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Editorial

Electron-driven processes from single collisions to high-pressure plasmas

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This Special Topical Issue of the European Physics Journal D (EPJ D) on "Electron-Driven Processes from Single Collisions to High-Pressure Plasmas" is published to honour Kurt H. Becker, who served as Editor-in-Chief for the journal from 2010 to 2016, on his 70th birthday.

Professor Kurt H. Becker has had a long and distinguished research career that spans from the early 1980s to the present. At the core of all of his work were electron-driven and electron-initiated processes [1, 2]. Throughout his scientific life, the study of electron-molecule collisions played a central role, particularly the measurement and calculation of electron ionization cross sections with molecules and free radicals of technological importance [3, 4]. His early work also dealt with elucidating the role of spin-dependent interactions in electron-atom collisions [5]. In the 1990s, Kurt Becker was one of the early researchers who studied microplasmas [6, 7], i.e. plasmas where at least one critical dimension is below 1 mm. In particular, a main focus of his interest was on microplasmas generated and sustained at atmospheric pressure.

Most recently, his work and professional interests not only include scientific research, but innovation and entrepreneurship as well. On the research side, he worked directly with New York University (NYU) scientists to expand their research interests. He helped to identify new, current and promising research topics and to create synergies with existing research interests and capacities. This support to scientists included obtaining third-party funding to promote collaborations within NYU, with industry and with other universities in the USA and internationally. In the area of innovation and entrepreneurship, he helped to create the structures and the framework at NYU's Tandon School of Engineering that enabled scientific knowledge to be translated into new products, processes or services through technology transfer. He directly helped build and enhance the NYU Tandon Future Labs which are the first public–private partnership with New York City (NYC) serving as a business incubation program focused on the success of new ventures and increasing economic impact in NYC.

Kurt H. Becker was the Vice Dean for Research, Innovation, and Entrepreneurship at New York University's Tandon School of Engineering in Brooklyn, New York, and a Professor of Applied Physics and Professor of Mechanical and Aerospace Engineering until 31 August 2023. He is now a Professor Emeritus. Prior to joining NYU Tandon in 2007, he was Professor of Physics in the Department of Physics at Stevens Institute of Technology (1997–2007) and also held faculty positions

Deceased: We appreciate the help and enthusiasm of Professor Michael Brunger when this project started and his early involvement. We were deeply saddened by his very untimely passing on 14th of September 2022. He was a valued colleague who will be missed by his many friends and colleagues. May he rest in peace.

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at Lehigh University (1984–1988) and at the City College of CUNY (1988–1997). He earned a Diplom in Physik (MS) degree and Dr. rer. nat. (PhD degree) from the Universität des Saarlandes (Saarbrücken, Germany) in 1978 and 1981, respectively. Kurt Becker is a Fellow of the American Physical Society, a Fellow of the National Academy of Inventors, the recipient of the Dr. Eduard-Martin Prize for Excellence in Research from the Universität des Saarlandes, the Thomas Alva Edison Patent Award and the SASP Erwin Schrödinger Medal. He also holds an honourary Professorship at the Leopold Franzens Universität Innsbruck, Austria.

As a researcher, in his academic career, Kurt Becker worked in the areas of experimental atomic physics and plasma science and technology. He published more than 240 research articles in refereed journals and books and over 600 conference presentations and abstracts. He holds numerous patents on the generation and maintenance of stable atmospheric-pressure plasmas and was involved in their commercialization through two start-up companies. This experience in plasma technology formed the basis for his ensuing interest in innovation and entrepreneurship, in exploring ways to develop new products, devices and processes that address important societal problems. Professor Becker has conducted extensive investigations into the fundamental processes occurring in plasmas and their interactions with materials, surfaces and biological systems. He has made significant contributions to the understanding and development of atmospheric pressure plasmas, plasma medicine and plasma-assisted material processing.

The plasma state is often referred to as the fourth state of matter; however, in principle it should be called the first state of matter since most of the matter in the visible universe is in the plasma state. Examples include the Sun and other stars, interstellar matter, cometary tails and planetary atmospheres as well as the terrestrial ionosphere. Naturally occurring plasmas on Earth are rare and include lightning, polar auroras and flames. A plasma is characterized by the presence of positive (and sometimes negative) ions and negatively charged electrons in a neutral background gas. Plasmas are generated often for technological applications, which include welding arcs, plasma torches, high-pressure and fluorescent lamps, ignition sparks in an internal combustion engine, and the vast range of low-pressure plasmas employed in the fabrication of microelectronic devices. Magnetically or inertial confined plasmas in nuclear fusion reactors are one of several choices to achieve the extreme conditions under which controlled nuclear fusion might occur in the laboratory.

Plasmas are created by supplying energy to a volume containing a neutral gas, so that a certain fraction of free electrons and ions is generated from the neutral constituents. In technical plasma devices, the plasma is mostly generated in electrical discharges and the input energy is supplied in the form of electrical energy.

Unlike thermal plasmas, which are in thermal equilibrium with their surroundings, non-thermal plasmas, also known as low-temperature plasmas in electrical gas discharges for technological applications, exhibit a wide range of electron and ion temperatures. Although mostly studied under low-pressure conditions, it is well known that non-thermal plasmas can also be generated at high gas pressure (including atmospheric pressure), albeit not easily in large volumes.

The properties of non-equilibrium plasmas are discussed in many books and publications (see, e.g. [8–12] and references therein), to which we refer the interested reader for further details. In any case, for plasmas the role of electron collisions is crucial in understanding the behaviour and characteristics of non-thermal processes. The electron energy distribution function (EEDF) often deviates from the Maxwell–Boltzmann distribution and may exhibit a high-energy tail, which indicates the presence of a population of highly energetic electrons [13]. In atomic and plasma physics, electron collisions with neutrals or other charged particles are crucial for understanding the behaviour of matter at the atomic scale. In single collisions, electrons can excite or ionize atoms, inducing changes in their energy levels or removing one or more electrons altogether. By studying the outcomes of single electron collisions, scientists can unravel the intricate mechanisms governing the behaviour of matter. As a result, their interactions with other particles strongly influence the plasma's behaviour and dynamics and affect the ionization balance, determining the density and energy of charged particles contributing to the overall electrical conductivity and energy transport properties of the plasma system [14]. Moreover, electron collisions can lead to the formation of excited states in plasmas. Excited atoms/molecules return to lower energy states by emitting photons. These emissions form characteristic spectral lines, which are utilized in diagnostics to infer the composition, temperature and density of a plasma. Due to electron collisions in molecular non-thermal plasmas the formation of reactive species, such as radicals and excited atoms/molecules, by dissociation is of importance. These reactive species play a vital role in numerous plasma applications, such as plasma medicine, surface modification and pollution control. Hence, understanding and controlling electron collisions in non-thermal plasmas are essential for optimizing plasma-based technologies, such as plasma processing for semiconductor fabrication, plasma displays and plasma medical devices.

In summary, electron-driven processes from single collisions to high-pressure plasmas definitely occupy a central position in atomic and plasma physics. Considering this, the Guest Editors compiled a broad range of original manuscripts that encompass the area of electron-atom [15] and electron-molecular collisions [16–23], respectively, low-temperature plasma research [24–29] and aligning with Kurt Becker's emphasis on science innovation [30–32] and entrepreneurship [33].

Theoretical predictions for differential cross sections based on Breit-Pauli and Dirac B-spline R-matrix calculations for electron-impact excitation of rubidium atoms have been compared with related experiments in the paper by Hamilton et.al. [15], whereas the reactions of O_2^+ with several volatile halogenated inhalation anaesthetics for breath analysis have been studied by Weiss et.al. in [16]. Another theme of this research group in Innsbruck is related to investigations of several volatiles and their fully deuterated analogues by high kinetic energy-ion mobility mass spectrometry [17]. Amorim et.al. performed an experimental determination of the appearance energies of cationic fragments by electron ionization of 2-butanol using mass spectrometry [18]. The method of ion mobility spectrometry has also been explored by Matas et.al. [19] to study the negative atmospheric pressure chemical ionization of NO_2 by $O_2^-.CO_2.(H_2O)_n$. Furthermore, Blasko and other researchers in Bratislava determined a spectral electron energy map of electron-impact induced emission of nitrogen measured by fluorescence in the range from 330 to 1030 nm [20]. Also from this group, Meszaros et.al. report on dissociative electron attachment to c-C_4F_8 molecules and clusters in [21]. As an interesting example for the importance of electron-impact ionization in planetary atmospheres the work by Carberry Mogan et.al. [22] can be regarded who investigated, in particular, the atmospheres of the icy Galilean satellites. Electron-induced molecule reactions are also studied for O and O_3 species in the effluent of an atmospheric pressure plasma jet operated with He and Ar, respectively, by molecular beam mass spectrometry in the paper by Hahn et.al. [23].

There are six papers that are mainly related to low-temperature plasma research. Hippler et.al. investigated the ion energy distribution function of plasma ions of a hollow cathode glow discharge in Ar/N_2 and Ar/O_2 gas mixtures by means of energy-selective mass spectrometry [24]. The paper by Atri et.al. [25] gives an interesting overview on observations of auroras on Mars since their discovery in 2005. The polarity dependence of CO_2 conversion in nanosecond pulsed large gap dielectric barrier discharges by Borghei et.al. [26] is an important contribution on plasma applications for environmental issues. Also from the research group at INP Greifswald is a study exploring the mechanisms leading to diffuse and filamentary modes in dielectric barrier discharges in N_2 with N_2O admixtures by Höft et.al. [27] which is a quite interesting paper on the formation of discharge regimes in atmospheric pressure plasmas. Wolff et.al. [28] used various diagnostics as laser schlieren deflectometry and high-speed camera observations as well as suitable models in order to verify different modes of a filamentary atmospheric pressure plasma jet. A theoretical study on the solution including multiple scattering effects of laser light propagation in a turbid medium has been performed by Stamnes et al. [29].

Finally, there are four papers which are closely related to novel technological applications of basic processes (e.g. electron-neutral collisions) in (high-pressure) plasmas. For instance, Auguste et.al. report in [30] on effects of cold plasma treatment on growth enhancement and on the chemical composition of sweet basil plants which is an exemplary illustration of the rather new area of plasma agriculture. An example for diagnostics in material science is the contribution by Zhang et.al. [31] where multifunctional nylon filaments have been designed for simultaneous ultra-violet and strain sensing. Microcavity plasma arrays have been used for ultrasound harmonic generation and atomic layer deposition of multilayer, deep-UV mirrors and filters by Kim et.al. [32] which is an excellent demonstration of emerging and disparate plasma applications. In order to transfer basic ideas of non-thermal plasma research into technological applications and, finally, into innovative products it is necessary to analyse the economic milieu. This point is discussed in detail in a paper by Schultz et.al. [33] where the impact of the National Science Foundation's innovation corps on academic innovation and entrepreneurship has been elucidated.

The present compilation of the articles reflects the current research interests and the activities of Professor Kurt Becker. It should be emphasized that the papers focus on various recent scientific and technological advances in this given area of physics, chemistry and technology of non-thermal plasmas.

The guest editors hope that the present topical issue will find a large community of interested researchers and that the archival record contained in this issue will be useful as well. We would like to express our appreciation to all of the authors and, in particular, to Tom Spicer, Muriel Bouquant, Isabelle Auffret-Babak and Sabine Lehr from the EPJD editorial team for their support in the publication process.

Finally, we offer our warm wishes and luck for enjoying life after retirement to our esteemed colleague Kurt H. Becker and hope for his continuing scientific support and advices in the exciting research area of "Electron-Driven Processes from Single Collisions to High-Pressure Plasmas".

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