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(*b*. Bremen, Germany, 30 August 1856: *d*. Göttingen, Germany, 3 January 1927)

mathematics, physics.

Runge was the third son of Julius Runge and his wife Fanny. His father, of a Bremen merchant family, had accumulated a comfortable capital during some twenty years in Havana, then retired to Bremen a few years before his early and unexpected death in 1864. Fanny Runge was herself the daughter of a foreign merchant in Havana, an Englishman of Huguenot descent, Charles David Tolmé. English was the language of choice between Runge's parents, and three of his four elder siblings eventually settled in England. There was thus a strong British element in his upbringing, particularly an emphasis upon sport, self-reliance, and fair play that, in combination with the civic traditions of the Hanseatic town, influenced his political and social views. All three of his brothers pursued commercial careers; but Runge, the most closely attached to his mother and an excellent student, pointed from his youth toward a more intellectual career.

At nineteen, after completing the Gymnasium, Runge spent six months on a pilgrimage with his mother to the cultural shrines of Italy. On his return at Easter of 1876, he enrolled at the University of Munich, registering for four courses on literature and philosophy and only one in science (taught by Jolly). But six weeks after the start of the semester, Runge had made up his mind to concentrate upon mathematics and physics. In his three semesters at Munich he attended several courses with Max Planck; they became warm friends and remained in close personal contact throughout Runge's life.[1] In the fall of 1877 Planck and Runge went to Berlin together; but Runge, not much attracted by the lectures of Kirchhoff and Helmholtz that he heard, turned to pure mathematics, becoming one of Weierstrass' disciples. In the winter semester 1878–1879 Runge also attended Friedrich Paulsen's seminar course on Hume.[2] A close and lasting personal friendship developed with Paulsen, whom Runge, upon the completion of his doctorate, placed alongside Weierstrass as one of the two men "to whom I owe the best of my knowledge and ability." The dissertation, submitted in the spring of 1880, dealt with differential geometry, a topic unrelated to Weierstrass' interest (or his own subsequent work). It stemmed from an independent study of Gauss's *Disquisitiones generales circa superficies curves* and was stimulated by the discussion of these questions in the Mathematischer Verein, the student mathematical society, in which Runge played an active role.

Although he had resolved upon an academic career. Runge, as was customary, spent the year following his doctorate preparing for the *Lehramtsexamen* for secondary school teachers. In the fall of 1881 he returned to Berlin to continue his education, largely transferring his allegiance to Leopold Kronecker. In his *Habilitationsschrift* (February 1883), influenced by Kronecker, Runge obtained a general procedure for the numerical solution of algebraic equations in which the roots were expressed as infinite series of rational functions of the coefficients, and the three traditional procedures for numerical solution of Newton, Bernoulli, and Gräffe were derived as special cases from a single function-theoretic theorem. This problem, which he treated as one in pure mathematics, was indeed to become Runge's characteristic *Fragestellung*—but only after his defection (1887) to "applied mathematics," and then from the diametrically opposite perspective, namely as a problem in numerical computation.

Meanwhile, accepted into Kronecker's circle in Berlin, Runge continued to work on a variety of problems in algebra and function theory. The feeling of being at the very center of the mathematical world dampened the urge to publish, and it was only after the promising young pure mathematician visited Mittag-Leffler in Stockholm for two weeks in September 1884 that his results were released in a spate in Mittag-Leffler's *Acta mathematica* (1885).

Runge—tall, lean, with a large and finely sculptured head—had developed exceptional skill as an ice skater in his youth; and in Berlin in the early 1880's, when that activity was becoming extremely fashionable, he cut a striking figure. He drew the attention of the children of Emil du Bois-Reymond: and, after three years of close friendship with that sporty clan, in 1885 Runge was betrothed to one of the daughters, Aimée. The precondition of the marriage—which took place in August 1887 and produced two sons and four liberated daughters— was a professorship. The first call, to the Technische Hochschule at Hannover, came in March 1886. Runge took up his duties immediately and remained there for eighteen years.

Within a year of his arrival at Hannover, Runge had undergone a thorough reorientation in his research interests and his attitude toward mathematics, a reorientation viewed by his former teachers and fellow students almost as treason. The initial step was Runge's immersion in the problem of constructing formulas, analogous to that which J. J. Balmer had recently found for hydrogen, giving the wavelengths of the spectral lines of other elements. Curiously, the stimulus for this investigation originated only very indirectly from the spectroscopist Heinrich Kayser, who had come to Hannover as professor of physics in the fall of 1885 and who was then lunching daily with Runge. Rather, Runge's attention was first drawn to these questions late in 1886 by his future father-in-law, who had been stimulated by a lecture and subsequent conversation with Kayser in Berlin in June 1885.[3] All three men became interested in the problem primarily because of its fundamental physical importance: "affording a much deeper insight into the composition and nature of the molecules [atoms] than any other physical process."[4] Runge set himself the goal of finding for each element a single formula giving all its spectral lines; "then the constants of this formula would be just as characteristic of the element as, let's say, the atomic weight."[5]

Runge began his investigations by using published data, especially those of G. D. Liveing and J. Dewar on the spectra of lithium, sodium, potassium, calcium, and zinc; he found many series of lines that could be represented by adding to Balmer's formula — $1\backslash\lambda = A - B\backslash m^2$—a third term, either C/m or C/m^4.[6] The inaccuracy of the available measurements made it uncertain what significance to attach to these formulas. Kayser, who had abandoned his spectroscopic researches in favor of the expansion of gases when he left Berlin, now responded to Runge's passion. He proposed "to make no use whatsoever of the available data, and … to determine anew the spectra of the elements from one end to the other"[7] with at least an order of magnitude greater accuracy.

This proposal was feasible with the photographic techniques and Rowland gratings that had become available in the preceding five years. Kayser's first spectrograms were made in May 1887; and for the next seven years, until his call to Bonn, he and Runge worked together at this task—Runge doing all the calculations of series and gradually taking a large role in the experimental work. They were aided by a number of grants for equipment from the Berlin Academy of Sciences (through the influence first of Helmholtz and subsequently of Planck).[8] Their results, published in seven *Abhandlungen der Preussischen Akademie der Wissenschaften*, ran to more than 350 pages.[9]

As the work progressed, the ultimate goal of unraveling atomic structure receded into the background, and was replaced by an overriding concern with precision of the data, of the methods of data reduction, and of the determination of the constants in the series formulas, without regard to their physical interpretation. Although Runge's approach to the problem of spectral series was thus far more "scientific" than that of Rydberg, whose treatise appeared simultaneously with Kayser and Runge's, by the turn of the century it was clear that Runge's formulas were physically rather barren while Rydberg's proved ever more fruitful.

After Kayser's departure Runge struggled on alone for six months. His second seven-year collaboration began early in 1895, when, following Ramsay's discovery of terrestrial helium, Runge induced Friedrich

Paschen to join him in an investigation of the spectrum of that substance. Paschen, an experimentalist of extraordinary virtuosity, had come to Hannover in 1891 as Kayser's teaching assistant but had thus far not participated in spectroscopic work. With great speed and accuracy Runge and Paschen now identified all the chief lines due to helium and, surprisingly, were able to arrange them all into two systems of spectral series.[10] This was the first instance of either achievement. The latter was taken as evidence that helium was a mixture of two elements until 1897, when Runge and Paschen, continuing the Kayser-Runge program of measurements, showed that oxygen too had more than one system of series.[11]

The final substantial collaboration with Paschen, and Runge's most important contribution to theoretical spectroscopy, occurred in 1900–1902, after Thomas Preston had presented evidence for a close connection between the type of splitting of spectral lines in a magnetic field and the type of series to which they belong. In part through contact with Paschen and in part through recognition of Rydberg's unreasonable success in extracting the "right" formulas from "inadequate" data, but perhaps also in part reflecting the changing methodological ideals in the exact sciences circa 1900, Runge had gradually come to allow a freer rein to fantasy and speculation in his own work. Now, analyzing their magnetic splitting data, Runge found not only that the splitting was characteristic of the series, and quantitatively as well as qualitatively identical for analogous series in the spectra of different elements, but also that all the splittings were rational fractions of the "normal" splitting given by the Lorentz theory of the Zeeman effect.[12] This last result, known as Runge's rule, brought him great applause and for twenty years remained an incitement to both theoretical and experimental spectroscopists. Eventually, however, it proved to be largely misleading.

The exceedingly solid work with Kayser and the brilliant work with Paschen drew the attention and approval of the numerous British and American spectroscopists and astrophysicists (but not of the German physicists, who on the whole showed remarkably little interest in spectroscopy). On visits to England (1895) and America (1897), Runge became acquainted with, and was found particularly congenial by, many physicists–including the two contemporaries whom Runge most admired, Lord Rayleigh and A. A. Michelson. Following Runge's visit to Yerkes Observatory, George E. Hale was moved to offer him a research professorship there.

After Paschen's departure for Tübingen in 1901, Runge continued his experimental spectroscopic work in collaboration with Julius Precht. When Runge transferred to Göttingen in October 1904, it was intended that his work on the Zeeman effect be continued there; and for this purpose extensive facilities were provided in Woldemar Voigt's new physical institute.[13] In fact, however, Runge never used them until after his retirement in 1925; his only experimental work in those two decades was performed with Paschen at Tübingen in October 1913.

First Kayser, then Paschen had been called to chairs at first-class universities, but Runge remained stranded at the Technische Hochschule. Planck tried more than once to arrange a call to Berlin, but could never persuade his colleagues to propose a man whom the mathematicians refused to recognize as a mathematician, nor the physicists as a physicist. In 1904, however, Klein, doubtless seconded by Woldemar Voigt, managed to persuade his Göttingen colleagues to include Runge among three nominees, albeit in last place. He then used his great influence with Friedrich Althoff, the head of the university section of the Prussian Ministry of Education, in order to have the position offered to Runge on most generous terms: 11,000 marks per year income and an independent institute comprising some fifteen rooms.[14]

Runge went to Göttingen as the first (and last) occupant of the first full professorship for "angewandte Mathematik" in Germany. It was as the leading practitioner–indeed, in a sense as the inventor and sole practitioner–of this discipline that he was best known among his contemporaries. Although the bulk of his publications had been in spectroscopy, Runge had never ceased to regard himself as a mathematician. The laborious reducetions of spectroscopic observations and computations with spectral formulas, as well as his preparation of courses for engineering students, had led him to conceive an "executive" branch of mathematics to be joined to the "legislative," or pure, branch of the discipline.

“Applied mathematics” as understood and practiced by Runge was not at all concerned with the rigorous mathematical treatment of models derived from the physical world, and very little concerned with the mathematical methods useful in physics and technology. Primarily it treated the theory and practice of numerical and graphical computation—with a great deal of emphasis on the teaching of the practice.[15] Some of the methods that Runge developed, notably the Runge-Kutta procedure for the numerical integration of differential equations,[16] have remained current or have gained in currency because they are suited for execution upon modern digital computers. On the whole, however, Runge’s work belongs rather more to mathematical *Zeitgeschichte* than to mathematical history: it formed one wing of a broad movement in pre-World War I Germany toward applied mathematics, of which Felix Klein was the chief ideologist and strategist, but which did not survive Germany’s defeat.

Runge, whose talent and pleasure in grasping and discussing the other fellow’s problems had been largely frustrated since leaving Berlin,[17] threw himself fully into the lively scientific (and sporting) life of Göttingen. The number and importance of his publications declined. His interest and energies were absorbed in the development of an instructional program in “applied mathematics”; in regularly attending the mathematical, physical, and astronomical colloquiums, as well as the Academy of Sciences; in mediating between the younger mathematicians and physicists and king Klein; and in service as Klein’s lieutenant in the movement for reform of mathematical curricula in Germany. Although Runge made no contributions to the quantum theory of spectra built upon Bohr’s model, he followed this work fairly closely and sympathetically.

Despite his liberal political views—open opposition to the annexationists during World War I and membership in the Democratic Party afterward— Runge retained the confidence of his colleagues and his influence within the university. When Peter Debye vacated his chair in the spring of 1920 without a successor having been appointed, he urged that Runge, “because of his authority and his great knowledge of physics, is in my opinion the only person in Göttingen” capable of managing the affairs of the physical institute.[18] And late in that year, when the Göttingen Academy was charged with forming the physics review committee of the Notgemeinschaft der Deutschen Wissenschaft, it elected Runge, its presiding secretary, as chairman-which immediately brought protests from physicists outside Göttingen, to whom he remained a “mathematician.”[19]

Runge reached the obligatory retirement age of sixty-eight in 1923, but continued to examine and to administer his institute until his successor, Gustav Herglotz, arrived in 1925. The chair then ceased to be one of applied mathematics in any sense, least of all in Runge’s sense; Runge had never even had any really talented students who had wished to be applied mathematicians in his sense. His scientific activity and his self-conception were too idiosyncratic, too heedless of conventional disciplinary boundaries and ideologies, too fully the free expression of his own broad mind and pleasure in scientific exchange. In excellent health at his seventieth birthday–doing handstands to amuse his grandchildren–he had several ambitious projects under way when he died suddenly of a heart attack six months later.

NOTES

1. Max Planck, “Persönliche Erinnerungen aus alten Zeiten” (1946), in his *Vorträge und Erinnerungen* (Stuttgart, 1949), 4.

2. F. Paulsen, *An Autobiography*, Theodor Lorenz trans, and ed. (New York, 1938), 278.

3. H. Kayser. “Erinnerungen aus meinem Leben.” typescript (dated 1936. presented by Kayser to W. F. Meggers and by Meggers to the Library of the American Philosophical Society, Philadelphia), 144–147, 164, represents Runge as having been “inoculated” by du Bois-Reymond before his arrival in Hannover. but otherwise gives an account agreeing essentially with Iris Runge. *Carl Runge* (1949). I have drawn upon Kayser’s “Erinnerungen” for information about the origins and style of the Kayser-Runge collaboration.

4. Kayser and Runge, “Über die Spectren der Elemente” [1st part], in *Abhandlungen der Preussischen Akademie der Wissenschaften* (1888),4–5.

5.*Ibid*., 7.

6. Runge. “On the Harmonic Series of Lines in the Spectra of the Elements,” in *Report of the British Association for the Advancement of Science* (1888), 576–577.

7. Kayser and Runge, *op. cit*., 9.

8.*Abhandlungen der Preussischen Akademic der Wissenschaften* (1891), xxi; (1893),.xxii; Runge to Kayser. 22 Dec. 1894. Subsequently the Academy supported Runge’s researches with Paschen (*Sitzungsberichte der Preussichen Akademie der Wissenschaften zu Berlin* [1900], 928) and Precht (*ibid*. [1903], 648).

9. The principal discussion of Runge’s series formulas is in the “Dritter Abschnitt.” dealing with the first column of the periodic table: *Abhandlungen der Preussischen Akademie der Wissenschaften* (1890): Range to E. du Bois-Reymond, 27 May 1890.

10. Runge and Paschen. “Über das Spectrum des Heliums,” in *Sitzungsberichte der Preussischen Akademie der* Wissenschaften zu Berlin (1895), 593, 639–643, presented 20 June 1895: “Über die Bestandtheile des Cleveit-Gases,” *ibid*., 749, 759–763. presented 11 July 1895; Runge to Kayser, 15 May 1895 and 13 July 1895.

11. Runge and Paschen, “Über die Serienspectra der Elemente. Saue toff. Schwefel und Selen.” in *Annalen der Physik*, **61** (1697), 641–686.

12. Runge to Kayser, 5 June 1900, 1 May 1901. 17 July 1901; Runge and Paschen. “Über die Strahlung des Quecksilbers im magnetischen Felde,” in *Abhandlungen der Preussischen Akademie der Wissenschaften* (1902), presented 6 Feb. 1902: “Über die Zerlegung einander entsprechender Serienlinien im magnetischen Felde,” in *Sitzungsberichte der Preussischen Akademie der Wissenschaften* (1902), 349, 380–386, presented 10 Apr. 1902; and “Über die Zerlegung … Zweite Mitteilung,” *ibid*., 705, 720–730, presented 26 June 1902. All three papers were translated immediately in *Astrophysical Journal*, **15** (1902), 335–351, and **16** (1902). 123–134. In Apr. 1907 Runge extended his rule to the particularly multifarious Zeeman effects of neon: “Über die Zerlegung von Spektrallinien im magnetischen Felde,” in *Physikalische Zeitschrift*, **8** (1907), 232–237.

13. Runge to Voigt, 10 July 1904: Göttinger Vereinigung …, *Die physikalischen Institute der Universität Göttingen* … (Leipzig, 1906), 43–47, 197–198.

14. Personalakten Runge, Universitätsarchiv. Göttingen: *Die physikalischen Institute der Universität Göttingen*, 95–111.

15. The most important of Runge’s textbooks of “applied mathematics” are *Graphical Methods* (New York. 1912), his lectures as exchange professor at Columbia in 1909–1910; and *Vorlesungen über numerisches Rechnen* (Berlin, 1924), written with Hermann König. See Runge, “Was ist ’angewandte Mathematik’?” in *Zeitschrift für den mathematischen und naturwissenschafilichen Unterricht*, **45** (1914). 269–271, and Wilhelm Lorey, *Das Studium der Mathematik an den deutschen Universitäten seit Anfang des 19, Jahrhunderts* (Leipzig–Berlin, 1916), 253–254, and *passim*, for the applied movement in general.

16. Runge, “Über die numerische Auflösung von Differentialgleichungen,” in *Mathematische Annalen*, **46** (1895), 167–178.

17. Important exceptions are Runge's suggestions to Paschen and Planck for, respectively, the experimental discovery and the theoretical deduction of the blackbody radiation law. See Hans Kangro, *Vorgeschichte des Planckschen Strahlungsgesetzes* (Wiesbaden, 1970), esp. the letter from Planck to Runge, 14 Oct. 1898, located by Kangro in the Stadtbibliothek, Dortmund.

18. Debye to Kurator, 29 Mar. 1920 (Personalakten Runge).

19. Steffen Richter, "Forschungsförderung in Deutschland, 1920–1936" (Ph.D. diss., University of Stuttgart, 1971). 37.

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I. Original Works. The most complete bibliography of Runge's publications is that in the biography by I. Runge (see below), 201–205. The following further items include the additional citations in Poggendorff, IV, 1286–1287; V, 1078–1079; VI, 2244; and in the bibliography published by Runge's son-in-law, Richard Courant, in *Zeitschrift für angewandte Mathematik und Mechanik*, **7** (1927), 416–419; "On the Line Spectra of the Elements," in *Nature*, **45** (1892), 607–608, and **46** (1892), 100, 200, 247; "On a Certain Law in the Spectra of Some of the Elements," in *Astronomy and Astrophysics*, **13** (1894), 128–130; "Spektralanalytische Untersuchungen," in *Unterrichtsblätter für Mathematik und Naturwissenschaften*, **5** (1899), 69–72; "Über das Zeemansche Phänomen" (abstract only), in *Sitzungsberichte der Preussischen Akademie der Wissenschaften* (1900), 635, written with F. Paschen; "Schwingungen des Lichtes im magnetischen Felde." in H. Kayser, ed., *Handbuch der Spectroscopie*, **II** (Leipzig, 1902), 612–672: "Über die spektroskopische Bestimmung des Atomgewichtes," in *Verhandlungen der Deutschen physikalischen Gesellschaft*, **5** (1903), 313–315; *Rechnungsformular zur Zerlegung einer empirisch gegebenen Funktion in Sinuswellen* (Brunswick, 1913), written with F. Emde; and "Method for Checking Measurements of Spectral Lines," in *Astrophysical Journal*, **64** (1926), 315–320.

When preparing the biography of her father, Iris Runge had available to her an exceedingly full *Nachlass*, including correspondence, diaries, programs of meetings, and newspaper clippings. In 1948 she deposited at the Deutsches Museum, Munich, a collection of letters, almost all to Runge, which cannot have been more than a small fraction of even the scientific correspondence in that *Nachlass*. The other materials presumably no longer exist (letter to the author from Wilhelm T. Runge, 8 May 1972), and may not have existed in 1948. The letters by Runge at the Deutsches Museum, and some six letters by Runge in other collections, are listed in T. S. Kuhn *et al*., *Sources for History of Quantum Physics* (Philadelphia, 1967), 80.

The largest group of letters by Runge is in the Darmstädter collection, H 1885, at the Staatsbibliothek Preussischer Kulturbesitz, Berlin-Dahlem: to Emil du Bois-Reymond, 12 Jan. 1885, 24 June 1885, 27 May 1890, 30 Apr. 1892; to René du Bois-Reymond, 29 Dec. 1903, 15 Jan. 1906; to Hans Geitel, 1 July 1899, 29 July 1899; to Heinrich Kayser, 22 Dec. 1894, 20 Jan. 1895, 17 Mar. 1895, 15 May 1895, 13 July 1895, 22 July 1895, 27 July 1895, 24 Nov. 1895, 28 Nov. 1895, 8 May 1897, 30 Oct. 1899, 5 June 1900, 9 Oct. 1900, 28 Dec. 1900, 1 May 1901, 17 July 1901, 9 Jan. 1902, 17 Jan. 1902, 22 Jan. 1902, 14 June 1902, 2 May 1903, 11 May 1903. 15 Nov. 1903. 15 Sept. 1905, 12 Apr. 1913, 29 July 1913, 31 July 1913; to Johannes Knoblauch, 15 Sept. 1886. The Nachlass Stark in the same depository includes letters from Runge to Stark of 10 Aug. 1906, 31 Aug. 1906, 25 Apr. 1907, 27 June 1907, 6 July 1910, 29 Oct. 1911, 7 Dec. 1911; and copies of Stark's letters to Runge of 25 July 1906, 2 Aug. 1906, 27 Aug. 1906, 20 Nov. 1906, 25 Apr. 1907.

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II. Secondary Literature. Iris Runge, *Carl Range und sein wissenschaftliches Werk* (Göttingen, 1949), which is Abhandlungen der Akademie der Wissenschaften zu Göttingen, Math.-phys. Kl., 3rd ser., no. 23, is by far the fullest and most authoritative source. Biographical data of which the source is not otherwise indicated are derived from this work. Runge's early spectroscopic work is discussed in William McGucken, *Nineteenth-Centurv Spectroscopy* (Baltimore, 1969); and his later magneto-optic work in James Brookes Spencer, *An Historical Investigation of the Zeeman Effect (1896–1913)* (Ann Arbor, Mich., 1964), issued by University Microfilms: and P. Forman, "Alfred Lande and the Anomalous Zeeman Effect, 1919–1921," in *Historical Studies in the Physical Sciences*, **2** (1970), 153–262.

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