Enskog, David | Encyclopedia.com

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(*b*. Västra Ämtervik, Värmland, Sweden, 22 April 1884; *d*. Stockholm, Sweden, 1 June 1947)

physics.

Enskog's father, Nils Olsson, was a preacher; his mother was Karolina Jonasdotter. He was educated at the Karlstads Läroverk (high school) and at Uppsala University, where he received the Ph.D. in 1917. After teaching in secondary schools and colleges for several years, he was appointed professor in mathematics and mechanics at the Royal Institute of Technology, Stockholm, in 1930. In 1913 he married Anna Aurora Jönsson.

Enskog is best-known for his development method for solving the Maxwell-Boltzmann transport equations in the kinetic theory of gases. These equations, describing the effect of molecular collisions and external variables (such as temperature gradients) on the flow of molecules, momentum, and energy in a gas, had originally been formulated by James Clerk Maxwell in 1867. The solution of the equations, however, depends in general on a determination of the velocity distribution function in a nonequilibrium gas. Maxwell was unable to determine this function. However, he did show that for a special molecular model—point centers of force with repulsive forces varying inversely as the fifth power of the distance between the molecules—the transport coefficients such as viscosity and thermal conductivity can be calculated even if the velocity distribution function is unknown. In 1872 Ludwig Boltzmann reformulated Maxwell's equations as a single integrodifferential equation for the velocity distribution function, but he was not able to find an exact solution except for the same special model that Maxwell had introduced.

Little progress was made toward solving the Maxwell-Boltzmann equations until 1911, when Enskog in Sweden and Sydney Chapman in England began their researches. In that year, Enskog obtained his philosophy licentiate (equivalent to the M.A.), partly for experimental work on gas diffusion, and also published two papers on a generalization of the Maxwell-Boltzmann kinetic theory. In the second of these papers he noted briefly the existence of a term proportional to the temperature gradient in the theoretical formula for the rate of diffusion in a mixture of two gases. Although it was not followed up at the time, this was later recognized as the first theoretical prediction of the important phenomenon known as thermal diffusion, established experimentally by Chapman and F. W. Dootson in 1917.

The calculations of Enskog and of Chapman, published in 1911–1912, while representing an advance over earlier work, were not yet satisfactory, since they depended on arbitrary assumptions about the nonequilibrium velocity distribution function. In 1912, David Hilbert published a short paper on the Maxwell-Boltzmann equation, in which he applied methods developed earlier in his general theory of integral equations. Enskog immediately saw the value of Hubert's approach and used it with some modifications to work out a systematic series expansion of the velocity distribution function. The results were presented in his 1917 dissertation at Uppsala, shortly after Chapman published his own calculations based on an equivalent method. Chapman was one of the first scientists to recognize the value of Enskog's work, and in the monograph on *The Mathematical Theory of Non-Uniform Gases*, now the standard work on the subject, he used Enskog's procedure for solving the Maxwell-Boltzmann equations in preference to his own. It was also partly on Chapman's recommendation that Enskog obtained his chair at Stockholm in 1930, although according to Chapman, "His transfer to a university chair seemed rather to bring him new duties than increased leisure, and this, with renewed ill-health, reduced his productivity in later years."

With their new methods Chapman and Enskog were able to calculate accurately a number of the transport properties of gases, such as the coefficients of viscosity, thermal conduction, and diffusion, without having to rely on the mean-free-path approximation introduced by Clausius in 1858 and used by Maxwell in his early work. (Although Maxwell himself abandoned the mean-free-path method, it continued to be used by other scientists and is still discussed in most modern textbooks.) Whereas earlier kinetic theories had been limited to the use of very special molecular models, such as elastic spheres or the Maxwellian inverse fifth-power repulsive force, the Chapman-Enskog theory now made it possible to do calculations with a much larger class of models, including both attractive and repulsive forces varying with any power of the distance.

The Chapman-Enskog theory would have been quickly taken up and exploited by many other scientists during the 1920's if that had not been the time when quantum theory was being vigorously developed. It did not become clear until the 1930's that the classical kinetic theory of gases is still valid over a large range of temperatures and densities, even though the nature of the intermolecular force law is determined by quantum-mechanical considerations. Thus the main impact of the work of Enskog and Chapman before 1920 was not apparent until after 1945, when it provided the basis for a revival of activity in kinetic theory, including applications to phenomena such as sound propagation, shock waves, aerodynamics. the behavior of electrons in metals, and the diffusion of neutrons in nuclear reactors.

One other contribution by Enskog played an important role in the postwar development of kinetic theory. In 1922, he proposed a generalization of the Maxwell-Boltzmann equations to higher densities, taking account of the effect of finite diameter of the molecules. He assumed that the frequency of collisions would be changed by an amount that could be related to the equation of state (equilibrium pressure-volume-temperature relation), since that also depends on collision rate. In this way he obtained formulas for the transport coefficients in which the variation with density can be determined empirically if the equation of state is known from experimental measurements, or theoretically for simple models if the equation of state itself can be calculated theoretically. Until 1965 the Enskog theory of dense gases remained the only accepted theory that had been sufficiently worked out to permit experimental verification, although many more elaborate theories had been attempted. It is only in the last few years, as a result of the work of J. Weinstock, J. R. Dorfman, E. G. D. Cohen, R. Goldman, E. A. Frieman, and J. V. Sengers, that the kinetic theory of dense gases has definitely progressed beyond the point reached by Enskog from a fundamental basis; and according to the most recent calculations of Sengers, the numerical results for the transport coefficients computed from Enskog's theory are probably accurate to within 5 percent as compared with the exact theory.

BIBLIOGRAPHY

I. Original Works. Enskog's major works on kinetic theory include *Kinetische Theorie der Vorgänge in mässig verdünnten Gasen* (Uppsala, 1917) and "Kinetische Theorie der Wärmeleitung, Reibung und Selbstdiffusion in gewissen verdichteten Gasen und Flüssigkeiten," in *Kungliga Suenska vetenskapsakademiens handlingar*, n.s. **63,** no. 4 (1922). Translations of these works and references to others will be found in the book by S. G. Brush cited below.

II. Secondary Literature. On Enskog's kinetic theory of gases, see Sydney Chapman and T. G. Cowling, The *Mathematical Theory of Non-Uniform Gases* (Cambridge, 1939; 2nd ed., 1952). On the history of kinetic theory, see S. G. Brush, *Kinetic Theory*, 3 vols. (Oxford, 1965-); vol. III (in press) includes translations of the two major works of Enskog listed above and a discussion of more recent work.

For further biographical details, see *Hilding Faxén, Svenskt biografiskt lexikon*, XIII (Stockholm, 1950), 765–767.

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