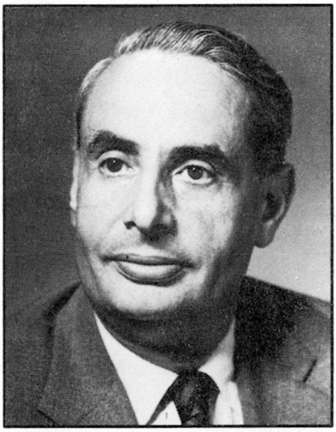
Memorial to Walter M. Elsasser
1904–1991

BRUCE D. MARSH
Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, Maryland 21218



Chances are small that anyone will ever again make such fundamental discoveries in physics, meteorology, and geophysics as Walter Elsasser, who died essentially of old age on October 14, 1991, in Baltimore, where he was Homewood Professor at Johns Hopkins University.

Born March 20, 1904, in Mannheim, Germany, to Dr. Moritz (a judge) and Johanna (née Masius) Elsasser, Walter attended public school in Pforzheim. He began his university education in 1922 at the University of Heidelberg where, upon recognizing his talent for physics, he was encouraged to transfer to the University of Munich to study under Arnold Sommerfeld. His graduate education came at the University of Göettingen under Max Born and James Franck, receiving in 1927 one of the first Ph.D. degrees in quantum mechanics.

Browsing in the Göettingen library in 1925 at the age of 21, Walter found a newly completed dissertation by Louis de Broglie (perhaps hastily passed over by Born) containing the suggestion that matter such as electrons might also behave as waves. Walter made the fundamental observation that the hitherto confusing and unexplained experimental results of electron interaction with metals from Bell Laboratories were in fact confirmation of de Broglie's hypothesis. This discovery characterized Walter and established him as a scientist of world class. (Two others later received the Nobel Prize for the same observation made two years after Walter's.)

Encouraged by his classmate, the American J. Robert Oppenheimer, Walter became in 1927 a postdoctoral research assistant to Paul Ehrenfest in Leiden, Holland. Well known for his intensity and temperamentalness, Ehrenfest angrily dismissed Walter one morning in protest over the strong odor of hair tonic Walter had just involuntarily received with a haircut. His self-esteem shaken, it was some months before Walter recovered enough to accept a second postdoctoral position under Wolfgang Pauli in Zurich, Switzerland. This went much better, and in a short time he was eager to try his hand at teaching. He never forgave Oppenheimer.

Walter's first teaching positions were at Polytechnical School in Kharkov, Russia, and Berlin, Germany, in the years 1928 to 1930. He found teaching much to his liking and moved on in 1930 to become instructor of physics at the University of Frankfurt, where he stayed until 1933, when the rise of Hitler made Germany inhospitable. He then became research fellow in the Henri Poincaré Institute at the Sorbonne in Paris. Here in the laboratory of Frederic Joliot he continued his theoretical investigations on the structure of the atomic nucleus and was seminal in development of the shell model and in introducing the concept of quantum magic numbers so important to understanding nuclei stability. This work continued until about 1936, when Walter came to the United States as research fellow in atmospheric physics at the California Institute of Technology (Caltech). Much to the good fortune of earth science, this forever changed Walter's research interests; it came about largely as a result of his discussions with Robert A. Millikan of Caltech.

A prospect of taking part in building a strong physics department at nearby UCLA much interested Walter. Millikan, however, dissuaded Walter on the grounds that he and others did not favor strong physics in California at places other than Berkeley and Caltech; moreover, in his opinion, the best future for physics was geophysics. In no position to argue with someone as influential and insightful as Millikan, Walter continued research in atmospheric physics until 1941 when America entered World War II. This work resulted in what is now known as the Elsasser model of atmospheric radiation, which was the first physically satisfying band model to be developed.

During the war and until 1947, Walter worked with the U.S. Signal Corps, attached to Columbia University, on a series of technical reports and manuals on electromagnetic wave propagation with application to short-wave communication and radar echoes. Whether this research in electromagnetism was chosen by Walter or was simply handed to him as a wartime duty because of his expertise in atmospheric physics is unclear, but it had a profoundly serendipitous effect on his thinking on the origin of Earth's magnetic field. Just prior to taking up this work in electromagnetism, Walter had published his first two papers (1939 and 1941) on the magnetic field. He modeled the field by placing an ensemble of magnetic sources at scattered locations within the earth. By matching the power spectrum of the model to that of the actual geomagnetic field, he was able to place constraints on hypotheses of the distribution and strength of this virtual field source. But the model was clearly unsatisfactory in considering only static sources, being unable to account for the characteristic temporal (i.e., secular) field variations. This work, nevertheless, thoroughly grounded him in the essential observations of geomagnetism. And the wartime work allowed him to thoroughly refresh himself on the fundamentals of electromagnetism. Moreover, his meteorological work over the previous five years, during which time he produced nine papers (although dealing primarily with the spectroscopy of water vapor in atmospheric radiation), firmly acquainted him with the fluid dynamic fundamentals of low-viscosity, rotating global fluids. He was now acquiring all the essential ingredients from which his far-ranging and remarkable imagination could construct the first fully dynamic and comprehensive geomagnetic field model. His model combined the electromagnetic fluid of Earth's outer core, Earth rotation, and the Coriolis effect to generate the magnetic field.

Beginning in 1946 Walter produced three landmark papers, each titled "Induction Effects in Terrestrial Magnetism." These papers explained the fundamental concepts and mathematical relations governing generation of Earth's magnetic field via a self-exciting dynamo or generator. Radial motions due to thermal convection of the relatively inviscid, metallic fluid of the outer core, heavily influenced by rotation, drag and stretch current or flux lines, which are effectively frozen in the strongly conductive fluid, into a series of loops that give rise to a magnetic field. Loops locally degenerate alternatively into poloidal (pole-parallel) and toroidal (pole-circling) fields through continuous, competitive regeneration. The kinetic energy of thermally induced fluid motion is thus transferred through flux-line stretching and reorientation into magnetic field energy. Any small thermoelectric or intragalactic field can spawn the dynamo.

Over the next ten years (1948–1958) Walter wrote 15 papers on geomagnetism and dynamo theory; "Hydromagnetism I and II" (1956) and "Hydromagnetic Dynamo Theory" (1957) are classic review papers, and the student account for *Scientific American* (May 1958) sold more than 10,000 copies. In combining meteorological fluid dynamics (or hydrodynamics) with electromagnetism, Walter put himself squarely at the focus of one of the most complex and fascinating areas of earth science, physics, mathematics, and astronomy—namely, magnetohydrodynamics. Results from paleomagnetism, seismology, Earth rotation, stellar dynamics, plasma physics, and fluid dynamics all came together in this melding of Maxwell's equations of electromagnetism and the Navier-Stokes equations of hydrodynamics. Walter was now irreversibly an earth scientist, an affiliation he thoroughly enjoyed for the rest of his life.

During this era Walter had the opportunity to explain his insights to Albert Einstein. Einstein had hypothesized that magnetism might be simply a fundamental property of planetary rotation, and this theory spurred P.M.S. Blackett to build extremely sensitive magnetometers (later used so effectively in paleomagnetism) to obtain his famous negative result with rotating spheres. Einstein listened carefully and earnestly to Walter and asked detailed questions in the vein of an electrical engineer, involving motors and wires. Not sure of Einstein's opinion of the matter, Walter later discreetly probed Einstein's assistant for an answer. "Oh," he said, "he didn't much believe it. He simply could not believe that something so beautiful could have such a complicated explanation."

In recognition of his accomplishments, Walter was elected to the National Academy of Sciences in 1957, received the William Bowie Medal of the American Geophysical Union in 1959, and was elected a Fellow of the American Physical Society. This era was also academically busy for Walter. In 1947 he became associate professor of physics at the University of Pennsylvania, and in 1950 moved as professor to the University of Utah, where he experimented with electronic computing. In 1956, when the University of California at La Jolla was established, he became one of the founding professors, and in 1960 he became chair of the physics department at the University of New Mexico.

Until this time Walter had always been academically labeled a physicist, but his work and interests had become increasingly geophysical. His dynamo theory had become the playground of mathematicians and physicists; there was less and less to hold his imagination. As was his nature, he sensed through developments in paleomagnetism the dawning of a major revolution in earth science, and he was convinced by Harry Hess, the father of that revolution, to go to Princeton as professor of geophysics. Delivered to the very doorstep of seafloor spreading, he was a major influence to the fresh postdoctoral fellow Jason Morgan, and also wrote over the next ten years a series of papers on early Earth history, the definition of lithosphere, mantle thermal convection, and heat-flow equality. Out of these papers came more fundamental ideas: core formation by accumulation of iron droplets in the mantle and downward Rayleigh-Taylor diapirism; lithosphere as a stress guide; and propagation of stress by a diffusive process via what is now called the Elsasser equation.

He remained at Princeton until 1967 when he became research professor in applied mathematics at the University of Maryland and then joined the Department of Earth and Planetary Sciences at Johns Hopkins University as professor of geophysics in 1975. There he continued his work on mantle convection and presented persuasive evidence of whole-mantle convection.

Throughout his highly productive and academically itinerant life, Walter had other intellectual interests too numerous to discuss; one long-lasting and consuming priority, however, was theoretical biology. His initial interest was the application of quantum mechanics to "living matter"(1951). The more he worked the more he became impressed with the inherent complexity of life, and the more skeptical he became of the popular reductionist view of organisms as collections of tiny machines. He wrote 23 papers and three books in this area, one of which, *Atom and Organism* (1966), engendered widespread interest and was translated into French and Spanish.

As a man, Walter was modest, generous, and gentle, somewhat shy in crowds, and not particularly interested in material possessions. He had a keen eye for art but no talent at all for working with his hands doing experiments or even chores at home. He believed this was due to his European upbringing with no easy early access to a home workshop. His sister Maria, however, said that from an early age Walter was a reader, a thinker, and an intellectual, and not a boy eager for the street or playground. As a young man he was known to be difficult and moody, and perhaps because of his own sensitivity he was unusually perceptive of the personalities, feelings, and situations of others. To the very end he was fascinated by the mind and concepts of Freud and Jung. He enjoyed solitude and was wary of science done in big groups. In teaching he was always well prepared, dryly animated, and exceedingly popular. "Potential theory," he was overheard telling his class, "is much like tennis. To be good at it, you simply have to practice." Although he was aware of his stature, he was always approachable and without pretense. He thought nothing of traveling from La Jolla to Caltech to help the young G. J. Wasserburg in his quest to understand the water molecule in magma. In the academic world, when necessary, he was tough, unyielding, and persuasive. When writing, he aimed at two pages a day in longhand with a fountain pen. He was fond of children and they of him.

His style of doing science was poetical and philosophical. He would imagine, at both the most fundamental and grand scales, natural processes that compete and interrelate. His sense of what might be possible in nature was sharp, and he built on this by quantitatively modeling these ideas through preliminary calculations. In an iterative fashion he would feel his way along until he abandoned an idea entirely or tailored it to a fully fleshed-out, lucid, and robust piece of science. His papers reflect this process and are models of engaging clarity. Not a powerful mathematician, he thought long and intricately before he began digging. Comprehensive, careful thought was his forte. Ideas excited him; he judged them by their beauty, simplicity, and grace. He thought and worked until the end.

Walter's later era of scholarship brought more awards: the John A. Fleming Medal of the American Geophysical Union (1971), Fellowship of the American Academy of Arts and Sciences (1972), the C. F. Gauss Medal (1977) on the 200th anniversary of Gauss's birth, the Penrose Medal of the Geological Society of America (1979), and the National Medal of Science from President Reagan (1987).

Walter first married Margaret Trahay (1937) and they had two children, Barbara and William; he later married Suzanne Rosenfeld (1964). His sister Maria lives in California. Walter's autobiography, *Memoirs of a Physicist in the Atomic Age,* was written in 1978.

Perhaps no other scientist in this century has had as profound an effect on so many fields of science.

SELECTED BIBLIOGRAPHY OF W. M. ELSASSER

1925 Bemerkungen zur Quantenmechanik freier Elektronen: Naturwissenshaften, v. 13, p. 711.

1933 Sur le principe de Pauli dans les noyaux: Journale de Physique, v. 4, p. 549.

1934 Equations de mouvement d'un neutron: Académie des Sciences Comptes Rendus, v. 198, p. 441.

—— Sur le principe de Pauli dans les noyaux, II: Journale de Physique, v. 71.

—— Sur le principe de Pauli dans les noyaux, III: Journale de Physique, v. 5, p. 635.

1937 On quantum measurements and the role of the uncertainty relations in statistical mechanics: Physical Review, v. 56, p. 987–999.

—— On some properties of the water vapor spectrum and their relation to atmospheric radiation: Monthly Weather Review, v. 65, p. 323.

—— The self-consistent field and Bohr's nuclear model: Physical Review, v. 51, p. 55.

1938 Far infrared absorption of atmospheric water vapor: Astrophysical Journal, v. 87, p. 497.

—— Mean absorption and equivalent absorption coefficient of a band spectrum: Physical Review, v. 54, p. 126.

—— Note on atmospheric radiation caused by the rotational water band: Physical Review, v. 53, p. 786.

1939 On the origin of the earth's magnetic field: Nature, v. 143, p. 374.

1941 A statistical analysis of the earth's internal magnetic field: Physical Review, v. 60, p. 876.

1942 Heat transfer by infrared radiation in the atmosphere: Cambridge, Massachusetts, Harvard University Press, 100 p.

1946 Induction effects in terrestrial magnetism: Physical Review, v. 69, p. 106.
—— Induction effects in terrestrial magnetism, II: Physical Review, v. 70, p. 202.
1947 Induction effects in terrestrial magnetism, III: Physical Review, v. 72, p. 821.
1950 Causes of motions in the earth's core: American Geophysical Union Transactions, v. 31, p. 454.
—— The earth's interior and geomagnetism: Reviews in Modern Physics, v. 22, p. 1.
—— The hydromagnetic equations: Physical Review, v. 79, p. 183.
—— (with Swift, C.) True meaning of the geomagnetic secular variation: Physical Review, v. 78, p. 64.
1951 Quantum mechanics, amplifying processes and living matter: Philosophy of Science, v. 18, p. 300–326.
—— Quantum-theoretical densities of solids at extreme compression: Science, v. 113, p. 105.
1953 A reformulation of Bergson's theory of memory: Philosophy of Science, v. 20, p. 7–21.
1954 Dimensional relations in magnetohydrodynamics: Physical Review, v. 95, p. 1.
—— Dynamo theories of geomagnetism: American Geophysical Union Transactions, v. 35, p. 73.
—— (with Takeuchi, H.) Fluid motions near the core boundary and the irregular variations in the earth's rotation: Journal of Physics of Earth, v. 2, p. 39.
1955 (with Takeuchi, H.) Non-uniform rotation of the earth and geomagnetic drift: American Geophysical Union Transactions, v. 36, p. 584.
1956 (with Ney, E. P., and Winckler, J. R.) Cosmic-ray intensity and geomagnetism: Nature, v. 178, p. 1226.
—— Earth's magnetism: Smithsonian Contributions to Astrophysics, v. 1, no. 1, p. 67.
—— Hydromagnetic dynamo theory: Reviews of Modern Physics, v. 28, p. 135.
1957 Some dimensional aspects of hydromagnetic phenomena, *in* Landshoff, R. K. M., ed., Magnetohydrodynamics: Stanford, California, Stanford University Press.
—— The terrestrial dynamo: National Academy of Sciences Proceedings, v. 43, p. 14.
1958 (with Munk, W. H.) Geomagnetic drift and the rotation of the earth, *in* Contributions in geophysics (in honor of B. Gutenberg): New York, Pergamon Press.
—— The Earth as a dynamo: Scientific American, May.
—— The physical foundation of biology, an analytical study: New York, Pergamon Press, 219 p.
1959 (with Urey, H. C., and Rochester, M. G.) Note on the internal structure of the moon: Astrophysical Journal, v. 129, p. 842.
1961 Quanta and the concept of organismic law: Journal of Theoretical Biology, v. 1, p. 27–58.
—— Secular magnetic variations; magnetohydrodynamics, *in* Encyclopedic dictionary of physics: New York, Pergamon Press, p. 442–443.
1963 Early history of the Earth, *in* Earth science and meteoritics: Amsterdam, North-Holland, p. 1–30.
1966 Atom and organism. A new approach to theoretical biology: Princeton, New Jersey, Princeton University Press, 143 p.
—— Thermal structure of the upper mantle and convection, *in* Hurley, P. M., ed., Advances in earth science: Cambridge, Massachusetts, MIT Press, p. 461–502.
1967 Earth, *in* Encyclopaedia Britannica (1962, revised 1967), 7 p.
—— Interpretation of heat flow equality: Journal of Geophysical Research, v. 72, p. 4768.
1968 Submarine trenches and deformation: Science, v. 160, p. 1024.
—— The mechanics of continental drift: American Philosophical Society Proceedings, v. 112, p. 344.
1969 Acausal phenomena in physics and biology; a case for reconstruction: American Scientist, v. 57, p. 502–516.

1969 Convection and stress propagation in the upper mantle, *in* Runcorn, S. K., ed., The application of modern physics to the earth and planetary interiors: New York, Wiley Interscience.

—— Patterns of convective creep in the Earth's mantle, *in* Argon, A. S., ed., Physics of strength and plasticity: Cambridge, Massachusetts, MIT Press, p. 365–375.

—— What is theoretical biology?, *in* Marois, M., ed., Theoretical physics and biology: Amsterdam, North-Holland, p. 74.

1970 The so-called folded mountains: Journal of Geophysical Research, v. 75, p. 1615.

1971 Existence of an asthenosphere: Journal of Geophysical Research, v. 76, p. 7296.

—— Philosophical dissonances in quantum mechanics, *in* Yourgrau, W., and Van der Merve, A., eds., Perspectives in quantum theory: Cambridge, Massachusetts, MIT Press, p. 199–218.

—— Sea-floor spreading as thermal convection: Journal of Geophysical Research, v. 76, p. 1101.

—— Two-layer model of upper-mantle circulation: Journal of Geophysical Research, v. 76, p. 4744.

1975 The chief abstractions of biology: Amsterdam, North-Holland, 261 p.

1978 Memoirs of a physicist in the atomic age: New York, Science History Publications, 268 p.

1979 (with Olson, P., and Marsh, B. D.) The depth of mantle convection: Journal of Geophysical Research, v. 84, p. 147.

1981 Principles of a new biological theory: A summary: Journal of Theoretical Biology, v. 89, p. 131–150.

1984 Outline of a theory of cellular heterogeneity: National Academy of Sciences Proceedings, v. 18, p. 5126–5129.

Printed in U.S.A. on Recycled Paper 12/93