THE HISTORY OF QUANTUM MECHANICS AS A DECISIVE ARGUMENT FAVORING EINSTEIN OVER LORENTZ*

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Einstein's papers on relativity, quantum theory, and statistical mechanics were all part of a single research program; the aim was to unify mechanics and electrodynamics. It was this broader program—which eventually split into relativistic physics and quantum mechanics—that superseded Lorentz's theory. The argument of this paper is partly historical and partly methodological. A notion of "crossbred objects"—theoretical objects with contradictory properties which are part of the domain of application of two different research programs—is developed that explains the dynamics of revolutionary theory change.

Introduction. The Lakatos-Zahar Analysis of Two Rival Research Programs and Its Drawbacks. What are the reasons for Einstein's victory over Lorentz? Almost all the existing explanations deal with the Michelson-Morley experiment (Grünbaum 1961; Holton 1969; and others). But it is the account of Elie Zahar (1973), based on Lakatos's "Falsification and the Methodology of Scientific Research Programmes," (Lakatos 1970) that raises the most interesting set of historical and methodological questions. Zahar revealed that the sequence of Lorentz's ether theories as well as Einstein's special and general theories of relativity (SR and GR) were developed within different competing programs. Lorentz's theories were by no means *ad hoc*, and until 1905 their development remained a "progressive problemshift." According to Zahar, Lorentz's program was superseded by Einstein's relativity program only in 1915 because of the explanation of precession of Mercury perihelion. Only with the creation of GR did Einstein's program predict observations that were not derivable from Lorentz's.

However, a more thorough history-of-science analysis reveals the following:

1. Although Einstein's SR was accepted by many prominent scientists by 1910–12, Zahar can only fully rationalize its acceptance after 1915 (Schaffner 1974).

2. By 1915, or very shortly after, SR had been professionally accepted

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and put into use to an extent that GR had not achieved even thirty or forty years later (Kuhn 1980).

3. The scientific community shared no "Relativity Programme" from 1905 to 1910: Einstein's work had not yet been disentangled from Lorentz's. At the time there was only one theory in existence for the majority of scientists; namely, the Lorentz-Einstein theory (Miller 1974).

4. Zahar never mentions the hard core of Einstein's full program, though he mentions a program that contains the relativity principle together with the principle of the constancy of *c*. In 1905 this program started to degenerate, while Lorentz's program was advancing. To preserve continuity with GR, Zahar concentrated on Einstein's heuristic to the complete exclusion of the hard core (Feyerabend 1976).

5. Lorentz's research was aimed at showing that electromagnetic phenomena in moving bodies can be explained on the basis of a variety of processes, all of them taking place in accordance with Maxwell's equations *in vacuo*. Only part of this program was superseded by SR and GR in 1915. The remainder was superseded by quantum theory. Until we can admit that three of Einstein's papers of 1905 and his later works on statistics were parts of a single research program, we cannot make the statement that Lorentz's program was superseded in general by any other program (Feyerabend 1974).

In this paper an attempt is made to provide such an explanation for Einstein's victory over Lorentz that takes into account arguments 1 to 5 against Zahar's standpoint. It turns out that in order to improve Zahar's analysis one must further develop the "Methodology of Scientific Research Programmes." I believe Zahar's drawbacks arise because Lakatos's primary model of programs' competition is too *rough* to describe the occurrence of theory-choice situations. (The notion of "theory-choice situation" denotes a situation in which several empirically equivalent theories co-exist. These theories result in the same empirically testable consequences.) What does Lakatos's model look like?

"When two research programmes compete, their first 'ideal' models usually deal with different aspects of the domain (for example, the first model of Newton's semi-corpuscular optics described light-refraction; the first model of Huyghens's wave optics, light-interference). As the rival research programmes expand, they gradually encroach on each other's territory and the *n*-th version of the first will be blatantly, dramatically inconsistent with the *m*-th version of the second" (Lakatos 1970, p. 158).

But, unfortunately, neither in "Falsification and the Methodology of Scientific Research Programmes," nor in his later works, does Lakatos explain the following properties of the competition process.

(1) If the ideal models of the first program are dealing with one aspect

of the domain while the ideal models of the second program are dealing with another, how can the theories in both programs lead to the same empirical consequences? The existence of a theory-choice situation is considered merely a fact of external history.

(2) Lakatos's primary model admits the cases where $K (K \geq 2)$ rival programs compete. Though actual appraisals are always comparative in the "Falsification and the Methodology of Scientific Research Programmes" (Methodology of SRP), the single criterion in terms of which such appraisals are made is applicable to an individual research program alone. Choosing between several programs, one first locates each individually on the fruitfulness scale; and only then does one compare them. Since the competing programs deal first with different aspects of the domain, we can imagine a situation with $N (N > 2)$ rival programs. Some of them degenerate while the others keep successfully predicting novel facts, each with respect to its own aspect. In this case Lakatos's rules of SRP-elimination seem to be insufficient.

(3) All the Methodology of SRP case studies consider *two* competing programs (Lakatos 1970; Howson 1976). But why only two programs? In Methodology of SRP the facts about competition of two programs belong to external history.

(4) *Real* competition process can arise only when the rival programs are *alternative*. This means that the decision to accept one of them should simultaneously be the decision to abandon the other. Therefore the hard cores of alternative programs should be incompatible. And this is exactly the case when each novel prediction of one program appears to be a vital factor in the degeneration of its rival. All the "novel facts" produced by one program will be "puzzling anomalies" for another only when their domains of validity coincide. But Lakatos's model, with the research programs dealing with different aspects of the domain, admits the existence of *complementary* programs (corpuscular optics, wave optics, and quantum theory of light).

So, in the course of its further development, the Methodology of SRP should properly explain and theoretically reproduce the process of occurrence of theory-choice situations. Hence, having criticized the Methodology of Lakatos, I would like to suggest a modified version of it and show how this modified version can deal successfully with the historical facts considered by Lakatos and Zahar as examples of their methodology. Therefore, in the second section of my paper I present a methodological model of occurrence of theory-choice situations, and in the third section it is applied to the Lorentz-Einstein transition.

2. Methodology of Reductionistic and Synthetic Research Programs. An abstract theoretical object of a set of abstract theoretical objects of any mature theory belongs either to a subset of *basic* theoretical objects or to a subset of the derivative theoretical ones. According to their definitions, the relations between basic objects are described by fundamental laws of the mature theory. The relations between the derivative objects are described by the consequences from the fundamental laws. For instance, "the electric field at a point," "the magnetic field at a point," and "current density" are the basic theoretical objects of Maxwellian electrodynamics. The relations between them are described by Maxwell's equations. "The material point," "the force," "the inertial system of reference" are the basic theoretical objects of Newtonian mechanics. The relations between them are described by Newton's laws. The derivative objects of Newtonian mechanics are: "an absolutely rigid body," "central field," "harmonic oscillator," etc. The relations between them are described by the particular laws of Newtonian mechanics; that is, by the laws of a rigid rotation, movement in central field, etc. The basic objects form the *basis* of a mature theory. It means that each derivative object can join the system of theoretical objects only as a result of constructing it from the basic objects according to certain rules. The basic theoretical objects are constructively independent; that is, none of them can be constructed from the others.

So, the abstract objects of each mature theory are organized in a complicated system including the subsystems connected with each other according to the level-hierarchy principle (Stepin 1976). The subsystems of the lower level are subordinated to a basic subsystem.

Completion in the creation of any mature theory (for example, T_1) gives rise inevitably to questions about the relation of T_1's basis, (B_1), to the system of basic objects, (B_2), of an other mature physical theory, T_2. Are basic theoretical objects B_1^k and $B_2^l (k,l = 1, 2,\ldots,n,\ldots,m)$ constructively independent? Or is it likely that (B_1) belongs to a subsystem of derivative objects of T_2 (or vice versa)?

It is impossible to answer these questions without taking into account the following peculiarities of the derivative-object-construction rules.

(1) The rules for construction of the derivative objects from the basis are not clearly and definitely formulated algorithms. They are vaguely determined by the problem-solving examples or paradigms included in the theory during the process of its genesis (Kuhn 1969).

(2) Application of these rules for reducing the basis to the subsystem of the derivative objects presupposes that one should take into account the peculiarities of empirical reality. Those peculiarities vary from one field of investigation to another.

(3) When the physical theories are different, then the construction rules differ from each other, being determined by different paradigms.

The account, (1) to (3), demonstrates how difficult it is to reveal that T_1 is subordinate to T_2. Therefore in everyday scientific practice, simple conjunction of (B_1) and (B_2) usually is assumed to form a new basis.

The true necessity of analyzing the interrelations of (B_1) and (B_2) emerges in science only when the use of both theories together is needed to explain certain experimental data. It is assumed that experimental data can be described by a system of derivative objects constructed from the basic objects of both theories. Such derivative objects will be called "*crossbred objects*" or simply "*crossbreeds*." The system of derivative crossbred objects will be the subsystem of T_1 and simultaneously the subsystem of T_2. The relations between the crossbreeds will be described by both laws of T_1 and T_2.

Joint application of T_1 and of T_2 may become necessary for several domains of reality. Therefore one may also create several systems of crossbreeds.

The process of T_1 and T_2 joint application for solving a problem will be called "*theories' cross*," while T_1 and T_2 will be named "*cross-theories*." The set of statements describing the relations between the crossbreeds will be given the name of a "*crossbred theory*." For instance, the completion of Maxwellian electrodynamics gave rise to problems dealing with the relations of its basis to the system of basic objects of Newtonian mechanics. The problems of a theoretical description of a black-body radiation spectrum, electromagnetic radiation process, construction of a theoretical model of an atom necessitated the joint application of the theories (Poincaré 1890; Planck 1906).

Consider these examples more thoroughly. (a) While solving the problem of theoretical description of a black-body radiation spectrum, J. Jeans (1905) investigated the system of standing electromagnetic waves in a closed cavity. The treatment of such waves as a system of harmonic oscillators (the construction of crossbred theoretical objects) enabled him to use a well-known law of statistical mechanics (the equipartition theorem). And it was the first time that the temperature and frequency dependence of black-body radiation energy were discovered in this way. The system of crossbred theoretical objects, the correlations of which form a model of black-body radiation, is the subsystem of classical electrodynamics (i.e., the system of standing electromagnetic waves). On the other hand, it is this model that forms the subsystem of derivative objects of classical mechanics (a mechanical system with an infinite number of degrees of freedom). (b) Lorentz's theory of electrons, which explained and predicted a large number of phenomena referring to electrodynamics of moving bodies, provides a classical example of a crossbred theory. Initially, following Maxwell and his disciples' (Lenard, Hertz, et al.) traditions, it was assumed that the charges could be imagined as a kind of ether perturbation process. This assumption was based on the key idea of Maxwell's electromagnetic theory on the identity of displacement current to conduction current. It enabled him to represent the density of electric current in the form of an electromagnetic field flow through a cover. But under the influence of atomistic ideas, Lorentz built electrodynamics based on the notion of charges' currents as a system of electrons interacting with the electromagnetic field. Being a system of moving particles, the system of electrons belongs to the subsystems of classical mechanics. But as a system of electromagnetic field sources, it is a subsystem of Maxwellian electrodynamics.

The relations between the crossbred objects are described by T_1 statements as well as by T_2 statements. The crossbreeds belong to the subsystems of both theories. Hence *the operation of constructing crossbred objects is identical to that of endowing the crossbred objects of each cross-theory with new properties*. These additional properties of derivative objects of one cross-theory correspond to a new set of their relations transported from the other one. The systems of derivative objects of each cross-theory were constructed before they crossed. Each of these systems is a generalization of the corresponding experimental studies carried out independently of the investigations referring to another mature theory. Therefore it is no wonder that there can appear theorctical objects with incompatible properties resulting from the operation of crossbreed construction in one and the same subsystem of derivative objects of one of the cross-theories. In the above case studies, the appearance of objects with incompatible properties was characterized by physicists as "ultraviolet catastrophe" (P. Ehrenfest), "the paradox of an unstable atom" (W. Wien), etc.

Consider these paradoxes in more detail. (a) As a result of constructing a crossbreed system, the electromagnetic field appeared to possess an additional property, transferred from mechanics—that is, "to be a mechanical system with infinite number of degrees of freedom."

Einstein, independently of Rayleigh and Jeans, making use of classical statistics, demonstrated that at an arbitrary but finite temperature, the density of the electromagnetic field energy should be infinite. Indeed, at an arbitrary finite temperature on each degree of freedom, there falls one and the same amount of energy proportional to temperature. However, the infinity of the electromagnetic field density is incompatible with the second principle of thermodynamics which is properly based from a statistical-mechanical point of view. One can always extract energy from the cavity containing such radiation and set perpetuum mobile of the second kind to motion.

Therefore, the property of thermal radiation being a mechanical system with an infinite number of degrees of freedom is incompatible with its

property "to be a system of standing electromagnetic waves." (b) As it was later emphasized by Einstein, "the weakness of the theory lied in the fact that it tried to determine the phenomena by combination of partial and exact differential equations. This method is unnatural. The insufficient part of the theory manifests itself in the necessity of admitting finite dimensions of elementary particles and besides, in the necessity of evading the fact that the electromagnetic field on their surfaces should be infinitely great. The theory was unable to explain the tremendous forces that hold charges together on the surfaces of elementary particles . . ." (Einstein 1936).

The system of theoretical statements is that of statements dealing with the relations between abstract theoretical objects. Therefore, in the system of derivative objects, the objects characterized by incompatible properties should give rise to the mutually contradicting statements in both cross-theories.

Bearing in mind Podgoretzky and Smorodinsky's notion (1980), I would like to note the appearance of incompatible statements, when the theories cross, by "cross-contradiction." To give examples of cross-contradiction, it suffices to list statements in the black-body radiation theory and in electrodynamics of moving bodies. (a) "There exists heat equilibrium of radiation with matter" (the theorem follows from the second law of thermodynamics, see Planck 1906), and "there does not exist heat equilibrium of radiation with matter" (the consequence of Rayleigh-Jeans law; see Lorentz 1909). (b) "What do all these difficulties result from? Lorentz's theory contradicts the purely mechanical notions to which the physicists hoped to reduce all the phenomena of the Universe. Indeed, while there is no absolute motion of bodies in mechanics and there exists a relative one only, in Lorentz's theory there is a peculiar state corresponding physically to an absolute—rest state; it is the state when a body is immobile relative to ether" (Einstein 1910).

The cross-contradiction results from the crossbred-object construction. To eliminate this cross-contradiction, one should, therefore, think of theory T_3 satisfying the requirement: it should comprise both cross-theories so as to exclude the opportunity of constructing crossbreeds. Theory T_3 will be called a "*global*" theory.

According to a methodological model I develop, two ways of global-theory creation are logically admissible: "reductionist" and "synthetic." (R): Application of a reductionist method of creating a global theory is based on the assumption that the bases of both cross-theories refer to different levels of theoretical object organization. Hence D_1, the domain of validity of T_1, is a part of D_2, the domain of validity of T_2. The basis of T_2 acquires the title of a "true" basis. And T_2 itself is declared a "fundamental" theory, while T_1 a "phenomenological" one.

To make sure of the validity of a phenomenological theory, one has to construct its basic objects from the basis of a fundamental theory and prove that its main laws follow from those of a fundamental theory. Lastly, the basis of a phenomenological theory should occupy the place of a derivative system of a fundamental theory. The opportunity to construct a phenomenological basis from the basis of a fundamental theory should also be grounded. The problems proving such opportunities are of special importance. They are called "*the fundamental problems.*" For instance, having completed the system of Maxwell equations with the system of Newton equations together with the expression for "Lorentz force," the author of *The theory of electrons* unified the basic objects of mechanics and electrodynamics in a single theory. But, as we have already pointed out, this unification appeared to be unsatisfactory. Nevertheless, "Lorentz had an idea that went beyond the boundaries of his theory. A charged body is always surrounded by a magnetic field which makes a valuable contribution to a body's inertia. Is it possible to explain the whole inertia of the body in an electromagnetic way? It is clear that this problem can be solved successfully if the particles can be interpreted as regular solutions of the electromagnetic equations . . ." (Einstein 1936). Thus, Lorentz had an opportunity to eliminate the cross-contradiction in a reductionistic way. Classical electrodynamics was acknowledged to be a fundamental theory, while Newton's mechanics was termed a phenomenological one. The fundamental problem of Lorentz's program consisted of the construction of an electron electromagnetic field-theoretical model.

"Indeed, one of our most important fundamental assumptions will deal with ether not only occupying all the space between the molecules, atoms and electrons but penetrating them all. We add the hypothesis that although the particles are at rest or in motion, ether is always at rest. We can reconcile with this, at first sight, striking picture if we consider the particles of matter as some *local perturbations of ether*" (Lorentz 1909). (C): The application of a synthetic way of creating a global theory is based on the following assumption. Basic objects of both cross-theories are supposed to be constructively independent of each other. Their bases belong to one and the same object-organization level. Hence, cross-contradiction must be resolved by creating such a system of global objects from which the bases of both cross-theories could be constructed. The fundamental laws of both cross-theories should be deduced from those of the global theory. Finally, the bases of T_1 and T_2 should occupy the positions of the derivative subsystems of the global theory.

What are the differences between the reductionist and synthetic ways of global-theory creation?

The synthetic way is to result in the creation of a new system of abstract theoretical objects. The rules of basis reduction to the derivative subsys-

tems are determined in the global reductionist theory by the puzzle-solving examples contained in the fundamental theory. On the contrary, *the rules for constructing the basic objects of synthetic global theory do not exist at all.* The usage of the ways of eliminating cross-contradiction is based on two assumptions, equally reasonable, but mutually incompatible. Therefore, in order to realize these assumptions, alternative programs—two reductionist and one synthetic—of the global-theory construction should be involved. Each program is to create its own sequence of scientific theories on the basis of one of the above assumptions. That is why, following Lakatos, we call these fundamental assertions the "hard cores" of the reductionist and synthetic scientific research programs. I feel that the applicability of Lakatos's concept can be shown if one examines his "Falsification and the Methodology of Scientific Research Programmes." "For instance, Prout never articulated the 'Proutian programme': the Proutian programme is not Prout's programme. It is not only the ('internal') success or the ('internal') defeat of a program which can be judged only with hindsight: it is frequently also its content" (Lakatos 1970, p. 119).

Neither a single "crucial" experiment nor a sequence of such experiments can definitely point out which program—reductionist or synthetic—is able to resolve successfully the cross-contradiction. For example, one can conclude that a reductionistic program is unable to resolve the contradiction only if it becomes clear that this program is unable to solve the fundamental problems. In SRP methodology the role of the "hard core" can be played by any "metaphysical proposition" that is "irrefutable by the methodological decision of its protagonists" (Lakatos 1970, p. 134). Thus Lakatos's hard cores are irrefutable by *convention*. And where do they come from? The only hint I could find in Lakatos's work is in a footnote, a kind of methodological comparison: "The actual hard core of a program does not actually emerge fully armed like Athene from the head of Zeus. It develops slowly, by a long, preliminary process of trial and error. In this paper this process is not discussed" (Lakatos 1970, p. 133). I feel that the author of "Falsification and the Methodology of Scientific Research Programmes" avoided disclosing the relations of "hard cores" to objects in the real world. Moreover, Lakatos frequently emphasized his "deep methodological instrumentalism." He believed that the hard core of a program may be false, serving only as a powerful creative tool that enriches our knowledge. "With sufficient brilliance, and some luck, any theory even if it is false, can be defended [progressively] for a long time" (Lakatos 1971, p. 150). All this makes Lakatos's theory of rationality apparently conventionalist and, thus, produces a considerable number of ambiguities in the content of "hard core." In my model some of them are eliminated partially.

Each $(n + 1)$th version or a reductionist or synthetic sequence of theories represents a more perfect realization of a program than the nth version. Each of these sequences tends to a certain limit or *ideal* of the global theory. It is the ideal that determines the direction of development of each SRP type. The third feature of a program that enables it to develop successfully is the so-called 'protecting belt of auxiliary hypotheses' around the core against which the "*modus tollens*" are redirected.[1] The protecting belt of the reductionist program consists of a number of assertions describing the relations between the theoretical objects of a fundamental theory. The protecting belt of synthetic SRP "does not actually emerge fully armed like Athene from the head of Zeus. It develops slowly by a long preliminary process of trial and error." In this paper the process is not discussed.

For free development of a scientific program, some auxiliary hypotheses setting out the order of research are of special necessity. Following Lakatos, I call the set of such hypotheses a "positive heuristic" of SRP.

Thus, my model can demarcate a "hard core" from "positive heuristic." In Lakatos's model, the boundary between these important features of each SRP is too vague. The "positive heuristic" of Lakatos's SRP consists of metaphysical principles that are more flexible in comparison with hard core principles. Hence, it is the methodologist himself who distributes a given number of metaphysical principles between the "positive heuristic" and the "hard core." Such an opportunity increases arbitrariness of hard core since Lakatos permits scientists to change a "positive heuristic." Moreover, "it occasionally happens that when a research program gets into a degenerating phase, a little revolution or a creative shift in its positive heuristic may push it forward again" (Lakatos 1970, p. 137). A methodologist who works within Lakatos's historiographical research program can always characterize an arbitrary sequence of theories as a progressing program, having reconstructed its "hard core" and "positive heuristic" in an appropriate way.

If the program is finished successfully, and the global theory is created, say, in a reductionist way, it cannot be created by synthetic means. Otherwise it is possible to construct one and the same basis of the phenomenological theory for sufficiently different domains of reality from one and the same basic system of the synthetic global theory.

[1]The term "protecting belt of auxiliary hypotheses" was introduced by Imre Lakatos to characterize its main function: "to bear the brunt of tests and get adjusted and re-adjusted, or even completely replaced to defend thus a hardened core" (Lakatos 1970, p. 133). In its final form this notion is not completely appropriate for my model since reductionist and synthetic hard cores are irrefutable as different means of cross-contradiction elimination. Nevertheless, I restore Lakatos's term following 'Occam's razor'.

Nevertheless, suppose that all three programs are successfully realized, and three global theories (two reductionist and one synthetic) are created. Let us compare them.

All the ideals contain both T_1 basic objects and basic theoretical objects of T_2. The domain of validity of each ideal contains the T_1 domain of validity together with the domain of validity of T_2. The subsystems of theoretical objects of each ideal contain one and the same derivative objects of both cross-theories. The relations between basic and derivative theoretical objects are described in each ideal by the same equations, i.e., the partial and fundamental laws of both cross-theories. *Each ideal describes, explains and predicts experimental results, using the languages of the same partial theories belonging to both cross-theories.*

Any verification (or refutation) of a reductionist global theory is verification (or refutation) of a synthetic global theory also. Any consequence of a reductionist global theory may also be obtained from a synthetic global theory. On the other hand, any consequence of a synthetic theory, referring to the domains of validity of T_1 and T_2, can also be obtained from a reductionist global theory. Therefore with respect to the domains of validity of both cross-theories, *the limits of all alternative programs are empirically equivalent.* (In general, the ideals of all alternative programs are empirically equivalent only homomorphically. That is, each corroboration of a reductionist global theory is simultaneously the corroboration of a synthetic global theory, but an opposite statement is invalid. As a matter of fact, various global theories differ in their ways of organizing the same objects of both cross-theories into a unified body.)

But to achieve more than one ideal is impossible. Only one of three alternative sequences will tend finally to its limit. That is why in a real "alive" history of science we can register the simultaneous existence of theories from the sequences that belong to unfinished, alternative programs. The theories from unfinished programs cannot be empirically equivalent with respect to each other in the strict meaning of this term. They are empirically equivalent only approximately, with the accuracy to the limit approach.[2]

The fact of the simultaneous coexistence of theories from unfinished alternative programs became known in philosophy of science as the 'theory-choice situation'. Since the genesis of the competing theories was

[2]The constructed methodological model enables us to propose a certain resolution of the well-known 'equivalence paradox' (Moore 1922; Malcolm 1940; Hanson 1951, 1961, 1964). The paradox consists in the following. If all the terms of Θ_1 and Θ_2 (equivalent theories) are synonymical, then these theories are completely identical. Hence Θ_1 and Θ_2 are one and the same theory. If they are not, the question arises: how can mutually untranslatable theories lead to the same empirical consequences?

A more accurate and detailed analysis of the paradox will be given elsewhere.

usually underestimated, the methodologists falsely concluded that resolution of a theory-choice situation should consist in choosing a single theory. The account of this process testifies to the fact that a theory-choice situation should be resolved by choosing a program not a theory. Not theories but research programs are decisive. A program must be chosen that can provide successful resolution of cross-contradiction. It is obvious that the theory-choice situation can be (and sometimes was) resolved before global-theory creation: when, for example, the inability of the reductionist program to solve its fundamental problems was revealed. The fate of Lorentz's reductionist program depended on the investigations in the domain of the electron theory. The history of the electromagnetic electron began with Thomson's classic paper, "On the Motion of Electrified Bodies" (1870). He showed that if a charged particle moves with velocity v, its electromagnetic field has a kinetic energy $T = fe^2v^2/2Rc^2$. (Here f denotes the form factor, R the radius of the particle, e its charge.) Consequently, we can consider $m_{(em)} = fe^2/Rc^2$ as the electromagnetic mass. The whole kinetic energy is $(m_o + m_{em})\, v^2/2 = mv^2/2$. We have an opportunity to put $m_o = 0$. Thomson used it.

But the works of Abraham (1903) and Poincaré (1906) disclosed that a contractile electron cannot be constructed from the electromagnetic field. The single opportunity for further realization of the reductionist program was in constructing a structureless electron model. But it failed in 1909 because of Lorentz's calculation of the force with which an electron acts on itself:

$$\bar{F}_{self} = \int \rho\left(\bar{E} + \frac{1}{c}[\bar{v}, \bar{B}]\right) d^3r = (-4/3)\, W_{self}\, \bar{\alpha} + (2e^2/3c^3)\, \dot{\bar{\alpha}}$$
$$- (2e^2/3c^3) \sum_{h=2}^{\infty} d^{(h)}\bar{\alpha}/c^h dt^n + 0(R^{(h-1)});$$

where $W_{self} = (1/2)\int(\rho(r)\rho(r^1)/|\bar{r} - \bar{r}^1|)d^3r d^3r^1$, $\dot{\bar{\alpha}} = d\bar{\alpha}/dt$; $\bar{\alpha}$—the acceleration, ρ—the charge density, R—the radius of an electron. If we try to eliminate the structure-dependent terms by tending the radius R to zero, the W_{self} term diverges. This is meaningless from a physical point of view. An attempt to construct an elementary particle from the field fails together with the program of reducing mechanics to electrodynamics. The global theory could be constructed only by synthetic means.[3]

[3]Electromagnetic theory of an electron cannot be created on the basis of SRP (Rohrlich 1967). But it does not make this theory dubious since the problem of electromagnetic mass is not fundamental for Einstein's program.

3. Favoring Einstein over Lorentz. In order to give a rational reconstruction of the histories of the creation and the acceptance of special relativity (SR) by the scientific community, we must give up a traditional comparison of Lorentz's ether theory with only Einstein's "On the Electrodynamics of Moving Bodies." To have the right to speak about Einstein's program, one must also take into account his other works.

A rational reconstruction of the Lorentz-Einstein transition that conforms to the methodology of SRP liberal restrictions has been presented by Elie Zahar. His account of the transition part is accurate. However, it cannot properly explain why SR theory was accepted by the scientific community. Within the severe limits of Zahar's explanation, it is difficult to account for both the indistinguishability of SR and Lorentz's theories,[4] and the fact of almost simultaneous publication of Einstein's epoch-making papers of 1905.[5] Moreover, experimental confirmation of general relativity is insufficient to explain SR recognition. Lorentz's last ether theory, L′, is closer to a general theory of relativity than SR; for "it yields the constancy of C as a contingent fact" while in Einstein's theory the constancy of C is a "basic law" (Feyerabend 1976). To give a more complete reconstruction, we have to assume that three papers of 1905 and, at least, some of Einstein's previous (and subsequent) works represent the components of a single research program. It is obvious that, for determining its hard core, we have to turn to Einstein's papers. We must restrict the scope of the papers analyzed to the period from 1905 to 1912. The imposed restriction leads directly to Einstein's report, "On the development of our views on the essence and structure of radiation," i.e., to Einstein's almost only serious effort to analyze his works as a whole. The report was made at the eighty-first meeting of German natural scientists and physicians (in Salzburg, 1909). This was his first attempt to explain SR foundations in public. The report began with a brief account of ether theory. To put a final touch to his account, he said: "But today we must consider the hypothesis of ether as obsolete." Why?

It is worth emphasizing that in searching for an answer Einstein resorted not to the Michelson-Morley experiment but to "numerous facts in the domain of radiation which show that light possesses a number of fundamental properties that can be understood with the help of Newton's emission theory considerably better than with the help of the wave theory.

[4]In his paper, "On the Method that Determines the Ratio between Transversal and Longitudinal Masses of Electron," published in 1905, the author of SR compares the experimental consequences of three theories: the theory of Bucherer, the theory of Abraham, and that of Lorentz and Einstein. (See Einstein 1906b.)

[5]The paper on SR was received by "Annalen der Physik" on March 19th, 1905. The paper on the photo-effect, on September 27th, 1905.

That is why I consider that the further phase of development of physics will give us the theory of light, which will be in some sense unification of the wave theory with the theory of Newton."

So, the purpose of Einstein's program was to unify mechanics and electrodynamics. To explicate the content of its "hard core" and, especially, the positive as well as negative *heuristic*, we must turn to Einstein's (1905a) photo-effect paper, "On an *heuristical* point of view concerning the processes of occurrence and transformation of light."

The first of Einstein's three 1905 epoch-making papers—for which he got the Nobel Prize *that was not awarded for his work on relativity*—dealt with the introduction of light quanta.

One often reads the statement that Einstein was concerned in this paper with an explanation of the photo-electric effect. Yet, study of the paper reveals that this is not the case. In fact, at that time the measurements of this effect were not sufficiently accurate to point undoubtedly to a violation of classical behavior (Ter Haar 1967). In his paper, Einstein sketches how he came to the idea that a ray of light propagating through space is not continuously spread over it, but consists of a finite number of light quanta. It becomes clear from his account that he was worried not so much by the evidence dealing with photo-effect. Einstein appealed to fluorescence, photo-electricity, and photo-ionization data only as indirect evidence in favor of his thesis. The problem situation that induced Einstein to do the work was created not by the appearance of new experimental data, but by revelation of a contradiction between mechanics and electrodynamics. This is clear from the very beginning of his paper (translated in Ter Haar 1967). "There exists an essential formal difference between the theoretical pictures physicists have drawn of gases and other ponderable bodies and Maxwell's theory of electromagnetic processes in so-called empty space."

What does this difference consist in? "Whereas we assume the state of a body to be completely determined by the positions and velocities of an, albeit very large, still finite number of atoms and electrons, we use for the determination of the electromagnetic state in space continuous spatial functions, so that a finite number of variables cannot be considered to be sufficient to fix completely the electromagnetic state in space."

But this difference can give rise to a situation where "a theory of light involving the use of continuous functions in space will lead to contradictions with experience, if it is applied to the phenomena of the creation and conversion of light." Hence: "It seems to me that the observations of black-body radiation, photoluminescence, the production of cathode rays and other phenomena involving the emission and conversion of light can be better understood on the assumption that the energy of light is distributed discontinuously in space."

And in the first part of his paper Einstein discloses that the joint application of mechanical and electrodynamical "theoretical pictures" for description of black-body radiation leads to a paradox and (consequently!) to contradiction with experiment. To demonstrate it Einstein used *gedankenexperiment* with theoretical objects of both theories. He considered a cavity containing a free electromagnetic field, gas molecules, and Hertz resonators. As a result, we have the joint application of mechanics and electrodynamics which leads unavoidably to Rayleigh-Jeans law for energy density of black-body radiation. But "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 ether and matter," since "the greater we choose the range of frequencies of the resonators, the greater becomes the radiation energy in space and in the limit we get

$$\int_0^\infty \rho_\nu d\nu = (R/N)(8\,\pi/L^3)\int_0^\infty \nu^2 d\nu = \infty."$$

Thus, Einstein pioneered in demonstrating that the contradiction between mechanics and electrodynamics led to "ultra-violet catastrophe."

On the basis of statistical mechanics laws, Einstein discovered a complete analogy between the expressions for gas entropy and the entropy of radiation. He concluded that in the region where Wien's law is valid, one can say that, thermodynamically speaking, monochromatic radiation consists of independent energy quanta of magnitude $h\nu$.

Having shown that light quanta are likely to exist proceeding from black-body radiation, Einstein provides then a 'theoretically progressive problemshift' to his program. He points out that one should expect the emitted light to have a lower frequency than the incident one in fluorescence (Stokes' rule); and energy, E, of the electrons freed from a metal by an incident light ray to be independent of the intensity of the light (in the photo-electric effect); and, finally, the light frequency to exceed a limiting value for photo-ionization.

"But if the monochromatic radiation (of sufficiently small density) in the sense of entropy dependence upon volume behaves as a discontinuous medium, consisting of energy quanta $R\beta\nu/N$, a question occurs: are there not laws of creation and conversion of light, such that light consists of similar energy quanta?"

This is the question Einstein asked at the end of one of his paper's sections. But it is the concept of ether that hampers a positive answer. Indeed, mechanical and purely electromagnetic phenomena have in common that in both cases the electromagnetic field is considered as the state of the special medium that fills the whole space. It is this point where above interpretations radically differ from Newton's emitting theory according to which light consists of moving particles. According to Newton, space should be considered as containing neither weighty matter nor light rays; that is, as absolutely empty (Einstein 1909a).

To create the quantum theory of radiation, we need electromagnetic fields as independent formations that can be emitted by the sources "just as in Newton's emitting theory." It means that the energy emitted should not be scattered in space but completely preserved until an elementary act of absorption. However, from the ether theory viewpoint the electromagnetic field is considered as a special state of ether; that is, the state of the medium, continuously distributed in space. In this medium an elementary radiation act is connected only with spherical waves. Moreover,

> While in the molecular-kinetic theory there exists the reverse process for each process in which only few elementary particles participate (for instance, for each collision of molecules), the picture is quite different for elementary processes within the wave theory.
>
> An oscillating ion, according to the above theory, radiates an outgoing spherical wave. The reverse process, as an elementary process, does not exist. Nevertheless, an ingoing spherical wave is mathematically possible; but its approximate realization needs a great number of elementary radiating centres. Hence, an elementary process of radiation is irreversible. It is in this case where, to my mind, our wave theory does not fit reality. It seems to me that in this point Newton's emitting theory is more valid than the wave theory of light. (Einstein 1909a)

Secondly, giving up ether and accepting Newton's emitting theory, he admits the interpretation developed later by Walter Ritz in 1908. According to his "ballistic hypothesis," the velocity of quanta depends upon its source velocity. Light-and-source velocities should be added following the Galileo addition formulae of classical mechanics. But this contradicts all the action-at-a-distance (or field) notions on which Maxwell electrodynamics is based. The finite velocity of the propagation of electromagnetic-perturbation *in vacuo* (that is, independent of the perturbation form and source velocity) is a direct consequence of Maxwell equations. But Einstein (unlike Ritz) did not intend to give up Maxwell theory, just as 300 years before him, Newton, creator of the emitting theory, did not reject the wave theory. In his photo-effect paper, Einstein emphasizes that "the wave theory operating with the point continuous functions is excellently justified when describing the purely optical phenomena and, perhaps, would not be replaced by another theory" (Einstein 1905a).

In Lorentz theory this problem did not even exist since, in the system, which is at rest relative to ether, light propagates with constant velocity

independent of the source motion. Therefore, if we want to give up the idea of ether and disown a ballistic hypothesis but at the same time retain Maxwell theory and the action-at-a-distance notion, we have to establish a special "principle of constancy of light."

"Einstein simply postulated what we tried, with some efforts, and not always satisfactorily, to deduce from the basic equations of the electromagnetic field" (Lorentz 1909).

These two postulates, according to Einstein, suffice to create the electrodynamics of moving bodies. But "to avoid contradictory consequences of the theory based on these two principles, it is necessary to reject the common rule of velocity addition or, better, exchange it for something else" (Einstein 1909a).

It was done in his 1905 paper, "On the Electrodynamics of Moving Bodies," published several months after the paper on photo-effect. Einstein revealed a hidden assumption—the basis of Galileo's law of velocity addition—that the statements of time as well as of the forms of moving bodies have a sense independent of the motion state of the coordinate system. He showed that acceptance of the 'relativity principle' together with the 'principle of light-constancy' is equivalent to modification of the simultaneity concept and to a clock-delay in moving systems of reference.

"Thus, theory of relativity changes our views on the nature of light in the sense that light appears in it not in any connection with a hypothetical medium but as something existing independently, similarly to matter. Then this theory, *similar to the corpuscular theory of light*, differs in that it acknowledges mass-transition from a radiator to an absorber" (Einstein 1909a).

However, the arguments could hardly have been improved if, in the paper introducing revolutionary changes in our understanding of space and time, he had referred to the hypothesis resulting in even more revolutionary shifts in our understanding of physics. Argumentation was hampered by scientists' lack of direct experimental evidence in favor of light quanta. These data appeared only in 1923 (Compton effect). That is why the photo-effect paper differs from the SR paper both by a more careful title, "On an heuristic point of view . . ." and by a less categorical tone in the main conclusion: "In the following, I shall communicate the train of thought and the facts which led me to this conclusion, in the hope that the point of view to be given *may* turn out to be useful for some research workers in their investigations"; (compare this with: "Insufficient understanding of these peculiarities *is* the root of the difficulties that have to be overcome by electrodynamics of moving bodies," Einstein 1905b).

So, in his SR paper, Einstein refers neither to his paper on light quanta nor to cross-contradiction in the black-body theory, but instead he starts his SR paper with the description of asymmetry between the motions of a conductor and magnet, which is, as has been mentioned, the manifestation of contradiction between Newtonian mechanics and Maxwell theory in the electrodynamics of moving bodies.

Taken alone SR theory neither explained any unexplainable experiment nor predicted any new experimental fact. To clarify the reasons for Einstein's victory over Lorentz, comparison of the ether program with a relativist subprogram is insufficient. Hence, the quantum subprogram has to be included in this consideration.

Einstein's arguments for light quanta presented in 1905a are completely different from those of Planck given five years earlier. As demonstrated by Kuhn, Planck's first quantum papers were not attempts to supply an entirely new theory. They aimed to fill a previously recognized gap in the derivation of his older theory. In particular, the arguments in Planck's first quantum papers did not seem to place any restrictions on the energy of *gedankenexperiment* resonators introduced to equilibrate the distribution of energy in the black-body radiation field. These resonators absorbed and emitted energy continuously at a rate governed by Maxwell equations.

Contrary to Planck, Einstein proceeded from the Wien law, using only the Boltzmann law. He cites Planck twice.

But one of these citations is in the paper written a year before Planck's quantum paper. In the second citation, Einstein quotes Planck's distribution law but only as an expression, adequately describing the experimental radiation spectra. Drawing his own conclusions, Einstein did not use Planck's results.

"It seemed to me at that time that Planck's radiation theory *contradicted my results*. But new considerations presented in the first paragraph of this paper, showed me that . . . Planck's theory in a hidden form applies the hypothesis of light quanta" (Einstein 1906a).

Thus, what brought Einstein to the black-body problem in 1904 was the 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).

In 1906 P. Ehrenfest and Einstein first recognized that Planck's black-body law could not be derived without restricting the resonator energy to integral multiples of $h\nu$. Their demonstrations had little apparent impact, but the paper, presented by Lorentz in 1908, caused a rapid change in the attitude, at least of German physicists, towards the quantum. After all, "other recognized experts on radiation—most notably Wien, Planck himself, and probably James Jeans—followed Lorentz's lead during *1909 and 1910. By the end of the latter year* most of the theorists who had

studied the black-body problem in depth were convinced that it demanded the introduction of discontinuity" (Kuhn 1978, p. x).

After 1910 the black-body problem lost its central role in the development of quantum concepts. Further progress depended on the investigation in other areas of the quantum application. Leadership in the investigation of quantum passed from the black-body problem to that of specific heats at low temperatures. The important application spheres that made for an empirically progressive shift in the quantum subprogram became Roentgen radiation, luminescence, and Bohr spectra.

The first Solvay congress (1911) demonstrated the inability of classical mechanics and classical electrodynamics to solve the problems in radiation theory.

So, in spite of the fact that the light quanta hypothesis had to wait for more than ten years for general recognition, the success of quantum theory revealed the unfitness of the wave theory and the ether notion which constituted the foundations of it. The last serious blow was delivered with Bohr's theory. Only because of its creation did Einstein's program predict the effects which could not be assimilated by Lorentz's program.

"Einstein was extremely surprised and told me: it follows that the frequency of radiated light does not depend at all on the frequency of electron rotation in an atom. This is a great achievement. Consequently, Bohr's theory is valid" (Kuhn, Heilbron et al. 1961).

The limits of space here do not allow me to give a more detailed picture of the development of the quantum subprogram. However, it is unnecessary since it is, indeed, well known.

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