Studies on Scattering of Charged Particles in Plasmas

Most of the phenomena that are observed in a plasma environment are borne by the scattering processes in the plasma. Free charges in a plasma mainly result from the collisional ionizations which, along with the slowing down of charged particles due to the collision, play a conclusive role in the electrical break-downs [1]. Heat transport and current flows are virtually determined by the scattering of electrons form atoms and molecules. Calculations regarding radiation and transport properties of a plasma requires the data of scattering cross sections. Cross sections of the capture processes are often required for plasma diagnostics [2, 3]. Data for collisional excitations of atoms are are necessary for calculating line profiles and intensities of the atoms. For instance, the cross sections in the scattering of hydrogen atoms from the electrons and the protons are necessary for calculating line profiles and intensities of the hydrogen atom in the astrophysical regimes where the collisional excitation of hydrogen atoms is relevant [2, 3]. Atomic collisions play a significant role in the controlled fusion research [4].

In this thesis we mainly focus on the scattering of charged particles in plasma environments. In particular, electrons and protons (or ions in general) are our main concern. Most of the physical and kinematic properties of a plasma are governed by the scattering of particles in the plasma [5, 6]. In fact, several important characteristics of a plasma, such as electrical conductivity, transport coefficient, diffusion coefficient, are calculated directly from the scattering cross section. It is well-known that a pair of charged particles in vacuum interacts with other via Coulomb potential (CP). Also, the problem of scattering between two particles interacting with a potential which depends on the relative distance between the particle is equivalent to the problem of scattering of a particle (of mass equal to the reduced mass of two particles) from the interacting potential. The problem of scattering from the Coulomb potential can be solved analytically both from classical point of view and quantum mechanical point of view [7]. The total cross section comes out to be divergent for all energies. The divergent nature of the total cross section is a consequence of the long range behaviour of the Coulomb potential [7]. The interaction potential between a pair of charged particles gets screened in a plasma. Though it has not been possible to solve the Schrodinger equation corresponding to the screened potentials, the approximate solutions show that the total cross section is convergent for the non-zero values of the screening parameter for all energies, except at the zero-energy for which the total cross section diverges for the attractive potentials for the critical screening parameters [7]. In fact, scattering from the screened potentials which support bound states has several interesting features. The screening of interaction potentials in a plasma depends on the state of the plasma and can be represented by a suitable pseudopotential (or effective potential). The Debye-Huckel potential (DHP), given by (in a.u.),

$$V_{\mathrm{DH}}(r) = \frac{e^{-\mu r}}{r}, \tag{1}$$

is used to describe the effective potential in a weakly coupled plasmas. It is one of the well-known screened potentials of wide applicability. The parameter μ ($= \lambda_D^{-1}$, λ_D being the Debye length), known as the screening parameter, connects the plasma frequency ω_P and thermal velocity v_T by $\mu = \omega_P/v_T$. A modified Debye-Huckel (MDH) potential of the form (in a.u.):

$$V_{\mathrm{MDH}}(r) = \frac{e^{-\mu r}}{r} \cos(\mu r) \tag{2}$$

is used to describe the effective potential around a test charge of mass m embedded in a quantum plasmas, wherein the quantum force dominates over the quantum statistical pressure.

Based on fully quantum mechanical calculation, several approximate methods have been used to study the problem of scattering of a charged particle from the DHP or the MDHP [[8]-[13]]. The problem can even be solved with amazing accuracy by employing numerical techniques [[14]-[19]].

In a nonideal classical plasma with nonideality parameter γ and correction coefficient $c(\gamma)$, the effective potential can be obtained as (in a.u.) [20]:

$$V_{\mathrm{NCP}}(\vec{r}) = q_1 q_2 \frac{10 + \gamma(e^{-\sqrt{\gamma} r/\lambda_D} - 1)(1 - e^{-2r/\lambda_D})}{10[1 + c(\gamma)]} \frac{e^{-r/\lambda_D}}{r}. \tag{3}$$

Describing the strongly coupled (nonideal) classical plasma by the effective potential of the form of equation (3), Baimbetov *et al* [20] computed the electrical conductivity of the plasma with in the framework of the First Born Approximation. Electrical conductivity of fully ionized hydrogen plasma described by the pseudopotential (3) was computed by Nurekeno *et al* [21] within the Chapman-Enskog method. For a partially ionized hydrogen plasma wherein the interaction of the charged particles is governed by the pseudopotential of the form of equation (3), Ramazanov *et al* [22] calculated the transport coefficient by applying Chapman-Enskog method.

The effective range theory was employed by Omarbakiyeva *et al* [23] to calculate the phase shifts in electron-atom scattering in a dense partially ionized plasma (semi-classical plasma), described by the pseudopotential,

$$V_{\mathrm{SCP}}(r) = -\frac{1}{\sqrt{1 - 4\mu^2 {\lambda_B}^2}} \left(\frac{e^{-Ar}}{r} - \frac{e^{-Br}}{r} \right), \tag{4}$$

where

$$A = \left(\frac{1 - \sqrt{1 - 4\mu^2 {\lambda_B}^2}}{2{\lambda_B}^2} \right)^{1/2}, \quad B = \left(\frac{1 + \sqrt{1 - 4\mu^2 {\lambda_B}^2}}{2{\lambda_B}^2} \right)^{1/2} \tag{5}$$

and λ_B is the thermal de Broglie wave length of the interacting particles. The transport coefficient in dense a semi-classical plasma, described by the pseudopotential (4), was calculated by Ramazanov *et al* [24] by solving the Calogero equation.

In this thesis, we make an attempt to study the scattering of charged particles (electron and proton/ion) under different plasma environments based on fully quantum mechanical calculations. We consider four different plasmas, namely weakly coupled plasma, nonideal plasma, semi-classical plasma and quantum plasma. Pseudopotentials of the forms of equations (1), (2), (3) and (4) are used to represent particle-interactions in weakly coupled plasmas, quantum plasmas, nonideal plasmas and semi-classical plasmas respectively. As the pseudopotentials representing the screened interactions in nonideal classical plasma, semi-classical plasma and quantum plasma reduce to the DHP in the limit of the screening parameters, we do not intend to make sperate discussion for weakly coupled plasmas; rather cases of weakly coupled plasma are discussed alongside the other plasmas. Scattering parameters are calculated accurately by resorting to the Schwinger variational principle in the momentum space. Our endeavour is to make a detailed study on the nature of various cross sections with varying plasma screening parameters. Particular emphasis is given to explore the dynamics of low-energy scattering.

This thesis consists of six chapters. Chapter 1 is devoted to the discussions of some fundamental quantities and ideas which deem desirable for the understanding of the studies made in this thesis. It particularly includes the description and classifications of plasmas, shielding effect and its derivation in various plasmas. In Chapter 2, we make a brief discussion on the Schwinger variational principle. The scattering of charged particles in nonideal classical plasmas has been studied in Chapter 3. The effects of semi-classical plasma and quantum plasma on the scattering of charged particles have been studied in Chapter 4 and Chapter 5 respectively. Finally in Chapter 6, we present a summary of the thesis along with the future perspective of the present studies. We try to make each chapter of the thesis self contained so that each chapter can be read quite independently.