vols. (Leipzig, 1806). Of particular historical interest are Ritter's hitherto unpublished first paper on galvanism addressed to the Naturforschende Gesellschaft zu Jena in Oct. 1797 (vol. I); his paper on his thought process in the discovery of untraviolet radiation delivered to the same society in 1801 (vol. II); and a dictation of the first part of his 1803–1804 lectures on galvanism given at Jena (vol. III). In all, 36 separate papers and letters are printed. His address at the founding ceremony of the Royal Bavarian Academy of Sciences was published as *Die Physik als Kunst, ein Versuch die Tendenz der Physik aus ihrer Geschichte zu deuten* (Munich, 1806; repr. Berlin, 1940).

Ritter founded the journal *Der Siderismus, Neue Beiträge zur nähern Kenntnis des Galvanismus*; only one volume appeared (1808). He also collected a series of aphorisms concerning his views on life and science in *Fragmente aus dem Nachlass eines jungen Physikers; Ein Taschenbuch für Freunde der Natur*, 2 vols. (Heidelberg, 1810).

The Royal Society *Catalogue of Scientific Papers*, V, 217–219, lists some twenty other journal articles.

II. Secondary Literature. Although Ritter has not received a full-length biographical treatment, various aspects of his scientific influence and work have been repeatedly analyzed since the mid-nineteenth century. In an influential work R. Haym, *Die Romantische Schule* (Berlin, 1870), 612–619, discredited the scientific merit of Ritter's research, even though E. Du Bois-Reymond, *Untersuchungen über die tierische Elektrizität*, II (Berlin, 1849), 320 ff., had assessed clearly the empirical value of Ritter's work in electrophysiology. More recently, D. Huffmeier, "Johann Wilhelm Ritter. Naturforscher oder Naturphilosoph?" in *Sudhoffs Archiv für Geschichte der Medizin und der Naturwissenschaften*, **45** (1961), 225–234 has reinforced the latter view.

The scientific authenticity of Ritter's research on electrochemistry has been established by W. Ostwald, *Abhandlungen und Vorträge*, (Leipzig, 1904), 359–383; and H. Schimank, "Johann Wilhelm Ritter; Der Begründer der wissenschaftlichen Elecktrochemie," in *Abhandlungen und Berichte des Deutschen Museums*, **5** (1933), 175–203. C. von Klinckowstroem explored in detail the nature of Ritter's association with the Jena circle: "Goethe und Ritter; mit Ritters Briefe an Goethe," in *Jahrbuch der Goethe Gesellschaft*, **8** (1921), 135–151; "Drei Briefe von Johann W. Ritter," in *Der grundgescheute Antiquarius*, **1** (1921), 120–130; "Johann Wilhelm Ritter und der Electromagnetismus," in *Archiv für die Geschichte der Naturwissenschaften und der Technik*, **9** (1922), 68–85.

Three recent collections of writings by Ritter, with extensive historical commentary, provide the best historical material available: F. Klemm and A. Hermann, eds., *Briefe Eines Romantischen Physikers; Johann Wilhelm Ritter an Gotthilf Heinrich Schubert und an Karl von Hardenberg* (Munich, 1966), contains not only an informative set of 8 hitherto unpublished letters with commentary but also an excellent bibliography of secondary works about Ritter; K. Poppe, ed., *Johann Wilhelm Ritter: Fragmente aus dem Nachlass eines jungen Physikers* (Stuttgart, 1968); and A. Hermann, ed., "Begründung der Elektrochemie und Entdeckung der ultravioletten Strahlen von Johann Wilhelm Ritter; eine Auswahl aus den Schriften des romantischen Physikers," in *Ostwalds Klassiker der exakten Wissenschaften*, n.s. **2** (1968), provides an excellent introduction, commentary, and bibliography of primary source material.

The archives of the Bavarian Academy of Sciences, Munich, contain much of Ritter's personal notes and library. The Deutsches Museum, Munich, has a collection of experimental apparatus used by Ritter.

Robert J. McRae

RITZ, WALTER (*b.* Sion, Switzerland, 22 February 1878; *d.* Göttingen, Germany, 7 July 1909), *theoretical physics*.

Ritz, the second of five children of Raphaël Ritz, a well-known landscape painter, was inclined from his youth toward science and mathematics. Following graduation from the *collège cantonal* in Sion (1895), he attended the *cours technique* at the *lycée cantonal* there for two years, studying calculus in his spare time. In the fall of 1897 he passed the entrance examinations to the Eidgenössische Technische Hochschule and the family moved to Zurich. Just prior to this, in September 1897, Ritz suffered a trauma that he regarded as the origin of the ill health from which, soon after, he began to suffer.[1] 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.

At Zurich, Ritz soon abandoned his original intention of becoming an engineer, ostensibly because of poor health, and joined the score of students—among them Albert Einstein—in the heavily mathematical "pure" section (Abteilung VI).[2] Here he studied especially Riemann's works and the two thick volumes of Woldemar Voigt's recently published *Compendium der theoretischen Physik* (1895–1896). At Easter 1901 following a severe case of pleurisy that the humid Zurich climate was presumed to aggravate, Ritz transferred to Göttingen. There he studied principally with Voigt (also with Max Abraham, T. Des Coudres, David Hilbert, Walter Kaufmann, Felix Klein, Georg E. Müller, and E. Riecke).

It was consistent with the interests and methods of the professors of physics, Voigt and Riecke, that Ritz chose as his dissertation topic a theory of spectral series. Moreover, he approached the problem not in terms of the avant garde conception of electrons but, rather, by conceiving atoms to be elastic continua.

Ritz postulated that line spectra—for which the doubly infinite generalized Balmer formula for the frequencies of the spectral lines emitted by hydrogen, $\nu = N(1/n^2 - 1/m^2)$, $m, n = 1, 2, 3, \ldots$, was taken as the paradigm—originate in the proper vibrations of two-dimensional structures (indeed, in the transverse normal modes of a plane square plate).[3]

Since it was well known from the researches of Poincaré, Rayleigh, and others that the wave equation resulting from the action-by-contact of the theory of elasticity cannot give a Balmer-like distribution of frequencies, Ritz's object was to invent an interaction that would. "Leaning as fully as possible on mechanics and electrodynamics, one puts forward physically visualizable mathematical operations of which the interpretation as the vibrations of an appropriate 'model' leads to the laws of series spectra."[4] Ritz obtained the desired result, $\nu = N(1/n^2 - 1/m^2)$, from a tenth-order partial differential equation.[5] In constructing that equation he was obliged to put forward, for the energy of deformation of his elastic plate, mathematical expressions of which the physical interpretation as action-at-a-distance forces increasing with the separation between the points of the plate certainly exceeded the limits of physical plausibility, and perhaps the limits of visualizability as well.

Among spectroscopists there was evidently general agreement that Ritz's "theoretical foundation is not worth much."[6] If, nevertheless, they studied his dissertation "with great interest" in the spring of 1903, that was because of the novel series laws that Ritz was able to extract from his mathematical operations, largely by means of his thorough familiarity with the empirical data and his talent for generalizing empirical regularities. These operations themselves were of interest to mathematicians and stimulated research by Ivar Fredholm and Jacques Hadamard into the theory of integral equations with an infinite number of eigenvalues (frequencies) within a finite interval.[7]

A solution of his tenth-order equation with a Balmer distribution of frequencies had of course required appropriate boundary conditions; altering these gave the Balmer formula but with m and n replaced by infinite series $m + a + b/m^2 + c/m^4 \ldots$, $n + a' + b'/n^2 + c'/n^4 + \cdots$. The first approximation, $\nu = N/(n + a')^2 - N/(m + a)^2$ was Rydberg's formula, which was known to represent at least roughly the series in other elements. Ritz maintained that in the atoms of all elements the spectral vibrator is a face of one and the same cube, with appropriate differences in the constraints at its edges; that N, being expressed in his theory in terms of the size, mass, and "elastic" constants of the face itself, was a rigorously universal constant; and that the Rydberg formula was thus to be improved not by adjusting N but by adding the next term in the series, b/m^2. Ritz showed that such a formula represented the spectral series, particularly the lines in the red and infrared corresponding to low values of m and n, with unprecedented accuracy. Moreover, the structure of his formula allowed him to adopt all of Rydberg's proposed interrelations between the several series of a given element. [Anticipating the notation Ritz himself introduced five years later:[8]

principal series: $\nu = (1.5, s, \sigma) - (m, p, \pi)$
sharp series: $\nu = (2, p, \pi) - (m, s, \sigma)$
diffuse series: $\nu = (2, p, \pi) - (m, d, \delta)$,

where $(m, a, \alpha) \equiv N/(m + a + N\alpha/m^2 + \cdots)^2$.] He achieved this impressive agreement with experiment and "put into the shade" all previous formulas,[9] even though he used substantially fewer adjustable parameters. And in fact, as emerged twelve years later from Sommerfeld's work, Balmer's, Rydberg's, and Ritz's formulas are successive approximations to the energy of a Rutherford-Bohr atom.[10]

Ritz's dissertation was accepted by Voigt late in 1902, and the oral doctoral examination was passed *summa cum laude* on 19 December. By the beginning of March 1903 the dissertation was ready for submission to the *Annalen der Physik*; and at the end of March, Ritz set off for Leiden (via Hannover, in order to discuss some spectroscopic questions with Carl Runge).[11] At Leiden, Ritz, with Paul Ehrenfest, attended lectures and seminars of H. A. Lorentz, whose electron theory was then coming to occupy the central position in theoretical physics. The six-week visit was made jointly by these two young theorists, who had formed a close friendship during the preceding three semesters at Göttingen. Ehrenfest, Ritz's junior by almost two years, enormously admired the cool, restrained personality; the quick, sarcastic wit; the fertile imagination; the rigorous mathematical talent; and, above all, the penetrating criticism of the physical theories of others. Although their scientific predilections soon diverged widely, Ritz exerted a great influence upon Ehrenfest's intellectual development.[12]

Ritz left Leiden with, if anything, even less of an inclination toward Lorentz's views. By late May or early June 1903 he was at work in Bonn, where Heinrich Kayser's institute offered the best spectroscopic facilities in Germany. Within a few weeks Ritz had found the missing $m = 4$ diffuse series line of potassium precisely where, in his dissertation, he had predicted it.[13] But after this initial success the work progressed slowly—August Hagenbach, then

Kayser's assistant, thought that "for experimental work he [Ritz] had neither the physical strength nor the necessary patience."[14] During the summer holidays Ritz was in Zurich, where Ehrenfest visited him for a week in September.[15] Shortly after returning to Bonn in November 1903, unable to obtain a piece of apparatus he wanted, Ritz abandoned his work and went to Paris.

With a recommendation from Pierre Weiss, Ritz was received into Aimé Cotton's and Henri Abraham's laboratory at the École Normale Supérieure, where he labored through that winter and into the following summer on a process for preparing infrared-sensitive photographic plates. Apparently it was primarily with an eye to an academic career that Ritz undertook experimental work at all—it was necessary in order to qualify for other than the exceedingly few positions available to pure theorists. His choice of this particular problem resulted from the crucial importance for his series formulas (and, four years later, for his "combination principle") of spectral lines in the red and infrared, a region that, because of inadequate means of detection, had been neglected by spectroscopists. Ritz had begun to obtain very promising results when, in July 1904, his health failed and he was compelled to retire to Zurich.

For the next three years Ritz resided outside the scientific centers, seeking the restoration of his health in various reputedly salubrious climes: St. Blasien in the Black Forest, Waldkirch in the canton of St. Gall, Sion, and Nice. During this period he published nothing, and during the first two years accepted the medical opinion that he should work as little as possible. In 1906 Ritz began to work intensively again, and that winter, despairing of recovering his health, he resolved to deprive himself of scientific companionship no longer.[16]

Late in September of 1907 Ritz settled in Tübingen, his mother's family's home but also a center of spectroscopic research.[17] Hoping that a few years remained to him, and anxious about his financial situation, in the spring of 1908 he moved to Göttingen, resolved to qualify as a lecturer. The *Habilitation* took place in February 1909, though Ritz was no longer strong enough to exercise the privilege of delivering a course of lectures or to join in any other way in the social-scientific life of the town. In mid-May he entered the Göttingen medical clinic, where, seven weeks later, he died.[18]

In Ritz's last year and a half (early 1908 through mid-1909), the fruits of six years of thinking and three years of working came forth in a spate: eighteen publications running to some 400 pages. These papers fall under three general topics: theoretical spectroscopy, the foundations of electrodynamics, and a method for the numerical solution of boundary-value problems—with each group of investigations largely conceptually independent of the others.

In December 1904 the Paris Academy of Sciences had announced as the subject of the Prix Vaillant (4,000 francs), to be awarded three years hence, "to perfect in some important respect the problem in analysis relating to the equilibrium of an elastic plate in a rigid frame, that is, the problem of integrating the equation $\partial^4 u/\partial x^4 + 2\partial^4 u/\partial x^2 \partial y^2 + \partial^4 u/\partial y^4 = f(x, y)$ with the condition that the function u and its derivative normal to the boundary of the plate be zero. To examine more particularly the case of a rectangular boundary."[19] Ritz's dissertation had given him extensive experience closely related to this question. Moreover, in his financial dependence and professional isolation, this type of competition and reward seemed especially attractive. Returning to work in 1906, he threw himself into the problem of developing a rigorous yet practicable procedure for directly constructing the solution by successive approximations.

Ritz recast the problem from the integration of this partial differential equation, $\Delta\Delta u = f$, to the variation of an integral $J \equiv \int [\frac{1}{2}(\Delta w)^2 - f(x) \cdot w]\, dx$. (In order to avoid inessential complexities the one-dimensional case will be discussed here.) The object then was to find among all possible deformations $w(x)$ of the system that particular one, $u(x)$, for which this integral, expressing the potential energy as a function of the deformation and the distribution of applied forces $f(x)$, assumes its minimum value. Introducing a complete orthonormal set of functions $\psi_i(x)$—the choice of which was guided by the geometry of the case—the solution u was expressed formally as $\sum_{i=1}^{\infty} a_i \psi_i$, and the problem became: to construct a sequence of functions

$$w_1 \equiv a_1^{(1)}\psi_1\,,\ w_2 \equiv a_1^{(2)}\psi_1 + a_2^{(2)}\psi_2\,, \ldots$$
$$w_n \equiv a_1^{(n)}\psi_1 + a_2^{(n)}\psi_2 + \cdots + a_n^{(n)}\psi_n$$

that would converge to u. Ritz simply substituted these linear combinations of basis functions ψ_i with undetermined coefficients $a_i^{(n)}$ into J, the integrand of which thus became an explicit function of x. The integration could then be carried through, yielding $J^{(n)}$ as a function of the n parameters $a_i^{(n)}$. Their values were now ingeniously fixed as the roots of the n equations $\partial^{(n)}J/\partial a_i^{(n)} = 0$—that is, the condition that w_n be that linear combination of the first n basis functions for which J is a minimum. Drawing heavily upon Hilbert's recent work in the calculus of variations, Ritz proved rigorously that for the equation of elasticity, $\Delta\Delta u = f$ (and also for Dirichlet's problem, $\Delta u = f$), the w_n constructed in this way converge to the solution u.[20]

Ritz then proceeded to show that although this proof could be carried through only for the case of static equilibrium, the corresponding equation for standing waves, $\Delta u = k^2 u$, could be formally subjected to the same procedure, and that the sequence of approximate solutions thus obtained converged with extraordinary rapidity.[21] Two years later, as a striking demonstration of the power of his method, Ritz calculated the sequence of Chladni figures for a square plate up to the thirtieth harmonic. "That has fatigued me, but there is no relation at all between the fatigue and the celebrity of this problem which remained insoluble despite all efforts."[22]

Ritz's memoir, one of a dozen submitted for the prize, did not win even an honorable mention from the distinguished jury, for which H. Poincaré, E. Picard, and P. Painlevé were the *rapporteurs*.[23] In April 1909, however, Ritz had the satisfaction of being sought out at Göttingen by Poincaré, who apologized in the name of the Academy for the injustice and promised Ritz a prize that year as "reparation."[24] For indeed, following Ritz's publications in 1908 the significance of his work was immediately recognized—and his method was immediately adopted—especially by theoretical engineers, notably Hans Lorenz, Aurel Stodola, Theodore von Kármán, Arpad Nadai, and S. Timoshenko.[25]

The prize memoir was completed before the 31 December 1906 deadline; after repaying the overdraft upon his reserves of strength with some weeks of fever, early in 1907, while still at Nice, Ritz returned to the question of the mechanism responsible for the production of line spectra. His recent experience with elastic plates persuaded him that the approach he had taken since 1902—construing the spectral frequencies as those of a quasi-elastic body of which the potential energy of deformation has an anomalous form—"must, after trying for years in every direction, be discarded as a misguided idea."[26]

But Ritz did not abandon his methodologic predilections and thus "came *a priori* finally to the result that vortical processes must be involved here, and with it the idea of the magnetic field immediately arose," namely that the frequency of circulation of a charged particle under the influence of magnetic forces, although proportional to the square root of the force in accord with Rayleigh's rule, is directly proportional to the magnetic field giving rise to these forces.[27] Ritz set himself to inventing mechanisms for producing magnetic fields that followed the Balmer formula. The first of these (March 1907) utilized a rather Victorian apparatus of particles suspended by inextensible wires. The second, definitive mechanism (June 1907) was of a remarkable simplicity. Observing the similarity between the Balmer formula and the field of a thin bar magnet at a point on its axis, $H \propto (1/r_1^2 - 1/r_2^2)$, Ritz proposed to construe $\nu = N(1/2^2 - 1/m^2)$ as the frequency of circular vibration (Larmor frequency) of a charged particle situated at a distance $2a$ beyond the end of a row of $m - 2$ identical linear magnets, of length a, arranged end to end. Shifting the position of the charged particle immediately gave the Rydberg formula, but unfortunately Ritz's own series formula did not follow so naturally.[28] Late in 1907, at Tübingen and in "resonance" with Paschen, Ritz applied his model to the Zeeman effect; although the predictions differed from those of the electron theory and from Runge's rule, Ritz maintained that his results gave the better agreement with the data.[29]

Ritz was ambivalent about the ontologic status of his model, now arguing that it was physically more plausible than the Lorentz electron theory, now seeing it as possessing "the advantage from the epistemological standpoint that it need make no assumptions about the form of the elements out of which the atoms are thought to be built up, but operates only with rigid lengths or separations."[30] The theory seems to have been viewed most favorably, and the model taken quite seriously, among spectroscopists.[31] As a mechanism for emission of radiation, it differed from the vibrating continuous-media models in one very important respect: the various lines of a series, rather than all being emitted simultaneously *qua* harmonics, were each emitted by a different system or a different state of the system. As Ritz duly emphasized,[32] recent experiments on resonance radiation seemed to support such a view—which proved to be at least half the truth.

A far more important contribution to theoretical spectroscopy was Ritz's "combination principle," which presented itself to him at Göttingen in April or May 1908. Undoubtedly a central topic in the discussions between Ritz and Paschen the preceding winter had been the relation of the series that Arno Bergmann had recently found (in the infrared spectra of the alkalies) to the three types of series previously recognized: principal, first subordinate, and second subordinate. Ritz concluded that Bergmann's series were analogous to the hypothetical

$$\nu = N(1/3^2 - 1/m^2)$$

series of hydrogen—which in a very limited sense they are—therefore analogous to the Balmer series, and therefore a type of first subordinate or diffuse series.[33] (Before Bohr, the Balmer series was generally regarded as the diffuse series of hydrogen.)

Carl Runge, on the other hand, had concluded that the limits of Bergmann's series stand in the same relation to the limits of the diffuse series as the limits of the second subordinate (sharp) series stand to the limits of the principal series—which indeed they do—and therefore surmised erroneously that the parallel was complete, that Bergmann's series are a type of principal series.[34] After vigorously attacking Runge's interpretation, Ritz came to see that the question of whether the Bergmann series were diffuse or principal had no clear meaning, that Runge had pointed out a valid relation—Ritz gave only niggardly acknowledgment and no apology—and that the important question was how the interconnections between the series formulas, which Rydberg had propounded, ought to be extended and generalized.[35]

Ritz's answer, the combination principle, although amply exemplified, was none too clearly stated. Essentially Ritz emphasized that in Rydberg's series formulas, and in his own improvement upon them, the frequency of a spectral line was given as the difference between two terms, a running term and a constant term or series limit, and that the latter was a particular value of the running term in some other series formula. Ritz generalized this relation along the lines of the generalized Balmer formula: that apart from certain restrictions on the minimum values of the integer in the running term of a given type (p terms, 2; d terms, 3; b terms, 4)—which restriction was an important generalization of a circumstance that had puzzled Ritz since 1902, and could now be explained as a necessary consequence of his "atomic magnets" theory—the subtractive (or additive) "combination" of any two terms from any two series, or even from one and the same series, gives the frequency of an actually existing spectral line. Subsequently, in a semipopular article, Ritz gave two brief statements of his law: "that by the addition or subtraction of two observed lines or series one obtains the frequency of a new line or series of lines" and "that each of the two terms of the formula has, in some manner, an independent existence, and that one obtains the lines of a spectrum by combining such terms with each other in various ways."[36]

Although Ritz had thus already gone too far, he went still further, reifying not merely the terms themselves but also the symbols in his formulas for the terms. In this erroneous way Ritz "derived," for example, the Bergmann terms from the doublet p terms, $(m, b, \beta) = (m, p_1 - p_2, \pi_1 - \pi_2)$, and boasted "that almost the whole of the new lines and series recently discovered in the alkalies by Lenard, Konen and Hagenbach, Saunders, Moll, Bergmann, and others can be precisely derived from the known series formulas for these elements—without introducing any new constant whatsoever."[37] Moreover, on the basis of his principle Ritz predicted a great many lines in the infrared spectra of other elements. In his first publication he was able to announce the confirmation of a considerable number of these lines by Paschen, whose experiments in the spring of 1908—including the search for the "Paschen series" of hydrogen, $\nu = N(1/3^2 - 1/m^2)$—Ritz had been prompting by mail.[38]

Ritz's work on theoretical spectroscopy and boundary-value problems was fully appreciated by his contemporaries and was incorporated in the cognitive edifices they were constructing. It was otherwise with his work on the foundations of electrodynamics, to which he gave his most continued effort, about which he expressed himself with the greatest vigor, and for which he vainly wished a few more years of life. While Ritz was coming of age scientifically, electrodynamics as reformed by Lorentz was "being made the pivot of a new conception of nature, replacing the older mechanical conception." But instead of enthusiastically espousing this new conception as did so many others at Göttingen, Ritz felt a certain antipathy toward it and directed his critical attention to "the logical fundaments of this vast intellectual edifice."[39] To Ritz's critical eye the structure seemed ill-founded and poorly suited to experience. Maxwell's equations admitted far too large a class of solutions; and even after this class had been arbitrarily restricted by additional equations (such as the "Lorentz condition"), there still remained unphysical advanced potentials and convergent spherical waves, as well as the not directly observable electric and magnetic fields.

Ritz, like Einstein, was particularly concerned with the conflict between the classical principle of the relativity of motion and the Maxwell-Lorentz theory, with its immobile ether as a privileged reference system (which experiment seemed unable to put into evidence). But Ritz concluded that the incompatibility ought to be resolved in the opposite way from that which Lorentz, Poincaré, and Einstein were then choosing and which the community of physicists would soon adopt.[40] Instead of altering kinematics and dynamics through the Lorentz transformations in order to accord with Maxwell's field equations, Ritz insisted—invoking his critique of Maxwell's theory—that it was electrodynamics and optics that required modification in order to satisfy the classical principle of relativity: "The only conclusion which . . . appears possible to me is that the ether does not exist, or more exactly, that it is necessary to renounce the use of that image; that the motion of light is a relative motion like all the others; that only relative velocities play a role in the laws of nature; finally, that it is necessary to renounce partial differential equations and the notion of a field. . . ."[41]

In Ritz's positivist program not merely the ether but also the electromagnetic potentials, the fields derived from them, and the equations governing them were to be replaced by "elementary actions" between spatially separated charged particles. The expression for these elementary actions was to involve not the prior times $t = r/c$, as in the Lorentz-Einstein theory, but the times $t = r/(c + v_r)$, where r is the radial distance between the charges and v_r is their relative radial velocity at the prior time. This, Ritz stressed, was thus an "emission" theory; "luminous energy is to be regarded as *projected*, and not as *propagated*." "Fictitious" particles of light are emitted with velocity c from radiating charges; "the waves of the ether will be replaced by a distribution of the emanation, periodic in time and in space."[42]

In principle there were an infinite number of different forms for the elementary action satisfying this condition and compatible with existing experiments; Ritz the positivist regarded this as the most important advantage of his approach: simply by adding further terms to the interaction, further phenomena—particularly gravity—might be accounted for.[43] In practice, Ritz was never able to find a fully satisfactory form even for the electrodynamic interactions alone.

Returning to Göttingen in the spring of 1908, Ritz found insuperable resistance to his electrodynamic ideas; they were simply "monstrous."[44] Although there was no experimental fact that told squarely against Ritz until 1924 (when the Michelson experiment was performed with astronomical light sources),[45] the point of view that he brought forward never received the critical attention or sympathetic extension it deserved.

NOTES

1. It is clear that Ritz died of tuberculosis (specifically, lung hemorrhage)—Mrs. L. Ritz to P. Ehrenfest, 20 July 1909—but it is unclear just when the disease was diagnosed.
2. C. Seelig, *Albert Einstein. Eine dokumentarische Biographie* (Zurich, 1954), 29, 159; *Eidgenössische technische Hochschule 1855–1955* (Zurich, 1955). The vita appended to Ritz's Göttingen dissertation, *Zur Theorie der Serienspektren* (Leipzig, 1903), lists the following as his teachers at Zurich: Wilhelm Fiedler, Franel, K. F. Geiser, Hirsch, Lacombe, Minkowski, Pernet, H. F. Weber.
3. Ritz, *Zur Theorie der Serienspektren*; *Oeuvres*, 17–18, 78–80.
4. *Ibid.*; *Oeuvres*, 3.
5. Riecke had previously constructed a tenth-order differential equation that gave the Runge formula,
$$v = a + b/m^2 + c/m^4 + \cdots.$$
Physikalische Zeitschrift, **1** (1899), 10–11.
6. I. Runge, *Carl Runge*, 110. Runge to H. Kayser, 11 May 1903 (Staatsbibliothek Preussischer Kulturbesitz, Berlin, Darmst. H (11) 1885).
7. J. Hadamard, in *Société française de physique*, *Bulletin des séances*, **35** (1907), 73*.
8. Ritz, "Über ein neues Gesetz der Serienspektren," in *Physikalische Zeitschrift*, **9** (1908), 521–529; *Oeuvres*, 142.
9. Arthur Schuster, "Spectroscopy," in *Encyclopaedia Britannica*, 11th ed. (1911), XXV, 625a.
10. J. L. Heilbron, *A History of the Problem of Atomic Structure* . . . Ph.D. diss., Univ. of California, Berkeley, 1964, available on University Microfilms (Ann Arbor, Mich., 1965), 359.
11. Ritz to Runge, 25 Mar. 1903 (Deutsches Museum).
12. M. J. Klein, *Ehrenfest*, 41, 45, 165–166, 182, 188, 204.
13. Ritz, "Über das Spektrum von Kalium," in *Annalen der Physik*, 4th ser., **12**, 444–446, dated 4 July 1903; *Oeuvres*, 85–87.
14. Hagenbach, "J. J. Balmer und W. Ritz," 454.
15. Klein, *op. cit.*, 47.
16. Ritz to R. Fueter, Winter 1904–05, quoted in *Verhandlungen der Schweizerischen naturforschenden Gesellschaft*, **92** (1909), 100; Ritz to Fueter, Winter 1906–1907, quoted *ibid.*, p. 102.
17. Ritz to Ehrenfest, 19 Oct. [1907].
18. Ritz to Ehrenfest, 22 Dec. [1908], 19 Feb. 1909; Ritz to Runge, 29 May 1909.
19. *Comptes rendus . . . de l'Académie des sciences*, **139** (1904), 1135.
20. Ritz, "Über eine neue Methode zur Lösung gewisser Variationsprobleme der mathematischen Physik," in *Journal für die reine und angewandte Mathematik*, **135** (1908), 1–61; *Oeuvres*, 192–250. Summarized in "Über eine neue Methode zur Lösung gewisser Randwertaufgaben," in *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen*, Math.-phys. Klasse (1908), 236–248, presented 16 May 1908; *Oeuvres*, 251–264.
21. *Oeuvres*, 246–250, 263–264.
22. Ritz to P. Weiss, 15 Dec. 1908, quoted in *Oeuvres* xvi–xviii. Ritz, "Theorie der Transversalschwingungen einer quadratischen Platte mit freien Rändern," in *Annalen der Physik*, **28** (1909), 737–786, dated Jan. 1909; *Oeuvres*, 265–316.
23. *Comptes rendus . . . de l'Académie des sciences*, **145** (2 Dec. 1907), 983–984. Among the five memoirs that received some mark of distinction from the jury, not one appears to have treated the question as anything more than one in pure "analysis."
24. Ritz to Ehrenfest, 17 Dec. 1908; Ritz to R. Fueter, quoted in *Verhandlungen der Schweizerischen naturforschenden Gesellschaft*, **92** (1909), 101. Ritz was posthumously awarded a prize of 2,000 francs from the Fondation Leconte "for his works in mathematical physics and mechanics." *Comptes rendus . . . de l'Académie des sciences*, **149** (20 Dec. 1909), 1291.
25. C. Runge and F. A. Willers, in *Encyklopädie der mathematischen Wissenschaften*, II, pt. 3 (1915), ch. c2, par. 21. Ritz's method became known as the "Rayleigh-Ritz method" because it had been employed in a particular case thirty years earlier by Rayleigh in his *Theory of Sound*, a work that Ritz knew well.
26. Ritz to Ehrenfest, 19 Oct. [1907].
27. Loc. cit.
28. Ritz, "Sur l'origine des spectres en séries," in *Comptes rendus . . . de l'Académie des sciences*, **144** (18 Mar. 1907),

634–636; *Oeuvres*, 91–94. Ritz, "Sur l'origine des spectres en séries," *Comptes rendus . . . de l'Académie des sciences*, **145** (16 July 1907), 178–180; *Oeuvres*, 95–97.

29. Ritz to Ehrenfest, 19 Oct. [1907]; Ritz, "Magnetische Atomfelder und Serienspektren," in *Annalen der Physik*, **25** (1908), 660–696, dated Tübingen, Jan. 1908; *Oeuvres*, 98–136.
30. *Ibid.*; *Oeuvres*, pp. 110–111.
31. Ritz to Ehrenfest, 19 Oct. [1907], reporting Paschen's reaction; Runge to Ritz [n.d., draft, *ca.* October 1907] (Deutsches Museum); H. Deslandres, *Société française de physique, Bulletin des séances*, **37** (Jan. 1909), 3*; Pierre Weiss, *Journal de physique théorique et appliquée*, **9** (1910), 986–988; H. Poincaré, *ibid.*, **2** (1912), 352; A. Cotton, *Revue générale des sciences pures et appliquées*, **22** (1911), 597; Anon., *Archives des sciences physiques et naturelles*, **26** (1908), 425–427.
32. *Oeuvres*, 112–113.
33. Ritz, "Über die Spektren der Alkalien. Bemerkungen zu der Arbeit des Herrn C. Runge," in *Physikalische Zeitschrift*, **9** (1908), 244–245, dated Zurich, Mar. 1908; *Oeuvres*, 137–140.
34. C. Runge, "Über die Spektren der Alkalien," in *Physikalische Zeitschrift*, **9** (1908), 1–2.
35. Ritz, "Über ein neues Gesetz der Serienspektren," *ibid.*, 521–529, dated Göttingen, June 1908; *Oeuvres*, 141-162. I. Runge, *Carl Runge*, 134–135.
36. Ritz, "Les spectres de lignes et la constitution des atomes," in *Revue générale des sciences*, **20** (1909), 171–175; *Oeuvres*, 170–180, on 173.
37. Ritz, "Über ein neues Gesetz . . .," *Oeuvres*, 141. In an undated MS abstract of this work Ritz stated explicitly the principle involved: "By additive or subtractive combination, be it of the series formulas themselves, or be it of the constants that enter into them, new formulas are formed, which allow the new lines in the alkalies discovered in recent years by Lenard and others to be calculated completely from those previously known, and which admit of extensive applications to other elements also, in particular He." *Oeuvres*, 162.
38. Letters from Ritz to Paschen, Apr.–July 1908, quoted in *Oeuvres*, 521–525. See also P. Forman, "Paschen," in *Dictionary of Scientific Biography*.
39. Ritz, "Recherches critiques sur l'électrodynamique générale," in *Annales de chimie et de physique*, **13** (1908), 145–275; *Oeuvres*, 317–426. Summarized in "Recherches critiques sur les théories électrodynamiques de Cl. Maxwell et de H.-A. Lorentz," in *Archives des sciences physiques et naturelles*, **26** (Aug. 1908), 209–236; *Oeuvres*, 427–446. Both quotations on 429.
40. Ritz to R. Fueter, late 1905, quoted in *Verhandlungen der Schweizerischen naturforschenden Gesellschaft*, **92** (1909), 101.
41. *Oeuvres*, 369; also 429–430, 436–437.
42. *Oeuvres*, 459–460. Ritz never made, and would have repudiated, any connection between his fictitious light particles and Einstein's heuristic light quanta. Consistent with the fundamentally reactionary character of Ritz's scientific and methodologic inclinations, he was most unsympathetic to the quantum theory and regarded the failure of the Maxwell-Lorentz theory to yield a nonabsurd blackbody radiation formula as but one more example of the demonstrated capacity of the theory to yield unphysical and indeterminate solutions. Ritz, "Über die Grundlagen der Elektrodynamik und die Theorie der schwarzen Strahlung," *Physikalische Zeitschrift*, **9** (1908), 903–907; *Oeuvres*, 493–502.
43. *Oeuvres*, 517.
44. Ritz to P. Weiss, Whit Monday 1908, quoted *Oeuvres*, xx.
45. Loyd S. Swenson, Jr., *The Ethereal Aether*; *A History of the Michelson-Morley-Miller Aether-Drift Experiments, 1880–1930* (Austin, Tex., 1972), 205.

BIBLIOGRAPHY

I. Original Works. Walter Ritz, *Gesammelte Werke. Oeuvres* (Paris, 1911), edited, with a biographical introduction, by Pierre Weiss, includes Ritz's published scientific papers, a few brief MSS, and some extracts from his correspondence. Not included or mentioned by Weiss is Ritz's anonymous feuilleton, "Die N-Strahlen," in *Neue Züricher Zeitung*, no. 259 (18 Sept. 1906), 1–2.

The manuscript of Ritz's entry in the competition for the Prix Vaillant of 1907, 38 pages in folio, together with a rapporteur's summary, is in the archives of the Académie des Sciences, Paris.

Eleven cards and letters from Ritz to Paul Ehrenfest are in the Ehrenfest Scientific Correspondence, Rijksmuseum voor Geschiedenis der Natuurwetenschappen, Leiden, and the Archive for History of Quantum Physics: 27.10.03, 27.7.07, 17.9.07, 19.10 [07], 10. 12. 07, 17.12.07, 17.12.08, 22.12.[08] and draft of E.'s reply, 12.2.09, 19.2.09, 18.6.09. Further a dozen letters from Ritz's mother, 1909–1912, are in the Ehrenfest Personal Correspondence in the same archives.

Five cards and letters from Ritz to Carl Runge are in the Handschriftensammlung of the Deutsches Museum, Munich (signature 1948/49): 23 May [1902], 25 Mar. 1903, 28 Mar. [1903], Tübingen [n.d., *ca.* Oct. 1907; with draft of Runge's reply], 29 May 1909. The disposition of the MSS and correspondence extracted in the *Oeuvres* is unknown.

II. Secondary Literature. The principal biographical sources are Weiss's preface to the *Oeuvres* and Rudolf Fueter, "Walter Ritz," in *Neue Züricher Zeitung* (1 Sept. 1909), repr. in *Verhandlungen der Schweizerischen naturforschende Gesellschaft*, **92** (1909), Nekrologe, 96–104. All biographical data in the present article for which no other source is given derive from these or from the vitae published in Ritz's doctoral dissertation and in the *Chronik der Georg-August-Universität zu Göttingen* (1908–1909), 11–12, upon his *Habilitation*. (Weiss's insertion of an "h" in Ritz's given name is at variance with all contemporary sources. Both Weiss and Fueter give spring 1900 as the date of Ritz's transference to Göttingen, but I have followed the vitae. The dissertation, and it alone, gives Ritz's birthday as 28 February.) August Hagenbach, "J. J. Balmer und W. Ritz," in *Naturwissenschaften*, **9** (1921), 451–455, is largely derivative.

Valuable biographical information is in Iris Runge, *Carl Runge und sein wissenschaftliches Werk* (Göttingen, 1949), including an extract from Runge's funeral oration, July 1909 (p. 135); and Martin J. Klein, *Paul Ehrenfest*, I, *The Making of a Theoretical Physicist* (Amsterdam, 1970).

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