CHAPTER - I

INTRODUCTION
1.1. PRELUDE

In this thesis we shall present our findings on some very important topics of atomic physics. These are i) electron-atom scattering ii) heavy charged particle -atom scattering and iii) atomic charge exchange scattering. In the last few decades there have developed vast literature on electron-atom scattering. A glimpse of the vast literature developed for electron-atom elastic scattering and atomic excitation may be obtained from chapter - II of the present thesis, particularly those which have bearings with our works. Chapter - III and - IV display our new results in this field. The heavy charged particle-atom scattering shall be dealt with in chapter - V. The charge exchange scattering shall be reviewed in chapter - VI in the light of our new results for the same. In the introduction of the thesis (viz., the present chapter), however, we present a very general treatment of the scattering processes mentioned above.

1.2. UNITS

Throughout the present thesis, whether it be a review of the past works or our new works we shall, in general, use atomic units. Atomic units (a.u.) are such that $\hbar = m = e = 1$, where $m$ is the mass of the electron and $e$ the absolute value
of its charge. $\hbar$ is the well known Planck's constant, $\hbar$ divided by $2\pi$. The atomic unit of length is the Bohr radius $a_0 = \frac{\hbar^2}{m e^2}$, and the unit of energy is $e^2/a_0$, i.e. twice the Rydberg. In some of our new works, however, conversion to other units have been made in order to compare our results with the experimental ones. In such cases the units shall be explicitly stated.

1.3. ELECTRON-ATOM SCATTERING

We shall consider electron-atom scattering at intermediate and high energies. As such, whenever reference is made to low energies we shall mean the lower range of the intermediate energies and is of the order of a few Rydberg units, and the term intermediate energy shall be used to fill the breach between these low energies and the high energies where the Born series approximations and variants are sufficiently accurate. The interaction of an electron with an atom can involve elastic scattering and inelastic scattering. Inelastic scattering can again be divided into two classes — excitation and ionization. The recent substantial progress in the ability of computations to reproduce experimental results for elastic scattering and for excitation of low lying states does not extend as yet to ionization. Significant unsolved problems occur in this area. In the present
thesis we consider elastic scattering, atomic excitation and ionization problems. In case of elastic scattering we have considered scattering both by hydrogen and helium atoms – viz., the processes

\[ H(1s) + e^- \rightarrow H(1s) + e^- \]

\[ \text{He}(1s) + e^- \rightarrow \text{He}(1s') + e^- , \]

whereas, for the latter cases, the hydrogen atom only has been considered i.e.:

\[ H(1s) + e^- \rightarrow H(2s) + e^- \]

\[ H(1s) + e^- \rightarrow H^+ + e^- + e^- . \]

Over the last few years, experimental techniques have been developed which have allowed the absolute measurement of the differential cross sections for the above scattering processes. The existence of these measurements has stimulated theoretical studies which have achieved appreciable success. Various theoretical models have come up with applicability to particular energy ranges. Thus we have the target eigen function expansion methods, e.g., close-coupling or pseudo-state approximation etc. suitable for low and intermediate energies. For high energies we have the eikonal-Born series method, distorted-wave second Born approximation method and the optical-potential method etc. The various theoretical models have been reviewed in chapter II.
Good review articles in this subject may be obtained in the works of Callaway (1980) and Bransden and McDowell (1977, 1978). Callaway (1980) has emphasized on elastic scattering and excitation of the lowest few excited states. Only occasional remarks have been made about ionization. In view of the extensive interesting material, Bransden and McDowell presented their work in two parts. Part I (1977) contains an account of most of the theoretical models, with only a few illustrative comparisons of theory with experiments. Part II (1978) contains collection of experimental data for the scattering of electrons by selected light atoms and comparisons with the predictions of the theoretical models discussed in Part I. The target atoms include hydrogen, helium, the alkali metals and so on. The data discussed by Bransden and McDowell include elastic scattering, and discrete excitation, but ionization is not covered. A recent, short comment article is available in the work of Kingston and Walters (1982).

Recently Das [see, in this context, Das (1979); Das, Bera and Patra (1981) and Das and Biswas (1981)] proposed a method for the scattering of electrons by atoms. This method has been proved to be very fruitful as is evident from the results of the various published works using the method of Das. It is no more difficult than the second Born approximation but yields results surprisingly good. All our new works are in the light of the method of Das and its variants. So our review includes the works, done recently, based on the method of Das.
1.4. HEAVY CHARGED PARTICLE SCATTERING BY ATOMS

As in the case of electron-atom scattering, heavy charged particle scattering by atoms can involve elastic scattering and inelastic scattering. Inelastic scattering can again be divided into excitation and ionization problems. As regards the inelastic scattering, some works have already been done in this field. Few experimental results are also available. But, as regards the elastic scattering, this topic is still in the course of development. In this thesis we have considered the following two elastic processes:

\[ H^+ + H(1s) \rightarrow H^+ + H(1s) \]

and

\[ He^{++} + H(1s) \rightarrow He^{++} + H(1s) \]

i.e., the heavy charged particles considered are proton and the alpha-particle, with the target atom being hydrogen.

For the proton-hydrogen elastic scattering experimental measurements have recently been made by Park (1982) for 60 keV energy. These experimental results encouraged Wadehra and Shakeshaft (1982) to take up the theoretical study for the same. Wadehra and Shakeshaft (1982) presented their results for the energy range 15 - 200 keV. The results of Wadehra and Shakeshaft (1982) are in slight disagreement with the experimental ones. Our results for this process (chapter-V)
may be considered to be quite accurate, and thus can be regarded as standard of estimate over a wide energy range. However, more experimental results, for the processes considered in the present section, are always welcome.

1.5. CHARGE EXCHANGE SCATTERING

One very important class of problems in atomic physics is the charge exchange scattering. Simplest of this class of problems is the charge transfer of proton on hydrogen. A more general type of problem is the electron capture by bare nucleus from one-electron atom. A similar set of problems but of higher complexity is the electron capture by a bare nucleus from atoms with more than one electron. Physicists over many decades have taken profound interest in these problems. As may be easily guessed proton-hydrogen problem received the greatest attention. But even this problem could not be solved exactly because of its inherent three body nature. However, in the process of approximate solution of this problem many interesting and controversial points cropped up, some of which have been resolved by this time.

The first attempt on solving this problem was made by Thomas (1927) on the basis of classical binary encounter theory. He obtained the cross section whose asymptotic behaviour is

\[ \sigma \sim E_0^{-1/2} \]
\( E_0 \) being the energy of the incident proton. Soon after this publication appeared the quantum mechanical calculations of Brinkman and Kramers (1930). They considered the conventional first Born amplitude, omitting the internuclear potential, partly to avoid computational difficulties and partly for their belief that this omission will not affect the result much. They obtained as the total cross section for the electron capture in the ground state

\[
\sigma_{\text{B K}} = \frac{2^6 (\pi \alpha_0^2)}{5 E_0 (E_0 + 1)^5}
\]

where \( E_0 \) is expressed in units of 100 keV. Thus the B K (Brinkman and Kramers) cross section at high incident energy behaves as

\[
\sigma_{\text{B K}} \sim \frac{2^6 (\pi \alpha_0^2)}{5} E_0^{-6}
\]

Then after a long gap appeared the work of Jackson and Schiff (1953) who employed the full first Born amplitude. They obtained very good agreement with the experimental results available at that time. The asymptotic behaviour of their result is

\[
\sigma_{\text{J S}} \sim 0.661 \sigma_{\text{B K}}
\]

but later experimental work ruled out this asymptotic behaviour.
In the article of Jackson and Schiff (1953) a footnote was added communicating the comments of Wick. This stated that at higher energies the internuclear potential should not contribute and that a simple canonical transformation may be made to remove this unwanted term from the internuclear potential. In fact, later on Bates (1958) established an approximation in which the internuclear potential is completely eliminated. He did a first order computation and obtained result which behaves asymptotically as BK result. At that time, a great controversy was raised, whether to retain the internuclear potential in an approximate calculation, particularly when the retention of this potential gave so nice a fit with experimental data of that time. The controversy has practically eroded by now. It is now known that the asymptotic form of the experimental results do not follow the Jackson-Schiff result. Secondly, the retention of this internuclear potential gives unphysical result in other charge exchange scattering. Thirdly, the BK type calculation [Nikolaev (1967)], though overestimates the cross sections, gives the correct trend over wide energy ranges and for varied systems. Fourthly, most second order calculations [Cheshire (1964), McCarrroll and Salin (1967), Carpenter and Tuan (1970), Das (1972, 1974)] agree with the second Born result [Drisko (1955), Dettmann and Leibfried (1969)] first derived by Drisko, in the high energy limit, in which the internuclear potential
simply drops and these are supposed to give the correct trend high energy data. The asymptotic form of this result is

\[ \sigma_{\text{Drisko}} \sim (0.3 + 10 \pi E_0^{1/2}/2^{1/2}) \sigma_{B\kappa} \]

so that at the extreme high energy limit

\[ \sigma_{\text{Drisko}} \sim E_0^{-1/2} \]

which agrees with the classical result of Thomas (1927).

At this point, we bring to the reader's notice that in this thesis we contradict the present belief that the second Born result has the correct asymptotic form for the scattering process under consideration. It is expected that the higher order terms may contribute significantly to the cross section, however small the contributions may be. In this thesis we shall present calculations for the process

\[ H^+ + H(1s) \rightarrow H(1s) + H^+ \]

for non-relativistic high energies, using the method of Das (see subsection 2.2.1) which extends beyond the second order calculation. The peaking approximation which has been used by us, has been shown to be valid for high energies by Simony
and McGuire (1981). Hence the results obtained by us are claimed to be quite accurate. As such, the second Born result which differs though very slightly but significantly from our result even at energies above 10 MeV, is inaccurate and fails to describe correctly the asymptotic behaviour. For further details, one may refer chapter - VI of the present thesis.