Aerosol Science and Technology: History and Reviews

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About the Cover

The cover depicts an important episode in aerosol history—the Pasadena experiment and ACHEX. It includes a photograph of three of the key organizers and an illustration of a major concept of atmospheric aerosol particle size distribution. The photograph is from Chapter 8, Figure 1. The front row shows Kenneth Whitby, George Hidy, Sheldon Friedlander, and Peter Mueller; the back row shows Dale Lundgren and Josef Pich. The background figure is from Chapter 9, Figure 13, illustrating the trimodal atmospheric aerosol volume size distribution. This concept has been the basis of atmospheric aerosol research and regulation since the late 1970s.

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Othmar Preining

An Austrian Pioneer of Modern Aerosol Research (1927–2007)

Helmuth Horvath

Othmar Preining was one of the pioneers of aerosol science in Europe. He influenced the development of aerosol research not only in Europe, but also in Japan and the United States. He was born and lived in a country that was shattered by both social unrest in the early 20th century and by World War II —times in which research money was very tight. Despite this, he managed to establish a strong aerosol research group in Vienna and to maintain contacts at the most important centers of aerosol research around the world.

Youth and School Education

Preining (Figure 1) was born on June 28, 1927, in Vienna. His father, Franz Preining, was employed by the Vienna Tramway, and the Preining family lived in Wien-Döbling. At first, they lived in the apartment of a relative. After his death, they moved in with Preining's grandmother. In 1930, the Preining family obtained their own apartment at Döblinger Gürtel 11. Preining lived very close to this location most of his life. His primary school was around the corner. Because his parents were Old Catholics, the family chose a school for Preining that offered classes in the Old Catholic religion. The school was located at Unterberggasse in the 20th district, near Augarten. Preining attended the school without any problems. Unfortunately, in 1939, he had a very severe inflammation of the throat; his tonsils were removed. This surgery caused septicemia, and

Figure 1. Othmar Preining, approximately 1985.
Photo: Courtesy of the author.

he spent 3 weeks in bed at home. Finally, Preining was transferred to the children's hospital of the Vienna general hospital, where he was one of the first patients to be treated with sulfonamides. Unfortunately, the dose was too high because doctors did not know much about this new drug in those days. As a consequence, Preining developed heart problems and had to report to the hospital twice a week.

In 1939, Preining missed 400 hours of instruction in school, but he was still a good student. His physical fitness was very poor, and in 1942, he collapsed on the way to school, was taken to the hospital by ambulance, and was diagnosed with a kidney infection with bleeding. Again, he was treated in the hospital and had to report frequently to the hospital thereafter. With so many absences from school, Preining had to repeat the 5th class (9th grade) at a school at Scheuchgasse in the 9th district of Vienna. This was 1942, and World War II was in full swing. The school was soon needed as a military hospital, and Preining was transferred to his previous school building. This building was also commandeered by the army, and Preining transferred to a school in the 3rd district.

Because of his bad health, Preining was ineligible for military service. Instead, he was taken to a village in the area of Wechsel, about 100 km southwest of Vienna. In a small hotel, he supervised young children who were evacuated from Vienna. The building was completely infested with bedbugs! At the age of 15, he was supposed to learn on his own in the morning and work with the children in the afternoon. He again suffered an infection and was sent home to Vienna. Treatment with antibiotics gave some relief, but in the fall of 1944, Preining developed general inflammation of his joints. Toward the end of the war, all men able to fight—teenagers as well as old men—were drafted into the "Volkssturm." Preining was ordered to come to field exercises, but he could not. A military doctor came to the apartment to get him but soon realized that Preining really was unable to serve. This was fortunate because, of the 150 soldiers from the Volkssturm who were sent to Slovakia, only 3 returned.

Beginning in 1943, Vienna was bombed. People spent much of their time in basements of houses. Preining was very lucky. Of a series of bombs, the one that struck a few meters from the place where the family hid was a dud and did not explode. Fortunately, the family survived the war, but at the end of the war, society broke down and no food was available. Because they had good relations with a farmer, the Preining family had a supply of potatoes

in their cellar. Preining's uncle and aunt decided to stay with relatives in Unterretzbach, about 60 km northeast of Vienna, so the family crossed the Danube by climbing a destroyed bridge. The family, even the weakened boy, reached the destination on foot in 2 days, sleeping one night in a haystack. Their relatives were farmers and had some food reserves, so they had enough to eat. In the fall of 1945, Preining returned to Vienna and went back to school; he passed his final examinations with honors in 1946.

Preining's bad health did not allow any physical exercise; the doctors actually forbade him from participating in any kind of sport. To compensate for this, Preining developed a deep interest in mathematics and astronomy. With enthusiasm, he attended public lectures by Oswald Thomas on astronomy. As early as 1944, Preining bought an introductory book on mathematics for students of technical universities (Schrutka, 1924); later, he obtained a book on advanced spherical trigonometry. Because he was often unable to go to school because of sickness, Preining had time and energy to study his books. He completely understood the texts, and at his final examination, he impressed the committee with knowledge far beyond that of his peers. His mathematics teacher realized his gifts and strongly recommended to Preining's parents that he study mathematics.

Studies in Vienna

In 1946, Preining began studying at the University of Vienna. He started with mathematics, physics, chemistry, and astronomy. He realized that studying all of these subjects was not possible and dropped chemistry, because standing in the laboratory was too strenuous for his weakened body. For similar reasons, he also dropped astronomy. He then concentrated on mathematics and physics. He came to know physicist Felix Ehrenhaft, who impressed him very much. He attended all Ehrenhaft's lectures and the seminars that Ehrenhaft gave for the most interested students.

Ehrenhaft was a leading physicist at the University of Vienna from the beginning of the 20th century. In 1938, he escaped to the United States; he returned to Vienna in 1947 to stay until his death in 1953. Ehrenhaft started his work on the determination of the electric charge in 1907, using experiments similar to those of Robert Millikan. Unlike Millikan, who used oil droplets, Ehrenhaft used solid selenium particles, which caused additional problems. Although determining the forces on a charged particle in a

capacitor is straightforward in principle, the difficulties arise with the details. One must account for the shape factor, slip correction, Brownian motion, light pressure, motion in temperature gradients, orientation in a field and other effects, and techniques for observation of submicrometer particles. Ehrenhaft analyzed these phenomena thoroughly, and his students worked mostly on photophoresis or optical and mechanical problems of particles with diameters smaller than 1 μm. Thus, in 1950, Preining was already a specialist in what is now called "nanosize" aerosol.

Preining was accepted by Ehrenhaft as a PhD student (then the only degree available at the University of Vienna). At that time, possibilities for doing a thesis were scarce. There were usually several competitors for each place in the laboratory. Young PhD candidates had to work one semester as a "kuli" (or "coolie," named after the hard-working Chinese railroad workers who built the transcontinental railway in North America in the 1860s). Preining started building an apparatus to determine photophoretic movement of steel particles in a magnetic field. This experimental setup included two carbon arc lamps, switchable magnetic fields, and visual observation. He bought old used telephone relays and automated the experiment as much as possible, which at that time was a considerable achievement. The apparatus was a big success; and Preining and four other students did their scientific work with this setup. For his thesis, Preining worked on magnetophotophoresis of sputtered steel particles (Preining, 1951). In July 1951, he obtained his PhD.

Postdoctoral Work in Vienna and at California Institute of Technology

Shortly before Preining submitted his doctoral thesis, the University of Vienna offered him a position. He started on January 1, 1951. Among other duties, he was responsible for the preparation and demonstration of impressive experiments in the experimental physics lectures.

In 1955, he married Ida Schneider; in 1991, they were divorced. Their son, Peter, was born in 1964. Peter graduated from the University of Mining (Montanuniveristät), Leoben, Austria. He works for the Austrian oil company OMV and currently is located in Pakistan, responsible for prospecting and drilling.

For all students, graduation is a landmark, and usually young PhDs look for new ideas. Preining was a gifted experimentalist. The physics institute at the University of Vienna had a very strong connection to the electricity grid.

Preining found some leftover equipment in the basement of the institute, and when he was not preparing experiments for lectures, he conducted plasma physics experiments with a high-current-density electric arc with reduced cross-section to study very high temperatures (he reached 55,000° K with an arc discharge in a rotating water annulus; Preining, 1954). The experiments were very successful, but for more systematic research, Preining needed more extensive equipment than the leftovers from previous investigations. He soon realized that this would be much too expensive in a country just recovering from a disastrous war, so he dropped the idea of plasma physics research.

It was quite natural that Preining then accepted an offer to investigate aerosols with Alexander Goetz at the California Institute of Technology (Caltech) in Pasadena (Figure 2). Goetz started his scientific career in Germany and was in Göttingen in the 1920s (for a biography of Goetz, see Pueschel, 2005). In 1927, Robert Millikan brought him to Pasadena, where Goetz became Millikan's assistant. Preining and Goetz both had knowledge in submicrometer particles, and in the 2 years (1958–1960) of his stay, Preining would do research successfully at the cutting edge of aerosol science. Preining's and Goetz's main research topic was an investigation of particles

Figure 2. Othmar Preining (left) measuring with the Goetz aerosol spectrometer (far left) in Sequoia National Park, 1958.
Photo: Courtesy of the author.

at the lower detection limit, which was then a few tenths of a micrometer. While Preining was at Caltech, the institute developed and optimized a new centrifugal aerosol spectrometer (Goetz et al., 1960). Researchers used this instrument for environmental studies involving submicrometer aerosols: particle sources, stability, photochemically produced particles, and ambient background particles, in both urban and remote areas. The particles were deposited on foils and counted by dark-field microscopy in those days, which limited particle sizing to particles larger than 50–100 nm.

Caltech was the Mecca of natural sciences, and the laboratory where Preining worked had contacts with a vast number of American and foreign research institutions. In and near Pasadena, leading scientists in both basic science and environmental research included Linus Pauling, Richard Feynman, Arie Haagen-Smit, and others. Preining enjoyed fruitful discussions with these researchers, their assistants, and their students. He gained many new ideas and stimulus for his future research. In 1960, A. T. Rossano founded the Institute of Environmental Engineering at Caltech. It was intended as a research and training center on air pollution in Los Angeles and funded by the U.S. Public Health Service. Rossano offered Preining the opportunity to lead this institute and to stay permanently in Pasadena. Preining did not accept this generous offer but instead returned to Vienna after his 2-year stay in California. He suggested Sheldon Friedlander for the position. Friedlander accepted the offer, and they formed a lifelong friendship.

"Assistent" in Vienna and Many Visits to Other Laboratories

In Vienna, Preining continued his work on ultrafine particles, obtaining the *venia docendi* in 1963. The title of the work he submitted was "Zum Problem der Eichung fraktionierender Meßgeräte für Stäube der Kongrößen zwischen 0.1 und 1 Mikron mit Hilfe von Testaerosolen" ("On the Calibration of Fractionating Sizing Instruments Using Test Aerosols of Sizes between 0.1 and 1 μm"; Preining, 1962). He started building his own research group, and his first PhD students were Axel Berner, Helmuth Horvath, and Dieter Hochrainer. Preining's interest in submicrometer particles brought him back to the United States many times. In 1965, he visited J. P. Lodge at the National Center for Atmospheric Research, who had one of the first Royco optical particle counters. Unfortunately, the counter did not work, so Preining investigated the particles formed during atomization and found a considerable

contribution by ultrafine particles. It took only a few weeks to detect this, but it needed almost a year of discussion with the editor of the *Journal of Colloid and Interface Science* to convince him that these ultrafine particles, although small in mass, were important. Today we know this, but then it required a lot of persistence to get the results communicated to the public.

During this visit to the United States, Professor A. T. Rossano, who then was at the University of Washington in Seattle, offered Preining the opportunity to establish an institute on environmental engineering. Preining accepted neither this offer nor an offer made by Dr. Weickmann, who established a new National Oceanic and Atmospheric Administration laboratory in Boulder, Colorado. Preining preferred to be based in Vienna and to do research and teach at the University of Vienna, educate students, and visit other laboratories and universities as frequently as possible.

Optical particle counters were an important innovation in the 1960s. Whereas size classification with the aerosol centrifuge required hours of operation counting the particles with a microscope and time-consuming data evaluation, the particle counters did the classification in real time. On the one hand, many questions remained unanswered, but on the other, new possibilities opened up with this instrument. Therefore, Preining looked for laboratories that had working particle counters. In 1966 and in 1968, he worked with Kenneth Whitby and Benjamin Y. H. Liu of the University of Minnesota Particle Technology Laboratory, who had a working particle counter that he could use to investigate ultrafine particles. In a 4-month visit to the University of Minnesota in 1968, Preining substituted for Whitby's technical thermodynamics lecture for engineers.

From 1966 to 1968, Preining also had part-time employment with the *Bundeministerium für Soziale Verwaltung* (Ministry for Social Affairs) working with the *Bundestaatlich-bakteriologisch-seriologische Untersuchungsanstalt, Abteilung für Radiologie und Lufthygiene* (Public Health Laboratories for Clinical Bacteriology and Serology, Radiology and Air Hygiene Division), an agency that was responsible, among other things, for measurements and recommendations regarding air quality. He was always very worried about a clean environment, especially air quality, and he used all occasions to support environmental activities.

Professor at the University of Vienna and Many Other Duties

On March 27, 1968, Preining was appointed associate professor, and on March 1, 1970, he was appointed full professor for experimental physics at the University of Vienna (Figure 3). He held this position until reaching the status of professor emeritus on September 30, 1995. Besides the experimental physics lecture, a 2-year, 5-hours-per-week class, he gave many special classes for interested students on subjects such as information theory, fractals, aerosols, and climate. He educated his students in basic physics, but he also urged them to search for the essential and to see the interrelations. His presentations were always up to date and very demanding. Under his guidance, about 60 students completed their master's and PhD theses, and 7 young scientists obtained habilitation (or qualification). He had high standards and expected students and coworkers to do their best. Preining's examinations were difficult, and he selected challenging topics for theses, expecting students to find solutions. Preining had a facility for solving problems, whether they were experimental, theoretical, or personal. With his immense knowledge of many fields of science, he made many helpful suggestions, always had patience, and offered encouragement.

Figure 3. Energetically entering the lecture hall of the Institute of Experimental Physics of the University of Vienna.
Photo: Courtesy of the author.

Scientists usually do not have much love for administration. Preining was no exception, but he realized that good academic administration can be very fruitful for science and the university. He served as deputy dean (*Prädekan*, 1984–1985) and later became dean (*Dekan*, 1985–1987) of the Natural Science Faculty of the University of Vienna, and vice rector (*Prorektor*, 1987–1988) of the University of Vienna. He did these jobs with devotion. He was able to successfully solve unresolved problems. These activities were time and energy consuming, and can best be characterized by one short remark that Preining

made to me after a commission discussed a problem for the *n*th time: "I am feeling more like the psychiatrist of the faculty than the dean."

As an expert in the atmospheric environment, Preining was invited to become a member of various advisory boards. In 1971, he was appointed a member of an environmental hygiene advisory committee for the Austrian Ministry for Health and Environment. He served on this board for more than 30 years and was a delegate to many government conferences. Later, he became a member of the Austrian CO_2 Commission. Preining was very active and used every occasion to convince politicians that activities to reduce CO_2 emissions were needed urgently. He was very dismayed that the CO_2 Commission was neutralized because the minister of the environment could not tolerate any more warnings from the commission regarding increased CO_2 emissions and the need for political action.

Preining's duties at the University of Vienna included, among other things, a 2-year advanced course in physics. This course was taught by three professors, so after 2 years, there was again time for longer visits to other universities or research institutions. Despite his teaching obligations at the places he visited and the short time he had available, Preining always managed to do research in the new environment and to publish papers on new aspects of aerosol research (e.g., Preining, 1967, 1983a; Preining et al., 1967, 1976; Boscoe et al., 1973; Matteson et al., 1972, 1973, 1974). In the academic year 1971–1972, Preining was the National Science Foundation guest professor for a full year at the Georgia Institute of Technology in Atlanta, working with Clyde Orr. Preining then returned to his duties in Vienna. For one quarter in 1975, he was with the Atmospheric Sciences Department of the University of Rolla, Missouri. Part of this time he spent participating in field experiments in the Gulf of Mexico (Figure 4). He remembered this experience because it was very hot. In 1981, he spent half a year with the Atmospheric Science Department at the State University of New York at Albany. As a consequence of Preining's visits abroad, many scientists stopped in Vienna to present seminars or to participate in joint experiments. This helped to keep the standard of aerosol research in Vienna at a high level.

In 1979, the American Chemical Society invited Preining to participate in its joint meeting with the Japanese Chemical Society in Hawaii; this invitation had considerable consequences for the development of aerosol research in Japan. Preining met Professor Koichi Iinoya, the Japanese pioneer in aerosol science. Iinoya arranged for Preining and Sheldon Friedlander to make a

Figure 4. Field measurements in the Gulf of Mexico, Padre Island, June 1975.
Photo: Courtesy of the author.

scientific visit to Japan. The time schedule was very tight. Within 2 months, Preining visited eight different universities and research institutions, gave innumerable lectures on all aspects of aerosol science, visited laboratories, and had long discussions about what could be done to promote aerosol research. Success was evident. Many groups initiated research on aerosol topics, and today, aerosol research is a well-established science in Japan. The contacts with Japanese scientists that Preining established still exist today. Japanese scientists and students continue to come to Vienna for discussion and scientific work, and their Austrian counterparts visit Japan.

Preining was not only active abroad; he also established the Vienna School of Aerosol Physics. The strength of this group is its combination of excellent experimental skills and sound theoretical foundation, as Preining showed by example. His guidance was gentle and cautious and one of the secrets of the school's success. He demanded that his coworkers spend time abroad, a condition without which no permanent position could be gained on his team, and he inspired them to excel in their respective specialties to become established scientists in their own right. Seven of his coworkers obtained their habilitation at the University of Vienna.

Preining was elected as a corresponding member of the Austrian Academy of Sciences in 1983 and as a full member in 1990. Beginning in 1969, he was a member of the Clean Air Commission of the Austrian Academy of Sciences. From 1990 to 2002, he was the chair of the Clean Air Commission

(see Chapter 6 of this volume for a historical sketch of the commission), which he guided with his expertise. During his chairmanship, the commission established and improved many air-quality criteria.

Professor Emeritus, 1995 to 2007

Preining's official retirement from the University of Vienna did not change any of his activities, except that he no longer had teaching obligations. Whereas many other academics use this time to look back on a successful life and write memoirs, Preining remained very active in many organizations, especially as a life member of the Austrian Academy of Sciences.

As chair of the Clean Air Commission, Preining concentrated on one of the most important newer aspects in aerosol research, namely the biological effects of aerosol particles. He was able to motivate a multidisciplinary group consisting of physicists, chemists, medical doctors, biologists, public health officers, hygienists, city administrators, and researchers with the Austrian Environmental Protection Agency to cooperate in the Austrian Project of Health Effects of Particulates (AUPHEP) of the Austrian Academy of Sciences (Hauck et al., 2004a).

Preining also became a member of the *Kommission für Geschichte der Naturwissenschaften, Mathematik und Medizin* (Commission for the History of Natural Sciences, Mathematics, and Medicine) in 1996 and chaired it from 1998 to 2002. Many interesting public lectures and symposia have been organized under his guidance. He organized the first Symposium on the History of Aerosol Science in Vienna (August 31–September 2, 1999; see also Preining & Davis, 2000). This conference was the start of a series on the history of aerosol science (subsequent symposia were held in Portland, Oregon, in 2001, in St. Paul, Minnesota, in 2006, and in Helsinki, Finland, in 2010).

As a representative of the Austrian Academy of Sciences at the European Council of Applied Sciences and Engineering (Euro-CASE), Preining attended many meetings and worked hard to integrate the technical sciences in the European Academies of Sciences. He gave many invited lectures at large conferences or for learned societies. His presentations were always up to date and never without surprises (see, e.g., Preining, 1998, 2000).

The serious health problems that Preining had as a young boy stayed with him all his life, but he was always able to cope with his problems. He did the most he could and usually hid his problems. In 1994, he had serious heart

surgery with three bypasses. He quickly learned to live with the new situation and usually others did not notice his condition. In January 2006, he developed severe kidney problems, resulting in several surgeries. From this time on, he had to stay within a 2-hour radius of the Vienna University Hospital in case of inflammations or other problems. This limited Preining's activities to Vienna and its vicinity, but he remained fully active. Instead of traveling to other places, Preining invited scientists for lectures and discussions in Vienna and organized minisymposia. Beginning around 2000, Preining also fought cancer. Several times he received the maximum permissible dose of X-rays. When absolutely no more irradiation with X-rays was possible, the doctors switched to chemotherapy. Preining scheduled the treatments such that they were after important meetings, lectures, or other events so he could participate with full energy. He had to spend considerable time in the hospital. To optimize his stays, he always took scientific journals with him and read them whenever possible. He reported his newest knowledge to his visitors, and it always was a challenge to discuss scientific or societal or ethical viewpoints with him. Around the middle of September 2007, Preining stumbled while emptying the wastebasket from his apartment into the garbage container in the courtyard, and he hurt his head seriously. He was immediately hospitalized, but the necessary routine treatments could not be done. He did not recover and died on September 26, 2007, in Vienna.

The Austrian Academy of Sciences and the Clean Air Commission of the Austrian Academy of Sciences

The Austrian Academy of Sciences is an independent learned society. It contributes decisively to ensure highly competitive Austrian research and advises decision makers in politics, business, and society on science-related issues, while informing the interested public about major scientific discoveries. Members support this process by making their broad range of expertise available for the academy's activities. Persons with significant scientific reputations are elected as members. This is considered an important honor. As mentioned earlier, Preining was elected as a corresponding member of the Austrian Academy of Sciences in 1983 and as a full member in 1990. He was a very active member of the academy and attended all meetings, even when he was seriously ill. He represented the academy in international organizations and chaired the Clean Air Commission and the Commission for the History of Natural Sciences, Mathematics, and Medicine.

The Austrian Academy of Sciences founded the Clean Air Commission in 1963 (see also Chapter 6, on the commission, in this volume). Its chief aim is to supply up-to-date scientific knowledge about how to achieve a clean environment. Preining joined the commission in 1969. As an independent organization, the commission was frequently asked by the federal or provincial governments for advice about air pollution or possible consequences of political decisions (e.g., location and operation of power plants). The commission elaborated air-quality criteria for various pollutants. With Preining's active participation, the air-quality criteria for SO_2 and NO_x were produced in 1975 and 1987. With Preining as deputy chair (*Stellvertreter*, 1986–1990) and chair (*Obmann*, 1990–2002), the commission published the air-quality criteria for photo-oxidants (ozone, 1989), volatile organic compounds (1996), and an update of nitrogen oxides in the atmosphere (1998). Furthermore, the commission published volumes on *Consequences of Climate Change for Austria* (1992); *The Scientific Basis for a National Plan for Environmental Protection with Respect to Climate, Air, Odor, Noise* (1993); and *Guidelines for Rating Indoor Air Quality* (2002). All these works contained up-to-date collections of scientific knowledge and recommendations on actions and limitations that were the basis for decisions made by politicians and administrators.

Preining thoroughly investigated the scientific literature for various air pollutants when elaborating air-quality criteria, and he found a need for research about the health effects of particles in the atmosphere. So he started his most ambitious project, AUPHEP. Using his well-established contacts with all agencies in Austria concerned about air pollution, and with the help of his careful diplomacy, Preining helped to start a joint project in 1998. All agencies contributed instruments, data, financing, and so forth. The main financing came from the ministry responsible for the environment. It was the aim of the project to investigate experimentally the health effects of particulate pollution. The pollution was characterized by separately sampling all size fractions of aerosols, including ultrafine particles. The samples were analyzed chemically for major inorganic components and for a large number of organic compounds. Furthermore, the essential gas components were analyzed continuously. One rural site and three city sites were selected; at each site, the sampling was performed for 1 year. This study characterized the local atmospheric aerosol at several locations using the latest technologies, while simultaneously investigating the health and lung function in cohorts

of school and kindergarten children. The large quantity of data permitted the medical group to study the effect on preschool children, as well as schoolchildren and the elderly. The project was operational from 1998 until 2003. Many publications have appeared based on the project. The final report was published in 2004 (Preining & Hauck, 2004; Hauck et al., 2004a). The outcomes of this study are surprising and will have far-reaching consequences in legislation and public thinking.

The academy requires the chair to resign when he or she reaches the age of 75, but Preining remained a very active member of the commission and organized symposia, public lectures, and other activities. He always planned a long time ahead: Günther Oberdörster gave a public lecture on "Ultrafine Nano-Particles: Wolves in Sheep's Clothing?" on November 12, 2007, 6 weeks after Preining's death, although Preining had planned and completely organized the lecture half a year ahead.

Preining's Scientific Work

Preining's scientific work had many facets. He was active in many fields of physics. Besides aerosol science, he worked and published on plasma physics (Preining, 1954), health physics (Zweymüller & Preining, 1969a, 1969b), demonstration experiments (Preining, 1957, 1958a, 1958b, 1958c, 1958d, 1963), nuclear fallout (Ernst et al., 1962a, 1962b; Sedlacek et al., 1963; Preining et al., 1963), entropy and information (Preining, 1965, 1968, 1972), gaseous pollutants (Preining et al., 1969), pollution and economics (Preining, 1974, 2003), fractals (Preining, 1980, 1988, 1990a), and science history (Preining, 1983b, 1986, 2001). He had broad interests in all fields of science and devoted much of his time to investigating the literature on subjects unrelated to aerosol science. This broad knowledge enabled him to immediately see connections to aerosol science, and this ability allowed him to advance far ahead of other researchers. He must have been very proud of this. Whenever he submitted a curriculum vitae with selected publications, he always included the papers that were forerunners.

In the first years of his scientific career, Preining worked on photophoresis. He did his investigations with great care and in full depth. Thus he became a recognized expert in this field and contributed a chapter on photophoresis in the pioneering book *Aerosol Science*, edited by C. N. Davies (Preining, 1966). With similar enthusiasm and great dedication, Preining did the demonstration experiments for physics lectures and, in many cases, developed new methods

and techniques for impressive experiments. A representative example of this is a method that Preining developed to demonstrate anomalous dispersion (Preining, 1958d).

During his 2 years at Caltech, Preining used the new Goetz aerosol spectrometer for investigations of submicrometer aerosols: particle sources, stability, photochemically produced particles, and ambient particles in both urban and remote areas (see, e.g., Goetz et al., 1961). In those days, microscopic counting was the only possible way to detect the particles, and it was very time consuming. Also, it limited the particle sizing to about >50 nm. Very early, Preining realized the importance of nanoparticles, and he always wanted to investigate particles below this limit, although many researchers at that time were not convinced about the importance of particles that small. Nanoparticles interested him his whole life and he published several papers explaining their existence, their properties, and the need to do research in this field (Preining et al., 1967; Preining & Berner, 1979; Preining, 1981, 1992c, 1998; Pui et al., 2000). Today, this is obvious, but 40 years ago, many researchers doubted it.

In Vienna, he continued research on nanoparticles, eventually leading to the development of the Size Analyzing Nucleus Counter (Wagner, 1975) and many applications (e.g., Porstendörfer et al., 1985; Liu et al., 1982, 1984; Ankilov et al., 2002a, 2002b)

At Caltech (1958–1960), a colleague recommended Leon Brillouin's (1962) book on information theory to Preining. He was very interested in this subject, gave lectures on it at the University of Vienna, and used it in his research (e.g., for his paper on the detection of spatially inhomogeneous particle clouds; Preining, 1983a). With this publication, he was decades ahead of his time. Similarly, he learned about fractals around 1980 (Mandelbrot, 1977), and he presented many lectures and wrote papers about the application of fractals in aerosol science at a time when no application was recognized (Preining, 1980, 1988, 1990a). Today, fractals are widely used in aerosol science (e.g., Herrera et al., 2008).

His participation as a delegate of the Austrian government to a CO_2 conference brought him in touch with the global warming problem. He thoroughly investigated the available literature and immediately realized the role of aerosol particles, which was then mostly overlooked. He published several papers on this subject well before other aerosol scientists were aware of it (Preining, 1991a, 1991b, 1992a, 1992b, 1993a, 1993b, 1993c, 1993d, 1995, 2000).

Preining actively guided the science of his coworkers, supplied valuable information, and suggested many improvements. Thus he earned the right to be coauthor of many papers (e.g., Berner & Preining, 1964, 1984; Abed-Navandi et al., 1976; Berner et al., 1979; Horvath et al., 1980, 1982, 1994a, 1994b; Preining & Reischl, 1982; Kasper et al., 1978).

As president of *Gesellschaft für Aerosolforschung* (GAeF, or Association for Aerosol Research; Figure 5) from 1986 to 1990, he searched all available sources to learn about Marian Smoluchowski (1872–1917), who also had been a professor at the University of Vienna and who was selected the figurehead for the annual award bestowed by GAeF. As with everything, Preining researched his subject comprehensively and with great care. We now know very much about this man, mostly unknown before Preining's work (Preining, 1986, 2001). The importance of Smoluchowski's scientific work can be estimated by a few facts put together by Preining. The number of citations of Smoluchowski's publications from the first decade of the 20th century is far larger than the number of citations to Einstein's famous papers. Preining enjoyed being in the library and digging in old literature; thus, he unearthed historic measurements of the atmospheric CO_2 concentration in 1880 (Preining, 1983b).

*Figure 5. Othmar Preining as president of GAeF (*Gesellschaft für Aerosolforschung*, or Association for Aerosol Research).*
Photo: Courtesy of the author.

Preining's participation at high-level conferences either as a government representative or as a member of the Austrian Academy of Sciences directed his publications toward programmatic or policy-oriented papers. Preining tirelessly worked for a sound and clean environment. His publications represent his personal opinion, and he oriented his personal life in accordance to his opinion. His policy-oriented publications dealt with topics such as using a system analytical approach to aerosol characterization (Preining, 1984), aerosol climatology (Preining, 1990b), global ecology (Kontratyev et al., 1992; Preining, 1992a, 1992b), particulate matter and health (Hauck & Preining, 1998a, 1998b), and energy policy (Preining, 2002). Despite the presence of

his opinions, Preining's work was always grounded in science and was up to date; for example, shortly after his retirement from the University of Vienna, Preining published a review containing the newest results of investigations on nanoparticles (Preining, 1998).

As mentioned earlier, Preining realized very early that health effects of particulate matter merited further investigation. The capabilities for doing this existed in Austria, but the field needed a driving force, an organizer, and a coordinator. Beginning about 1995, Preining invested all of his energy and diplomatic talents in putting together scientists and equipment and raising money for AUPHEP. The project was very successful, as can be seen by the many papers for which Preining is author or coauthor (Neuberger et al., 2001, 2002, 2004; Hauck et al., 2001, 2004a, 2004b; Horak et al., 2001; Preining & Hauck, 2004; Gomiscek, 2004a, 2004b; Puxbaum et al., 2004; Berner et al., 2004).

The Vienna Aerosol Group

After Preining's return from his first visit to the United States, he had his first PhD students and built the Vienna Aerosol Group. Preining's leadership helped to develop, over time, the size analyzing condensation nucleus counter (SANC/CAMS), a high-resolution aerosol centrifuge, a diffusion battery, low-pressure cascade impactors permitting sizing down to 10 nm, and later a family of differential mobility analyzers, as well as various optical techniques for size spectrometry and atmospheric visibility studies.

Preining required his coworkers to have both experimental skills and sound theoretical abilities. He expected his group members to spend sufficient time in laboratories abroad to greatly increase their horizons of scientific knowledge and their experimental techniques. Working abroad was a mandatory (albeit unwritten) requirement for permanent positions in his department. With theoretical knowledge and experimental skills, as well as good support from the institute's machine shop, Preining's students developed excellent aerosol instruments under his gentle guidance. They were used intensively for aerosol investigations. These instruments have become well established and actually are brand names of the Vienna School of Aerosol Physics. A few examples are the Berner impactor (or Hauke impactor), developed by Axel Berner (PhD with Preining, 1964); the University of Vienna telephotometer, developed by Helmuth Horvath (PhD under Preining's guidance, 1966); the Vienna type differential mobility analyzer,

developed by Georg Reischl (PhD, 1971); the SANC/CAMS, developed by Paul Wagner (PhD, 1974); and the dual wavelength optical particle spectrometer, developed by Wladyslaw Szymanski (PhD, 1981). Preining was always very interested in the progress and success of his coworkers and supplied them with many ideas. His contacts with aerosol research institutions all over the world created many opportunities for collaboration and brought frequent visitors to Vienna, increasing everyone's knowledge.

With the accumulated knowledge and instrumentation, members of the Vienna Aerosol Group participated in international research projects such as Visibility Impairment due to Sulfur Transport and Transformation in the Atmosphere, the Southern California Air Quality Study, and EUROTRAC. Vienna was also an ideal location for workshops such as the Workshop on Ultra Fine Aerosols (held in Vienna in 1979 and 1980; see Liu et al., 1982; Porstendörfer et al., 1981), and the intercomparison workshop on particle counters (Reischl & Wagner, 2002). Members of the Vienna Aerosol Group successfully organized conferences and symposia in Vienna. With knowledge available on practically all fields of aerosol science, the Aerosol Group organized a much-esteemed summer school in 2007. Preining was able to attend the first half day. One could easily see his satisfaction with the success of his group, the seed of which he had laid around 1960.

Honors and Awards

Being so versatile, innovative, and energetic, Preining received many awards. The awards were bestowed for his scientific merits by societies such as the Austrian Academy of Sciences, the European Aerosol Assembly, and the International Aerosol Research assembly. Awards from the Austrian government honored Preining's tireless engagement with the environment and public health. In chronological order, his awards included:

- Felix Kuschenitz Award of the Austrian Academy of Sciences, April 1962;
- Österreichisches, Ehrenkreuz für Wissenschaft und Kunst I. Klasse, 1978;
- Erwin Schrödinger Award of the Austrian Academy of Sciences, 1982;
- Fuchs Memorial Award of the International Aerosol Research Assembly, 1994;
- Ehrenpreis der österreichischen Elektrizitätswirtschaft, 1995;
- Preis der Stadt Wien, 1995; and
- Junge Award of the European Aerosol Assembly, 2005.

Othmar Preining: The Person

Preining was an admirable person. As we know from the previous sections, he was an excellent scientist, ingenious organizer, and gifted diplomat. But this is only half the story: he was tops in almost every category. He educated himself in nearly every discipline. With his profound knowledge of Austrian history, he always impressed not only visitors to Vienna but also the locals. Likewise, he knew American history, Indian culture, and Asian history. He was well informed about Christianity, Buddhism, and Hinduism, and he could explain the rites of a Mass in such an excellent way that nobody noticed he was an atheist. He also had deep interest in literature; he must have read one book per week. I have the impression that he liked the scurrilous. For a while, the Austrian poet Fritz von Herzmanovsky-Orlando was his favorite. For some time, he would recite whole paragraphs from Hermanovsky-Orlando's book *Der Gaulschreck im Rosennetz*. The students in his classes always found it amusing when he read mathematical poems; his favorite was the *Ballade vom kleinen Epsilon* (the ballad of the small epsilon, which could not find the corresponding delta).

Preining was interested in cultural events of any kind. He enjoyed going to the theater and the opera, listening to concerts, and visiting museums. There were ample occasions for these events in Vienna, but this was not enough. When participating in conferences, Preining frequently went a day early to visit famous museums or to see theater performances or ballets. The conferences, 1-day symposia, or invited lectures that Preining planned, especially those dealing with the history of science, always had musical performances at the beginning and the end.

The environment was very important to Preining, and he used all his energy to fight for a clean environment. He enjoyed nature and loved to be outdoors. Although he never was in good health, he climbed mountains, skied, and went rock climbing (Figure 6). Just like everything else, he did these things with full energy, as long as his health made it possible. He was so enthusiastic about rock climbing that he convinced two of his students to learn it, and they both still enjoy it. One of Preining's specialties was climbing in caves, and he invited his two students to join him on his expeditions.

As mentioned previously, Preining was very accessible. It was easy to make contact with him and, being an excellently educated man, he was able to converse about practically any topic. He tried to help everybody, whether their problems were scientific or personal. His priorities were always

(1) helping other people; (2) benefitting the general public, science, and culture; and (3) taking care of himself. He never sought personal gain, and his actions were always guided by how others could benefit. A few examples illustrate this.

Preining's aunt (with whom he walked as a young boy to Unterretzbach after the end of the war) became very old and no longer had any close living relatives. Preining considered it his obligation to visit her regularly, even when he was very sick himself.

Figure 6. Othmar Preining demonstrating his love for the mountains and the environment.
Photo: Courtesy of the author.

At times, when computing was still exotic and scientists had to use computer centers, Preining found it absolutely necessary to establish easy access to computing, so he volunteered to serve as the codirector of Vienna's inter-university computing center from 1976 to 1979. This was a time-consuming, nerve-wracking job, which definitely deteriorated his quality of life. Likewise, Preining volunteered in the information campaign on nuclear energy, which the Austrian government launched in 1976. He chaired several sessions that were attended by about 500 persons, many of whom opposed nuclear energy. He prepared himself well and, although the sessions were turbulent and generally lasted far past midnight, they never got out of control.

Preining was always open-minded about innovations. The first and, for a long time, the only facsimile machine in the physics building was purchased upon Preining's request. When computers still were considered unnecessary, he lent two of his research rooms to the "Prozessrechenanlage Physik." In this way, he made sure that the physicists got optimum online computer service. To my knowledge, he was the only professor who supplied "his" rooms for innovative technologies to benefit the public. Usually the opposite occurs.

Preining's talent for sensing future scientific need has been mentioned several times. He was one of the founding members of GAeF, which later became the nucleus or role model for associations of aerosol scientists in Europe, America, and around the world. He set the stage for the first

European Aerosol Conference (EAC, 1987) in Lund, Sweden, which took place under his presidency (1986–1990). This conference has become a major international event for aerosol science.

Epilogue

On September 26, 2007, a few months after celebrating his 80th birthday (Figure 7), Preining died. For his burial he wished to have no speeches and no flowers; he wanted all to be very simple. Knowing him as a person, this was expected.

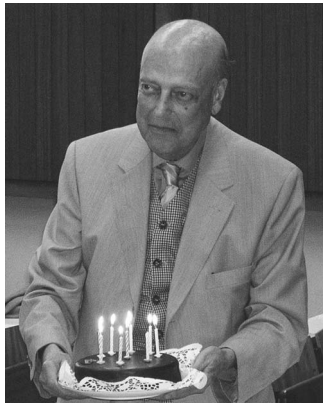

Figure 7. Othmar Preining being handed a birthday cake during the celebration of his 80th birthday.
Photo: Courtesy of the author.

We can now look back on a successful scientific life. Preining remains a towering figure in aerosol science: a visionary scientist who shaped the field in many areas that were later to become the most important and a leader who inspired others around him for many decades. He was a man with great respect for society and the environment. He put benefit to the community above personal gain. He worked tirelessly; even serious illness could not stop him. He was a good friend to all of us.

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