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Photo by Marianne Kischke

Foreword for the Gerhard Ertl Festschrift

In an attempt to deign Gerhard Ertl's scientific oeuvre, we will start with a review of his curriculum vitae and then continue to highlight his scientific achievements.

Gerhard Ertl was born on October 10, 1936, in Bad Cannstadt, Germany, which today is part of Stuttgart. Shortly after the family moved to Fellbach (Germany) he went to school at the Kepler-Gymnasium in Bad Cannstadt. After his "Abitur", he started studies in Physics at the University of Stuttgart in 1955. Interrupted by two short excursions to study at the University of Paris (1957/58) and the University of Munich (1958/59) he finished his studies with a diploma thesis entitled "Eine Temperatursprungmethode zur Untersuchung schneller Dissoziationsreaktionen mit Hilfe eines Mikrowellenimpulses" ("Temperature jump experiments to study fast dissociation reactions using microwave pulses") in 1961, supervised by Heinz Gerischer, who at that time was working at the Max Planck Institute of Metals Research in Stuttgart.

When Heinz Gerischer accepted an offer to join the Technical University of Munich faculty as a Professor of Physical Chemistry in 1962, Gerhard Ertl followed him as an "assistant" and worked under his supervision on a thesis that he finished in 1965, entitled "Über die Kinetik der katalytischen Oxidation von Wasserstoff an Germanium Einkristallen" ("On the kinetics of the catalytic hydrogen oxidation on Germanium single crystals"). After the defense of his thesis and receiving a Ph.D. (Dr. rer. nat.) in physical chemistry, he started to work on a habilitation project. Only two years later, he finished this project and became private docent ("venia legendi in physical chemistry"). The topic of his habilitation thesis was "Surface structural and reactivity studies using low energy electron diffraction" ("Untersuchung von Oberflächenstrukturen und -reaktionen mittels Beugung langsamer Elektronen"). He had been granted one of the first commercial LEED-UHV machines in Germany and thus introduced the field that today is known as "surface science" in the country. The first groundbreaking paper already appeared in 1966 in the journal *Surface Science* (whose regional editor he was from 1977 to 1986) and dealt with surface structures and reactions on copper single crystal surfaces. Obviously, it is one of Gerhard Ertl's many prominent

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Eine Temperatursprungmethode zur Untersuchung schneller Dissoziationsreaktionen mit Hilfe eines Mikrowellen-Impulses

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(Vorgetragen von G. Ertl anläßlich der 60. Hauptversammlung der Deutschen Bunsen-Gesellschaft für physikalische Chemie e.V. in Karlsruhe am 12. Mai 1961)

Bei der Störung eines chemischen Gleichgewichts durch eine sprungartige Temperaturerhöhung können durch Beobachtung des zeitlichen Verlaufs der neuen Gleichgewichtseinstellung Aussagen über die Kinetik des Reaktionssystems gewonnen werden. Es wird ein Verfahren beschrieben, in dem zur schnellen Aufheizung die mit der dielektrischen Relaxation verknüpfte Energieabsorption polarer Moleküle benutzt wird. Für Wasser liegt das Absorptionsmaximum bei 10^{10} Hz (= 3 cm Wellenlänge), einem Frequenzbereich, in dem Energiestrahler mit sehr hoher Leistung zur Verfügung stehen. In einer geeigneten Anordnung kann damit die Temperatur um 0,7°C innerhalb weniger µsec erhöht werden. Zur Erprobung der Methode wurden die Geschwindigkeitskonstanten der Dissoziationsreaktion des Wassers ermittelt.

Figure 1. Copy of the title and abstract of the paper resulting from Ertl's work. This paper is the first of more than 600 publications of Gerhard Ertl so far (see the full list in this issue). Reprinted with permission of Deutsche Bunsen-Gesellschaft fuer Physikalische Chemie. Copyright 1961.

abilities to recognize the potential of scientific developments early and then simply lead the field.

In the year of his habilitation (1967), only at the age of 31, a chair of physical chemistry at the University of Hannover was offered to him. He accepted this offer in the same year and became Professor and Director at the Institute of Physical Chemistry and Electrochemistry of the Technical University of Hannover. In Hannover a number of co-workers joined Gerhard Ertl's group, among them Jürgen Küppers, Klaus Christmann, and Klaus Wandelt.

When Gerhard Ertl, after not accepting an offer to join the Institute for Interface and Vacuum Physics (IGV) in the so-called Kernforschungsanlage Jülich, became Georg-Maria Schwab's successor on the chair for physical chemistry at the Ludwig-Maximilians University in Munich in 1973, the entire crew followed along from Hannover to Munich. During the coming, scientifically very fruitful years, Gerhard held guest professorships at Caltech in Pasadena (1976/77), in Milwaukee (1979), and at the University of California at Berkeley (1981/82), but he remained in Munich despite two very tempting offers by the University of California at Santa Barbara and the University of Münster, both in 1983.

It was only in 1985, after he was offered the succession of his teacher Heinz Gerischer as a Director at the Fritz-Haber-Institute in Berlin that he left Munich and took up the position. At the same time, he became Honorary Professor at the Technical University in Berlin and the Free University of Berlin. After the wall came down in 1989, he was also made Honorary Professor at the Humboldt-University of Berlin, becoming probably the first individual to be Honorary Professor at all three Berlin universities. When Gerhard decided to move to Berlin, again, the entire group followed him, bringing the Department of Physical Chemistry at the Fritz-Haber-Institute, that he leads, temporarily to a size of more than 100 co-workers including supporting staff and students.

It is perhaps interesting to note that with Gerhard Ertl's coming to Berlin a cycle of scientific "family relations" is closed: One of Fritz Haber's scientific collaborators was Karl-Friedrich Bonhoeffer from 1923 to 1930 who became scientific director of the Fritz-Haber-Institute from 1948 to 1949. He was the thesis advisor of Heinz Gerischer who became director of the Fritz-Haber-Institute in 1973 as mentioned above and who turned the directorship over to his former student Gerhard Ertl.

Gerhard had more than 100 Ph.D. students. Many of whom are well-known scientists today. He had also many postdoctoral associates from all over the world including many who came to join Gerhard as Humboldt fellows or Humboldt-Awardees (see the list in this issue).

Gerhard Ertl's scientific achievements are extremely broad and widespread. It is impossible to review it fully within this summary. We refer to the complete list of publications appearing later in this issue.

As mentioned above, Gerhard has been interested in studying elementary processes of surface chemical reactions right from the start of his scientific career. In the beginning, it was the interaction of small molecules such as O_2, CO, H_2, N_2, NO, etc. with metal and alloy surfaces, which was in the focus of attention. The determination of structures of adsorbates via the dynamic analysis of LEED intensities was introduced in Gerhard Ertl's group in collaboration with Michel van Hove and later with Wolfgang Moritz. This information was the basis for studies on the kinetics and dynamics of reactions using molecular beam techniques to investigate reactive scattering and later combining it with laser spectroscopy in collaboration with Herbert Walther to study energy dissipation among the various vibrational, rotational, and translational degrees of freedom in such processes. All these investigations were aimed at understanding mechanisms in heterogeneous catalysis. A highlight of Gerhard's efforts in the seventies was a series of publications on the mechanism of ammonia synthesis.

One could perhaps appreciate Gerhard's work on ammonia synthesis if one recalls some historic facts:

Since the discovery of ammonia synthesis by Fritz Haber during the years 1905−1908, who received the Nobel prize for this work in 1918, many researchers have tried to unravel and prove the mechanism of this reaction, which has had such far reaching technical and economic consequences.

It was only in 1975 when Paul Emmett himself stated on the occasion of a Batelle Colloquium on the physical foundation of heterogeneous catalysis "The experimental work of the past 50 years leads to the conclusion that the rate determining step in ammonia synthesis is the chemisorption of nitrogen. The question, however, as to whether the nitrogen species is molecular or atomic, is still not conclusively resolved". Shortly after, Gerhard Ertl's group showed via the application of surface science tools that the active species is dissociatively adsorbed (atomic) nitrogen, which is stepwise hydrogenated.

Continuously, the understanding of the atomic structure of surfaces under the influence of adsorbates has been and is an

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Surface Science and Catalysis—Studies on the Mechanism of Ammonia Synthesis: The P. H. Emmett Award Address*

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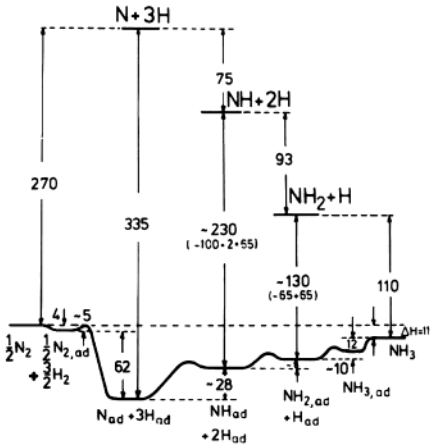

FIG. 14. Potential energy diagram for ammonia synthesis catalyzed by an iron surface. (Energy values in kcal/mole.)

Figure 2. Gerhard Ertl's paper on the occasion of the P. H. Emmett Award, 1979. Reprinted with permission of Marcel Dekker, Inc. Copyright 1980.

important issue in Gerhard Ertl's scientific interest. Shortly after the scanning tunneling microscope was described in 1982 by Gerd Binning and Heinrich Rohrer, when many researchers were still very skeptical about the reliability of the method, Gerhard Ertl's group set up an STM to look at surface reconstructions under the influence of adsorbates. Parallel to the development of tools to investigate structure, the group also introduced very sensitive tools to investigate the electronic structure of surfaces. Already in the early 70s, he set up a UV−photoelectron spectrometer from his startup funds in Munich. In the 80s it was the extremely surface sensitive scattering of metastable He^* atoms and the subsequent measurement of the kinetic energy of emitted electrons (MIES) that led to new insight into the bonding of molecules to surfaces.

One of the most intensively studied reactions in Gerhard Ertl's group has been CO oxidation. In this process, a chemisorbed CO molecule reacts with an also chemisorbed oxygen atom to form a very weakly bound CO_2 molecule that under reaction conditions immediately leaves the surface. Already in 1982, Gerhard Ertl and his group reported kinetic oscillations in the course of CO oxidation reactions on single crystal surfaces, a phenomenon that had so far only been found in technical reactors. Such nonlinear phenomena express themselves in an oscillating rate of CO_2 formation often measured as a CO_2 pressure change above the solid surface. Gerhard and his group showed in a series of groundbreaking publications that a microscopic model for such oscillations may be developed. The interplay between adsorption of carbon monoxide, resulting in lifting of the reconstruction of the platinum surface, the reaction

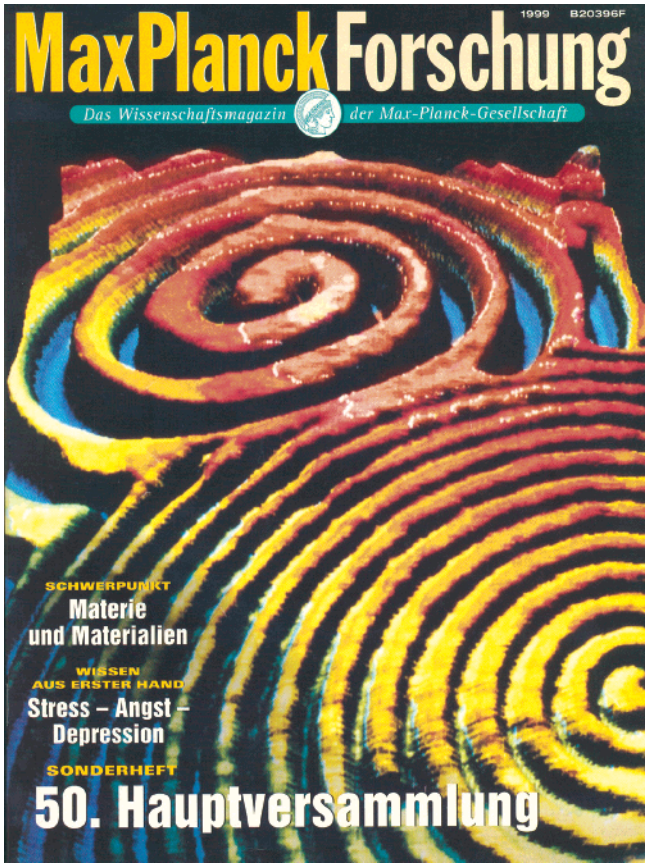

Figure 3. Cover of the journal of the Max-Planck-Society printed upon its 50th birthday. One of the spatio-temporal patterns, i.e., a spiral, is depicted to represent a typical example. Reprinted with permission of the Max-Planck-Gesellschaft. Copyright 1999.

and the higher sticking probability of the nonreconstructed surface toward oxygen, inducing switching of the system between the reconstructed and nonreconstructed surface phases and therefore oscillations of reaction rate. Such oscillations may be regular, but can also, by changing the reaction conditions, become chaotic.

After Gerhard Ertl moved to Berlin, the investigation of nonlinear phenomena reached a second stage of detail:

The above-mentioned temporal oscillations represent the integral behavior of the system. Of course, however, the state variables of a system also depend on spatial coordinates in oscillating reactions. We know this from the Belousov−Zhabotinsky reaction, where the spatio-temporally resolved state of the reaction can be diagnosed by the color.

To image the spatio-temporal patterns at a surface, a photoelectron microscope was developed in the Fritz-Haber-Institute and it allowed us to follow the local variations of concentrations at a surface in real time under vacuum for the first time in history. As the spatio-temporal variations are mesoscopic phenomena, resolution just below the micrometer range was sufficient. Following the observations and their theoretical modeling the development of an ellipsometric microscope finally also allowed the observation of such phenomena in situ, i.e., in the presence of a gas phase up to atmospheric pressure.

The quickly developing STM techniques led to insight, thought to be impossible for a long time, into the structure and, particularly, the defect structure of metal surfaces. Gerhard's group made it possible to visualize directly diffusion processes using a high speed STM, and thus verify macroscopic laws,

such as Fick's law of diffusion, directly at the atomic scale or to visualize the mesoscopic phenomena at a smaller length scale.

Moving to smaller and smaller length scales was accompanied by setting up a group within the Physical Chemistry Department of the Fritz-Haber-Institute in the late 80s, looking into ultrafast processes at surfaces. Pump−probe experiments using femtosecond laser technology opened deep insight into the electron dynamics during photon excitation and concomitantly into energy transfer processes upon adsorbate excitation, these phenomena are relevant in laser-induced desorption from surfaces, a field in which Gerhard Ertl and Manfred Neumann published a first paper in 1972.

Parallel to those fundamental experiments on model substrates Gerhard Ertl always kept an interest in real catalysis. In his department a group performed groundbreaking mechanistically oriented experiments on real powder catalysts. Ammonia synthesis had in addition to other reactions, always been one of Gerhard's key interests, and it was reinforced when it became obvious that in addition to the classic iron based catalyst, also ruthenium based catalysts could be technically beneficial. Work in this and other directions has resulted in a variety of important contributions to the science of catalysis. He has edited together with Helmut Knözinger and Jens Weitkamp the *Handbook of Heterogeneous Catalysis*, a five-volume encyclopedia on heterogeneous catalysis, which has set the standard in the field.

It is only natural that the advice and leadership of a scientist of Gerhard Ertl's caliber has been sought nationally and internationally. In Hannover and in Munich he has been dean of the faculty, in Munich he was spokesperson of the center of excellence, financed by the German Science Foundation (DFG). He has served the scientific community and its societies via memberships of numerous committees. In the beginning of the 1990s, he was very active in evaluating science in the former GDR, and was "Kommissarischer Direktor" of the Max-Planck-Institute in Halle until the new directors were installed. In Germany he advised the German Science Foundation in various committees as one of its elected referees (1988−1995), at last as one of its vice presidents (1995−2001), as well as the ministry for science and technology (BMFT) from 1981 to 1988 as a member in the committee responsible for synchrotron radiation research. He has been on the advisory editorial board of many journals (see list) and he was the chairman of the 8th International Congress on Catalysis held in Berlin in 1984. He is an ordinary or foreign member of ten academies including the National Academy of Science of the United States (since 2001).

Gerhard Ertl received many honors: In addition to his three honorary professorships, which were mentioned above, he received five honorary doctorates, the first one in 1992 from the Ruhr University in Bochum, and the latest in 2003 from Aarhus University in Denmark.

Out of the numerous awards he was honored with, we mention only the Liebig Denkmünze of the German Society of Chemists in 1991, the Japan Prize in 1992, the Medard A. Welch Award of the American Vacuum Society in 1998, and in the same year, the Wolf Prize in Chemistry. In 1992, he received the "Grosse Verdienstkreuz der Bundesrepublik Deutschland" (see the complete list of honors in his vitae).

Gerhard Ertl's vitae and his scientific achievements are admirable. When he retires this year from his position as director at the Fritz-Haber-Institute, he will leave a gap that will be hard to fill. We are sure, however, this will not set an end to his scientific curiosity, and we wish him a lot of fun whatever he decides to tamper with. He is known to be an excellent pianist and we are sure that together with his wife Barbara, his two children, and their three grandchildren they will enjoy music and perhaps also the extra time they may have together. He and Barbara will spend extended vacations in their beloved town of San Gimiginano and enjoy the delicacies of the Toscan kitchen and the superb local wines.

Gerhard Ertl has, as no one else, influenced the fate and direction of surface science and we are grateful for it.

All friends, colleagues, students, and associates wish Gerhard Ertl and his family all the best: the tranquility of retirement, the time to have new ideas, the best of all worlds, and may all his wishes come true.

Hans-Joachim Freund
Helmut Knözinger
Guest Editors