Summary of thesis

The thesis presents the work carried out in three parts. The first part concerns with the development of the Proton Induced γ–ray emission (PIGE) facility at Chandigarh Cyclotron machine, the second part deals with the L-subshell ionization cross-section measurements of heavy elements bombarded with heavy ion projectiles and the third part includes the applications of PIXE and PIGE techniques for trace element analysis in medicinal plants and water samples. The literature survey regarding the theoretical and experimental aspects regarding ionization of inner atomic shells by heavy ion projectiles is discussed in chapter 1. Applications of PIXE and PIGE techniques are also discussed in this chapter. The theoretical aspects of the ion-atom induced ionization processes and subsequent decay processes are discussed in chapter 2. In chapter 3, theoretical aspects of PIXE and PIGE techniques are discussed. The details of the experimental set-up at the Chandigarh Cyclotron and the NCCCM, Hyderabad are given in chapter 4. Details of the experimental set-ups used for L-subshell ionization cross-section measurements at IOP, Bhubaneswar are also included in chapter 4. The x-ray measurements were performed using energy-dispersive detection set-up involving low energy Ge and Si(Li) detectors. Chapter 5 deals with the a systematic study of L sub-shell ionization of some heavy elements ($66 < Z < 73$) by heavy ion projectiles ($4 < Z < 9$) in the energy range 0.5-1.5 MeV/amu. Application of PIXE and PIGE techniques to various environmental samples is discussed in chapter 6.

In chapter 1, the ionization of inner atomic shells by heavy charged particles is discussed from both theoretical and experimental points of view. For heavy-ion projectiles, the disagreement between the experimental measurements and theoretical interpretation for L-subshell ionization often reaches an order of magnitude especially at low projectile energies. The principal reason for such discrepancies is the fact that the theoretical approaches are treating L-subshells independently, neglecting the coupling effects. The possible vacancy transfer between subshells during the collision modifies the L-subshell ionization cross-sections. So, it will be worthwhile to measure L-subshell ionization cross-sections for some high Z elements using heavy ion projectiles with different energies, to contribute to the existing experimental data for systematic studies further. The advantages of PIXE and PIGE techniques for trace element analysis have been discussed.

In chapter 2, available theories about ion-atom collision have been discussed. The purely classical treatment is considered in Binary Encounter Approximation (BEA) theory. The quantum mechanical approach is given in Semi Classical Approximation (SCA), Plane Wave Born Approximation (PWBA) and Perturbed Stationary State (PSS) including the effects of increased Binding energy (B), Polarization of the atomic orbit (P), Relativistic effect for inner shell electrons (R), Coulomb deflection (C) and the Energy loss of the projectile (E) for ionization (ECPSSR) theories. It is further modified to ECUSAR theory to include the United and Separated Atom (USA) treatments of the electron wave function. The ECUSAR theory is further modified as ECPSSR-IS theory in which Intra-shell coupling effect is included. This theory is in better agreement with the experimental data in the lower energy ranges. Inner shell vacancy production although studied for a long time, both experimentally and theoretically, is far from being completely understood. Apart from the intrinsic interest of ion-atom interactions the investigations of the basic ion-solid collision is necessary to understand the various phenomena associated with the penetration of ions through the solid matter. More extensive study and experiments are needed for better understanding of inner shell ionization by heavy ions. This interest is due to the fact that inner shell ionization cross-sections are required in different kinds of applications, e.g. calculations of stopping power, ion implantation, study of solids, plasmas and PIXE technique for trace element analysis of rare earth elements.

In chapter 3, the basic principles of ion-atom interaction processes have been discussed. The process of excitation and ionization of inner shells by heavy charged particles has been investigated. Different processes subsequent to the creation of inner shell vacancies, viz., x-ray, Auger and Coster Kronig transitions are also discussed. Ion-atom collision involves several basic phenomena notably, stopping power, ionization, Rutherford scattering, nuclear reactions etc. Conventionally, protons and alpha particles have been used as major probes for the study of these interactions. Later on, the availability of precisely controlled heavy ion beams from various heavy ion accelerators has broadened the scope of these types of studies. The studies of ion-atom collisions and inner shell ionization by heavy ions, have proven to be an important tool in understanding the complex mechanisms involved in ion-atom interactions.

In chapter 4, the experimental set-up for PIXE measurements at National Centre for Compositional Characterization of Materials (NCCCM), Hyderabad and PIGE set-up at Variable Energy Cyclotron (VEC) have been discussed. Elemental analysis of medicinal plants and water samples has been carried out using PIXE technique. For analysis of PIXE spectrum, the GUPIXWIN code was chosen for qualitative as well as quantitative analysis. GUPIXWIN determines the intensities of characteristic x-ray peak in PIXE spectrum by fitting a model spectrum Mj to the measured spectrum Yj using the non-linear least squares technique. The L x-ray cross-section measurements were performed using heavy ion beams at Institute Of Physics (IOP), Bhubaneswar. Details of experimental chamber and detection system have been discussed in this chapter. A Si(Li) detector was used for the x-ray detection. Data acquisition was done using computer code CANDLE in which a non-linear least squares fitting routine involving fitting of multiple-Gaussian functions plus polynomial background is used. The PIGE set up has been calibrated for thick targets of at Cyclotron lab in Chandigarh and results are discussed in chapter 4. The PIGE set-up was calibrated for ^{7}Li, ^{19}F, ^{23}Na and ^{27}Mg using thick standards. Five standard samples having different concentrations of spectroscopically pure NaF, Mg and LiF powder and graphite powder were prepared and bombarded with the proton beam. From the measured yields, calibration curves have been obtained for ^{7}Li, ^{19}F, ^{23}Na and ^{27}Mg. In the present work, solid state semiconductor detector was used for the detection of γ-rays. The absolute efficiency was determined by means of calibrated radioactive sources of ^{60}C0, ^{133}Ba and ^{152}Eu, placed at target position. The sources of continuous background of gamma spectra induced by ion bombardment have been discussed. It was shown that background has two main contributions – the Bremsstrahlung from the accelerator and the Compton interaction in the detector of radiation lines produced by natural radioactivity, by interaction of the beam with materials found in its path (magnets and slits) and by interaction of the beam with the target.

Chapter 5 includes the results and discussion on measurements of L-subshell cross-section of heavy elements for boron and fluorine ion beams. The ionization of the inner atomic shells by highly charged particles is an important field of atomic collision physics from both theoretical point of view and applications. For highly asymmetric collisions (i.e., $Z_1/Z_2 << 1$, where Z_1 and Z_2 represent the atomic numbers of the projectile and the target, respectively, the direct Coulomb ionization mechanism is a dominating process. In recent years, measurement of x-ray production cross-sections and studies of atomic inner-shell ionization have proven to be important in understanding the complex mechanisms that are involved in ion-atom interaction because various information can be extracted dependent upon the ion-atom collision system and incident particle energies. The L-subshell ionization cross-sections were measured for ^{74}W, ^{79}Au,

^{82}Pb, ^{83}Bi and ^{90}Th atoms bombarded by boron and flourine ions in the energy range 0.4-1 MeV/amu. These measurements were performed at the IOP Bhubaneswar, using 3 UD pelletron (9SDH2 from NEC, USA) facility. The ionization cross-sections for L_1, L_2, and L_3 subshells of studied elements bombarded by boron and fluorine ions were derived from the measured x-ray production cross sections for $L\alpha_{1,2}$, $L\gamma_1$, $L\gamma_{2,3}$ x-ray transitions using recent values of fluorescence yields and Coster-Kronig (CK) transition probabilities. The efficiency of the Si(Li) detector was precisely obtained from the measurement of K and L x-rays induced in thin calibrating targets of Ni (340 μg/cm^2), La (57.3 μg/cm^2), Dy (50 μg/cm^2) , Au (150 μg/cm^2) and Pb (150 μg/cm^2) by 3 MeV protons from the tandem accelerator. In this method for determination of total detector efficiency the "reference" K-shell and L-shell ionization cross-sections of Paul and Muhr were used, together with the Fluorescence yields of Chen *et al.* and the emissions rates of Schofield. The ion beam changes its charge state when it is made to pass through the target. The measured ion beam current has been corrected using the computer code ETACHA, which calculated the distribution in charge state of ion beam after passing through the target and its backing material. It was found that the ionization cross-sections for the ^{11}B and ^{19}F with different energies are almost independent of the charge state. Thus, the ionization cross-sections mainly depend upon the incident ion energy. The measured L_i subshell ionization cross-sections were compared with those calculated using different theoretical approaches viz. PWBA, ECPSSR and ECPSSR-IS. In the ECPSSR-IS theory, the intrashell (IS) coupling is accounted for by multiplicative factors of Sarkadi and Mukoyama normalized. For the singly ionized atoms, recent values of fluorescence and CK yields were used. The L_i subshell ionization cross-sections measured in the present work are about three times lower than those calculated using PWBA based ionization cross-sections at lower energies. Better agreement was found between experimental data and the predictions of the ECPSSR-IS theory. While the IS transitions had practically no influence on L_3-subshell ionization, at small impact parameters L_2-subshell ionization was particularly strongly enhanced and the probability for L_1 ionization was depressed.

In chapter 6, trace element analysis of medicinal plants and water samples has been discussed. Samples of the different medicinal plants were collected from various areas of Chandigarh, a northern state of India. Thirteen different elements namely S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Cu, Zn and Se were detected at different concentrations. The concentrations of potassium and calcium were relatively high and found to be major elements in these plants. The minor elements include sulfur, chlorine and iron. The trace elements include scandium, titanium, vanadium, Chromium, Manganese, copper, zinc and selenium. Comparison of elemental concentrations in some medicinal plants common to this study and other similar studies was done and considerable differences in the concentration values were found. These differences can be attributed to several factors like differences between sites from where the plant samples were collected, preferential absorbability of the plant, use of fertilizers and irrigation water and difference in techniques used for trace element analysis. Water samples were collected from the villages and dams near Chandigarh and villages of Bathinda district. For sample preparation, preconcentration technique was used. Results indicated that the concentrations of heavy elements are at elevated levels in the villages of Bathinda district as compared to the locations near Chandigarh. Thus, presence of these toxic elements in drinking water samples from Bathinda area can be the cause of a large number of cancer deaths in the area. Toxic nature of water and soil due to the presence of heavy metals is responsible for the rise in cases of heart and lung diseases in Bathinda region. PIGE analysis of soil and water samples has been done. Soil and water samples were collected from different areas around Chandigarh and Malwa region of Punjab. Concentrations of F and Na was found in these samples using PIGE technique.