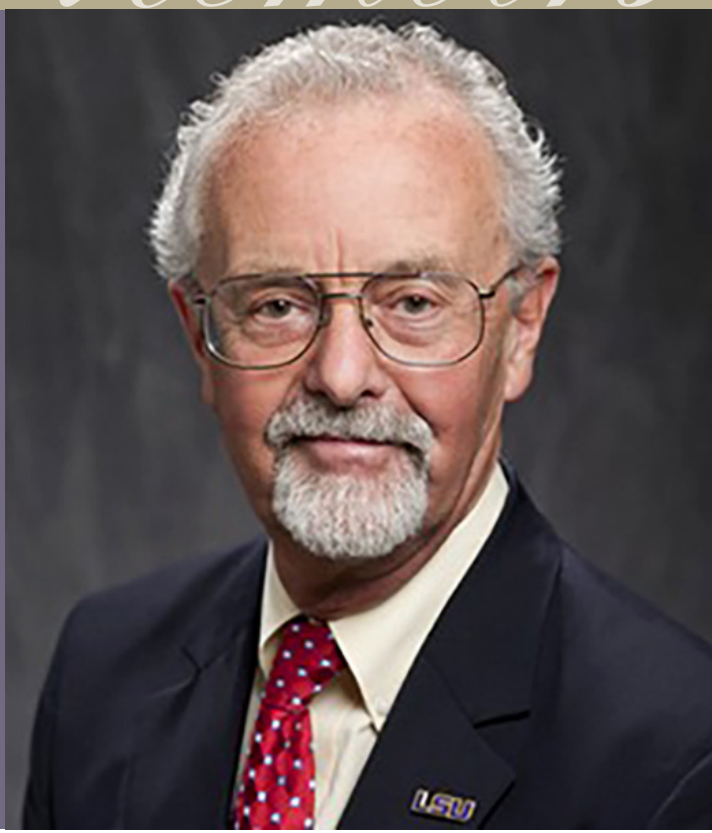
E. Ward Plummer

1940–2020

BIOGRAPHICAL *Memoirs*



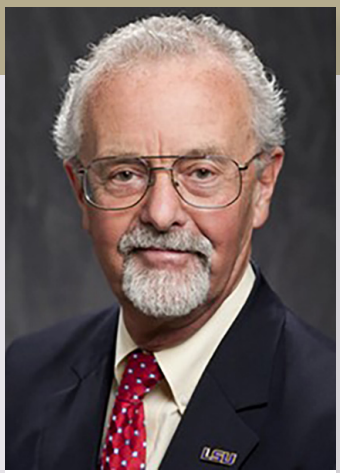
A Biographical Memoir by Peter D. Johnson, Wilson Ho, Eugene J. Mele, Mike Klein and Johanna Plummer

NATIONAL ACADEMY OF SCIENCES

EARL WARD **PLUMMER**

October 30, 1940–July 23, 2020

Elected to the NAS, 2006



By Peter D. Johnson, Wilson Ho, Eugene J. Mele, Mike Klein and Johanna Plummer

"My legacy will be the minds I molded; not the papers I wrote or the prizes I won."— E. Ward Plummer

Earl Ward Plummer was one of the world's leading experts in electron spectroscopy and its application to the study of the electronic structure of a range of materials, with a particular emphasis on surface properties. He was a central part of the team that developed single-electron spectroscopy, which enabled the first-ever glimpse into electronic energy levels of atoms at the surface of a metal. Among many other firsts, he developed conceptual and experimental field emission spectroscopy to the point where electron spectroscopy of single atoms could be carried out. Much of the condensed-matter-physics field's current research on critical phenomena in low-dimensional systems was inspired by his discovery of charge-density waves at the metal/semiconductor interface.

Plummer graduated with a B.A. in physics and mathematics from Lewis and Clark College in 1962 and earned his Ph.D. degree in physics at Cornell University in 1967. After completing a National Research Council Postdoctoral Fellowship at the National Institute of Standards and Technology (NIST), he remained as a staff scientist at the institute until 1973. In the fall of 1973 he accepted a faculty position in the Department of Physics and Astronomy at the University of Pennsylvania. Over the next 19 years he rose to the rank of professor and served as director of the Penn Laboratory for Research on the Structure of Matter. In 1993 he took a joint appointment as a Distinguished Professor of Physics at the University of Tennessee and as a Distinguished Scientist at Oak Ridge National Laboratory. While in Tennessee, he was instrumental in the conception of the Joint Institute for Advanced Materials at the university and served as its director until his departure in 2009. In January 2009 he moved to Louisiana State

University, where he was named Boyd Professor of Physics in 2017 and served as special assistant to the Vice President of Research & Economic Development.

Earl Ward Plummer, one of two sons, was born on October 30, 1940, in Warrenton, a small fishing and timber town near Astoria, Oregon, to Emily and George Washington Plummer. His father was a fisherman who frequently took Ward, as he was generally called, out on his boat in the summer months. While these working summers enabled Ward to acquire enough funds to later buy a 1954 Corvette that he lovingly restored, the work also convinced him that fishing was not in his future. However, from an early age his father was also his scout master, and Boy Scouting was a pastime Ward pursued with an enthusiasm that would characterize his later scientific activities. As evidenced in the adjacent picture, Ward excelled and became an Eagle Scout.

Ward, the Eagle Scout proudly displaying his many accomplishments.

Ward also excelled as a student and credited his math teacher with his interest in math, which would ultimately lead him to physics. Graduating from high school, Ward enrolled in Lewis and Clark College, where he graduated with a B.A. degree in physics and mathematics, *summa cum laude*, in 1962. In later years the college would honor him with its Distinguished Alumnus Award. While at Lewis and Clark Ward met his future wife, Elizabeth "Betty" Miller, a student in medical technology. Upon Betty's graduation in 1964, they married and subsequently had two children, Johanna and Brent. Moving to Cornell University, Ward carried out research for his Ph.D. under the supervision of Professor Thor N. Rhodin. His chosen area was in the application of the field emission technique to the study of metallic surfaces, resulting in a thesis entitled "*Binding of the 5d-Transition Elements on Single-Crystal Tungsten Surfaces*." In 1967 Ward moved to the National Bureau of Standards (NBS—later renamed the National Institute of Standards and Technology-NIST), in Gaithersburg, Maryland, as a postdoc and continued his work on the field emission technique with colleague Russell Young. At the time, Young was developing an electron tunneling device, the topografiner, which measured vertical surface features at the sub-0.1 nm level. Subsequently, the IBM Research Laboratory in Zurich developed a similar device—the scanning tunneling microscope—which, in addition, achieved

atomic resolution within the surface plane, work that was recognized with the Nobel Prize in 1986 for its creators, Gerd Binnig and Heinrich Rohrer.

Ward's work together with Young on resonance tunneling resulted in an article, published in *Solid State Communications,* [1] that was selected as one of the 100 noteworthy achievements during the first 100 years of NBS/NIST. It was also published in Century of Excellence in Measurement, Standards and Technology, NIST Special Publication 958, on the occasion of the NBS/NIST 100th anniversary. The *Solid-State Communications* paper was the first work in which the electronic-energy-level spectra of adsorbed atoms could be observed and theoretically interpreted.

All subsequent electron-energy-level spectroscopy of adsorbed atoms and molecules, whether based on tunneling processes such as in this work or on photon-induced processes, can legitimately be considered as logical consequences of this pioneering study. The spectroscopic information so obtained is the essential ingredient required in all quantum mechanical modeling of chemical bonding, catalysis, dynamics, and reactivity at solid surfaces, and it is for this reason that the advances reported in the paper have had a lasting and historical significance. It is interesting to note that the enhanced resonance tunneling current through the adsorbed atoms is identical with the tunneling mechanism upon which the scanning tunneling microscope is based. [2] Ward's work with Bill Gadzuk on field emission spectroscopy culminated in an important review paper, [3] which remains his most highly cited paper.

Into Academia

In 1973 Ward moved to the University of Pennsylvania as an associate professor in the Department of Physics. There he rose through the ranks, becoming a full professor in 1977, the William Smith Professor of Physics in 1988, and the director of the Laboratory for Research on Structure of Matter in 1990. At Penn, Ward continued his work on metallic surfaces using field emission but now developed a new interest in the use of photoelectron spectroscopy for the study of surface electronic structure and, in particular, the electronic structure of adsorbed atoms.

The early 1970s were a time when the research community was just beginning to explore the use of synchrotron radiation as the light source in photoemission experiments. Indeed, Dean Eastman, a member of the Academy, had just demonstrated the possibility by using the synchrotron facility that had been built at MIT. Ward and Eastman collaborated on a study of the electronic structure of carbon monoxide (CO) adsorbed on

nickel (Ni) and palladium (Pd) surfaces, for which they made use of a Wisconsin-based particle accelerator named Tantalus—effectively the first dedicated electron storage ring in the world. This pioneering study extended Ward's interest in the electronic structure of adsorbed molecules. In particular, by examining the electronic structure of the adsorbed CO at a number of different photon energies and comparing it with gas phase CO, Ward and his colleagues were able to identify the orbitals involved in the bonding. [4,5] The first referenced paper was subsequently one of a select few to be republished in the journal *Solid State Communications*, in 1993 to celebrate the journal's 30th anniversary.

With the experience he gained from the collaboration with Eastman, Ward set out to design and construct a new beamline at the Tantalus storage ring, now dedicated to the needs of his own research programs. Thus the new facility, based on the use of a toroidal grating monochromator, was constructed and commissioned, enabling a whole range of studies of metallic surface states, adsorbed molecules, and some of the first studies of the effects of correlations in the photoemission spectra. Indeed, a review of the use of angle-resolved photoemission in the study of surfaces, written during this period, resulted in Ward's second-most-cited paper. [6] Its important observation was that the ability to tune the incident photon energy using synchrotron radiation gave researchers a new handle to distinguish surface electron states from bulk states. In particular, Ward and his group carried out comprehensive studies of the surface electronic structure of Ni, which required a detailed understanding of the satellite structure that characterized the multi-electron excitations or correlations in this material. These studies also resulted in a highly cited paper. [7] While at Penn, Ward also developed a considerable research program in the application of angle-resolved inelastic electron scattering or electron-energy-loss spectroscopy (EELS) to the study of vibrations of adsorbed molecules, as well as surface-collective-plasmons modes in a variety of materials.

During the mid-70s, plans evolved to build a new storage ring at Brookhaven National Laboratory (BNL), in Upton, Long Island, New York. The initial plan was for a single ring targeting the x-ray range, and as a "second generation" facility it would exploit the capabilities of insertion devices, undulators, and wigglers to produce even more intense photon fluxes to be used in a range of experiments. Under pressure from the outside community, BNL added a second ring to exploit these same capabilities in the UV range. Thus, by the early 80s Ward's operation, along with those of Bell Labs, IBM, and several other groups, had relocated from Tantalus to the new storage ring capability, the National Synchrotron Light Source at BNL. While continuing with research programs already well established, Ward and collaborators now pushed to exploit the high fluxes available from

the insertion devices at BNL and elsewhere to study in detail the excitation spectra of gas phase molecules. These studies helped lay the foundation for the use of insertion devices, now the cornerstone of activities at synchrotron radiation facilities worldwide.

In 1990 Ward became the Director of U. Penn's Laboratory for Research in the Structure of Matter (LRSM), which hosted an NSF-funded Materials Research Laboratory (MRL). Although Ward only led the LRSM for two years, he succeeded in getting it organized to face the increasingly competitive environment, where universities such as Princeton and UC Santa Barbara sought NSF support for their own terrific materials programs. Ward brought passion and an element of military-style organization to the LRSM, and above all he started the lab's transition to a sense of collective purpose. Importantly, he emphasized outreach programs and championed the process, organizing a consortium including Exxon, Princeton, UC-Sant Barbara, and Penn to secure Department of Energy funding to build a beam line at Advance Photon Source-Argonne National Laboratory (APS-ANL) at the University of Illinois-Chicago. These multiple outreach efforts set the stage for the LRSM to compete successfully in securing research funding for an NSF Materials Research Science & Engineering Center (MRSEC), after the NSF-MRL program was discontinued.

U. of Tennessee-Knoxville and LSU

Ward's energetic and colorful personality always made an impact wherever he went. In 1992 he moved to the University of Tennessee-Knoxville (UTK) as a Distinguished Professor in a joint appointment with Oak Ridge National Laboratory (ORNL), where his title was Distinguished Scientist. At ORNL he was initially associated with the Solid State Division, which later evolved into the present-day Materials Science and Technology Division. But anywhere he was, Ward was driven by science. He was very fond of quoting in his seminars a sentence by the famous Wolfgang Pauli: "God made solids, but surfaces were the work of the devil." Consequently, he found it irresistible to study those surfaces and unravel their secrets. At Tennessee he continued working in this primary passion, the physics of surfaces, exploring the surface properties of different materials with scanning tunneling microscopy, photoemission, and electron energy-loss spectroscopy. [8] Among his areas of focus were both the electronic and vibrational properties of surfaces and interfaces and studies on an atomic scale of phase transitions in reduced dimensionality. [9]

His interests, however, shifted rather abruptly in the late 1990s from studying "simple" model systems to complex materials, many of which are now under the broad umbrella

LSU recognizes one of its most distinguished scientists, Ward Plummer, at the start of a football game.

of fashionable "quantum materials." He made several important discoveries, including the existence of multipole plasmon modes localized at surfaces of simple metals. These modes are currently of interest in the growing field of nano plasmonics, an area that Ward and collaborators offered insights into in a review article.[10]

During his career Ward mentored more than 100 graduate students and postdoctoral fellows and authored more than 400 scientific articles. Evidence of his impact included the Davisson-Germer Prize in Atomic and Surface Physics of the American Physical Society in 1983 and the Medard W. Welch Award of the American Vacuum Society in 2001. The citation of the Welch Award read

For the development of novel instrumentation, its use to illuminate new concepts in the surface physics of metals, and the mentoring of promising young scientists.

Ward's ebullient personality could not be tamed by just the surfaces! He was always planning and dreaming. Several of his efforts proved fruitless, but they were always interesting, forcing people to think outside the box. One of those efforts was tremendously successful and impactful on UTK. In 2000 he became the director of the Tennessee Advanced Materials Laboratory, a state-funded Center of Excellence. With others, Ward was able to secure generous funding from the state and Federal governments to construct a new building on a recently developed portion of University-owned land across the Tennessee River from the main campus. In 2006 the Advanced Materials Laboratory evolved into the Joint Institute for Advanced Materials of the University of Tennessee and Oak Ridge National Laboratory. The Joint Institute has evolved again and is now called the Institute for Advanced Materials and Manufacturing. Anyone visiting that building is impressed by its enormous size and design.

In 2009 Ward moved to Louisiana State University (LSU). He was named the Boyd Professor of Physics and Astronomy, LSU's highest and most prestigious distinction, and served as special assistant to the Vice President of Research & Economic Development. He worked tirelessly to improve research infrastructure in the university system with the clearly stated goal of wanting to produce the next generation of great scientific leaders in Louisiana. His leadership and vision enabled the addition of best-in-class instru-

mentation facilities capable of manipulating functional materials in the pursuit of new technologies and fundamental science, and in 2013 he became director of the Institute for Advanced Materials at LSU.

Ward continued to explore in detail the properties of two-dimensional systems but now also in tailored materials, including superlattices, heterostructures, and associated interfaces. One area he looked into was the physics of charge-density wave formation and the relationship between charge-density waves and electron-phonon coupling, which resulted in another important article. [11] Other areas of his research included the close coupling between spin, charge, and lattice influenced by the perturbation of the broken symmetry at surfaces.

As an ardent believer in the benefit of international science, Ward promoted many international collaborations, including many between the United States and Japan and China in condensed matter physics. In 1998, along with academician Mike Klein, he visited the Joint Research Center for Atom Technology, in Tsukuba, Japan. This resulted in an important collaboration with Yoshi Tokura, who provided many of the complex materials used in Ward's research programs, including the manganites and ruthenates. [12,13]

Ward with wife Betty on a trip to China.

For almost two decades Ward worked to build collaborative research and education programs with scientists in China, specifically at the Institute of Physics (IOP) of the Chinese Academy of Sciences (CAS) in Beijing. In 2006 he was named the Guangbiao Jianzuo Professor of Physics at Zhejiang University, Hangzhou, China. He mentored many young scientists studying in the United States and actively encouraged them to return to China. In 2000, with Enge Wang and Zhenyu Zhang, he founded the International Center for Quantum Structures, or ICQS, in the IOP and served as the chief scientific advisor. ICQS has produced many leading Chinese physicists and fostered scientific collaborations that have resulted in numerous influential research achievements. Ward was particularly interested in the development of a new High-Resolution Electron-Energy-Loss Spectrometer (HREELS) for the study of surface dynamics, long an interest of his. This instrumentation was ultimately funded by the IOP and CAS.

Ward's work was recognized with a number of awards, including Fellow of the American Physical Society in 1981, the APS Davisson-Germer Award in 1983, the American Vacuum Society's Medard Welch Award in 2001, election to the National Academy of Sciences in 2006, Fellow of the American Association for the Advancement of Science in 2008, and election to the American Academy of Arts and Sciences in 2014. China recognized his contributions with three major awards: the International Scientific Cooperation Award from CAS in 2016, the Friendship Award from the State Administration of Foreign Experts Affairs in 2017, and the International Science and Technology Cooperation Award in 2018.

Personal Life

Ward was a devoted family man, raising two children with his lifelong wife, Betty. Aside from family duties and physics, he also had a passion for cycling. Indeed, he had a custom racing bike made for him at the Pinarello factory in Italy and completed a six-day, 620-mile cycling 'Tour of Italy' with Wilson Ho, a former student and now a member of the Academy. Ward clearly also enjoyed fast cars, as evident in the picture where he is seen in his favorite 1954 Corvette. This was the car that was purchased with funds raised by working on his father's fishing boat during the summer months, and then lovingly restored. At a later stage the Corvette was replaced by a red Porsche 944 that he bought in Germany in 1986 while there on a Guggenheim Fellowship. After being shipped to the United States, the Porsche did not have a good ending, but Ward survived to tell the tale. In Ward's later years, he and Betty very much enjoyed their custom-built lake house in Spring City, Tennessee, where he spent time boating and helping her with her gardens. Ward died on July 23, 2020, at age 79.

Ward enjoying the fruits of his labor, the restored 1954 Corvette.

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