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FROM ELECTRON MOLECULE SCATTERING CROSS SECTIONS TO PLASMA APPLICATIONS : PHYSICS OF NON-EQUILIBRIUM LOW-PRESSURE DISCHARGES

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The purpose of this review is to summarize the activities of the Gaseous Electronics Laboratory of the Institute of Physics, University of Belgrade. The common component in all the projects carried out by the Laboratory is that discharges are not in thermodynamic or local thermodynamic equilibrium. In fact quite commonly even the equilibrium between energy gained from the field and lost in collisions is not achieved. Such physical situation allows applications of gas discharges including determination of the scattering cross sections and specially tailored plasma chemical processes. In addition some very interesting kinetic phenomena occur such as negative differential conductivity, negative differential resistance of low current discharges and non- linear transition from Townsend discharge to glow.

The specific characteristics of particle swarms is that the mean energy can be adjusted by external electric field and thus it can be used to scan accross the set of collisional cross sections. The transport coefficients are normally sensitive functions of the absolute magnitude of the cross sections. In order to obtain unique sets of cross sections it is required to provide experimental transport data including the drift velocities, characteristic energies, excitation and ionization coefficients in as broad range of electric field to gas number density parameter (E/N) as possible. The conditions for swarm type measurements can be achieved in non- selfsustained discharges and in the low- current Townsend type (dark) discharges.

Our studies include measurements of excitation coefficients in nitrogen, argon, hydrogen, methane, neon and in different mixtures of gases, as well as measurements of other coefficients in collaboration with several laboratories around the world. The cross sections for low energy electron scattering for hydrogen, deuterium, argon and some other gases have been determined as well.

Apart from the well established numerical techniques used to obtain the solution to the Boltzmann equation, approximate but analytical or semi- analytical theories are useful in providing physical insight into the phenomena such as negative differential conductivity, applicability of Blanc's law, influence of reactive collisions on transport coefficients and many other. Due to importance of rf discharges it is also necessary to develop techniques for studying the electron transport in rf fields under swarm conditions. A number of unusual processes develop that cannot be predicted on the basis of dc transport, including the anomalous anisotropic diffusion, relaxation, modulation of transport coefficients and time dependent negative differential conductivity.

A special situation occurs at low pressures, below the Paschen minimum. Electrons never reach equilibrium and thus their mean energy, EDF and all the transport properties become position (and pd) dependent. Under the same cirmcumstances the heavy particles gain enough energy to participate in excitation and even ionization, sometimes even a couple of orders of magnitude more efficiently than electrons.

In order to study theoretically the processes at high E/N reliable experimental data are required. Thus we measure spatial distribution of absolute emission intensity, multiplication, electron and ion EDF and other observables for the actual experimental conditions. General knowledge is extracted from those data when we apply theoretical analysis either simple beam- like models or Monte Carlo simulations specially tailored to suit the experimental conditions.

For Townsend discharge conditions, the voltage versus current characteristic is usually assumed to be flat. It turns out however that even at very low currents some small perturbation to the field due to the background of slowly moving ions exists which leads to negative differential resistance (NDR). Due to negative V-I characteristics oscillations may occur for low current discharges. At somewhat higher currents a transition to constricted glow discharge occurs, which is one of the first studied self organizatio processes in physics.

Spatially resolved and space-time resolved spectroscopy of rf and dc discharges provedes a good non-intrusive diagnostics that allows us to study the mechanisms that maintain the discharge. In case of rf discharges in electronegative gases most of the ionization occurs due to the development of double layers. Models of rf discharges require time consuming non- local electron kinetics to be followed over a large number of periods together with complex ion and chemical kinetics. Yet a very good qualitative and quantitative agreement has been achieved for most systems. The most recent chalenge is the study of inductively coupled non- equilibrium discharges.

The effect of anomalously broadened Doppler profiles of $H\alpha$ radiation produced in dissociative excitation of hydrogen bearing molecules was unexplained for a long time. We have established that the broadest wings of the profiles observed mainly along the axis of the electric field are due to excitation by fast neutrals produced in charge transfer collisions and by reflection from the cathode.

Non- equilibrium discharges allow us to tailor the plasma chemical processes according to the requirements for plasma etchning, diamond like thin film deposition, plasma cleaning and conditioning of surfaces, nitrous oxide removal from flue gases, plasma sterilization, ozone production, freon removal and many other applications. All the above mentioned applications were studied in our laboratory.