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Physics in Perspective

Ritz, Einstein, and the Emission Hypothesis

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Just as Albert Einstein's special theory of relativity was gaining acceptance around 1908, the young Swiss physicist Walter Ritz advanced a competing though preliminary emission theory that sought to explain the phenomena of electrodynamics on the assumption that the speed of light depends on the motion of its source. I survey Ritz's unfinished work in this area and review the reasons why Einstein and other physicists rejected Ritz's and other emission theories. Since Ritz's emission theory attracted renewed attention in the 1960s, I discuss how the earlier observational evidence was misconstrued as telling against it more conclusively than actually was the case. Finally, I contrast the role played by evidence against Ritz's theory with other factors that led to the early rejection of his approach.

Key words: Emission theories of light; relativity; Walter Ritz; Albert Einstein; H.A. Lorentz; Paul Ehrenfest; John G. Fox.

Introduction

To solve theoretical problems in optics while unifying the branches of physics, physicists around 1900 tried to modify the theories of mechanics and electromagnetism through various innovative schemes. In due course, Albert Einstein's theory of relativity of 1905 became widely accepted as the solution to the problems at issue and many others. Einstein established a new foundation for physics, such that the laws of electromagnetism retained their form, whereas those of mechanics were modified. The opposite approach was taken by the Swiss theoretical physicist Walter Ritz,* who deemed the equations of electromagnetism to be the root of the difficulties and hence argued for their radical revision. In 1908 Ritz outlined an emission theory of light that was consistent with classical mechanics in an attempt to develop a new electrodynamics of moving bodies. While Einstein posited that all light rays travel with the same speed in empty space, Ritz argued that their speeds vary depending on the motion of their sources at the instant of emission, as with any other projectile. His approach was soon rejected by the physics community mainly, physicists said, because experimental and astronomical evidence was at variance with his fundamental premise. But even

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** Pierre Weiss, the editor of Ritz's collected works, inserted an "h" in Ritz's given name, although this is at variance with all contemporary sources; it thus has become common to give it as "Walther" instead of "Walter," although I use the latter spelling. See Forman, "Ritz, Walter" (ref. 1), p. 481.

Fig 1. Walter Ritz (1878–1909). *Source*: Société Suisse de Physique, Ritz, *Gesammelte Werke* (ref. 5), frontispiece.

before any empirical evidence against his work had become available, Ritz's theory had been dismissed by most physicists. Historian Paul Forman commented, "the point of view that he brought forward never received the critical attention or sympathetic extension it deserved."[1]

The story of Walter Ritz's foray into electrodynamics is instructive for several reasons. Ritz (figure 1) was not one of the elder physicists who objected to Einstein's theory in favor of more traditional approaches; he was young and regarded his approach to electrodynamics as far more radical than Einstein's. Moreover, at first Ritz received more appreciation and support from the established physics community than Einstein. But Ritz's prolific labors ended abruptly when he died in 1909 at the age of 31. His incomplete theory of electrodynamics was rejected. By 1965, however, all of the empirical evidence that had been taken to refute Ritz's approach had been reexamined and shown to be as compatible with his emission hypothesis as with Einstein's theory. Thus, Ritz's fledgling work in electrodynamics provides not only a window into the time when physicists were still struggling to solve fundamental problems, but also a telling example of how empirical evidence is sometimes reinterpreted following the advance of scientific understanding. I will trace the salient developments concerning the emission theory of light in the hands of Einstein, Ritz, and others.

Ritz's Critical Outlook on Electrodynamics

Walter Ritz was born in Sion, Switzerland, on February 22, 1878. From an early age he exhibited a disposition for science and mathematics. Yet, also from an early age, his studies were hampered by recurring ill health. He first began to suffer from respiratory ailments at the age of nineteen, following a traumatic experience in September 1897: "Climbing Mont Pleureur with friends, he looked back to see a group of them slip on fresh snow and plunge over a cliff; the emotional stress was compounded by physical overexertion and overexposure in the rescue efforts."[2] Nevertheless, that fall he took and passed the entrance examination to the Zurich Polytechnikum (later the Eidgenössische Technische Hochschule), to study engineering. But he soon turned to "pure science," that is, to theoretical physics.

Albert Einstein, a year younger than Ritz, also was a student at the Zurich Polytechnikum. Einstein studied in the same section as Ritz, but had entered a year earlier, in 1896. The two registered for some courses with some of the same professors, including Hermann Minkowski and Heinrich F. Weber. Einstein graduated in 1900, while Ritz left in 1901, after severe illness, to study further at the University of Göttingen. Ritz had made a better impression at Zurich than Einstein. For example, while Einstein was reportedly described by Minkowski as a "lazy dog,"[3] Ritz went to David Hilbert in Göttingen with amicable words from him.[4] There Ritz also studied under Max Abraham, Theodor Des Coudres, Walther Kaufmann, and Felix Klein, but especially Woldemar Voigt, under whom he wrote his dissertation. Thus began Ritz's pioneering work in theoretical spectroscopy, a field in which he became best known for his "combination principle" and for what came to be known as Rayleigh-Ritz perturbation theory. This work served as a stimulus not only to other experimental and theoretical atomic spectroscopists such as Carl Runge, Friedrich Paschen, and Arnold Sommerfeld, but also to mathematicians who developed Ritz's methods. Ritz prepared his dissertation for publication in early 1903 and then went to the University of Leiden in the company of his close friend Paul Ehrenfest (figure 2) to attend H. A. Lorentz's lectures on the theory of the electron.

Unlike many theorists at the time, Ritz was not impressed by Lorentz's approach to problems in electrodynamics. At Göttingen Ritz had become familiar with the theory of the electron through the works of Abraham, Kaufmann, and Emil Wiechert, and in his dissertation had wrestled with combining electrodynamics and mechanics to ascertain the laws of spectral series. At Leiden and later he became increasingly antagonistic to Maxwell's theory in general and to Lorentz's electrodynamics in particular. In 1908 he began to publish his objections to the prevailing approaches in electrodynamics and optics. Meanwhile, in 1903–1904, he had continued his work in spectroscopy at the University of Bonn in Heinrich Kayser's institute and at the École Normale Supérieure in Paris in Aimé Cotton's and Henri Abraham's laboratory. But Ritz then became seriously ill and had to withdraw completely from work for a period of two

Fig. 2. Paul Ehrenfest (1880–1933). The inscription reads, "If you are worried – grandmother!" and is dated October 15, 1901. *Credit*: V. Ia. Frenkel, Leningrad Physico-Technical Institute; coutesy of American Institute of Physics Emilio Segrè Visual Archives.

years. In 1906, while still in poor health, he resolved to continue his researches. His labors in spectroscopy and his failing health account for his delay in pursuing electrodynamics intensively until then.

Ritz set out on a research program consisting of two parts. First, he undertook a critical study of the contemporary theories of electrodynamics and identified their essential problems and inadequacies. He then sought to devise an alternate synthesis of optics with a new electrodynamics that would account better for the experimental facts and provide a foundation on which to advance further. He published his analyses in a

130-page paper entitled "Recherches critiques sur l'électrodynamique générale," which appeared in the *Annales de Chimie et de Physique* in 1908.[5] He followed up this work with a series of papers in which he recapitulated and elaborated his arguments.

According to Ritz, the essential difficulties in electrodynamics were rooted in the field equations of electromagnetism. He stressed that Maxwell's equations admitted far too many possible solutions, infinitely many in principle, and that this plethora of solutions involved absurd physical consequences. He argued that advanced potentials were devoid of physical significance; he denied the plausibility of convergent spherical waves; and he complained that Maxwell's equations allowed for the existence of a perpetuum mobile.[6] To avoid the ambiguous multiplicity of solutions of Maxwell's equations, Ritz claimed that retarded potentials had to be taken as fundamental. These equations embodied a delay required for electromagnetic effects to traverse distances in space. By allowing only retarded potentials, only past states of a system could determine its present state, and energy could be radiated only from matter, rather than, say, be drawn out infinitely from a surrounding ether.

Ritz complained that the fundamental electric and magnetic fields were not directly observable, and he argued, like Henri Poincaré before him, that their physical interpretation involving the hypothesis of a stationary ether violated the principle of action and reaction. He disdained the ether as a "mathematical phantom," quite undeserving the wide acceptance it had gained.[7] Likewise, he regarded the electric and magnetic force vectors as playing the role of mathematical constructs useful only in particular cases, and he questioned their exact physical significance. Like Heinrich Hertz and others, Ritz deemed only relations of space, time, and matter as fundamental and therefore complained that electrodynamics was based on forces. He concluded that Maxwell's field equations, or more generally partial-derivative equations, were fundamentally inadequate to describe exactly the laws of propagation of physical actions.

Ritz directed his criticisms mainly at Lorentz's electrodynamics, although he was well aware of the related contributions of Poincaré, and of Einstein's theory. Like most other physicists during the first decade of the twentieth century, Ritz regarded Einstein's theory essentially as a generalized reformulation of Lorentz's. He distinguished between the two theories, but thought they both led to identical consequences. Ritz's papers suggest that he appreciated Einstein's theory somewhat, however, since he repeatedly turned to it to undermine Lorentz's. For example, although the Lorentz-Maxwell theory involved a stationary ether, Ritz pointed out that Einstein had shown that Lorentz's equations were independent of the concept of absolute motion, and hence of the ether. Ritz also argued that Einstein had proven that the FitzGerald-Lorentz contraction was not a true physical effect, but merely an appearance, a consequence of an arbitrary definition, that is, of the procedure for determining the simultaneity of events.[8] Nonetheless, to Ritz, Einstein's work was basically a refinement of a fundamentally inadequate theoretical program. In renouncing classical mechanics, Einstein had paid too high a price to resolve the difficulties at issue; and however radical, his theory stopped short of altering Maxwell's equations. In general, Ritz just did not care for Einstein's theory. It not only preserved the core of the Maxwell-Lorentz electrodynamics, it also seemed to preserve a vestige of the ether by postulating the constancy of the velocity of light. To Ritz, Einstein had renounced too hastily key parts of classical mechanics, which seemed to be immensely less problematic than electrodynamics and optics. Ritz also claimed that Einstein's theory was inadequate, because it conflicted with d'Alembert's principle,* and more generally, it conflicted with the theory of dynamics as applied to reference systems (as Einstein had admitted).[9]

Ritz complained that Lorentz, Poincaré, and Einstein dealt with the problems of electrodynamics by invoking too many complicated hypotheses, and leaving the fundamentally problematic equations of electromagnetism untouched. Lorentz had assumed Maxwell's equations as fundamental and used them, along with supplementary conditions, to derive equations of electrodynamics and optics. In so doing, it seemed to Ritz that Lorentz, and likewise Poincaré and Einstein, had placed excessive confidence in Maxwell's equations.[10] By contrast, Ritz attempted to replace the fundamental field equations of electrodynamics. Like Poincaré and Einstein, Ritz was especially concerned with the tension between the principle of relativity of classical mechanics and Lorentz's assumption of a stationary, non-mechanical electromagnetic ether. But instead of revising classical kinematics and dynamics by extending the applicability of the Lorentz transformation equations, as Einstein had done, Ritz attempted to retain classical mechanics and modify the equations of electromagnetism.

Ritz's Emission Theory

Ritz required that electromagnetic and thus optical phenomena agree with the principle of relativity, exactly like mechanical phenomena. Consequently, the emission of light should be identical mechanically to other physical emissions: the speed of light relative to a given reference frame should depend on the motion of its source at the instant of emission, just as the speed of a projectile depends on the motion of its source. Light then should spread out in concentric spheres around its source, so long as the source does not accelerate. To visualize light processes, Ritz used the term "projection" to describe the transmission of light instead of "propagation," since the latter evoked the image of waves advancing in a medium.[11] He wanted to eliminate all expressions and concepts relating to absolute motion and the ether. He argued that light or radiated energy should be conceived better as consisting of infinitely small particles in motion, which he referred to as "fictitious" particles.[12] Einstein had advanced his "heuristic" concept of light quanta earlier in 1905, but that same year in his relativity theory he had left the question of the constitution of light open, writing about "rays" of light, which applied to both wave and particle conceptions.

Ritz regarded Einstein's relativity theory as an insufficient departure from Lorentz's and saw his own "Relativtheorie" as a more radical break.[13] Yet, prior to 1905, Einstein himself had considered and abandoned the idea of an emission theory of light. In hindsight, he referred to "Ritz's conception, which by the way was also mine before relativity theory."[14] Einstein had abandoned the emission hypothesis because he had

* D'Alembert's principle is the rule of classical mechanics that reduces problems of dynamics to problems of statics, for example, by adding a fictitious "inertial" force equal in magnitude but opposite in direction to the resultant of the driving and constraining forces acting on a system.

found no way to use it to solve all of the problems that concerned him, and because it involved additional difficulties that otherwise could be avoided. As he explained: "I rejected this hypothesis at the time because it leads to tremendous theoretical difficulties (*e.g.*, the explanation of shadow formation by a screen that moves relative to the light source)."[15] Einstein "was convinced that all light is defined by frequency and intensity alone, completely independently of whether it comes from a moving or resting light source."[16] Hence, he adopted the "hypothesis of the independence of the velocity of light" on the motion of its source, owing to "its simplicity and easy practicability." Otherwise, he argued, "for the explanation of shadow formation, one must introduce the ugly assumption that light emitted by a resonator depends on the type of excitation (excitation by moving radiation or excitation of another type)."[17] Another subtlety was that on the emission hypothesis a train of light signals could reverse its sequence:

> If an appropriately accelerated light source emits light in one direction (*e.g.*, in the direction of acceleration), then planes of equal phase move with different velocities, and thus one can arrange it so that all the surfaces of equal phase come together at a given location, so that the wavelength there becomes infinitely small. From there on the light reverses itself, so that the rear part overtakes the front.[18]

There was no known evidence for this effect. Einstein also surmised that if the speed of light depends on that of its source, then the passage of light, even through a thin film, would modify its speed "so that the interference … would give rise to entirely unbelievable phenomena." Furthermore, to Einstein, the "strongest argument" against the emission hypothesis was that, "If there is no fixed light velocity at all, then why should it be so, that all light that is emitted by 'stationary' bodies has a velocity *completely independent of the color*? This seemed absurd to me. Therefore I rejected this possibility as a priori improbable."[19]

Objections such as these did not rest on evidence that conflicted directly with the emission hypothesis; they involved complications that made the hypothesis implausible to Einstein. Thus, for example, he expected that light approaching a mirror perpendicularly at a speed of $c+v$ would have to be reflected at a speed of $c-v$ instead of maintaining its same speed. To Einstein the ensuing mathematical difficulties seemed insurmountable: "These complications make it seem understandable why it has not proved possible so far to set up differential equations and boundary conditions that would do justice to this conception."[20] Likewise, late in life Einstein explained in a draft of a letter that, "It may be impossible to set up an electromagnetic theory" requiring that in every direction light waves may propagate with different speeds; this being "the principal reason why, even before the formulation of the special theory of relativity, I rejected this imaginable way out."[21] And he told an interviewer that by 1905 he had given up the emission hypothesis

> because he could think of no form of differential equation which could have solutions representing waves whose velocity depended on the motion of the source. In this case, the emission theory would lead to phase relations such that the propagated wave would be all badly "mixed up" and might even "back up on itself."[22]

In sum, Einstein rejected the emission hypothesis prior to 1905 not because of any direct empirical evidence against it, but because it seemed to involve too many theoretical and mathematical complications.

By contrast, Ritz was impressed by the lack of empirical evidence against the emission hypothesis, and he was not deterred by the mathematical difficulties it involved. It seemed to Ritz far more reasonable to assume, in the interest of the "economy" of scientific concepts, that the speed of light depends on the speed of its source, like any other projectile, rather than to assume or believe, with Einstein, that its speed is independent of the motion of its source even though it is not a wave in a medium; that nothing can go faster than light; that the length and mass of any body varies with its velocity; that there exist no rigid bodies; that duration and simultaneity are relative concepts; that the basic parallelogram law for the addition of velocities is not exactly valid; and so forth. Ritz commented that "it is a curious thing, worthy of remark, that only a few years ago one would have thought it sufficient to refute a theory to show that it entails even one or another of these consequences…."[23]

Since these "complications" seemed to stem from the concept of the ether, Ritz believed that his emission hypothesis would serve as a better way to explain the transmission of electromagnetic effects. He hypothesized that any source, for instance an electric point particle or electron, emits at each instant and in all directions minute particles possessing the same uniform speed relative to it. Based on this connection between an electron and particles of light, Ritz framed a "law of elementary action" to account for the forces between electric charges. His fundamental equation was a function of the relative spatial separations and of the relative velocities of the electric charges and light particles, and it entailed, he maintained, the impossibility of instantaneous action-at-a-distance.[24] Another of its alleged advantages was that it included several undetermined coefficients, which meant that the elementary interaction it described could assume many forms; it perhaps could even account for gravitational attraction and, in particular, for the unexplained motion of the perihelion of Mercury.

Ritz eliminated all reference to absolute motion in his force expressions by deriving equations that described electrodynamic interactions, which he then compared to those of Lorentz's electrodynamics, which were known to be experimentally valid. He showed, for example, that the action of magnets or closed electrical currents on ions was given correctly both by his analysis and Lorentz's. Likewise, the physical effects of closed circuits in relative motion, the phenomena of induction, the results of electrostatics, and matters relating to hertzian oscillators were described equally well by both theories. Ritz's scheme also yielded the correct form for the radiation reaction on an accelerating electron. In short, his approach apparently involved no contradictions with the well-known facts of electrodynamics, but was in as good agreement with them as Lorentz's theory.

So far so good, but how did Ritz's scheme fare with the optics of moving bodies? He was concerned primarily with electrodynamics rather than optics, but he did discuss his emission hypothesis in connection with the optical experiments – the ether-drift experiments – that had caused deep theoretical difficulties. He showed that his theory gave precisely the correct results for these experiments. The notorious null result of the Michelson-Morley experiment, for example, agreed naturally with his emission hypothesis, since in this experiment the light source was attached to the interferometer and hence the speed of light was constant in the reference frame of the apparatus. Likewise, the null result of Oliver Lodge's elaborate "whirling-machine" experiment could be explained easily, because Ritz's theory did not involve the assumption of an ether, and without one the rotating metal disks adjacent to the light beam in the apparatus could not affect the speed of light by an ether-dragging effect. Similarly, Ritz's emission hypothesis agreed with the experiments of Lord Rayleigh, Frederick Trouton, and Henry R. Noble, and it agreed with the observations on astronomical aberration simply by appealing to the vector addition of particle velocities. The main experimental phenomena that Ritz's scheme did not account for were those involving the propagation of light in moving media. Thus, Ritz did not offer a derivation of Augustin Fresnel's ether-dragging coefficient, nor did he provide an explanation of Armand Hippolyte Fizeau's moving-water experiment of 1850. These matters, by contrast, had been principal goals and successes of Lorentz's theory. Still, Ritz did not take these and other shortcomings of his theory to be insurmountable obstacles, since adequate explanations for them might be devised in due course.

Although Ritz repeatedly used the term "theory" to refer to his scheme, he emphasized that he did not regard it as a "true theory" but as a "*counterexample*" to Lorentz's theory.[25] Thus, his was mainly a formal demonstration showing that the Lorentz transformations by no means were indispensable. Hence, even though he never produced a finished, comprehensive theory, he had shown that the problems of electrodynamics could be resolved by reconstructing the foundations of electrodynamics, instead of appealing to Lorentz's theory, or instead of redefining kinematics and dynamics as in Einstein's theory of relativity.

Ritz's views on the nature of electromagnetic radiation pertained not only to electrodynamics and gravitation but also to thermodynamics and energy quantization. By employing his basic hypothesis of the outward projection of particles of energy, Ritz hoped to establish the microscopic basis of the second law of thermodynamics. He regarded the idea of reversibility, that a spherical wave of light might converge back into its source, as physically impossible. To Ritz, irreversibility was of fundamental importance in electrodynamics because electromagnetic radiation had never been observed to flow backwards. Einstein, by contrast, believed by 1909 that the apparent irreversibility of electromagnetic processes should not be grounded on the absence of empirical evidence for it or on the second law of thermodynamics. To Einstein, a theory of radiation should permit reversible processes, just as kinetic-molecular theory permits an inverse of every action.

Ritz and Einstein exchanged views on this question in the *Physikalische Zeitschrift*. In 1908 Ritz published a critique of electrodynamics and the blackbody problem in response to a paper by Lorentz (figure 3) and an earlier one by James Jeans.[26] Ritz argued that the "ultraviolet catastrophe" associated with the Rayleigh-Jeans law stemmed essentially from an improper use of advanced potentials in Maxwell's equations. He suggested that the exclusive use of retarded potentials would restrict the equipartition of energy and thus obviate the problem of an infinite total energy of emission.[27] Einstein joined the discussion in 1909, commenting on the views of Ritz, Jeans, and Lorentz, and expressing his own.[28] He advocated the use of the Maxwell-

Fig. 3. Hendrik A. Lorentz (1853–1928). *Credit*: Algemeen Rijkarcheif, The Hague; coutesy of American Institute of Physics Emilio Segrè Visual Archives.

Lorentz equations, since they yielded expressions for the energy and momentum of a system at any instant of time, while the exclusive use of retarded potentials required knowledge of the earlier states of a system to determine any future state. He denied that retarded potentials had some fundamental significance; he viewed them merely as auxiliary mathematical formulations. Ritz responded both in print and in person by visiting Einstein in Zurich.[29] This led them to publish a concise joint statement of their main differences of opinion in 1909.[30] Whereas Ritz granted physical meaning only to retarded potentials in the interest of obtaining irreversibility, Einstein deemed the apparent irreversibility of radiation phenomena to be grounded solely on probabilistic considerations.

Ritz's Last Year

This was an intense period in Ritz's life. He was thirty-one years old, and despite serious recurring illness, he had made significant contributions to spectroscopy; he was developing his theory of electrodynamics and optics; and he had begun work on the problem of gravitation.[31] In February 1909 he completed his *Habilitationsschrift* at Göttingen, and in early March he gave his inaugural lecture as *Privatdozent* on the principle of relativity in optics.[32] At that time, his reputation was such that a faculty committee at the University of Zurich considered Ritz to be the foremost of nine candidates to become their first professor of theoretical physics, noting that in the opinion of the Zurich physicist Alfred Kleiner, Ritz exhibited "an exceptional talent, bordering on genius."[33] Ritz, however, had to be excluded from consideration because he was too ill to carry the workload, so the job went to Einstein instead.[34] Then, between April and May, Ritz advanced his spectral combination principle. In April, Henri Poincaré visited him to apologize personally in the name of the Paris Academy of Sciences for not awarding him its *Prix Vaillant* for a paper he had submitted for a mathematical competition, promising that this injustice would be repaired. And just at this time also, as noted above, Ritz had engaged Einstein in a discussion on the blackbody radiation problem and the principles underlying the theory of radiation. All of this while Ritz was desperately ill with tuberculosis.

To gain further insight into this period in Ritz's life, consider the following account by physicist Max Born, who had become acquainted with Ritz through Leonard Nelson, a lecturer in philosophy at Göttingen. Born recalled that sometimes he and Nelson met to discuss philosophy and physics.

> On one such occasion he [Nelson] told me the story of Walter Ritz. He was a young Swiss mathematical physicist (four years my senior) who was considered a rising star and just admitted to "Habilitation" (*i.e.* to become a lecturer), but who was terribly ill, suffering from tuberculosis of the lungs, which had been neglected as he had not had the means to go to a sanatorium in the Alps. Nelson was deeply impressed by the man's genius and worried about his fate; he urged me to see him and I did so. I found Ritz in a small, simple room in an old house; his face was that of a martyr, thin and pale, the skin sharply drawn over the bones; beautiful, kindly eyes. He was sitting at his desk, coughing and working restlessly at his great paper on the vibrations of a rectangular elastic plate, a paper which contains the method of approximation known today on the Continent as Ritz's method. (In Britain it is usually called the Rayleigh-Ritz method, and in fact it is already contained in Lord Rayleigh's theory of sound, but without the rigorous proof of convergence given by Ritz.) He received me very kindly and sacrificed his precious time to discuss problems of physics with me. He was one of the first to attempt a theoretical derivation of the laws of spectral series and discovered the combination principle for spectral lines which became one of the fundaments of quantum theory. He was also deeply interested in electrodynamics of moving bodies and had worked out a comprehensive theory based on the hypothesis that the velocity of light, in spite of the wave character of the propagation, depends on the velocity of the source. I was at the time fascinated by Einstein's first papers on relativity which treated the same problems from an entirely different standpoint, and so we had some interesting discussions.
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> Yet that is not the story I intended to report; it concerns the human side of the encounter. I shared, of course, Nelson's feelings about Ritz's situation and we decid-

> ed that something ought to be done. Nelson suggested we should collect a sum of money which would allow Ritz to go to Arosa for a cure. We estimated the costs to amount to some thousand marks. I wrote letters to some of my well-to-do relatives, of the Kauffmann and Lipstein tribes, and the response was quite satisfactory in view of the fact that none of these people knew anything about Ritz nor of mathematical physics in general. But when Nelson and I met again it turned out that he had already got together his whole share (he was related to one of the big banking families in Berlin) while I had hardly half of mine. So I simply added the rest from my own pocket, quite a considerable sum, almost my yearly allowance. Then we approached Professor Voigt and asked him to hand the money over to Ritz as a prize given by an anonymous donor for his scientific achievements, with proper instructions for its use. But this help came too late. Ritz died in 1909, thirty-one years of age. Nelson was despondent and relieved his feelings by violently abusing our society in general and the Göttingen professors in particular.[35]

So, shortly after his joint communication with Einstein had appeared in the *Physikalische Zeitschrift*, Walter Ritz died on July 7, 1909, after seven weeks in the Göttingen medical clinic. In his last year and a half he had published a total of about four hundred pages of articles in the areas of theoretical spectroscopy, the foundations of electrodynamics, the problem of gravitation, and a method for the numerical solution of boundary-value problems. After his death the unfinished products of his labors were left in the hands of the physics community.

Two months after Ritz's death, in September 1909, his exchange with Einstein barely echoed at a meeting of the Deutsche Naturforscher und Ärtze in Salzburg, where Einstein delivered a lecture elaborating his views on the radiation problem but made no explicit reference to Ritz's views. Two years later, however, in November 1911, Paul Ehrenfest wrote a paper comparing Einstein's views on light propagation with those of Ritz.[36] Ehrenfest noted that although both approaches involved a particulate description of light, Ritz's theory constituted a "real" emission theory (in the Newtonian sense), while Einstein's was more akin to the ether conception since it postulated that the velocity of light is independent of the velocity of its source. Ehrenfest then suggested possible experiments to distinguish between the two theories and noted the necessity of carrying out some such empirical test.

Other Emission Theories

Emission hypotheses also were advanced independently by Daniel Frost Comstock, Richard Chase Tolman, and others in 1910, all apparently unaware of Ritz's work. Their common theme was that if the ether concept were abandoned and the emission hypothesis adopted, then the problematic results of the optical experiments could be explained without introducing Einstein's radical new idea of time and without complicating the simple system of classical mechanics. Comstock suggested that astronomical data could decide between the emission hypothesis and Einstein's postulate that the speed of light is independent of its source. He argued that if the velocities of light from stars approaching and receding from the earth were different, then irregularities should be observed in the orbital motions of double-star systems.[37] Meanwhile, Tolman asserted that the independence of the speed of light from its source lacked experimental justification and had been conjectured originally merely as a consequence of the ether theory of light. He therefore proposed an experiment to compare the speed of light from the approaching and receding limbs of the sun.[38] But he found no evidence that these speeds were different. Moreover, he deduced Einstein's postulated constancy of the speed of light from the results of experiments by Walther Kaufmann and Alfred H. Bucherer on the mass of electrons in motion, but here the "proof" seemed to be not quite definitive: It was conceivable that the electromagnetic force acting on rapidly moving electrons might not obey the Lorentz force law, so that the increase in mass they measured might only be apparent. Ritz had made a similar argument.[39]

At about this same time, a few other physicists also attempted to combine the emission hypothesis with the mechanics of the ether. In 1910 J. J. Thomson proposed a theory describing the structure of the electric field as consisting of discrete "tubes of force" attached to electrons, such that the velocity of light (transverse vibrations in these tubes) depended on the velocity of the electrons.[40] Jacob Kunz called this the "electromagnetic emission theory of light" and advocated it in favor of the ether-wave theory to explain experiments of Michelson, George Bidell Airy, and others.[41] This theory likewise was espoused by Oskar M. Stewart in 1911 as a "less revolutionary" alternative to Einstein's postulate of the constancy of the speed of light and its consequences.[42] Their views did not garner general support, but they did draw some attention to the emission hypothesis. For example, Robert D. Carmichael, a mathematician at Indiana University, acknowledged in a book on relativity that owing to Thomson's and Stewart's work, and despite Tolman's inclinations, "at present there is no undoubted experimental evidence for or against the postulate" that the speed of light is independent of that of its source.[43]

By 1912 Tolman had become aware of Ritz's work and, like Ehrenfest, he then emphasized the importance of an unambiguous experimental decision between "the relativity theories" of Einstein and Ritz.[44] Tolman, as well as Michele La Rosa, suggested that the Michelson-Morley experiment could provide the crucial, decisive evidence if instead of a light source attached to the interferometer one used light coming from the Sun.[45] But before such a modified version of the Michelson-Morley experiment could be carried out, the Dutch astronomer Willem de Sitter examined spectroscopic observations in 1913 and provided a convincing quantitative analysis of them showing that the orbital motions of binary stars did not exhibit the apparent eccentricities that would be expected on the emission theory.[46] Nonetheless, in 1924 the modified Michelson-Morley experiment was finally performed with light from extraterrestrial sources. Rudolf Tomaschek in Heidelberg used starlight, while Dayton C. Miller in Cleveland used sunlight. The results of both experiments seemed to agree clearly with Einstein's theory and to disagree with Ritz's.

When twenty-year-old Wolfgang Pauli wrote the article on "Relativitätstheorie" for the *Encyklopädie der mathematischen Wissenschaften* (published in 1921), he devoted the third section of Part I to a discussion of Einstein's light postulate and to a recapitulation of the experimental disproof of Ritz's emission hypothesis – apparently the longest discussion of the latter to date. Pauli rejected emission theories for several reasons. He argued that such theories required artificial auxiliary hypotheses to explain Fizeau's moving-water experiment; that they had not explained atomistic effects of refraction and interference; and that they conflicted strongly with observations of binary stars. Pauli concluded that Einstein's postulate of the constancy of the speed of light had been "proved to be correct," while Ritz's emission theory was "untenable."[47] In his preface to Pauli's article, Arnold Sommerfeld praised Ritz in a backhanded way by stating that the emission theory had been "criticized in the light of experimental evidence with a thoroughness which is commensurate with the stature of its originator."[48] After Tomaschek's negative evidence of 1924, Pauli added a note on it in a later edition of his article,[49] and in subsequent years physicists usually attributed the refutation of the emission hypothesis to the negative observations on binary stars and to the negative results of the modified Michelson-Morley experiment using extraterrestrial light sources. Einstein himself regarded Tomaschek's starlight experiment as the most decisive evidence against the emission hypothesis.[50] He also often cited de Sitter's analysis of the spectroscopic observations on binary stars as substantiating the constancy of the speed of light and its independence of that of its source.[51] Ritz's emission theory appeared to be dead by the end of the first quarter of the twentieth century.

Later Developments

Interest in the emission hypothesis, however, did not disappear completely in succeeding decades, especially in the 1960s. Some physicists still considered it as a plausible alternative to Einstein's postulate of the constancy of the speed of light. The January 1965 issue of the *American Journal of Physics* opened with an article entitled "Evidence Against Emission Theories" by John G. Fox (figure 4) of the Carnegie Institute of Technology in Pittsburgh.[52] Fox reevaluated Ritz's theory critically in light of recent experiments and a hypothesis on scattered radiation that harked back to Ritz's ideas. Thus, in his second article on electrodynamics, Ritz had argued that to ensure close agreement between his theory and Lorentz's, one had to suppose that when light waves set the ions in matter into vibration and are reemitted as secondary light waves, their center point moves with the same velocity as that of the incident light waves.[53] Ritz used this idea but admitted that on the emission hypothesis it might be expected instead that the center point of the secondary light waves would move at the same velocity as the ions, since they were emitted by them. Fox now adopted this hypothesis and indicated that the one used by Ritz was a key source of the difficulties of the emission theory, since it entailed that the speed of light when passing through any medium, even if the light were absorbed and reemitted, would not change.

Fox now reanalyzed Ritz's theory in light of the experimental evidence and showed that all of Pauli's objections to emission theories were faulty. Pauli had argued that source-dependent scattered waves could not interfere as required by the electron theory of dispersion, since their velocities would vary from one wave to another, but he erred here by assuming that the equality of velocities, instead of the equality of frequencies, was necessary for interference. On the emission hypothesis as applied to the

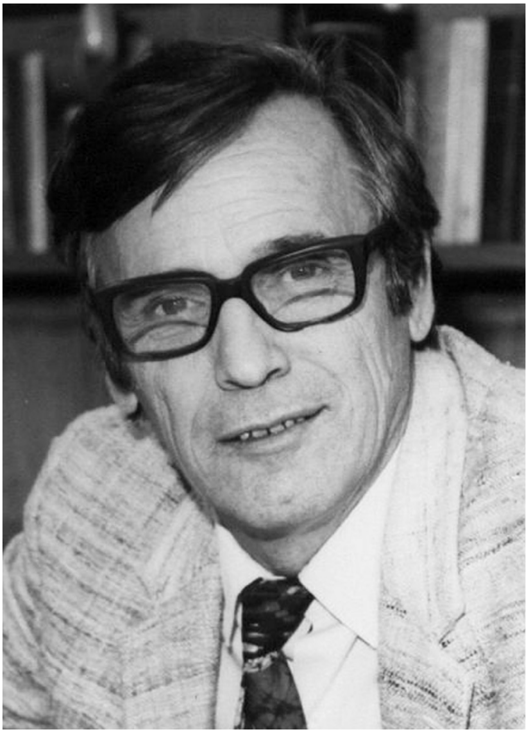

Fig. 4. John G. Fox (1916–1980). Courtesy of the Department of Physics, Carnegie Mellon University.

theory of dispersion, light entering a medium would be absorbed and reemitted by charged ions and its speed would be altered gradually, in accordance with a theorem of Paul P. Ewald and Carl W. Oseen.[54] The radiation thus would acquire a constant speed *c relative to the medium* after traversing one "extinction length," and any light passing through the earth's atmosphere, for example, would not have the same velocity it had when emitted from its source. Therefore, interferometric experiments like those of Tomaschek or Miller or those using Tolman's apparatus were "irrelevant" to the question of the dependence of the speed of light on the speed of its source. Similarly, de Sitter's observations on binary-star systems did not constitute evidence against the emission theory, since their common atmosphere as well as interstellar matter would give rise to the extinction process. Furthermore, Pauli had indicated that a difficulty for the emission theory was that it was not clear whether the stellar first-order Doppler effect would have to be interpreted as a shift in wavelength or frequency. Fox explained that in fact "there is a change in both wavelength and frequency and Pauli's difficulty disappears."[55] Fox also proved that laboratory experiments with moving mirrors too gave results that were expected on the emission theory as well as on Einstein's relativity theory. As for the experiments on the velocity of light in moving media (for instance, those of Fizeau, Michelson, and Pieter Zeeman), their results followed from the emission theory by adopting quantum expressions for the energy and momentum of light particles, as he showed by deriving the expression for the Fresnel dragging coefficient. The emission theory also seemed to be compatible with the experiments of F. Harress, Georges Sagnac, and Michelson, and those of Warren M. Macek and D.T.M. Davis on the behavior of light in rotating media, barring a qualitative ambiguity on how the velocity of radiation in moving media is not compounded in accordance with classical kinematics.

Fox did not confine his survey of evidence for the emission theory to Pauli's arguments against it. He also pointed out that the emission hypothesis was consistent with the aberration of light, including Airy's observation of stellar aberration with his water-filled telescope; with second-order Doppler effects, including those involved in Rudolf Mössbauer's recent gamma-ray experiments; and with the inertia of radiant energy, since the emission of particles involved the transfer of momentum. Fox also argued that the variation in mass of charged particles with their velocity, or the mass-energy balance in nuclear reactions, did not provide any clear evidence against Ritz's emission theory.

Still, Fox did find significant evidence against the emission theory. Together with T. A. Filippas, he carried out experiments on moving sources of gamma rays (π^0 mesons) that seemed sufficiently free of extinction complications to qualify as evidence against the emission theory.[56] He also took an experiment by G. C. Babcock and T. G. Bergman on the interference of light beams passing through moving glass plates,[57] as well as the earlier, well-known experiments that measured the time dilation in the lifetimes of mesons in rapid motion,[58] as further evidence against Ritz's theory. Moreover, while Fox's paper was being edited, more precise negative evidence became available, namely, an experiment by Torsten Alväger, F. J. M. Farley, J. Kjellman, and I. Wallin in 1964 on gamma rays from fast-moving mesons.[59] Fox concluded that, "Despite various misunderstandings in the interpretation of past experiments, we still have good reason to reject the emission theory."[60] Thus, the evidence against Ritz's theory was "different from and less than it has been thought to be."[61] In 1977 more evidence against the emission theory was published by Kenneth Brecher of the Massachusetts Institute of Technology in *Physical Review Letters*.[62] Brecher analyzed recent observations of regularly pulsating X-ray sources in binary-star systems and found strong evidence that the velocity of light is independent of the velocity of its source, because the propagation of very high-energy X rays was deemed to be less liable to the strictures of the extinction theorem. Brecher's results, along with those of Fox and of Alvager and his colleagues, became accepted as key evidence against the emission hypothesis.

The Early Rejection of Ritz's Approach

In light of the above, we may ponder again why Ritz's ideas were rejected originally. Fox remarked that, "It is a curious historical fact that the recent experiments with moving sources and even the first data on time dilation were not obtained until long after special relativity had completely displaced the emission theory in physics."[63] In fact, emission theories were believed to be untenable even before Tomaschek's and Miller's negative interferometer experiments with extraterrestrial light sources were carried out in 1924. One therefore might imagine that Ritz's theory was rejected by the physics community because the available empirical evidence seemed to be clearly against it. But other factors were involved also, because even before any apparently unambiguous negative evidence appeared (for instance, the arguments presented against it by de Sitter in 1913), Ritz's theory had been dismissed.

Ritz's theory met with immediate opposition. In a letter of 1908, Ritz complained that although no one had given him a single worthy objection, his ideas on electrodynamics were deemed "monstrous [*scheusslich*]."[64] Sommerfeld had said the same thing about Ritz's spectroscopic combination principle.[65] Ritz's emission theory garnered hardly any supporters, at least none who would develop it or express support for it in print. As noted above, in 1911, two years after Ritz's death, Ehrenfest wrote a paper contrasting Ritz's and Einstein's theories,[66] to which Einstein responded in several letters,[67] trying in vain to convince him that the emission hypothesis should be rejected. Then Ehrenfest became Lorentz's successor at Leiden, and in his inaugural lecture in December 1912,[68] he argued dramatically for the need to decide between Lorentz's and Einstein's theories, on the one hand, and Ritz's on the other. After 1913, however, Ehrenfest no longer advocated Ritz's theory. Ehrenfest and Ritz had been close friends since their student days, Ehrenfest having admired Ritz immensely as his superior in physics and mathematics; but following Ritz's death, Einstein came to play that role, as he and Ehrenfest became close friends.

Einstein himself never published any statements on Ritz's theory. He almost did in a long review article on electrodynamics and relativity that he wrote between 1912 and 1914 for the *Handbuch der Radiologie*. In the draft of this article he included several paragraphs on the emission hypothesis, explicitly ascribing it to Ritz and Ehrenfest, but he then crossed three of them out, inserting in their place comments that pointed essentially to de Sitter's recent negative results.[69] Einstein's manuscript perhaps illustrates how readily he accepted such negative evidence, since in it he misspelled de Sitter's name as "Pexider," which suggests that he had heard about the negative evidence indirectly. Be that as it may, Einstein (figure 5) settled on the statement that "a simple calculation shows that, indeed, if the underlying hypothesis were borne out by the facts, the indicated influence would have to be so considerable that it would have been absolutely impossible for the astronomers to miss it. The untenability of this conception can surely be viewed as definitively proven."[70]

But not everyone was convinced so quickly by de Sitter's arguments. The German astronomer Erwin Finlay Freundlich promptly argued in 1913 that current astronomical evidence did not support de Sitter's claims.[71] Einstein was in friendly correspondence with Freundlich and soon wrote to him: "I am also very curious about the outcome of your examination of double stars. If the speed of light depends even in the very least on the speed of the light source then my whole theory of relativity, including my gravitational theory is false."[72]

Other physicists dismissed Ritz's work without even specifying evidence against it. Most books on electromagnetism, optics, and relativity included no discussion of Ritz's theory. Thus, Max Laue, in his book *Das Relativitätsprinzip* of 1911, the first book ever published on Einstein's theory, did not mention Ritz's work, although in its second edi-

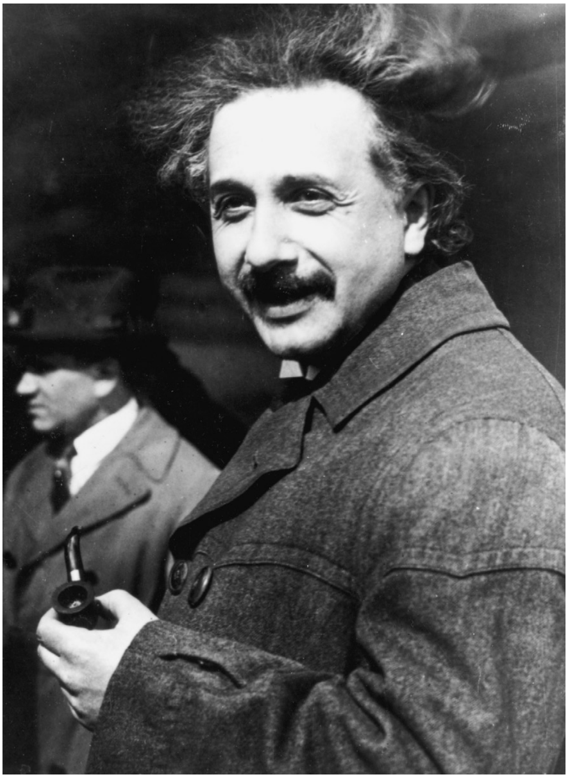

Fig. 5. Albert Einstein (1879–1955). *Credit*: American Institute of Physics Emilio Segrè Visual Archives.

tion of 1913 he added two sentences on it. He admitted that the null result of the Michelson-Morley experiment was explained very simply "by Ritz's idea," but he claimed that "these thoughts" were contradicted by other optical experiments, which he did not specify.[73] Similarly, Ludwik Silberstein, in another early and thorough book on relativity published in 1914, mentioned and rejected Ritz's work in a single sentence. Silberstein claimed that in accordance with the wave theory of light, the velocity of light is independent of that of its source, and then asserted that, "Newton's corpuscular theory, revived in a more elaborate form in the writings of the late Dr. Ritz, need not detain us here."[74] He gave no explanation for his opinion.

In those early days, physicists perhaps counted as evidence against the emission hypothesis experiments that remained unexplained by it. In particular, Fizeau's experiment on the speed of light in moving water stands out. Einstein emphasized its importance repeatedly as a "crucial experiment"—one that had helped him both to conceive and to justify his theory.[75] Einstein did not claim that Fizeau's experimental results contradicted the emission hypothesis, just that their explanation on that hypothesis did not seem to be straightforward, since they seemed to show that light did not travel at the same velocity in stationary as in moving water. They thus constituted evidence against Heinrich Hertz's electrodynamics, which assumed that the ether in a moving medium was completely carried along with it, and which therefore gave predictions equivalent to those of the emission hypothesis so long as the source of light was carried along with the moving water. Although this was not the case in Fizeau's experiment, Einstein discussed it in ways that emphasized its apparent discord with the traditional composition of velocities,[76] the mathematical basis of the emission hypothesis. Einstein suggested that Fizeau's experiment might be explained by ascribing the reduction of the speed of light in moving water to some effect involving the relative motion of the source of light.[77] Ritz himself had noted that his provisional equations led to the same incorrect result as Hertz's in the analysis of Fizeau's experiment, unless an *additional* hypothesis was introduced: that light particles experience a reaction that changes their velocity when traversing a moving medium.[78] But neither Einstein nor Ritz provided a mathematical derivation of Fizeau's result on such speculative grounds. Nor did anyone else. In a paper of 1911, after reviewing only Fizeau's experiment, Einstein noted that whereas Lorentz's theory, which assumed a stationary ether, accounted for Fizeau's and other experiments, "a theory fundamentally different from that of Lorentz, which would be based on simple and intuitive assumptions and would accomplish the same ends, could not be formulated."[79]

Prior to de Sitter's work of 1913, the evidence bearing on Ritz's and Einstein's hypotheses did not tilt the balance one way or the other, since although criticisms were raised against Ritz's emission hypothesis, criticisms also were raised against Einstein's theory. Indeed, many more objections were leveled against Einstein's theory than against Ritz's, if only because physicists neglected the latter. At any rate, Einstein's theory was accepted gradually notwithstanding some uncertainties about its experimental confirmation. Thus, for example, Wilhelm Wien in 1909 treated Einstein's theory favorably although he admitted that it was not supported clearly by the experimental evidence. Despite such experimental ambiguities, even to some extent because of them, Einstein's theory became the subject of constructive theoretical work by many physicists. The question remains why Ritz's theory did not.

By 1911 the "Lorentz-Einstein" theory of relativity had gained general acceptance in the physics community, especially in Germany. Hermann Minkowski had recast the theory in an innovative mathematical form in 1908,[80] prompting leading physicists such as Sommerfeld, Wien, and Alfred Bucherer to change their initial skeptical attitude toward it. Sommerfeld, for example, changed the topic of a talk he was scheduled to give in 1911 at a meeting of the Deutsche Gesellschaft für Naturforscher und Ärtze, stating that he had decided not to discuss relativity because it already was "a secured possession" of physics; he also declined to talk on relativity at the first Solvay Congress in October 1911 for the same reason. Max Planck too had been an early supporter of Einstein's theory and had encouraged his students, particularly Max Laue, to elaborate it. By 1911 a number of other talented young physicists, including Jakob J. Laub, Paul Ehrenfest, and Max Born, had begun to work on relativity. Meanwhile, no physicist, young or old, had pursued Ritz's emission theory actively.

Thus, there were institutional and social reasons, in addition to apparently negative evidence, that contributed to the neglect of Ritz's theory. There also were more broadly conceptual reasons for its neglect. For example, Ritz's and Einstein's exchange on irreversibility in electromagnetic phenomena echoed an earlier dispute between Planck and Ludwig Boltzmann. The probabilistic interpretation of the second law of thermodynamics espoused by Boltzmann had prevailed over Planck's belief in its exact validity. Both Einstein and Ritz had derived inspiration from thermodynamics in the formulation of their theories, but Ritz had based his on the exact validity of the second law. No wonder that Planck had "followed Walther Ritz's emission theory of radiation with great interest, even though he did not believe in it."[81]

At Göttingen, as mentioned above, Ritz had complained that his ideas on electrodynamics were deemed "monstrous." Physicists and mathematicians there had reasons to dislike Ritz's fledging theory. Their interest in electrodynamics had focused on elaborating an electromagnetic view of Nature. Göttingen physicists thus espoused Lorentz's electrodynamics enthusiastically. Almost unanimously, they rejected the conceptual structure of Einstein's relativity theory of 1905, but they appreciated his theory as a mathematical refinement of the Lorentz-Maxwell scheme. Ritz's approach, by contrast, lay outside this tradition. Einstein had stated succinctly that the concept of the ether was superfluous, while Ritz had argued emphatically that the ether did not exist and that such a concept had to be renounced entirely. And Ritz not only had criticized the concept of the ether; he also had antagonized Lorentz, Einstein, and Poincaré by criticizing their efforts to achieve a theory consonant with Maxwellian field theory. Einstein, by contrast, was far more restrained in his criticisms of the work of others. Ritz had urged that Lorentz's approach should be renounced, along with Maxwell's equations, and that the use of partial derivatives should be eliminated from fundamental physics. None of this would have seemed attractive to most physicists at the time.

Most physicists by then had stopped trying to reduce electromagnetic theory to classical mechanics, and Einstein had shown that the problems of electrodynamics and optics could be resolved by a careful revision of mechanical concepts. Yet, Ritz had proposed that classical mechanics be retained and field theory renounced – and in its place he had offered only a contrived, skeletal reconstruction of electrodynamics that reproduced results of Lorentz's theory awkwardly. Moreover, Ritz's equations included action-at-a-distance relations, a characteristic concept of the old mathematical theories that physicists by and large had replaced with the field concept. Ritz himself did not believe in action-at-a-distance, but he died before he could develop his theory in a way that was based systematically on the mediating action of particles of energy. Further, he had admitted that "from the point of view of mathematical elegance and simplicity, the advantage will remain often on the side of the theory of Lorentz."[82] And, of course, Einstein's theory was even simpler mathematically than Lorentz's.

Ritz also had described electromagnetic radiation as particles at a time when Einstein's light-quantum hypothesis was regarded with deep skepticism or apathy. Ritz did not use his particle theory to explain the emission and absorption of energy, but to provide an image for the propagation of energy through space. Precisely how Ritz viewed Einstein's light-quantum hypothesis is beside the point. What matters is that Ritz's use of particle imagery in 1908 to replace waves in the description of the transmission of light was yet another element that made his theory unattractive in the eyes of most of his contemporaries. Einstein, by contrast, formulated his approach to electrodynamics in a way that harmonized with both particle and wave conceptions of radiation.

Einstein's theory garnered prestigious supporters such as Planck, Sommerfeld, and Wien, who endorsed and protected it from the attacks of others, while Ritz's theory acquired no supporters. Ehrenfest and Tolman called for unambiguous empirical evidence to test Ritz's emission theory, but neither spent any effort in extending it, and soon they both espoused Einstein's theory unreservedly, especially following de Sitter's work. For a few years immediately following its publication, Ritz's theory may have seemed to be an odd and complicated curiosity, in comparison to the leading approaches in electrodynamics. Ritz, the one man who had both the skill and the motivation to advance it, had died.

Einstein had been an outsider in the physics community – he had been denied all university assistantships and positions before getting his professorship at Zurich – yet he soon saw his work incorporated into physics. Ritz, an insider, was welcomed into prestigious professional circles but his work was rejected summarily and eventually attracted the attention mainly of outsiders – skeptics and crackpot amateurs looking for alternatives to Einstein's theory of relativity. The prior success of Lorentz's electrodynamics encouraged physicists to accept Einstein's counterintuitive postulate of the constancy of the speed of light, while the apparent conflicts of Ritz's common-sense emission hypothesis with empirical evidence dissuaded physicists from taking a closer look at his ideas on electrodynamics. Einstein, who rebelled against authority, suffered the fate of being regarded as an authority, while Ritz, the uncompromising revolutionary, suffered the worse fate of having his ideas neglected by those who were most able to develop them.

In the end, however, although Ritz did not succeed in formulating an electrodynamics that was acceptable either to himself or to others, he did contribute to the rejection of the concept of the ether by physicists, and he helped to undermine Lorentz's theory, both of which, after all, were two of his major goals. While Einstein admired Lorentz and his work immensely and advocated various ether concepts throughout his life, most later writers on relativity belittled Lorentz's ideas and rejected the ether concept. Thus, ironically, the followers of Einstein who criticized the ether concept often echoed the tone of Ritz more than that of Einstein.

Acknowledgments

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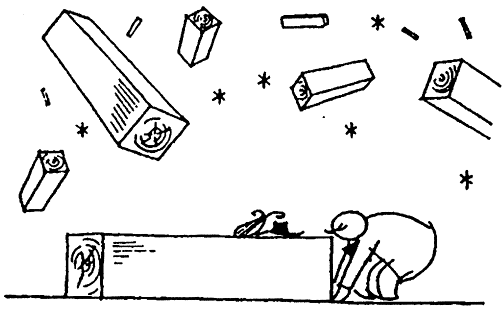

OUR OWN MOTES

The errors hardest
to condone
in other people
are one's own.

Piet Hein