

routes to Brazil. In catalog no. 508, item no. 15, of Maggs Bros. bookstore in London, there is a reference to "Codice de circa 1560 de Nunes (Pedro) y Vaz Fraguoso (Pedro)," containing the elements of navigation and routes to the East, which is believed to have been compiled by Vaz Fraguoso.

II. SECONDARY LITERATURE. See the following, listed chronologically: *Diccionario enciclopédico hispano-americano*, XIII (Barcelona, 1813), 1190-1198; Rodolfo Guimarães, *Sur la vie et l'oeuvre de Pedro Nunes* (Coimbra, 1915); Luciano Pereira da Silva, *As obras de Pedro Nunes, sua cronologia bibliográfica* (Coimbra, 1925); and A. Fontoura da Costa, *Pedro Nunes (1502-1578)* (Lisbon, 1938); and *Quarto centenário da publicação de Tratado de sphaera de Pedro Nunes* (Lisbon, 1938).

J. M. LÓPEZ DE AZCONA

NUSSELT, ERNST KRAFT WILHELM (*b.* Nuremberg, Germany, 25 November 1882; *d.* Munich, Germany, 1 September 1957), *heat transfer, thermodynamics*.

Nusselt was the first significant contributor to the subject of analytical convective heat transfer. He completed his schooling at a time when the problems of heating and cooling in the increasingly high-performance power equipment of the early twentieth century finally demanded accurate analysis. For a century Fourier's mathematical theory of heat conduction in rigid media had provided the only analytical attack on the problem, but it was inadequate to predict the heat flux in a flowing fluid. In 1915 Nusselt cut the Gordian knot. Although analytical solutions to the appropriate fluid-flow equations were so intrinsically complicated that they had to await the more fundamental work of others, Nusselt used dimensional analysis to show, in a single stroke, the functional form that such solutions would have to take. He thus made it possible to generalize limited experimental data.

Nusselt was the son of Johannes Nusselt, a factory owner, and Pauline Fuchs Nusselt. He completed his early education in Nuremberg in 1900 and then enrolled at the Technische Hochschule in Munich to study mechanical engineering. After six semesters he transferred to the Technische Hochschule of Charlottenburg, in Berlin, where he completed his studies. He then returned to Munich and passed his mechanical engineering diploma examination there.

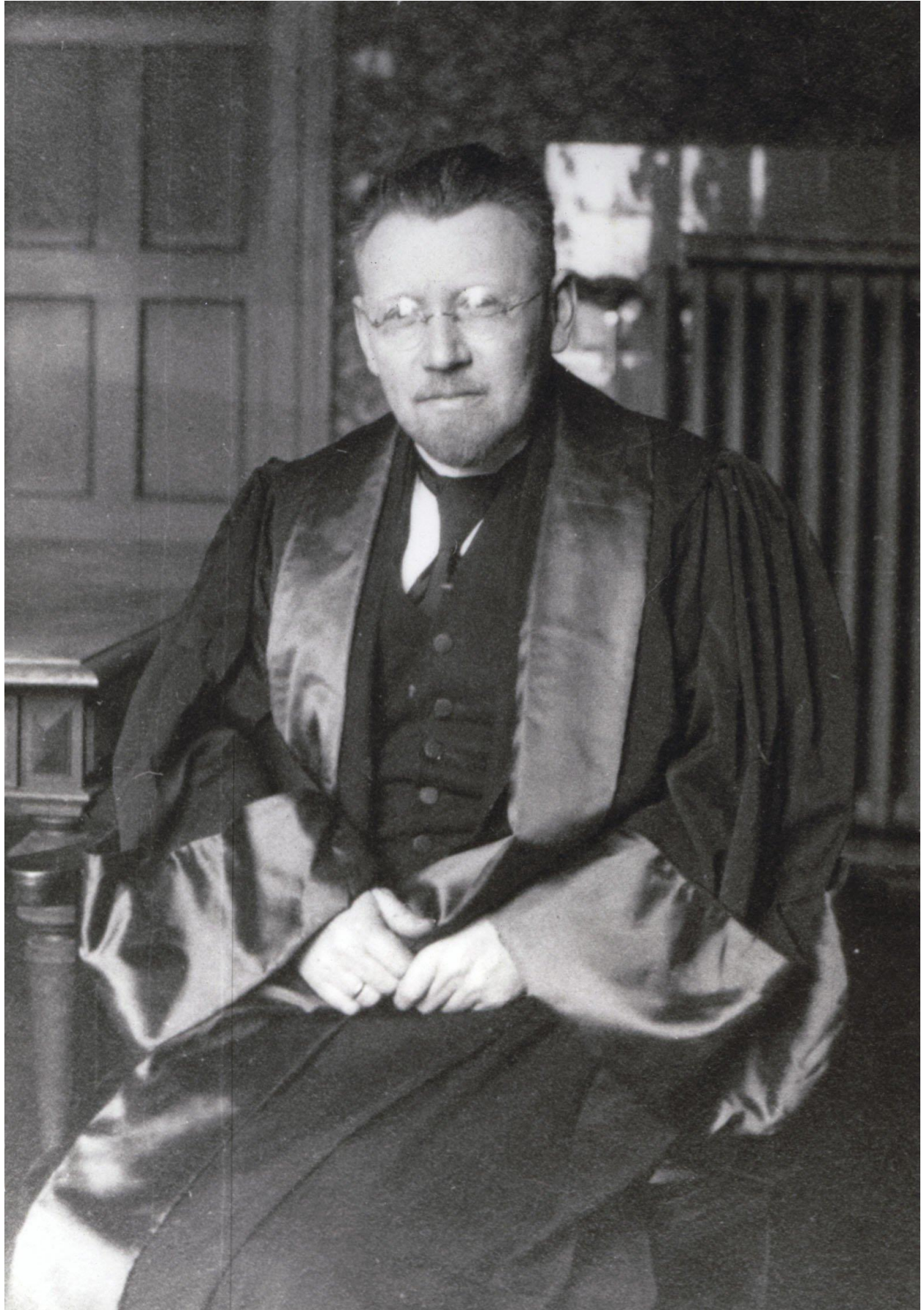
Nusselt began his studies toward a doctorate in mechanical engineering in Munich, and from 1906 through 1907 he served as an assistant to Oskar Knoblauch, who was also the teacher of another early

heat transfer luminary, Ernst Schmidt. He completed the degree in August 1907, and from then until 1925 he moved about Germany from post to post. From September 1907 to June 1909 he was assistant to the well-known thermodynamicist Richard Mollier at the Technische Hochschule in Dresden. He then worked in the heat technology division of the Sulzer brothers' firm in Switzerland (1909-1911). He returned to the mechanical laboratory in Dresden in 1913 and held indefinite teaching appointments until 1917. From January 1918 through March 1919 he returned to industry and worked at the Badische Anilin- und Soda-Fabrik in Ludwigshafen. In April 1920 he was appointed professor at the Technische Hochschule in Karlsruhe. In 1925, Nusselt was named to the chair in theoretical mechanics at the Technische Hochschule in Munich. He retired from this post in 1952 and was succeeded by Schmidt.

Two of Nusselt's most important works were completed during his years in Dresden. His paper on the similitude of convective heat transfer, "The Basic Law of Heat Transfer" (1915), followed his earlier work on the thermal conductivity of insulating materials and some work with heat convection coefficients. The scope of his 1915 paper, however, was far broader; in this work he set up the dimensionless functional equations for both natural and forced convection. He thus reduced the large number of physical variables that appear in the boundary layer equations to the familiar dimensionless groups that today bear the names "Nusselt number," "Reynolds number," "Prandtl number," and "Grashof number." He also noted additional groups that are needed when physical properties vary or when the full equations of motion are used to define natural convection. It was thus possible for experimentalists to reduce limited data into these few parameters and to form simple empirical equations among them. Such correlations have, in most cases, preceded heat transfer theory down to the present day.

His other major contribution during this period was a paper entitled "The Film Condensation of Steam" (1916), in which he provided a clear-headed and simple description of the film condensation of any liquid by linearizing the temperature profile and ignoring inertia in the liquid. Subsequent efforts to refine this heat transfer prediction have failed to alter his numerical results, except for liquid metals and the most extreme heat fluxes.

Nusselt's later works branched into radiant heat transfer, combustion, and a variety of applications of heat transfer and thermodynamics to power equipment. In 1930 he provided an important description of the similarity between heat and mass transfer, and



NUSSELT

in 1934 and 1944 he published the first and second volumes, respectively, of a book on technical thermodynamics.

Nusselt was married on December 12, 1917, while teaching at Dresden, to Susanne Thurmer. The couple had two daughters and one son. Nusselt was an energetic man, strongly inner-directed, soft-spoken, and self-contained. He was an avid mountain climber throughout his life, and he appears to have equated the methodical assault of a mountain to the kind of assault a man should make on the problems that beset him. He brought this same kind of energy and concentration to his technical work. He was, however, circumspect and, perhaps, even cautious.

During the 1930's and 1940's German scientists made great advances in heat transfer. But Nusselt did not wield great influence within the peer group that controlled this field. It was probably not in his makeup to do so, and he is known to have suffered from a chronic internal ailment during these years. Although he was an exacting taskmaster with his students, he apparently lacked charisma and he was not a good lecturer.

In 1947 Nusselt's son, Dietrich, also a mountaineer, fell to his death on the east wall of the Riffelkopf in the Wetterstein Gebirge. Nusselt did little more in his remaining years, and upon his retirement he left the university completely and lived out his life in relative seclusion.

BIBLIOGRAPHY

I. ORIGINAL WORKS. G. Lück and G. Kling (see below) both provide a bibliography of over 50 major works. Nusselt's most important writings include "Das Grundgesetz des Wärmeüberganges," in *Gesundheits Ingenieur*, 38 (1915), 872; "Die Oberflächenkondensation des Wasserdampfes," in *Zeitschrift des Vereines deutscher Ingenieure*, 60 (1916), 541, 569; "Wärmeübergang, Diffusion und Verdunstung," in *Zeitschrift für angewandte Mathematik und Physik*, 10 (1930), 105; and *Technische Thermodynamik*, 2 vols. (Berlin, 1934, 1944). Nusselt's autobiographical deposition for the American occupation force after World War II provides a wealth of personal detail.

II. SECONDARY LITERATURE. Poggendorff, VIIa, 455, lists several biographical articles; the most extensive is G. Kling in *Chemie-Ingenieur-Technik*, 24 (1952), 597-608, which includes a bibliography of works by both Nusselt and his co-workers. G. Lück's article on Nusselt's retirement in *Gesundheits Ingenieur*, 74 (1953), 7-8, also provides a similar bibliography. *Allgemeine Wärmetechnik*, 3 (1952), 161-163, includes a bibliography and a list of Nusselt's doctoral students and their theses.

JOHN H. LIENHARD

NUTTALL

NUTTALL, THOMAS (b. Long Preston, near Settle, Yorkshire, England, 5 January 1786; d. Nut Grove Hall, near St. Helens, Lancashire, England, 10 September 1859), *botany, ornithology, natural history*.

Very little is known of the early life of Nuttall. A bachelor throughout his life, he was extremely reticent about his personal affairs. Through careful frugality while in America, he was able to make numerous field trips collecting botanical specimens.

His father, James Nuttall, married Mary Hardacre in January 1785. He died before Thomas was twelve years old, and his profession is unknown. The family was not prosperous, and at the age of fourteen Thomas was apprenticed to an uncle to learn the printing trade. At the conclusion of his apprenticeship, he sought other employment. In 1808 he sailed for Philadelphia, and shortly after his arrival in America, he became a friend of and plant collector for Benjamin Smith Barton.

With Barton's encouragement Nuttall began to take a serious interest in American flora, teaching himself the principles of botany. In 1809 he made two field trips, collecting botanical specimens for Barton. The next year Barton outlined and financed a more ambitious collecting program, which was designed to take Nuttall through hazardous Indian country into Canada. Unable to complete Barton's itinerary, Nuttall joined an expedition of John Jacob Astor's Pacific Fur Company. The English botanist John Bradbury was also a member of this party. Traveling up the Missouri River, the two Englishmen collected new species of plants from lands that were botanically unexplored. At the conclusion of the expedition, Nuttall sailed for England in the fall of 1811. The War of 1812 prevented his return to America until 1815.

Nuttall published the results of his first western trip in *The Genera of North American Plants, and a Catalogue of the Species, to the Year 1817* (1818). As the first comprehensive study of American flora, this work established his reputation as a botanist. Although he classified his plants by the Linnaean system, Nuttall nevertheless discussed the natural relationships of the different genera he described. He thus provided American naturalists with an introduction to the merits of A. L. de Jussieu's natural system of classification. *Genera* described many western species new to botany and helped to stimulate an interest in the study of the plant life of the western United States.

From 1818 to 1820 Nuttall journeyed west again, collecting plants on the Arkansas River in Indian territory. In May 1820 he presented a paper describing