Hertz's thought-provoking papers. For instance, Hertz explicitly used the term 'asymmetry' in his 1884 paper. Hence it is no wonder that namely Hertz's papers constituted part of the background to Einstein's thinking on issues in electrodynamics (Hon and Goldstein 2005). Really, at the outset of his 1905d paper Einstein invoked Maxwell's equations in their Hertzian form, namely, in the symmetrical form that Hertz presented for the first time in his 1884 paper. In his 1905d STR paper Einstein is explicit about this: he appeals to the "Maxwell–Hertz" equations. However, Hertz took this asymmetry as purely formal, and he easily eliminated it by re-writing Maxwell's equations in a symmetrical form.

Thus the pivotal question is not how Einstein became aware of the asymmetries, but ***what made them so intolerable to him***. Einstein followed Hertz, Heaviside, Wien et al. in recognition that something was pathological in the Maxwell–Lorentz theory. Yet he had to provide a rather manifold 'diagnosis' and to choose a peculiar 'cure'.

The key to answer the aforementioned question lies in *other* works of Albert Einstein and first and foremost in his papers of 1905. It is well-known that Einstein published *nothing* on the topic of optics and electrodynamics of moving bodies prior to 1905. Moreover, it was Albert Einstein himself who had just disclosed *another asymmetry—and* ***of more profound nature***—in the 1905a paper "*On an heuristical point of view concerning the processes of emission and transformation of light*" that was published in the same journal "*Annalen der Physik*" but three months ***before*** the relativity paper. Behold the outset of his 1905a ground-breaking paper:

> There exists **a *profound formal difference*** between the theoretical conceptions physicists have formed about gases and other ponderable bodies and Maxwell's theory of electromagnetic processes in so-called empty space (Einstein 1905a, p. 86, my bold italics).

And in the first part of the trailblazing paper Einstein excavates that *joint* application of mechanical and electrodynamic "theoretical pictures" for scrutinizing the black-body radiation leads not only to the crying contradictions with experiment (his paper did not even cite Lummer and Pringsheim or Rubens and Curlbaum results), but to the startling ***paradox*** that cannot be circumvented by common expedients and evasions. To exhibit it, Einstein contrives the gedankenexperiment with the both theories. He contemplates an imaginary cavity containing free electromagnetic field, gas molecules and Hertz's resonators. In the sequel he arrives at a conclusion that the joint application of mechanics and electrodynamics leads *unavoidably* to Rayleigh–Jeans law for energy density of the black-body radiation. However,

> "this relation which we found as the condition for dynamic equilibrium does not only lack agreement with experiment, but it also shows that in our picture there can be no question of a definite distribution of energy between aether and matter", since "the greater we choose the range of frequencies of resona-

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tors, the greater becomes the radiation energy in space and in the limit we get $\int_0^\infty \rho_\nu d\nu = (R/N)(8\pi/L^3)T \int_0^\infty \nu^2 \rho_\nu d\nu = \infty$."

(Here R denotes the universal gas constant, N the number of "real molecules" in one gram-equivalent, T the absolute temperature, L the velocity of light, ν the frequency, and $\rho_\nu\, d\nu$ the energy per unit volume of that part of the radiation whose frequency lies between ν and $\nu + d\nu$).

Although it is commonly held that in the 1905a paper Einstein was concerned with an explanation of the photoelectric effect, the tentative study of the masterpiece discloses that this was not the case. The measurements of the effect at that time were not sufficiently accurate to point without any doubt to a violation of classical behavior (see Ter Haar 1967 for details). Einstein was worried not so much by the evidence dealing with photoeffect and appealed to fluorescence, photoelectricity and photoionization data only as to *indirect* evidence in favor of his thesis. Rather, Einstein had mostly delved into the contemplation of the profound *contradiction* between mechanics and electrodynamics and to the efficacious ways of resolving it.

So, ***what was a judicious reason of Einstein's deep interest to the contradictions*** between the mature physical theories?

I think that to find a weighty answer one has to turn to Einstein's 1946 '*Autobiographical Notes*' once more:

> It was Ernst Mach who, in his History of Mechanics, shook this dogmatic faith; this book excercised a *profound influence* upon me in this regard while I was a student. I see Mach's greatness in his *incorruptible skepticism* and independence; ***in my younger years, however, Mach's epistemological position also influenced me greatly***… (Einstein 1949a, p. 21; my bold italics).

Now it is clear why Tetu Hirosige (1976) shrewdly attributed Einstein's sensitivity to the inconsistencies between mechanics and electrodynamics to abiding influence of Ernst Mach, whose writings supposedly helped the inventor of special relativity to outdo the dogmatic adherence to the mechanistic worldview. Mach's "*Science of Mechanics*" is teeming with vehement attacks against classical mechanics imperious role in physics. For instance,

> The view that makes mechanics *the basis* of the remaining branches of physics, and explains all physical phenomena by mechanical ideas, is in our judgement a *prejudice*. Knowledge which is historically first, is not necessarily the foundation of all that is subsequently gained. As more and more facts are discovered and classified, entirely new ideas of general scope can be formed. We have no means of knowing, as yet, which of the physical phenomena go *deepest*, whether the mechanical phenomena are perhaps not the most superficial of all, or whether all do not go equally deep.[…] The science of mechanics does not comprise the foundations, no, nor even a part of the world, but only an *aspect* of it (Mach 1893/1999, pp. 495, 517; my italics).

Einstein could therefore freely and playfully juxtapose Newtonian mechanics, Maxwellian electrodynamics and statistical thermodynamics without reducing one to the others.

Renn and Schulmann (1992) take Einstein's anti-dogmatism as a crucial hallmark of his scientific style of reasoning that enabled a young man to comprehend the conceptual implications in the works of such masters as Lorentz, Hertz, Poincaré and Planck that they themselves were sometimes unable to discern.

Yet the crucial element of Machian epistemology that persistently accompanied Einstein's creativity beginning from 1897 and till his last days was Mach's famous Principle of Economy of Thought: "Physics is Experience Arranged in Economical Order" (Mach 1897/1984).

Mach commences his "*Science of Mechanics*" by maintaining that "Economy of communication and of apprehension is of the very essence of science" (Mach 1893/1999, p. 6). And through and through the whole book the principle is stubbornly and constantly applied to various physical epistemological and philosophical problems, so that "This economical office of science, which fills its whole life, is apparent at first glance, and with it full recognition all mysticism in science disappears" (Mach 1893/1999, p. 481).

Accordingly, in his review of STR genesis, published in "*Science*" in 1940, Einstein directly acknowledges that "the theory of relativity arose out of efforts to improve, with reference to *logical economy*, the foundation of physics as it existed at the turn of the century"(Einstein 1940/1954, p. 329; my italics. See also Einstein 1933/1954, p. 277; Einstein 1936/1954, p. 293 and Einstein 1944/1954, p. 23).

And a judicious explanation of Einstein's reasons for arriving at his 1905a paper and its connections with the other 1905 ones can be found again in his "*Autobiographical Notes*". According to Einstein, the first stage of "the revolution begun by the introduction of the field" (Einstein 1949a, p. 37) consisted in the invention and in the consolidation of the Maxwellian electrodynamics. All the pre-maxwellian accounts of physical interactions (the pre-eminent theories of Newton, Ampére, Weber, Riemann et al.) were theories of interactions between several *material points*. Owing to Faraday and Maxwell, the *Electromagnetic Field* was thrusted into the texture of the nineteenth century physics as a steadfast element of physical reality having equal rights with the *Material Point*. The problem situation was characterized by

> the dualism which lies in the fact that the material point in Newton's sense and the field as continuum are used as elementary concepts *side by side*. Kinetic energy and field-energy appear as *essentially* different things (ibid, p. 37; my italics).

Correspondingly, as an inevitable consequence of the dualism

> a "fundamental crisis set in, the seriousness of which was suddenly recognized due to Max Planck's investigations into heat radiation (1900). The history of this event is all the more remarkable because, at least in its first phase, *it was not in any way influenced by any surprising discoveries of an experimental nature*"(ibid, p. 37; my italics).

Max Planck's form of reasoning [ε = hν] apparently contradicted the mechanical and electrodynamical basis upon which his derivation depended. Yet it should be stressed that

> My own interest in those years was less concerned with the detailed consequences of Planck's results, however important these might be. My major interest was: What general conclusions can be drawn from the radiation formula … concerning the structure of radiation *and even more concerning the electro-magnetic foundations of physics?* (Einstein 1949a, p. 47; my italics).

Thus Einstein's attraction in the 1905a paper to the subject of theory of quanta was provoked by its *unifying possibilities*, for its capacities to arrive at a successful *fusion* of Maxwellian electrodynamics and Boltzmann's statistical thermodynamics. Hence he starts the paper with the heart of what troubled him most—the Rift, *the Duality* in the foundations of physics that was felt most sharply in Lorentz's Electron Theory (and "H. A. Lorentz knew this very well'; Einstein 1949a, 37). ***How did Einstein intend to eliminate the pivotal contradiction of his* 1905a *paper?***

While considering Einstein's way out of the predicament, one should take into account that *all* Einstein's papers from 1901 to 1905 have one trait in common: statistical-thermodynamics approach. Thomas S. Kuhn had punctuated that *what brought Einstein to idea of photon was a coherent development of a research program started in 1902*, a program "so nearly independent of Planck that it would almost certainly have led to the black-body law even if Planck had never lived" (Kuhn 1978, p. 171). From the outset of his scientific career Einstein was "deeply impressed" (Martin Klein) by the simplicity and scope of classical thermodynamics. But for him thermodynamics included the statistical approach he had imbibed from Boltzmann's works, and so he started to unfold statistical thermodynamics. The result was a series of three papers published in 1902, 1903 and 1904. It should be stressed that expressly *they provide the clue for apprehendnding his* 1905a *paper on quanta, his* 1905b *dissertation,* 1905c *work on Brownian motion and* 1905d *paper on special relativity.*

The first important result consisted in that for physical systems of extraordinary general sort Einstein had produced, by the summer of 1903, both a generalized measure for temperature T and entropy S, containing some universal constant χ. By the time he finished his 1903 paper, Einstein had recognized that χ could be evaluated in terms of the values of the gas constant and of Avogadro's number. But the theory that had led him to the constant was, however, applicable to systems far more general than gases. It should therefore have a correspondingly general physical foundation. The basis should reflect statistical–mechanical nature of the approach that led him to the constant, explaining not only its role as a scale factor for temperature, but also its position as a multiplier in the probabilistic definition of entropy. Physical significance of χ was the central problem attacked in Einstein's third statistical paper "*On the General Molecular Theory of Heat*", submitted to the "*Annalen*" in the spring of 1904. The solution of the problem consisted in the phenomena of energy fluctuations. Einstein elucidated that $\bar{\varepsilon}^2 = 2\chi T dE/dT$, where $\bar{\varepsilon}^2$ is a measure of thermal stability of the system, T—temperature of the system and E its energy.

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And it was comprehension of the constant physical sense that directed his attention to the black-body problem.

> The equation just found would permit an exact determination of the universal constant χ if it were possible to determine the energy fluctuation of the system. In the present state of our knowledge, however, that is not the case. Indeed, for only one sort of physical system can we presume from experience that an energy fluctuation occurs. That system is empty space filled with thermal radiation (Einstein 1904, p. 360]; translated in Kuhn 1978).

At least one more step in the programme of statistical thermodynamics advancement was needed, and Einstein took it in the ground-breaking 1905a paper. Its content suggests that Einstein had begun to seek a black-body law of his own, and that he had quickly encountered the paradox, evinced in the contradiction between statistical mechanics and maxwellian electrodynamics, and that he had opportunely dropped the search for the law in favour of an exploration of the paradox itself. This is clear from the very beginning of his already quoted paper (translated in Ter Haar 1967). The first part of the 1905a paper came to an end by revelation of the "ultra-violet catastrophe". ***Yet how did Einstein intended to resolve the paradox?***

In the second part of his 1905a chef-d-euvre Einstein applies thermodynamics, statistical mechanics and maxwellian electrodynamics to peer at the domain of empirical reality covered by Wien's radiation law. Einstein takes $\beta = h/k = Nh/R$ (R denotes the universal gas constant, N the number of "real molecules" in one gram-equivalent, h is Planck's constant and k is Boltzmann's constant) as undefined constant in 1905a paper and hence he writes $R\beta/N$ everywhere instead of h. The joint application of the three mature theories enables Einstein to arrive at apparently deductive argument: if monochromatic radiation of frequency ν and energy E is enclosed in the volume V_0, then the probability W that at any moment all the radiation energy will be found in the partial volume V of the volume V_0 is given by

$$W = \left(V/V_0\right)^{E/h\nu} \tag{1}$$

Yet in the same paper Einstein had previously ascertained that in the case of n independently moving particles enclosed in a volume V_0 the probability of finding them all momentarily in the subvolume V is

$$W = \left(V/V_0\right)^{n} \tag{2}$$

Comparing Eqs. (1) and (2), Einstein draws a startling conclusion that "*monochromatic radiation of small density behaves in thermodynamic respects as though it consists of distinct independent energy quanta of magnitude hν*".

Thus, the upshot that radiation in the cavity consists of independent energy quanta follows *directly* from application of general principles of thermodynamics and statistical mechanics to radiation phenomena.

But in 1905 all the available experimental data, relevant to fluorescence, photoelectricity and photoionization data, provided only *indirect* evidence in favor of quantum hypothesis. Hence, to carefully check the ultra-revolutionary hypothesis of quanta, Einstein had to perform a "*crucial experiment*" of a very peculiar, freaky kind. He had to compare the quantum results with the results of another entrenched, 'old' theory contrived *independently* of the 1905a hypothesis. It is important that this theory had to be sufficiently 'old' to accumulate the results of many experiments. So, if the 1905a paper results had matched the results of fairly different theory, that sprung out of substantially different problem situation, they would have provided an especially reliable verification of "photon hypothesis". Let us recall that

> A proposition is correct if, within a logical system, it is deduced according to the accepted logical rules. A system has truth-content according to the certainty and completeness of its coordination-possibility to the totality of experience. A correct proposition borrows its 'truth' from the truth-content of a system to which it belongs [Ein richtiger Satz erborgt seine 'Wahrheit' von dem Wahrheits-Gehalt des Systems, dem er angehört] (Einstein 1949a, p. 13).

In the opposite case the 1905a theory would have 'falsified' not by a single 'critical experiment' but by a whole multitude of the well-established experimental data. What I want to stress is that it was this 'holistic' stand that allowed Einstein as early as in 1906 to disregard the results of Kaufmann's "crucial" experiments, which seemed to corroborate the Abraham–Bucherer theory and to refute the "Lorentz–Einstein" theory (Holton 1968, p. 253; Miller 1981, p. 124).

As Einstein had put it, the rival theories (e.g. Abraham's electron theory)

> Have rather small probabilities, because their fundamental assumptions (concerning the mass of moving electrons) are not explainable in terms of theoretical systems which embrace a greater complex of phenomena (Einstein as quoted in Holton 1968, p. 253).

Thus the next—1905b—result turned out to be crucial for the 1905a verification. In the 1905b paper Einstein assiduously worked out the principles of Brownian motion that were directly verified by Perrin's experiments.

> My principal aim in this [1905b work on Brownian motion] was to find facts that would guarantee as much as possible the existence of atoms of definite size… The agreement of these considerations with experience together with Planck's determination of the true molecular size from the law of radiation (for high temperatures) convinced the sceptics, who were quite numerous at that time (Ostwald, *Mach*), of the *reality of atoms* (Einstein 1949a, pp. 45–47; my italics).

Though the importance of 1905b paper's for the 1905a one was promulgated by Einstein much later; he confessed to Max von Laue on 17 January 1952:

> When one goes through your collection of verifications of the special relativity theory, one believes that Maxwell's theory is firmly established. But in 1905 I knew *already with certainty* that it leads to the wrong fluctuations in radiation pressure, and consequently to an incorrect Brownian motion of a mirror in a Planckian radiation cavity (quoted from Rynasiewicz 2000, p. 177; my italics).

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This evident for 1905 Einstein result was posited to the scientific community only in 1909 when Einstein applied his theory of Brownian motion to a two-sided mirror immersed in thermal radiation. He demonstrated that the mirror would be unable to carry out a Brownian motion indefinitely, if the fluctuations in the radiation pressure on its surfaces were solely due to the effects of random waves, as predicted by Maxwell's theory. But only the presence of an additional term, corresponding to pressure fluctuations due to the impact of random particles, guarantees the continued Brownian motion of the mirror. Einstein exhibited that similar fluctuation terms in the energy were consequences of Planck's law. He took such fluctuation phenomena as the *strongest argument* for ascribing physical significance to the hypothetical light quanta (Stachel 2000). Only after this queer "crucial experiment", that is only *after* the 1905b paper could Einstein look forward for investigating the consequences of his light quantum hypothesis, and so he returned to his half-forgotten "unsere Arbeit uber die Relativbewegung", eine "kapitale Abhandlung". So far, so good.

> If the monochromatic radiation (of sufficiently small density) in the sense of entropy dependence upon volume behaves itself as a discontinuous medium, consisting of energy quanta $R\beta\nu/N$, a question occurs: if they are not the laws of creation and conversion of light such as if it consists of similar energy quanta? (Einstein 1905a, p. 236).

That is the question put up by Einstein at the end of § 6 of his 1905a. But ***the ether conception turned out to be a considerable snag***. *It prevented positive answer and put insurmountable obstacles in uncoiling Einstein's statistical-thermodynamics programme*. Indeed

> mechanical and purely electromagnetic interpretations of optical and electromagnetic phenomena have in common that in both cases electromagnetic field is considered as a special state of the hypothetical medium filling all the space. Namely in that point two interpretations mentioned differ radically from Newton's emission theory, in which light consists of moving particles. According to Newton, space should be considered as possessing neither ponderable matter, nor light rays, i.e. absolutely empty (Einstein 1905a, p. 236).

To *contrive* a quantum theory of radiation, one needs electromagnetic fields as *independent* entities that can be emitted by the source " just as in Newton's emitting theory" (i.e. the energy transmitted in a process of emission should not be dissipated in space, but should be *completely* preserved until an elementary act of absorption). However, within the Lorentz programme an electromagnetic field is taken as a specific state of ether—a state of medium that is *continuously* distributed in space. In such a medium an elementary process of radiation is connected only with a *spherical* wave.

Nevertheless, aversion to ether and acceptance of emission theory should lead to Walter Ritz's 1908 'ballistic hypothesis': velocity of quantum should depend on the velocity of its source. In Ritz's theory the velocity of light is not constant, but is equal to v + c, where v is a relative velocity of the observer and the source.

Later, in April of 1922, Einstein had confessed to Viscardini:

> I rejected this [emission] hypothesis at that time, because it leads to tremendous theoretical difficulties (e.g. the expectation of shadow formation by a screen that moves relative to the light source) (quoted from Rynasiewicz 2000, p. 182).

Thus Einstein, by contrast, never thought of downing Maxwell's theory, just as Newton, the inventor of the emission theory, did not reject the wave theory 300 years earlier. In the 1905a light-quanta paper Einstein had especially underscored that

> Wave theory operating with point continuous functions is *excellently* justified when describing purely optical phenomena and perhaps would not be replaced by another theory (Einstein 1905a, p. 237; my italics).

In Lorentz's theory this stumbling block was absent. Indeed, in the reference frame that is at rest relative to the ether light propagates with constant velocity *independent of the velocity of the source*. Hence, if one intends to give up the idea of ether, but to come to terms with Maxwell's theory at the same time, s/he should disown ballistic hypothesis and "raise to the rank of a principle the validity of the law of constancy of light velocity for all inertial frames" (Einstein 1936/1954, p. 307), i.e. ***postulate a special "principle of constancy of velocity of light"(I)***.

The second basic principle of STR—***"the principle of relativity"(II)***—follows immediately from the tenet that there is no luminiferous ether and, consequently, no absolute system of reference.

Just as Einstein colourfully recollected in the "*Autobiographical Notes*",

> Reflections of *this type* [i.e. on molecular structure of radiation] made it clear to me as long 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. The longer and the 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*** (Einstein 1949a, p. 51; my bold italics).

The latter point needs elucidation at the expense of delving into the basic source of 1905 Einstein's information on the history of physics—to Mach's fascinating "*Mechanics*".

The most profound case study of the interconnection between the principle of economy of thought and second law of thermodynamics in Mach's "*Mechanics*" is Stevinus's (1548–1620) theoretical scheme of statics. In the "*Hypomnemata Mathematica*" (Leyden 1605) Stevinus was one of the first to investigate the mechanical properties of the inclined plane. His ultimate aim was to set up a general theoretical principle and then to proceed to partial cases that can be easily treated by quantitative means. To produce the pivotal gedankenexperiment, necessary to set up his general principle, Stevin contrives a triangular prism with no horizontally placed edges. Over the prism he lays an endless string on which 14 balls of equal weight are strung and tied at equal distances apart. (The string can be advantageously replaced by an endless uniform chain).

Now, the chain will either be in equilibrium or not. If one assumes the latter to be the case, the chain, since the conditions of the event are not altered by its motion, must, when once actually in motion, continue to move forever. In other words, it must present perpetual motion, which Stevin takes apparently absurd. Hence only the first case is conceivable and *the chain always remains in equilibrium.*

It is crucial for Mach that in the basic premise from which Stevin starts, that *the endless chain does not move,* there is contained only a *purely instinctive* cognition. He feels at once, and we with him, that we have never observed anything like a motion of the kind referred to. This conviction has so much logical cogency that one accepts the conclusion drawn from it respecting the law of equilibrium on the inclined plane without the thought of an objection, *although the law is slyly presented as the simple result of the experiment*. We cannot be surprised at this when we reflect that all results of experiment are obscured by adventitious circumstances (as friction, etc.), and that every conjecture as to the conditions which are determinative in a given case are liable to error. Thus Stevinus ascribes to instinctive knowledge of this sort a *higher authority* than to simple, manifest, direct observations!

As a result, the following question forces itself upon us: w*hence does this higher authority come?* If one recalls that scientific demonstration, and scientific criticism generally can only have sprung from the consciousness of the individual fallibility of investigators, the explanation is not far to seek. We feel clearly, that we ourselves have contributed *nothing* to the creation of this "*Instinctive Knowledge*", that we have added to it nothing arbitrarily, but that it exists in absolute independence of our participation.

According to "*Mechanics*", Stevinus's deduction is one of the rarest 'fossile indicators' that we possess in the primitive history of mechanics, and throws a wonderful light on the process of the formation of science generally, on its rise from instinctive knowledge. Nevertheless, every experimenter can daily observe in his own person the guidance that Instinctive Knowledge furnishes him. If he succeeds in *abstractly formulating* what is contained in it, he will as a rule have made an important advance in science. And it is perfectly certain for Mach that the union of the strongest instinct with the greatest power of abstract formulation alone constitutes the great natural inquirer [Mach 1893/1999: p. 27].

But how does this "instinctive knowledge" originate and what are its contents?

Everything which we observe in nature imprints itself *uncomprehended* and *unanalysed* in our percepts and ideas. In these accumulated experiences we possess a 'treasure store' which is ever close at hand and of which only the smallest portion is embodied in fine articulate thought. The circumstance that it is far easier to resort to these experiences than it is to nature herself, and they are, notwithstanding this, free, in the sense indicated, from all subjectivity, *invests them with a high value*. "*It is a peculiar property of instinctive knowledge that it is predominantly of a negative nature*" [Mach 1893/1999: p. 28]. We cannot so well say what must happen as we can what cannot happen, since the latter alone stands in devastating contrast to the obscure mass of experience in us in which single characters are not distinguished.

Moreover, contends Mach, the other peculiar trait that is extremely important for the philosophy of science consists in that the reasoning of Stevinus has such a strong influence upon us because the result at which he arrives apparently contains *more* than the assumption from which he starts.

Furthermore, it often happens in the course of the advancement of science that a new principle perceived by some researcher in connection with a fact, is not immediately recognized and rendered familiar in all its generosity. If, throughout all facts, we clearly *see* and *discern* a principle which, though not admitting of proof, can yet be known to *prevail*, we have advanced much farther in the consistent conception of nature than if we suffered ourselves to be overawed by a specious demonstration.

Eventually,

> It is more in keeping, furthermore, with the *economy of thought* and with the aesthetics of science, directly to *recognise* a principle (say that of the statical moments) as the key to the understanding of *all* the facts of a department, and *really* see how it *pervades* all those facts, rather to hold ourselves obliged first to make a clumsy and lame deduction of it from unoblivious propositions that involve the same principle but that happen to have become earlier familiar to us [Mach 1893/1999, p. 82].

On my view, ***all the abovementioned Stevin–Mach recipes where ingeniously implemented by Einstein in formulating the basic STR principle—the principle of relativity***. Though due to ultra-revolutionary and extremely speculative nature of light-quanta hypothesis he could not afford himself to reveal the link with the 1905a paper directly. Hence he applied all the Stevin–Mach technique of conviction *to posit his electrodynamics of moving bodies in phenomenological wake.* One should especially take into account the *negative character of the relativity principle* and the manner of its connections with experiments and observations that is closer to instinctive knowledge subtle conviction technique than to coarse inductive way of inference. Look at the beginning of the STR paper:

> Examples of a similar kind, and the failure of attempts to detect a motion of the earth relative to the 'light medium', lead to the ***conjecture*** that not only in mechanics, but in electrodynamics as well, the phenomena ***do not*** have any properties corresponding to the concept of absolute rest, but that in all coordinate systems in which the mechanical equations are valid, also the same electrodynamic and optical laws are valid, as have already been shown for quantities of the first order. We shall raise this conjecture (whose content will be called 'the principle of relativity' hereafter) to the status of a postulate and shall introduce, in addition, the postulate, only seemingly incompatible with the former one, that in empty space light is always propagated with a definite velocity V which is independent of the state of motion of emitting body (Einstein 1905d, p. 140; my italics).

Appeal to *instinctive knowledge* easily explains the fact that the special relativity paper stands out in all the world scientific literature for the ***complete lack of quotations***.

And since, according to the "*Autobiographical Notes*", Einstein's new theory was created as a result of inevitable encounter of Newtonian mechanics and Maxwellian electrodynamics, its basis should consist of a *minimum* of two postulates, (**I**) the first drawn from classical mechanics (the principle of relativity) and (**II**) the second one transferred from the Maxwell–Lorentz electrodynamics (the principle of the constancy of light). Namely,

> **(I)** *Classical mechanics*, of which it could not be doubted that it holds with a close degree of approximation, teaches the equivalence of all inertial systems or inertial 'spaces' for the formulation of natural laws, i.e., the invariance of natural laws with respect to the transition from one inertial system to another (Einstein 1954, p. 369).
> **(II)** This [the special theory of relativity] takes over from the *theory of Maxwell–Lorentz* the assumption of the constancy of the velocity of light (Einstein 1940/1954, p. 370).

The two postulates, (**I**) + (**II**), the relativity principle plus the principle of constancy of velocity of light, are quite sufficient, according to Einstein, to contrive the electrodynamics of moving bodies. Yet, since "the theory based on these two principles should not to lead to contradictory results, one must renounce the customary rule of addition of velocities " (Einstein 1910, p. 125).

And namely that was done in the 1905d paper «*On the Electrodynamics of Moving Bodies*", published several months ***after*** the photon paper. Einstein had dug out the hidden assumption—the basis of the Galileo addition law—that the statements of time, as well as of the shapes of moving bodies have the sense independent of the state of motion of the reference frame. He revealed that the acceptance of the "principle of relativity" together with the "principle of constancy of light" is equivalent to modification of the simultaneity concept and to clock delay in moving reference frame.

It should be stressed that in no ways 1905 Einstein was an idle thinker contemplating on the essence of space and time. He was ***forced*** to elevated philosophical reflections on the nature of space and time by his ***research practice***, by a mundane physical problem of reconciling classical mechanics (the Principle of Relativity) with classical electrodynamics (the Light Constancy Postulate).

Hence, at least in that case, Einstein's use of Hume and Mach's philosophical writings was "*highly selective*" (Norton 2010, p. 359). His ultimate goals were not so much to apprehend Hume's and Mach's refined philosophical reflections as to find in them concrete ideas that may be useful in his mundane research practice.

Well, if all the aforesaid is true, the abovementioned question should be scrutinized: ***why Einstein in the* 1905d *relativity paper did not cite his* 1905a *paper on light quanta?***

To give a judicious answer one has to dwell into Einstein's 1905 correspondence. Writing to his close friend Conrad Habicht in 1905 and sending him the fruits of his labours at that time, Einstein called his light quanta paper "***very revolutionary***", while the relativity paper was humbly characterized as "***interesting*** in its kinematical part". So, *reference in the paper, making significant changes mainly of metaphysical character, on the hypothesis that had already introduced revolutionary changes and had obviously* ***contradicted*** *Maxwell's theory, could hardly make the arguments stronger.*

Einstein himself at the first Solvay Congress had to admit "provisional character of this concept [light quanta] which does not seem reconcilable with the experimentally verified consequences of the wave theory" (quoted from Pais 1979, p. 884). The situation was even worse since *direct experimental evidence* in favour of existence of light quanta was absent. It famously appeared only circa 1923 (the Compton effect).

Being taken independently, the STR did not explain any *new* experimental fact. Predictions of the Lorentz theory were identical to that of the STR, so that it would not be possible in any case to distinguish between the two theories on experimental grounds. Moreover, most of Einstein's contemporaries had scrutinized the "Lorentz–Einstein electron model", reflected on the "principle of relativity of Lorentz and Einstein", and so forth. At the time of publication of Lorentz's second order theory (1904) the only data available to test these theories were Kaufmann's notorious measurements of the masses of slowly moving electrons. But they were initially interpreted as contradicting *both* STR and Lorentz's theory. It took a year for Einstein to answer on Kaufmann's paper. One can imagine how the STR was evaluated by the scientific community in 1905–1906!

Furthermore, cautious Einstein did not promulgate the connections between 1905a and 1905d until 1909. However, *without this links the STR postulates can be evaluated as* ad hoc *hypotheses. And they were!* (The reaction of Henri Poincaré and of the French school is the most blatant example). So, being confronted with many rival theories, why did Einstein preferred special theory of relativity? What undisguised advantages did it have over the artful theories of Lorentz, Ritz and others?

The answer leads one to Einstein's unificationist approach once more. The unificationist stand illuminates Einstein's seemingly puzzling remarks that despite the underdetermination at any given time there **is** only one correct theory: the theory with the *greatest power of unification* at that time (Einstein 1918; see Beller 2000 for details).

We are usually told that in constructing special relativity Einstein had invented a "*theory of principle*", rather than a "*constructive theory*". Yet things are not that simple.

Indeed, it was Einstein himself who ascertained a thought-provoking distinction between 'principle' theories and 'constructive' ones. Constructive theories try 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" (Einstein 1919 as quoted from van Dongen 2010, p. 49). An example of a constructive theory is kinetic theory that attempts at reducing mechanical and thermal properties of gases to movements of molecules, as well as Einstein's light quanta hypothesis for the same reasons.

On the contrary, principle theories do not start out from hypothetical constructions, but rather from empirically ascertained principles.

> 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'. In explicitly Kantian terms Einstein in 1919 distinguishes between the abovementioned kinds of theories: "principal theories employ the *analytic*, not the *synthetic* method (quoted from van Dongen 2010, p. 50).

Prima facie it is to his boon companion Michele Besso that Einstein dedicated the only acknowledgement in his 1905d paper, the paper that stands out for its *lack of any reference to the literature*. Furthermore, in the 1905d paper "the failure of attempts to detect a motion of the earth relative to the 'light medium'" is used as evidential support only for *one* of the two basic postulates—for the "Principle of Relativity". The "Light Postulate" is introduced almost parenthetically, without any discussion of its experimental grounds. Only in the 1905e paper, while describing the 1905d paper results, Einstein drops a telling phrase: "the principle of the constancy of the velocity of light used there is of course contained in Maxwell's equations" (Einstein 1989, 172). Yet do not forget that for him the 1905d paper was only a provisional construct, only a milestone in realizing the unification programme. Einstein himself realized that

> a physical theory can only be satisfactory, if its structures are composed of elementary foundations. The theory of relativity is just as little ultimately satisfactory as, for example, classical thermodynamics was before Boltzmann had interpreted the entropy as probability (Einstein to Arnold Sommerfeld on 14 January 1909; quoted from Stachel 2000, p. 10]).

So, the statement that 1905d paper contstututed a theory of principle is merely *half of the truth.* In reality the 1905d theory was a constructive one that only *posited itself* as a theory of principle (possibly due to tactical reasons for Einstein probably tried to save the STR from the scathing criticism directed against the light quanta). That is why two years later, trying to elicit the STR foundations to broad physical community, Einstein humbly described his relativity theory as "an attempt to summarize the studies that have resulted to date from the *merger* of the H.A. Lorentz's theory and the principle of relativity" (Einstein 1907, p. 253).

But the situation could not last over a long period of time. Einstein had to throw his cards up and to unfold the link between his 1905a and 1905d papers 4 years later. In 1909, in Salzburg, he made a report at the 81-st meeting of German Natural Scientists and Physicians under the self-explanatory heading "*On the Development of our Views on the Nature and Structure of Radiation*". It represented practically the first effort to comprehend all his various papers as a whole. And it was one of the first public reports of the STR inventor dedicated to expounding of its foundations. The report starts with a succinct recapitulation of luminiferous ether theory that ends by an intriguing question: "However, today we must regard the ether hypothesis as an obsolete standpoint".

Why? - What I want to stress is that ***for the answer Einstein dwells not to the Michelson–Morley*** or Fizeau experiments, but elucidates that

> It is even undeniable that there is an extensive group of facts concerning radiation that shows that light possesses certain fundamental properties that can be understood far more readily from the standpoint of Newton's ***emission theory of light*** than from the standpoint of the wave theory. It is therefore my opinion that the next stage in the development of theoretical physics will bring us a theory of light that can be understood as a kind of ***fusion*** of the wave and emission theories of light (Einstein 1909, p. 379; my bold italics).

And the abovementioned experiments are brought into consideration only in the context of the "cardinal aspect in which the electromagnetic theory agrees with, or, more accurately, ***seems to agree*** with the kinetic theory" (Einstein 1909, p. 379; my bold italics).

4 Conclusions

The basic claim to put forward is that to conceive the important facets of Einstein's 1905 scientific creativity and all his 1905 papers ***as a whole*** as well as the subtle ***order*** of their presentation one should resort to Einstein's strenuous efforts to reconcile maxwellian electrodynamics and statistical thermodynamics. In creating the theory of light quanta and the special theory of relativity Einstein was operating according to a strong belief in the necessity for unity in science, as well as the coincidence of both constructing theory and integrating intuition of Principle. He is perhaps best known for the later, but in fact his ideas were built equally on the former. Hence identifying and resolving the paradox revealing the contradictions between the basic research traditions turns out a key part of the scientific method. It was exhibited that Einstein's method was construction of theory within the guidance of intuitive principles sometimes beginning with construction, sometimes with principle, but always demanding their consistency, and clear identification of well-documented paradox that forces us to consider a larger view of Nature's laws.

And to comprehend the importance of the latter one should turn to Mach's principle of the economy of thought that was implemented by Einstein through and through during all his life. Nevertheless, this is not to assert that 1905 Einstein was a committed Machian incapable to draw upon the other epistemological sources.

Nope. For instance, in mature, profound and thoughtful "*Physik und Realität*", published in "*The Journal of the Franklin Institute*" in March 1936, Einstein reconsidered the history of mechanics in *sharply* different from the author of "*Die Mechanik*" way:

> These two modes of application of mechanics [i.e. analytical mechanics and the mechanics of continuous media] belong to the so-called "phenomenological physics". It is characteristic of this kind of physics that it makes as much use as possible of concepts which are close to experience

> but, for this reason, has to give up, to a large extent, *unity in the foundations*. Heat, electricity, and light are described by separate variables of state and material constants other than mechanical quantities, and to determine all of these variables in their mutual and temporal dependence was a task which, in the main, could only be solved empirically. Many contemporaries of Maxwell saw in such a manner of presentation the ultimate aim of physics, which they thought could obtained purely inductively from experience on account of the relative closeness of the concepts used to experience. From the point of view of theories of knowledge St. Mill and *E. Mach* took their stand approximately on this ground. In my view, the greatest achievement of Newton's mechanics lies in the fact that its constant application has *led beyond the phenomenological point of view*, particularly in the field of heat phenomena. This occurred in the kinetic theory of gases and *in statistical mechanics in general*. The former connected the equation of state of the ideal gases, viscosity, diffusion, and hit conductivity of gases and radiometric phenomena of gases, and gave the *logical connection* of phenomena, which from the point of view of direct experience, had nothing whatever to do with one another (Einstein 1936/1954, 302; my italics).

Thus, inevitable divergences of opinion with Mach sprung out not only from stubborn development of atomic theory by Einstein through his 1905 scrutinizing of Brownian motion (Einstein 1905b). They also consisted in advancing the similar idea of 'atoms of light' (Einstein 1905a). In my view, to comprehend the more profound reasons of the abovementioned divergences one has to turn face to face to Einstein's true overall philosophical standpoint.

All in all, this standpoint can be characterized as '*eclecticism*', and one cannot elude quoting the famous passage from Einstein's 1949 "*Reply to Criticism*" where he acknowledges that

> The scientist, however, cannot afford to carry his striving for epistemological systematic that far. He accepts gratefully the epistemological conceptual analysis; but the ***external conditions***, which are set for him by the facts of experience, do not permit him to let himself be too much restricted in the ***construction of his conceptual world*** by the adherence to an epistemological system. He therefore must appear to the systematic epistemologist as a type of unscrupulous *opportunist*: he appears as *realist* insofar as he seeks to describe a world independent of the acts of perception; as *idealist* insofar as he looks upon the concepts and theories as the free inventions of the human spirit (not logically derivable from what is empirically given); as *positivist* insofar as he considers his concepts and theories justified only to the extent to which they furnish a logical representation of relations among sensory experiences. He may even appear as *Platonist* or *Pythagorean* insofae as he considers the viewpoint of logical simplicity as an indispensable and effective tool of his research (Einstein 1949b, 684; my italics).

More thoroughly, Einstein's own philosophy of science can be characterized as a *quaint fusion* of the elements drawn from sources as diverse as "Machian empiricism, Duhemian conventionalism and neo-Kantianism" (Howard 1994).

Lo and behold! The 1905a light quanta hypothesis is a ***constructive*** model of radiation; so in the 1949 *Autobiographical Notes* Einstein recalled of Mach's legacy:

> He [Mach] did not place in the correct light the ***essentially conctructive*** and speculative nature of all thinking and more especially of scientific thinking; in consequence, he condemned theory precisely at those points where its ***constructive–speculative*** character comes to light unmistakably, such as in the kinetic theory of atoms (Einstein 1949a, p. 13).

Hence the constructive character of light quanta hypothesis inevitably brings Einstein's thought closer to Kantian epistemology as was already pointed out by many Einstein scholars.

For instance, in Victor F. Lenzen's exquisite essay "*Einstein's Theory of Knowledge*" which Einstein himself hailed as "convincing and correct in everything it says", it is maintained that

> In so far as he acknowledges mathematical objects to be constructions, the theory of Einstein reminds one of Kant who held that objects of mathematics were *constructed in pure intuition* (Lenzen 1949, p. 380; my italics).

In his bona fide 1949 account of Einstein's epistemology Victor F. Lenzen stressed that during the second half of the XIX th century many scientists—but Ernst Mach particularly—regarded the ultimate goal of physical science as the representation of processes through concepts *inductively* derived from sense experiences. Yet on Einstein's fledged view the consistent application of Newtonian mechanics carried theoretical physics far *beyond* the pure phenomenological standpoint.

Likewise, according to the other earnest epistemologist from the abovementioned Schilpp volume

> Einstein himself occupies an intermediate position between Cassirer's neo-Kantianism and Mach's positivism (Ushenko 1949, p. 609; see also Northrop 1949, p. 390).

It is a platitude that Einstein stubbornly and constantly emphasized that the basic concepts of science are *free creations* of the human mind. In that respect Einstein's views were evidently close to Kant. And the positive drive for creative work could be found in Kant's ***constructivist*** foundation for scientific knowledge that restricted science to the realm of appearences stating that a priori knowledge of things in themselves is impossible. Much later Einstein had admitted:

> I did not grow up in the Kantian tradition, but *came to understand* the truly valuable which is to be found in his doctrine, alongside of errors which today are quite obvious, quite late. It is contained in the sentence: 'The real is not given [gegeben] to us, but put to us [aufgegeben]' [by way of a riddle] (Einstein 1949, p. 680; quoted from Ryckman 2005).

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Even mathematics—maintained to be most stable and certain because of its being analytical—was comprehended by Kant as an a priori *synthetic judgement.* As he stressed in "*Prolegomena*" (Kant 1783/2002), the essential feature of pure mathematical cognition, differentiating it from all other a priori cognition, is that it must throughout proceed not from concepts, but always and only through the ***construction*** of concepts. Because pure mathematical cognition, in its propositions, must therefore go beyond the concept to that which is contained in the *intuition* corresponding to it, its propositions can and must never arise through the analysis of concepts, i.e. analytically, and so are one and all synthetic.

Correspondingly, in the passage of the "*Autobiographical Notes'* relating to his childhood Einstein pointed out that "our thinking goes on for the most part without use of signs (words) and beyond that to a considerable degrees unconsciously" (Einstein 1949a, p. 9).

Hence for him, beginning from his early years

> the objects with which geometry deals seemed to be of no different type than the objects of sensory perception, 'which can be seen and touched'. This primitive idea, which probably also lies at the bottom of the well-known Kantian problematic concerning the possibility of 'synthetic judgement a priori' (Einstein 1949a, p. 11).

The Kantian tenet of the intuitive character of mathematics means the limiting of mathematics to those objects that are constitutable [Konstruierbar]. 'Intuitive' is equal to 'constitutable'. As Ludwig Wittgenstein has later coined it in genuinely Kantian fashion, "But the mathematician is not a discoverer, he is an *inventor*».

Kant contemplated objectivity of science as resulting from the manner in which the manifold of sensibility was ordered under the categories of the understanding by means of spatial and temporal categories. This is why mathematics could so effectively describe objective reality for Kant: mathematical constructs are related to the pure intuitions of space and time. (And this is why natural science must be mathematical).

Hence mathematical statements are true in virtue of their application in experience to exhibit the behavior of empirical bodies. While mathematical judgements are obtained through construction in pure intuition, they count as cognitions only because they are necessary connected to experience in the sense that geometrical space was contemplated as a condition of appearance (Kant 1787/1998, p. 196; my italics).

In a sense the abstract objects of a theory are constituted by the laws of the theory. And objectivity is connected not to the existence of things but to the *objective validity of relations*. Accordingly, in the 1905a paper, constructing the mathematical abstract object "light quanta" out of the basic objects of maxwellian electrodynamics and statistical thermodynamics, Einstein was bothered not with grasping the 'essences' of radiation phenomena. He grappled with the problems of ***reconciling*** the interrelations of different classical physics research traditions, i.e. maxwellian electrodynamics, statistical mechanics and thermodynamics. Let us recall that in their Proposal for Einstein's Membership in the Prussian Academy of Science, M. Planck et al. had famously emphasized that

> Einstein has a special talent for getting to the bottom of other scientists' newly emerging views and assertions, and for assessing *their relationship to each other* and to experience with surprising certainty (Doc. № 445 of Einstein 1987, p. 338; my italics).

It is well-known that Einstein's philosophical evolution after the General Relativity, i.e. after 1915 carried him further and further from Humean and Machian unimpressed empiricist bias toward profound Neo-Cantian tradition represented by Weyl, Eddington, Cassirer, Husserl et al. and the mathematical speculative methodology embodied in a sequence of unified theories. Thus I am not contending here that Einstein of 1905 was a thorough (neo) Kantian, trying to implement the murky and abstract tenets of "Critique" into his mundane research practice. Yet, in my humble opinion*, the Kantian facet (which needs to be trialed by future research), of the seeds of Einstein's late methodology lie in his 1905 activity connected with his fruitful efforts to reconcile maxwellian electrodynamics and statistical thermodynamics.*

To recapitulate, Einstein was undoubtedly influenced by Hume, Mach, Poincaré, et al., and this is evinced in innumerous documents that embrace letters, lectures, oral communications, etc. relating to different periods of his life. However, if one dwells into his scientific papers, trying to elucidate Einstein's *modus operandi*, one finds out sober reasons to believe that *actually*, at least in 1905, in his **actual** research practice, he had held an epistemological position that can be labeled as a quaint blend of Machian and Kantian epistemologies. And the most important Machian concept necessary to comprehend Einstein's 1905 activity as a whole is Mach's principle of economy of thought taken in the context of intuitive knowledge principle. Hence the ether notion was relinquished not because it was a metaphysical, idle concept, an obsolete superfluous contraption, but since it turned out a snag for reconciliation of maxwellian electrodynamics and statistical thermodynamics that promised to pave the way to theory of quanta. In theory choice situation one chooses the theory that is more fruitful in empirical respect and parsimonious in principle.

In a nutshell, Einstein's **'scientific method'** turns out to embrace the following necessary steps.

(1) Eduction of the **paradox** that cannot be circumvented by common expedients and evasions (the "ultraviolet catastrophe"). The startling paradox evinces the contradictions between the basic 'old' research traditions (maxwellian electrodynamics, classical mechanics and thermodynamics). The revealation of the paradox presupposes that the ultimate means of its resolution should consist in reconciliation of the 'old' research traditions in the 'new' synthesis.

(2) Awareness of the fact that the immediate resolution of the paradox is impossible since the necessary transformations of the 'old' research traditions are too radical.

(3) Nevertheless, the ultimate way of the resolution of the paradox is comprehended and the upper floors (light quanta hypothesis) of the future fusion theory are successfully constructed with the guidance of the corresponding intuitive principles (Kant). A subtle plan of unification that outlines how the changes should be

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performed from the upper floors to the lower ones, embracing a row of stages, is surmised.

(4) One of the intermediate stages of fusion—the enunciation, keeping with the economy of thought and with a help of Stevinus–Mach instinctive-knowledge technique, of the **Universal Formal Principle** that indicates the ways of transforming the 'old' theories. It is a peculiar property of instinctive knowledge that the Universal Formal Principle (the principle of relativity) is predominantly of a negative character.

(5) A thorough **recheck** of all the existing knowledge is carried out in order to eliminate the possible contradictions—either internal ones (the STR creation)—or the contradictions with other mature theories (the development of theory of energy and pressure fluctuations).

References

Beller M (2000) Kant's impact on Einstein's thought. In: Howard D, Stachel J (eds) Einstein: the formative years, 1879–1909. Birkhauser, Boston, pp 83–106

Brace DB (1905) The negative results of second and third order tests of the 'aether drift' and possible first order methods. Philos Mag 10:72–85

Darrigol O (2001) Electrodynamics from ampere to Einstein. Oxford University Press, Oxford

Einstein A (1902) Über die thermodynamische Theorie der Potentialdifferenz zwischen Metallen und vollständig dissozierten Lösungen ihrer Salze, und eine elektrische Methode zur Erforschung der Molekularkräfte. Ann Phys 8:798–814 (English translation by Anna Beck in: The collected papers of Albert Einstein. Vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 12–29, 1989) AQ2

Einstein A (1903) Eine Theorie der Grundlagen der Thermodynamik. Ann Phys 11:170–187 (English translation by Anna Beck in: The collected papers of Albert Einstein. Vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 48–67, 1989)

Einstein A (1904) Zur allgemeinen molekularen Theorie der Warme. Ann Phys 14:354–362 (English translation by Anna Beck in: The collected papers of Albert Einstein. Vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 68–77, 1989)

Einstein A (1905) Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt. Ann Phys 17:132–148 (English translation by Anna Beck in: The collected papers of Albert Einstein. Vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 86–103, 1989)

Einstein A (1905b) Eine neue Bestimmung der Moleküldimensionen. University of Zurich Dissertation (English translation by Anna Beck in: The collected papers of Albert Einstein. Vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 104–122, 1989)

Einstein A (1905c) Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen. Ann Phys 17 (English translation by Anna Beck in: The collected papers of Albert Einstein. Vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 123–134, 1989)

Einstein A (1905) Zur Elektrodynamik bewegter Körper. Ann Phys 17:891–921 (English translation in: The principle of relativity. Dover, New York, 1923. See also the translation of Anna Beck in: The collected papers of Albert Einstein, vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 140–171, 1989)

Einstein A (1905e) Ist die Trägheit eines Körpers von seinem Energienhalt abhängig? Ann Phys 18:639–641 (English translation of Anna Beck in: The collected papers of Albert Einstein, vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 172–174, 1989)

Einstein A (1907) Über das Relativitätsprinzip und die aus demselben gezogenen Folgerungen. Jahrbuch der Radioaktivität und Elektronik 4:411–462 (English translation of Anna Beck in: The collected papers of Albert Einstein, vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 252–311, 1989)

Einstein A (1909) Über die Entwicklung unserer Anschauungen über das Wesen und die Konstitution der Strahlung. Physikalische Zeitschrift 10:817–825 (English translation of Anna Beck in: The collected papers of Albert Einstein, vol 2. The Swiss years: writings, 1900–1909. Princeton University Press, Princeton, pp 379–394, 1989)

Einstein A (1910) Principé de relativité et ses consequencé dans la physique modern. Arch Sci Phys Nat 29:125–144

Einstein A (1918) Motive des Forschens. In: Zu Max Planks Sechszigstem Geburtstag. Ansprachen, gehalten am 26 April 1918 in der Deutschen Physikalischen Gesellchaft. Muller, Karlsruhe, pp 29–32

Einstein A (1933/1954) On the method of theoretical physics. Reprinted in: Ideas and opinions. Crown Publishing Inc, New York, pp 277–283

Einstein A (1936/1954) Physics and reality. J Frankl Inst 221(3). (reprinted in: Ideas and opinions. Crown Publishing Inc, New York, pp 297–332)

Einstein A (1940/1954) The fundaments of theoretical physics. In: Ideas and opinions. Crown Publishing Inc, New York, pp 323–330

Einstein A (1944/1954) Remarks on Bertrand Russell's theory of knowledge. In: Schilpp PA (ed) The philosophy of Bertrand Russell. The Library of Living Philosophers, Evanston, pp 278–292 (reprinted in Ideas and opinions. Crown Publishers Incorp, New York, pp 18–24)

Einstein A (1949a) Autobiographical Notes. In: Schilpp PA (ed) Albert Einstein: philosopher–scientist, vol 1–2. The Library of Living Philosophers, Evanston, pp 1–14

Einstein A (1949b) Remarks concerning the essays brought together in this co-operative volume. In: Schlipp PA (ed) Albert Einstein: philosopher–scientist, vol 1–2. The Library of Living Philosophers, Evanston, pp 665–688

Einstein A (1954) Relativity and the problem of space. In: Einstein A (ed) Ideas and opinions. Crown Publishing Inc, New York, pp 360–370

Einstein A (1987) The collected papers of Albert Einstein, vol 1. The early years, 1879–1902. In: Stachel J (ed). Princeton University Press, Princeton

Einstein A (1989) The collected papers of Albert Einstein. The Swiss years: writings, 1900–1909, vol 2. Princeton University Press, Princeton

Einstein A, Infeld L (1938) The evolution of physics. Simon & Schuster, New York

Einstein A, Marić M (1992) The love letters. In: Renn J, Schulmann R (eds) (translated by Syawn Smith). Princeton University Press, Princeton

Frank P (1949) Einstein, Mach and logical positivism. In: Schilpp PA (ed) Albert Einstein: philosopher–scientist, vol 1–2. The Library of Living Philosophers, Evanston, pp 271–286

Helmholtz H (1870/1882) Wissenschaftlische Abhandlungen. Repr. Barth, vol1, pp 611–628

Hertz H (1884) Ueber die Beziehungen zwischen den Maxwell'schen elektrodynamichen Grundgleichungen und den Grundgleichungen der gegnerischen Elektrodynamik. Ann Phys Chem 23:84–103

Hertz H (1890/1893) On the fundamental equations of electromagnetics for bodies at rest. In: Hertz HR (ed) Electric waves. L. Macmillan, New York, pp 195–240

Hirosige T (1976) The ether problem, the mechanistic world view and the origins of the theory of relativity. Hist Stud Phys Sci 7:3–82

Holton G (1968) Mach, Einstein and the search for reality. Daedalus 97:636–673

Hon G, Goldstein BR (2005) How Einstein made asymmetries disappear: symmetry and relativity in 1905. Arch Hist Exact Sci 59(11):437–544

Howard D (1994) Einstein, Kant and the origins of logical positivism. In: Salmon Wesley, Wolters Gedeon (eds) Language, logic and the structure of scientific theories: the Carnap–Reichenbach centennial. University of Pittsburgh Press, Pittsburgh, pp 45–105

Howard D, Stachel J (eds) (2000) Einstein: the formative years, 1879–1909. Birkhauser, Boston

Kant I (1783/2002) Prolegomena to any future metaphysics that will be able to come forward as science (Repr. translated by Gary Hatfield. In: Immanuel Kant. Theoretical Philosophy after 1781). Cambridge University Press, Cambridge

Kant I (1787/1998) The critique of pure reason (Repr. translated by Paul Guyer and Allen W. Wood). Cambridge University Press, Cambridge

Kuhn TS (1978) Black-body theory and quantum discontinuity, 1894–1912. Oxford University Press, OxfordYork

Lenzen VF (1949) Einstein's theory of knowledge. In: Schlipp PA (ed) Albert Einstein: philosopher–scientist, vol 1–2. The Library of Living Philosophers, Evanston, pp 357–384

Mach E (1893/1999) The science of mechanics: a critical and historical account of its developments (translated by T. J. McCormmach). Open Court, La Salle

Mach E (1897/1984) The analysis of sensations and the relation of the physical to the psychical (translated by C.M.Williams. Open Court, La Salle)

Miller A (1981) Albert Einstein's special theory of relativity. Addison-Wesley, London

Musgrave A (1974) Logical versus historical theories of confirmation. Br J Philos Sci 25:1–23

Northrop FSC (1949) Einstein's conception of science. In: Schlipp PA (ed) Albert Einstein: philosopher–scientist, vol 1–2. The Library of Living Philosophers, Evanston, pp 387–408

Norton JD (2010) How Hume and Mach helped Einstein find special relativity. In: Dickson M, Domski M (eds) Discourse on a new method: reinvigorating the marriage of history and philosophy of science. Open Court, Chicago, pp 359–386

Nugayev RM (2015) Communicative rationality of the Maxwellian revolution. Found Sci 20(4):447–478

Pais A (1979) Einstein and the quantum theory. Rev Mod Phys 51:863–914

Pais A (1982) Subtle is the Lord. The science and life of Albert Einstein. Oxford University Press, Oxford

Poincaré H (1902/1905) Science and hypothesis (Repr. The Walter Scott Publishing Co, London and Newcastle-on-Tyne)

Renn J, Schulmann R (1992) Introduction. In: Renn J, Schulmann R (eds) Albert Einstein/Mileva Maric: the love letters. Princeton University Press, Princeton

Ryckman T (2005) The reign of relativity: philosophy in physics 1915–1925. Oxford University Press, Oxford

Rynasiewicz R (2000) The construction of the special theory: some queries and considerations. In: Howard D, Stachel J (eds) Einstein: the formative years, 1879–1909. Birkhauser, Boston, pp 159–201

Seelig C (1960) Albert Einstein: Leben und Werk Eines Genies Unserer Zeit. Europa Verlag, Zurich

Slavov M (2016) Empiricism and relationism intertwined: Hume and Einstein‘s STR. Theoria 31(2):247–263

Speziali P (ed) (1972) Albert Einstein–Michele Besso: correspondence. Hermann, Paris

Stachel J (2000) Introduction to Einstein: the formative years. In: Howard D, Stachel J (eds) Einstein: the formative years, 1879–1909. Birkhauser, Boston, pp 1–21

Ter Haar D (1967) The old quantum theory. Pergamon Press, Oxford

Tolman R (1912) Some emission theories of light. Phys Rev 35:136–143

Ushenko AP (1949) Einstein's influence on contemporary philosophy. In: Schilpp PA (ed) Albert Einstein: philosopher–scientist, vol 1-2. Library of Living Philosophers, Evanston, pp 609–645

Van Dongen J (2010) Einstein's unification. Cambridge University Press, Cambridge

Vizgin VP (2011) Unified field theories in the first half of the 20-th century. Springer, Basel

Zahar E (1973) Did Einstein's programme supersede Lorentz's? Br J Philos Sci 24(95–123):226–262

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