vard College, where he was also to be responsible for establishing a school of mines. The school (which was later merged with the Lawrence Scientific School) opened in 1868, the same year in which the California geological survey was suspended after the state legislature refused to pass an appropriation for its continuation. Although Whitney remained as director of the nominal survey until 1874, only three volumes of its findings were published by the state; the Harvard Museum of Comparative Zoology aided him in publishing, in 1880, the important *The Auriferous Gravels of the Sierra Nevada of California*, and he himself brought out a volume of general geological observations in 1882.

Whitney returned to Cambridge permanently in 1875, and was reappointed to the Sturgis-Hooper professorship. He continued to teach at Harvard for the rest of his life, although his gruffness in the classroom and his cool, even unfriendly, personality limited his effectiveness as a teacher. His last major work, *Climatic Changes in Later Geological Times*, published in 1882, drew largely upon the researches he had conducted in the West.

Whitney was, perhaps, not so prominent a leader of American science as some of his contemporaries, and received fewer honors. He became a member of the American Philosophical Society and the National Academy of Sciences in 1865, and was later one of the few American foreign members of the Geological Society of London. Mt. Whitney, the highest point in the contiguous United States, is named in his honor. Whitney died at his summer retreat in New Hampshire; his wife, Louisa Goddard Howe, whom he had married in 1854, and his only child, a daughter, had both predeceased him in 1882.

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I. ORIGINAL WORKS. Whitney's scientific publications include *Report of a Geological Survey of the Upper Missouri Lead Region* (Albany, 1862); *Earthquakes, Volcanoes, and Mountain Building* (Cambridge, Mass., 1871); *Geology and Geological Surveys* (Cambridge, Mass., 1875); *The Auriferous Gravels of the Sierra Nevada of California* (Cambridge, Mass., 1880); *The Climatic Changes of Later Geological Times; a Discussion Based on Observations Made in the Cordilleras of North America* (Cambridge, Mass., 1882); and *The Azoic System and its Proposed Subdivisions* (Cambridge, Mass., 1884), a contribution to classification.

The Whitney Family Manuscripts Collection at Yale University has nearly one thousand letters between Josiah Dwight Whitney and his brother William Dwight Whitney. The Josiah Dwight Whitney MSS at the Bancroft Library of the University of California contain more than six hundred letters to his close associate William H. Brewer, dealing with both scientific and personal matters. The William H. Brewer manuscripts at Yale University relate to Whitney's California years, as does a published account, *Up and Down California in 1860–1864: the Journal of William H. Brewer*, Francis P. Farquhar, ed. (New Haven, 1930).

II. SECONDARY LITERATURE. The fullest account is the somewhat uncritical Edwin T. Brewster, *Life and Letters of Josiah Dwight Whitney* (Boston, 1909). See also William H. Goetzman, *Exploration and Empire: the Explorer and the Scientist in the Winning of the American West* (New York, 1966), a fine survey of Whitney's activities in the West; George P. Merrill, *The First One Hundred Years of American Geology* (Washington, 1924); and Gerald T. White, *Scientists in Conflict: the Beginnings of the Oil Industry in California* (San Marino, 1968), which deals with the controversy between Whitney and Benjamin Silliman, Jr., over oil in California, and is unduly critical of Whitney. Gerald D. Nash, "The Conflict Between Pure and Applied Science in Nineteenth Century Public Policy: the California State Geological Survey, 1860–1874," in *Isis*, **64** (1963), 217–228, summarizes Whitney's career as director of the California Geological Survey.

GERALD D. NASH

WHITTAKER, EDMUND TAYLOR (*b.* Birkdale, Lancashire, England, 24 October 1873; *d.* Edinburgh, Scotland, 24 March 1956), *mathematics, physics, philosophy.*

Whittaker was educated at Manchester Grammar School and Trinity College, Cambridge. He was bracketed second wrangler in the mathematical tripos of 1895, was elected a fellow of Trinity College the following year, and was first Smith's prizeman in 1897. In 1905 he was elected a fellow of the Royal Society, and was awarded the Sylvester and Copley medals of the society in 1931 and 1954 respectively. In 1906 he became astronomer royal for Ireland and from 1912 until his retirement in 1946 was professor of mathematics at the University of Edinburgh. From 1939 to 1944 Whittaker was president of the Royal Society of Edinburgh, and was an honorary member of several learned societies. In 1935 Pope Pius XI conferred on him the cross *pro ecclesia et pontifice* and a year later appointed him to the Pontifical Academy of Sciences. In 1945 Whittaker was knighted and in 1949 became an honorary fellow of Trinity College, Cambridge.

In 1901 Whittaker married Mary Boyd, daughter of the Reverend Thomas Boyd of Cambridge; they had three sons and two daughters. The second son, J. M. Whittaker, became a mathematician and was vice-chancellor of the University of Sheffield. Whittaker's elder daughter married the mathematician E. T. Copson.

Whittaker's deepest interest was in fundamental mathematical physics, and consequently much of his earlier work was concerned with the theory of differential equations. Perhaps his most significant paper in this field was the one published in 1902 in which he obtained the most general solution of Laplace's equation in three dimensions, which is analytic about the origin, in the form

$$\int_0^{2\pi} f(x\cos\alpha + y\sin\alpha + iz, \alpha)\, d\alpha$$

and the corresponding solution of the wave equation in the form

$$\int_0^{\pi}\int_0^{2\pi} f(x\sin\alpha\cos\beta + y\sin\alpha\sin\beta + z\cos\alpha + ct, \alpha, \beta)\, d\alpha d\beta.$$

The discovery of the general integral representation of any harmonic function brought a new unity into potential theory; the integral representations of Legendre and Bessel functions, for example, were immediate consequences. Moreover, entirely new fields of research in the theory of Mathieu and Lamé functions were opened up. Whittaker also made a detailed study of the differential equation obtained from the hypergeometric equation by a confluence of two singularities, and he introduced the functions $W_{k,m}(z)$, which now bear his name. Another lifelong interest of Whittaker's was the theory of automorphic functions and the standard English book on the subject by L. R. Ford owes much to Whittaker. He also wrote a few papers on special problems in algebra and on numerical analysis.

Whittaker had an intense interest in the theory of relativity and from 1921 onward wrote ten papers on the subject. In one of the papers he gave a definition of spatial distance in curved space-time, which is both mathematically elegant and practical. In other papers he extended well-known formulas in electromagnetism to general relativity, gave a relativistic formulation of Gauss's theorem, and dealt with the relation between tensor calculus and spinor calculus.

Whittaker will long be read, since his textbooks on several diverse branches of mathematics have become classics. *Modern Analysis* (1902) was the first book in English to present the theory of functions of a complex variable at a level suitable for undergraduate and beginning graduate students. Forsyth's *Theory of Functions* had appeared in 1893, but its contents had not penetrated to the general body of mathematicians. *Modern Analysis* was extensively revised and enlarged in 1915 in collaboration with G. N. Watson, whose name was then added to the title page. Whittaker's *Analytical Dynamics*, which was published in 1904, was the first book to give a systematic account in English of the superbly beautiful theory that springs from Hamilton's equations; and it was of fundamental importance in the development of the quantum theory. Then, in 1910 there appeared *The History of the Theories of Aether and Electricity*. In 1951 a revised version of the book was published and constituted the first volume of a new treatise with the same title; it deals with the history up to the end of the nineteenth century. The second volume, which appeared in 1953, describes the developments made between 1900 and 1926 and is concerned mainly with relativity and quantum theory. The two volumes together form Whittaker's *magnum opus*. A contemplated third volume dealing with later theories was never completed.

Notwithstanding the excellence of *Aether and Electricity*, the chapter in the second volume dealing with the special theory of relativity has been criticized for the emphasis it places on the work of Lorentz and Poincaré, and for the consequent impression it gives that the work of Einstein was of minor importance. The consensus is that Whittaker made an error of judgment. As early as 1899 Poincaré had thought it possible that there might not be such a thing as absolute space, and in 1904 he had discussed without mathematics the possibility of a new mechanics in which mass would depend on velocity and in which the velocity of light would be an upper limit to all physically possible velocities. Also, Lorentz had derived the transformation that now bears his name before Einstein published his paper in 1905, but Lorentz interpreted it in terms of absolute space and time, concepts that, according to Born, he was still clinging to a few years before his death in 1928. Likewise, Poincaré seemed to regard the Lorentz transformation (which he discussed in a mathematically impressive paper in 1906) as physically important only because Maxwell's equations are invariant under it. It was Einstein (who had doubts about the ultimate validity of Maxwell's equations) who derived the transformation law from more fundamental physical principles.

Soon after his arrival at the University of Edinburgh, Whittaker instituted a mathematical laboratory and lectured on numerical analysis. His book *The Calculus of Observations*, written with G. Robinson, grew out of these lectures and was published in 1924. At that time very little of its content was to be found in any other book in English.

Although Whittaker expended a tremendous effort on advanced study and research, he regarded his undergraduate teaching as of paramount importance and, in addition to lecturing to the honors classes, he lectured once a week to the first-year class on the history and development of mathematics. He was an outstanding lecturer and by his dignified bearing, his great command of language, his eloquent delivery, and his obvious mastery of his subject, he made a tremendous impression upon young students. They knew at once that they were in the presence of a scholar and teacher of the first rank and in all his prelections they saw at work a mind of astonishing accuracy and force, ranging at will over the whole field of ancient and modern mathematics and presenting with insight and great persuasive power the profundities there disclosed.

Whittaker was a deeply religious man all through his life and, after having belonged to several branches of the Protestant faith—including the Church of Scotland, of which he was an elder—he was received into the Roman Catholic Church in 1930. After retiring from his chair at Edinburgh, Whittaker spent much of his time studying the philosophical aspects of modern physics and the repercussions that recent developments might have on theology. He expounded his views in *The Beginning and End of the World* (1942), *Space and Spirit* (1947), *From Euclid to Eddington* (1949), and in a large number of papers. He wrote from an orthodox Roman Catholic point of view with great emphasis on natural theology and the work of Thomas Aquinas. He deplored that in modern life "the sense of creatureliness and dependence has passed away, and God is left out of account." He was undoubtedly one of the few men of his time who could speak with authority on both physics and theology.

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DANIEL MARTIN

WHYTLAW-GRAY, ROBERT (*b.* London, England, 14 June 1877; *d.* Welwyn Garden City, Hertfordshire, England, 21 January 1958), *physical chemistry.*

Whytlaw-Gray designed and utilized precision techniques for weighing both aerosols and gases, notably radon. The second son of a prosperous Australian businessman, he was educated at Glasgow. From 1896 to 1903 he studied and conducted research under Ramsay and Morris W. Travers at University College, London, beginning a lifelong career in the exact manipulation of gases. In 1903 Gray went to Bonn to continue his redetermination of Stas's atomic weight of nitrogen; he obtained a value of 14.01 ($O = 16$), compared with the then current standard of 14.04 and with the more recent standard of 14.008. After obtaining the Ph.D. in 1906, he returned to University College, becoming assistant professor in 1908. In 1911 he incorporated the matronymic Whytlaw to his name, possibly to distinguish himself from a colleague, J. A. Gray.

From 1906 to 1914 Gray measured the physical constants of gases in order to determine their atomic weights. Collaborating with Ramsay in the 1910–1911 classic determinations of the density of niton (now called radon), Gray used a modified Steele-Grant microbalance to weigh the minute quantity available—less than 0.10 cubic mm. The new gravity balance, announced in 1909, was constructed of fused quartz having a counterpoised sealed quartz bulb containing a known quantity of air. Balance was effected by varying the external pressure within the case. Absolute weight as a function of buoyancy could be determined by the original instrument with an accuracy of 10^{-7} gram, the instrument being about 100 times more sensitive than the Nernst microbalance. In 1910 their experiments yielded an average atomic weight of 220 for radon; they modified this value to 223 on the basis of their 1911 results. By this means they had well estimated the correct order of magnitude.

On the theoretical side, following the then accepted atomic weight for radium of 226.5, Ramsay