**INTRODUCTION:**

Ion–atom ionizing collisions are of considerable interest in atomic physics and play an important role in many applications, such as heavy ion inertial fusion, collisional and radioactive processes in the Earth’s upper atmosphere, atomic spectroscopy, ion stopping in matter and ion-beam lifetimes in accelerators. For example, electron clouds can form inside the accelerator due to residual gas ionization and cause two-stream instabilities\(^1\).

The recent resurgence of interest in charged particle beam transport in background plasma is brought about by the recognition that plasma can be used as a magnetic lens. To estimate the ionization and stripping rates of fast ions propagating through gas or plasma, the values of ion–atom ionization cross sections are necessary.

For the interaction of complex projectile and target atoms or ions, classical trajectory Monte Carlo (CTMC) simulations can be utilized. Classical mechanics approaches are typically simple to apply and yield fairly reliable total cross sections for collision processes at intermediate energies. The CTMC method consists of computing the electron trajectory in an atom when another ion or atom is passing by at a certain impact parameter\(^2\).

The cross section is obtained from the rate of occurrence of the outcome of the collision. The electron can remain close to one of the nuclei or it can move far away from both of them. The difference in atomic potentials can give error of about 20% compared with the calculations utilizing the more accurate Slater model. Therefore, in the following, we primarily use the latter model for the ion and atom potentials. There are many types of plasma source such as those based on discharges created by direct current, capacitive coupled radiofrequency, inductively coupled rf and microwaves. The technological applications of plasma formed in these sources are numerous and include thin film deposition,
semiconductor processing, materials treatments, lamps, light sources and displays, thick film deposition, waste treatment and material analysis³.

**SIMILARITIES AND DIFFERENCES OF PLASMA:**

All plasmas have a number of features in common. For instance, they are composed of equal amounts of positive and negative charges carried by particles that are arranged without any local ordering, being free to move. One way to begin a classification is to quantify:

(i) The density of the charge carriers (so many per cubic meter).

(ii) The thermal energy of electrons in particular.

Even with a small region of the density-energy parameter space there are innumerable distinctly different plasmas⁴.

**EQUILIBRIUM AND STEADY STATES OF PLASMA:**

The plasma state can be realized as a thermal equilibrium phase of matter beyond the conditions of gases. However, just as amorphous solids appear to be steady-state solids, so too laboratory-generated plasmas often exist as steady, non-equilibrium states. It must be noted also that the lifetime of individual particles in laboratory plasmas may only be a small fraction of a second, so the steady state is a kind of dynamic equilibrium⁵.

**LABORATORY PLASMAS- SUSTAINING THE STEADY STATE:**

Early laboratory experiments in which capacitors were discharged through a gas provided transient sources of ionized gas. Nowadays, continuous electrical discharges are often used to create a dynamic steady state in which there is a balance between production (sources) and loss (sinks). An overflowing water
tank maintains a dynamic steady state as water flows out at the same rate as it flows in.

Laboratory plasmas are formed when gas is ionized by driving an electric current through it, or by shining electromagnetic radiation into it. Generally, these means of plasma formation give energy directly to the free electrons in the plasma\(^6\).

**ORIGINS OF SPECIES IN PLASMAS:**

A laboratory gas discharge is confined; that is it has physical boundaries. Charged particles are created and lost both within the volume and at the confining surfaces to varying degrees. Not only does this provide a finer classification of plasmas but also it hints at the possible scaling issues for plasma sources

**PLASMA BOUNDARIES-SPACE CHARGE SHEATH:**

Electron impact ionization provides a continuous source of charged particles in the volume of discharge plasma. At the low pressure, gradients must therefore become established to derive an equivalent loss. Gradients in potential give rise to electric fields that accelerate the heavier, less mobile, positive ions while simultaneously slowing electron loss\(^7\).

The potential structure is initiated by negative charge that is quickly established on surfaces exposed to the plasma through the arrival of the more energetic electrons. Adjacent to the surface charge is a boundary layer of positive space charge, extending over a narrow region of space across which the potential changes rapidly. Poisson’s equation relates potential structure to space charge, \(\rho\): \[\frac{d^2\phi}{dx^2} = -\frac{\rho}{\varepsilon_0}\] (1)
The scale length $L$, of the sheath region can be estimated by the dimensional argument

$$\Phi \approx \frac{n_i e}{\varepsilon_0}$$

With $\Phi \approx K T_e/e$ and $n_i \approx n_0$, the plasma density,

$$|L| = \frac{\varepsilon_0 K T_e}{n_i e^2}$$

Which is known as the Debye length; it is the scale length of space charge regions where potentials comparable with or larger than $K T_e/e$ occur.

In the plasma, potential changes much more slowly on a scale length of $L$, which is effectively the size of the containing vessel.

$$\frac{d^2 \Phi}{dx^2} = \frac{(n_e-n_i)e}{\varepsilon_0}$$

So

$$\frac{\Phi}{L^2} \approx \frac{(n_e-n_i)e}{\varepsilon_0}$$

Since in the plasma $n_e \approx n_i$ the potential changes only over relatively large distances. As electrons and ions leave the quasi-neutral plasma, passing into the boundary sheath, a positive space charge must be develop and the potential must fall, according to the argument above. So, entering from the plasma

$$\frac{\partial p}{\partial V} = \frac{+ve \ change \ in \ space \ charge \ -ve \ change \ in \ potential}{< 0}$$

This condition sets a criterion for the speed at which ions enter the sheath.

The use of non-equilibrium, low-temperature plasmas for materials processing is the key to the advancement of many rapidly developing technologies. Despite these efforts, low-temperature plasma technology (LTPT) today
remains a discipline where technological advances routinely outpace the fundamental understanding of the key processes at a microscopic level. Even though process and reactor modeling and plasma diagnostics techniques made very promising advances, a serious lack of sufficient and sufficiently reliable collisional and spectroscopic data often prevents the exploitation of the full potential of modeling codes and plasma diagnostics techniques. This has been noted in a recent follow-up NRC report on “Modeling, Simulation, and database Needs in Plasma Processing”. The report cites three main reasons for the poorly developed status of the database,

(i) The continued comparatively low level of research efforts in this area.

(ii) Little coordination between the activities of the few groups working in this field, particularly poor coordination between experimental efforts and theoretical calculations.

(iii) A very serious lack of communication between the community that generates the data and the community that uses the data.

A quantitative and detailed understanding of the processes leading to the formation of the reactive plasma constituents and of their structure is important for three reasons,

(i) To determine the composition of the plasma and thus the plasma properties and the key plasma chemical reaction pathways.

(ii) To determine the flux of reactive plasma species to the wafer or substrate and thus the utility of a particular plasma for a specific processing application.
(iii) To provide the basis for optical and mass spectrometric diagnostics of the relevant gas phase and surface processes as well as for state-of-the-art computer simulations and CAD tools for process modeling and reactor design.

Electron and photon interactions with reactive plasma constituents under single collision conditions are a versatile probe of the structure and dynamics of the parent plasma constituents as well as of the dominant secondary plasma species such as chemically reactive radicals which are produced by collision-induced dissociation and ionization of the parent molecules. With average electron energies of 0.5 eV to 5 eV for typical technological low-temperature plasmas, the high energy tail of the electron energy distribution function (eedf) extends well into the impact energy regime above the thresholds of the cross sections for the electron-impact dissociation and ionization of the parent plasma constituents.

**THE ELECTRON-MOLECULE SCATTERING PROBLEM**

When an electron collides with a neutral atom, there are only three likely outcomes:

i) The electron scatters elastically off the atom leaving the atom in its original electronic state.

ii) The electron excites the atomic electrons leaving the atom in an excited state.

iii) The electron has sufficient energy to remove one or more electrons from the atom, leaving it positively ionized.

Additionally, the electron can be captured by the atom to form a negative ion but this requires an extra process such as the emission of a photon. When an electron collides with a neutral diatomic molecule, however, the story is far more complicated.
Firstly, the molecule has vibrational and rotational degrees of freedom which can be excited with little energy. Any of the above outcomes of electron-atom collisions can occur along with rotational or vibrational excitation of the molecule.

Secondly, the interaction between electron and molecule is multicentre and non-local which leads to additional complications.

Thirdly, the molecule can break up in a variety of different ways through dissociation, dissociative attachment and dissociative ionization (see figure 1.2).

![Figure 1.2](image)

**Figure 1.2:** The different possibilities for the breakup of a diatomic molecule due to electron impact.

At electron impact energies below the molecular ionization limit, the collision of electrons with a diatomic molecule AB can lead to a number of possible processes\(^{11}\).