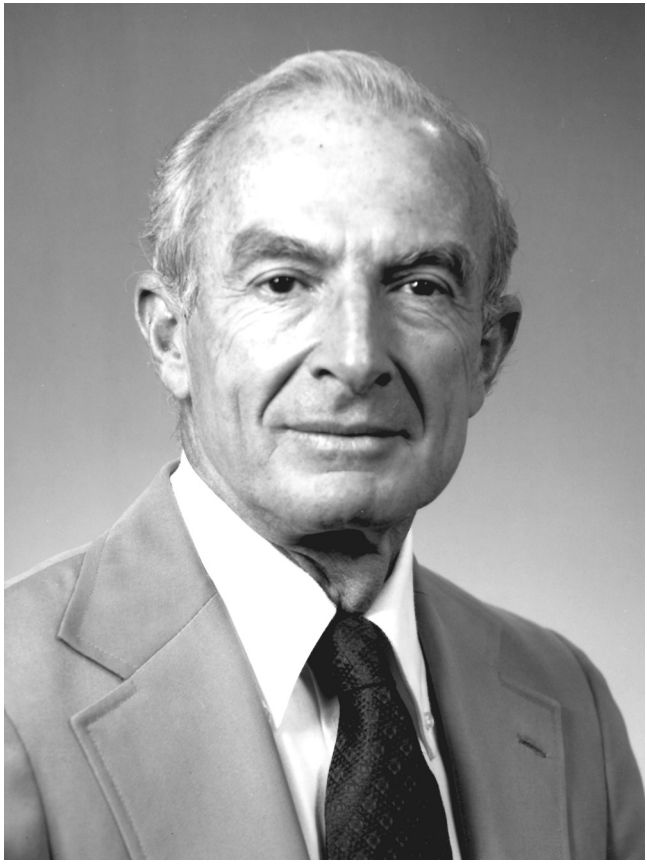

Sheldon K. Friedman

SHELDON K. FRIEDLANDER

1927–2007

Elected in 1975

"Contributions to the understanding of the origin and control of pollution by particulate matter."

BY HAROLD G. MONBOUQUETTE
SUBMITTED BY THE NAE HOME SECRETARY

SHELDON K. FRIEDLANDER, UCLA Ralph M. Parsons Foundation Professor of Chemical Engineering and director of the Air Quality/Aerosol Technology Laboratory, passed away on February 9, 2007, at his home in Pacific Palisades, California. He is considered a father of aerosol science and technology, which he promoted as an "enabling discipline."

Shel is widely known for his research on the various pollutants in smog and their quantification by source, and he championed the important goal of waste minimization in the chemical process industries—the conception, design, and operation of chemical processes that produce little or no waste. His great scientific and technological impact stems from a career of seminal contributions to aerosol research (the study of particles suspended in gases) that broadly advanced understanding of environmental aerosol and laid the foundation for the use of aerosol technology in chemical manufacturing. Further, he attracted a number of leading scientists to the field and profoundly influenced them.

Born November 17, 1927, in New York City, Shel was the only child of Irving Friedlander, a paper box manufacturer, and his milliner wife, Rose. He interrupted his undergraduate studies at Columbia University to serve in the Army just after World War II but returned to earn a BS in chemical engineering

in 1949 and an MS from the Massachusetts Institute of Technology in 1951. In 1950 he was hired as a research fellow by the Harvard School of Public Health on an Atomic Energy Commission contract; his research on the escape of radioactive particles from nuclear reactors sparked his academic interest in aerosols. He then joined the research group of H.F. Johnstone, who was known for aerosol research, and in 1954 earned his PhD in chemical engineering at the University of Illinois at Urbana-Champaign.

Working with Johnstone, Shel first applied the concept of "stopping distance" to the problem of transport of particles in turbulent flow to surfaces. He continued research in this area while an assistant professor of chemical engineering at Columbia (1954–1957) and during his subsequent appointments at Johns Hopkins (1957–1964) and Caltech (1964–1978). The concept has since been used routinely in descriptions of pollutant transport to soil, crops, trees, and large aquatic bodies by many environmental scientists throughout the world and, combined with his subsequent contributions on diffusion of particles to collection objects, forms the foundation of much modern work on particle removal from gases and liquids. In addition, his early research on aerosol deposition in the lung led to the development by others of methods to deliver therapeutic drugs directly to the lung.

As a young professor at Johns Hopkins, Shel also began publishing on self-preserving particle size distributions, which is considered one of the most elegant research works in aerosol science. He and his students discovered that size distributions of coagulating particles approach an asymptotic form independent of the initial distribution. This discovery has had a profound effect on understanding of particle coagulation in gases and liquids and most recently in gelation theory. It has enhanced knowledge of fly ash formation during coal combustion and has facilitated the design process for production of both particulate commodities (e.g., carbon black, titania) and sophisticated nanomaterials (e.g., catalysts, sensors, and biomaterials). While at Johns Hopkins, Shel was recognized with the Allan P. Colburn Award, given annually

by the American Institute of Chemical Engineers (AIChE) to a professor under the age of 36 for excellence in publications.

After moving to Caltech in 1964, Shel invented the "chemical element balance method," one of the most revolutionary contributions to both aerosol science and air pollution engineering and one that greatly influences current government policy and air quality management practice in general. Using this method, the origins of an atmospheric aerosol can be unraveled by relating its chemical makeup to the composition of emissions from various sources. He and his colleagues applied the method first to the fragmentary data then available on the Los Angeles aerosol. Shel was a key participant in the 1972 Aerosol Characterization Experiment, the first large-scale study of atmospheric aerosol funded by the California Air Resources Board. He and coworkers showed the importance of automobile and secondary emissions and the relative unimportance of the marine aerosol, contrary to a common belief at the time. Since this early study, the chemical element balance method has been applied to many city environments around the world and has contributed importantly to a new branch of environmental research known as "receptor modeling," since properties of pollutants are measured at a given point in the environment, the so-called receptor site. Receptor modeling is now applied over much larger scales than it was originally; regional-scale receptor models have been developed for source attribution for acid rain and arctic haze as well as for the regulation of transportation.

Shel moved to UCLA in 1978 as a founding member of its Chemical Engineering Department and chaired the department from 1984 to 1988. In 1982, he also helped found the American Association for Aerosol Research (AAAR). In the mid-1980s, his research group was searching for easier and cheaper ways to trap smokestack emissions and prevent pollution. Shel insisted, "We must find ways to control toxic wastes before they are produced, rather than ways of disposing of them afterward." In 1987 he secured a grant from the National Science Foundation to establish the nation's first Engineering

Research Center devoted to solving the problem of hazardous waste generation and management. He served as the Center's director for several years. Through this center and the AAAR he led a pioneering effort focused on the conception, design, and operation of chemical processes that produce minimal waste. The concept of waste minimization remains central to the efforts of engineers and scientists seeking to ensure a sustainable, environmentally friendly future for the chemical processing industry.

At UCLA, Shel brought rigorous science to the field of aerosol reactor engineering, and he and his students made important contributions to the design of aerosol reactors that are used today in the manufacture of various particulate materials. He also contributed significantly to understanding of the role of nanoparticles in the properties of materials. In 1996, while investigating how tiny particles are produced in coal combustion, Shel became aware that one of the biggest unknowns was the behavior of particles consisting of about 100 to 1,000 molecules. His group focused initially on the generation of titania particles and found that they band together to form chains that could be stretched and would retract upon stress release. This discovery suggested that such particle chains could be used to produce ceramic materials with some of the properties of rubber. The dynamics of strained nanoparticle chain aggregates developed into a new research direction of great importance both to understanding of the role of nanoparticle fillers such as carbon black in tires and to the synthesis of new high-performance nanocomposite materials.

Shel's remarkably fertile mind and unusual passion for research were always evident to those who worked with him—his faculty colleagues and the many students, postdoctoral fellows, and visiting scholars who spent time in his lab. He was a committed and generous mentor who took great pride in the accomplishments of his former students and postdocs. His enthusiasm for research carried over naturally to the classroom, and he created new courses in mass transfer, air pollution, nanoparticles, and aerosol technology. He also authored the classic text *Smoke, Dust and Haze: Fundamentals of Aerosol Dynamics* (1977), now in its second edition.

Throughout his career, he received numerous distinctions for his seminal contributions and pioneering work in the field of aerosol science and technology, including a Fulbright Scholarship (1960); a Guggenheim Fellowship (1969); and five AIChE awards: the Allan P. Colburn Award for Excellence in Publications by a Young Member of the Institute (1959), Alpha Chi Sigma Award for Chemical Engineering Research (1974), William H. Walker Award for Excellence in Contributions to Chemical Engineering Literature (1979), Lawrence K. Cecil Award in Environmental Chemical Engineering (1995), and Lifetime Achievement Award of the Particle Technology Forum (2001).

Shel was elected to the National Academy of Engineering in 1975 in recognition of his work on the origin and control of particulate pollution. He also received the Humboldt Senior Scientist Award from the West German Government in 1984–1985. Most notably he was the first recipient of three international awards—the Fuchs Memorial Award (1990) of the International Aerosol Research Assembly, the highest honor in the field of aerosols; the Junge Memorial Award (2000) of the European Aerosol Association; and the Aurel Stodola Medal (2004) of ETH Zurich—as well as many honorary lectureships. In 1997, AAAR established an award in his honor for the best PhD thesis in the field.

Shel gave generously of his time and energy in service to his profession and the nation. He served on the EPA Science Advisory Board and was a member of the National Academies' Board on Environmental Studies and Toxicology, Technology and the Environment Steering Committee, and Committees on Industrial Ecology and Environmentally Preferable Innovation, on Shipboard Pollution Control, and on Protecting Occupants of DoD Buildings from Chemical or Biological Release. Given his record of research, education, and service, his family, friends, and colleagues were surprised to find his name on a list of enemies during the administration of President Nixon.

Shel had diverse personal interests. He delighted both in trout fishing in small streams in the Angeles National Forest and in attending lectures at the Getty Museum. He also collected stamps, Persian rugs, and tile-top tables.

In addition to his beloved wife Marjorie, he is survived by four children: Eva Friedlander, Amelie Yehros (Ilan), Zoe Friedlander (Barry Greenberg), Josiah Friedlander (Katrinka Wolfson); and eight grandchildren: Zach and Lena White; Isaiah, Sam, and Ella Yehros; and Aaron, Rose, and Jack Greenberg.

Author's Note
The author is grateful for helpful comments and input from S. Pratsinis, R. Flagan, L. Mädler, D. Allen, and the Friedlander family, and for information from biographies written by P. Biswas (www.iara.org/AerosolPioneers.htm) and G. Hidy (*Aerosol Science and Technology: History and Reviews*, D.S. Ensor, ed., RTI Press, 2011).