CHAPTER I

GENERAL INTRODUCTION AND SCOPE AND CONTENT

OF THE PRESENT WORK
The energetic charged particles moving through a solid medium lose energy by elastic and inelastic interaction with electrons and nuclei of the atoms in the medium. It is known that the many body character of the problem imposes serious difficulties to understand the various mechanisms for the energy-loss process of the projectile when its velocity changes in traversing the solid. Attempts\textsuperscript{1-12} have been made to make the in-depth study of the process and to generate a suitable equation valid for all velocities and ion-target combinations. The energy-loss of the projectiles are considered to be due to a large number of small scattering angle collisions with electrons in the medium. These collisions produce excitation and ionisation of the electrons close to the path of the projectiles (close collisions). They also produce resonant excitation and ionisation far from the particle path (distant collisions). The energy-loss is shared between close and distant collisions.

The problem of energy-loss of a non relativistic positively charged particle was investigated by Bethe\textsuperscript{13} by inelastic encounter with the electrons in the stopping medium. The investigation led to the following expression

\[
- \frac{\mathrm{d}E}{\mathrm{d}x} = \frac{4\pi e^4 z^2}{\mu v^2} \, N \, Z \, \ln \left( \frac{2 \mu v^2}{1} \right) \quad \cdots \quad (1.1)
\]

where \(\mathrm{d}E\) is the energy transferred to the element of path length \(\mathrm{d}x\), to a homogeneous medium containing \(N\) atoms per cm\(^3\) each of
atomic number $Z$, $I$ is the average excitation potential of the medium, $m$ is the electronic mass and $v$ is the velocity of the incident particle. For relativistic electrons the energy loss was also worked out by Bethe\textsuperscript{14} using Møller's formula\textsuperscript{15} for scattering of electron by electron and the derived expression is

$$-\frac{dE}{dx} = \frac{2\pi Ne^4}{mv^2} Z \left[ \log \frac{mv^2E}{2l^2} - (2 \sqrt{1-\beta^2} - 1 + \beta^2) \log 2 \\
+ (1 - \beta^2) + 1/8 (1 - \sqrt{1 - \beta^2}) \right] \quad (1.2)$$

where $E$ is the energy of the electron and $\beta = v/c$.

The cross section of energy loss process depends on the impact-parameter of collision with the individual target atoms. The target material was assumed to be homogeneous and isotropic for the derivation of the expressions (1.1) and (1.2). The distribution of impact parameter was dependent on the relative orientation of the beam and the target. But in a crystalline target the distribution of impact parameters depends on the orientation of the target with respect to the beam. When a positively charged particle is incident along a high-symmetry axis in a crystal, it undergoes a series of correlated small angle collisions and the resulting guiding effect causes the particle to oscillate to and fro in the open 'channels' between atomic rows or planes as shown schematically in Fig. 1.1 (page 4). This effect is commonly known as channeling and the yields of close encounter processes (like Rutherford Scattering, energy-loss processes, secondary electron emission, nuclear reaction, X-ray
Fig. 1.1 Interaction of channeled particles with the string of linear arrays of atoms.
production etc.) are sharply reduced under these conditions.

Reports on the reduction of energy-loss for low and high energy ions in crystalline medium are available from the works of Davies et al\textsuperscript{16} and Dearnaley\textsuperscript{17}. A lot of works\textsuperscript{18-26} on channeling phenomena have accumulated. J. Lindhard\textsuperscript{19} made some theoretical investigations on channeling and assumed a continuous potential $U(r)$ on the moving particle provided the distance of closest approach towards an individual atom is larger than a certain critical distance. The particle is then subjected to conservation of its transverse energy given by

$$U(F) + E\psi^2(F) = E_\perp = \text{constant} \quad \cdots \quad (1.3)$$

$U(r)$ is small near the center of the channel and rises steeply if the particle approaches the atomic row or string where $E\psi^2(F) = \frac{1}{2} M_\perp^2$ is the kinetic energy of transverse motion of the particle and $\psi(F)$ is the instantaneous angle towards the row direction (Fig. 1.1 page 4) and $E = \frac{1}{2} Mv^2$ is the total kinetic energy of the particle. For high velocity of the particle the individual atomic fields will blur into composite effective potential called continuum potential, which can be obtained for a particular atomic row by uniformly smearing the atoms over the row. This potential is given by

$$U(F) = \frac{1}{d_\perp} \int^{+\infty}_{-\infty} V(\sqrt{\rho^2 + x^2}) \, dx \quad \cdots \quad (1.4)$$

where $V(F)$ is the ion-atom potential, $d_\perp$ is the distance between
successive atoms in the string. The ion atom potential contour for I ions along (011) rows of Ag is shown in Fig. 1.2 (page 7). The Thomas-Fermi type \( V(r) \) is

\[
V(r) = \frac{z z J e^2}{r} \phi_0 \left( \frac{r}{a} \right) \quad \ldots \quad (1.5)
\]

where \( \phi_0 (r/a) \) is the Fermi-function and \( r \) is not very large compared to \( a \), the screening length of the ion-atom interaction. From equations (1.5) and (1.4) we get

\[
U(\varphi) = \frac{2 z z J e^2}{d_1} f \left( \frac{\varphi}{a} \right) \quad \ldots \quad (1.6)
\]

where \( f(\varphi/a) = \ln \left[ 1 + \frac{C^2}{(\varphi/a)^2} \right]^{1/2} \) is the Lindhard-type screening function with \( C \), a constant of value \( \sqrt{3} \).

The continuum model of scattering is only valid for ions which remain relatively far from the atomic strings and at low transverse angle to them. The limiting condition may be expressed in terms of distance of closest approach \( \varphi_c \) or critical angle \( \psi_c \) as

\[
U(\varphi_c) = E \psi_c^2 \quad \ldots \quad \ldots \quad (1.7)
\]

Morgan and Van-Vliet\textsuperscript{27} using computer simulation, found a rather sharp transition between channeled trajectories at low transverse angles and non-channeled trajectories at higher angles. At the transition point of closest approach to the strings

\[
U''(\varphi_{\text{min}}) \simeq \frac{5 E}{d_1^2} \quad \ldots \quad \ldots \quad (1.8)
\]
TWO-COMPONENT WAVE FUNCTION IN DYNAMICAL DIFFRACTION THEORY

\[ \phi(r) = e^{ikr} u(r) \]

\[ u(r) = \text{function having periodicity of the lattice} \]

Schematic of two-component wave function for dynamical diffraction theory. Upper component has lower-than-normal interaction rate, while lower component has higher-than-normal interaction rate.

Fig. 1.2 - Taken from D. K. Brice.
Numerical solution of equation (1.8) can be given by using Moliere's potential as

\[ \rho_{\text{min}}/a \simeq \frac{2}{3} \sqrt{\alpha} \left( 1 - \sqrt{\alpha}/19 + \alpha/700 \right) \quad \ldots \quad (1.9) \]

where \( \alpha = \frac{zz_1 e^2 d_1}{a^2 E} \)

Again, the atoms are not located precisely along the string but are in fact slightly displaced due to their constant thermal vibrations. Barrett calculated the correction due to thermal vibration by using computer simulation and interpreted it as \( \rho' \simeq 1.2 \chi_{\text{rms}} \) where \( \chi_{\text{rms}} \) is the rms value of the vibrational amplitude. From both the calculations, the critical approach distance may be expressed as

\[ \rho_c^2 \simeq \rho_{\text{min}}^2 + (1.2 \chi_{\text{rms}})^2 \quad \ldots \quad (1.10) \]

In the high energy limit, the maximum allowed transverse angle \( \psi_c \) may be obtained from equations (1.6), (1.7) and (1.10) as

\[ \psi_c \simeq \left[ \frac{U (1.2 \chi_{\text{rms}})}{E} \right]^{1/2} \]

\[ \simeq \left[ \frac{2zz_1 e^2}{E \frac{d_1}{y}} \right]^{1/2} f (1.2 \chi_{\text{rms}}/a)^{1/2} \quad \ldots \quad (1.11) \]

Since \( f (1.2 \chi_{\text{rms}}/a)^{1/2} \) is generally of the order of unity \( \psi_c \) is of the order of Lindhard characteristic angle \( \psi_1 \) as

\[ \psi_1 = \left[ \frac{2zz_1 e^2}{E \frac{d_1}{y}} \right]^{1/2} \quad \ldots \quad \ldots \quad (1.12) \]
The trajectories of ions channeled in crystalline solids are governed by their interaction with the interatomic potentials of the atoms making up the planes or atomic strings. The magnitude of channeling is associated with the distance of the point of entrance of the particles from an atomic row or plane. Since the electron-density close to atomic planes is higher than that at channel center\textsuperscript{30}, the energy-loss of particles incident closer to the planes will be higher. Nelson and Thompson\textsuperscript{20} found that the penetration of 75 KeV protons through thin crystals of Au was greatly enhanced along major crystal directions. They also observed sharp minima in the scattering of 50 KeV H\textsuperscript{+}, He\textsuperscript{+}, Ne\textsuperscript{+} and Xe\textsuperscript{+} ions from a Cu crystal whenever the incident beam direction coincided with low index axes or planes of the target crystals. The strong dependence of nuclear reaction yields on target crystal orientation was observed for \((p, \gamma)\) reaction in a Si crystal\textsuperscript{31} and \((p, n)\) reaction in a Cu crystal\textsuperscript{32}. Transmission pattern recorded for 2.43 MeV protons incident along <111> direction of Ge-crystal\textsuperscript{33} shows a central dark-spot (star-pattern) which corresponds to regions of high particle intensity. Channeling of different energetic particles has also been observed\textsuperscript{34-38} by measuring range in different crystalline and polycrystalline targets.

Most of the studies on channeling have been carried out earlier with heavy and positively charged particles because of existing theoretical supports. Later electron channeling has
Fig. 1.3: Schematic illustration of the planar continuum potentials for (a) positrons and (b) electrons. The shaded areas correspond to the potential wells in which channeled particles can move.

Taken from D S Gemmell
however made its entry into the arena of studies on channeling phenomena. Study of materials with electron beam has an advantage over that with ions in that it produces less radiation damage in materials. Uggerhøj observed the channeling of electrons and positrons emitted by $^{64}$Cu embedded in single crystals of copper. A group of workers demonstrated the phenomena of channeling of 700 keV electrons through thin single crystals along various crystallographic directions. An anomalously large electron penetration in crystalline material was observed by Vorobiev et al., which was explained to be due to channeling phenomena. For electrons and other particles carrying a single negative charge the continuum potential is simply negative of that governing the motion of protons and positrons as in Fig. 1.3 (page 10). As a result positrons and protons are steered away from the higher potential regions of the rows of atoms and the electrons are attracted towards them. This leads to an increase in the probability for physical processes involving small impact-parameter collisions for the former particles and a decrease in such processes for the later. Studies of high voltage electron microscopy have established beyond doubt that in interaction of low energy electrons with crystals the quantum diffraction effects play a vital role. This interaction can be explained by dynamical diffraction theory. For electron energy less than 100 keV and for thick targets only two Bloch waves are excited with appreciable intensity. One wave has nodes
Fig. 1-4 Potential energy contours for I ions in the continuum potentials of $\langle 011 \rangle$ rows (R) of Ag atoms. All values are in eV are relative to the minimum (●) which has an absolute value of 72 eV.
at the atomic sites and the other has maxima at these sites (Fig. 1.4, page 12). The interaction rates with crystal atoms will be lower than average for components having nodes at the atomic sites and higher than average for components having maxima at these sites. The intensity with which Bloch-waves are excited depends on crystal orientation and the energy of the incident beam. It has been shown by previously referred workers that as many Bloch waves become excited the channeling behaviour become more nearly classical. Pyrlk observed crystal orientation dependence of electron (50 KeV) energy loss through monocrystalline silver films and suggested a possible explanation on the basis of dynamical theory of electron diffraction.

The applicability of classical mechanics to particle channeling depends on the velocity and mass of the incident particles, on the atomic number of the incident particle and target material and on symmetry directions and planes. For electrons with relativistic speed \((E > m_o c^2)\) the relativistic increase in mass will reduce the barrier tunneling effect and may lead to a more nearly classical solution to the problem. Models for interpretation of electron channeling using classical ideas include semiclassical theory of electron diffraction, Nip's weavon model, rossette motion of electrons around the rows of atoms etc.

The \(<100>\) axis of the ionic crystals like NaCl and KCl
has been found to be the most open channel for electrons\textsuperscript{42} and also for heavy positive particles\textsuperscript{56}. Mukherjee et al\textsuperscript{43} and Ba\textsuperscript{57}u et al\textsuperscript{57} have reported range measurements in KCl crystals. It was found that along the channels with low values of indices, the electron energy-losses are small and consequently the depths of electron penetration are large. An investigation of channeling with electrons was made by Kaplin and Vorobiev\textsuperscript{58} by measuring the Rutherford scattering of electrons in 28 \( \mu \)m KBr crystals. An anomalous transmission of swift electrons was observed in an ionic structure which was explained to be due to ionic electrostatic field.

So long the discussion was made on channeling phenomenon in solids, and with a little digression to another type of phenomenon, a relevant discussion may be made in this connection. An ion of energy \( E \) incident on a crystal at an angle \( \psi_1 \) is associated with a transverse kinetic energy \( (E\psi_1^2) \) and a transverse potential energy \( (\phi_1) \) at its point of entrance into the channel. While moving through the crystal the ion acquires additional transverse energy \( (E_{1\alpha}) \) due to multiple scattering\textsuperscript{59} by electrons, lattice vibrations and imperfections. If the total transverse energy \( (E_{1}) \) of the incident charged particle becomes larger than the critical value for stable channeling \( (E\psi_c^2) \), the particles are lost from the channel\textsuperscript{22,23}. This is always the case whenever the particles penetrate to some appreciable depth. On the average, \( E_1 \) drifts towards a higher value moving the
trajectory closer to the target atoms resulting in stronger interaction and dechanneling.

The theory of dechanneling is developed starting from Lindhard's point of view \(^{19}\). In this scheme, the dechanneling process is described by the angular dispersion of a collimated beam because of interaction both with the electrons and with the vibrating nuclei of the crystal. The transverse energy changes experienced by a channeled ion in a single elementary interaction is small and hence the overall dispersion can be described by a statistical treatment i.e. a diffusion in transverse energy under proper boundary conditions and symmetries \(^{19}\). The initial normalized distribution \(g(E_{\perp}, 0)\) of transverse energy for a beam incident parallel to a major axial direction is determined by its divergence outside the crystal. The divergence is a result of multiple scattering and the transverse continuum potential energies acquired by the beam particles as they uniformly illuminate and enter the axially aligned rows of atoms. For a well collimated beam and for a clean and structurally perfect crystal surface, the distribution \(g(E_{\perp}, 0)\) is sharply peaked about \(E_{\perp} = 0\). Under these conditions the development of \(g(E_{\perp}, x)\) as the beam proceeds into the target will initially be determined mostly by the dominating electronic multiple scattering. As the transverse energy increases, the nuclear multiple scattering plays a growing and eventually a dominant role. For individual beam particles the changes in transverse
energy at successive scatterings are in the nature of a random walk process, there being a net drift towards higher transverse energies. The distribution in transverse energy can therefore be described by a diffusion equation

\[
\frac{\partial g(E_\perp, x)}{\partial x} = \frac{\partial}{\partial E_\perp} \left[ D(E_\perp) \frac{\partial}{\partial E_\perp} g(E_\perp, x) \right] \tag{1.13}
\]

where \( D(E_\perp) \) is the diffusion function. Once the initial distribution \( g(E_\perp, 0) \) is given then \( g(E_\perp, x) \) can be found by solving (1.13). If one makes the assumption that those beam particles with transverse energies greater than some critical value \( E_\perp, \text{crit} \) are dechanneled, the dechanneled fraction as a function of depth is given by

\[
1 - f_{\text{ch}}(x) = \int_{E_\perp, \text{crit}}^{\infty} g(E_\perp, x) \, dE_\perp \tag{1.14}
\]

Dechanneling has been calculated in this fashion by Morita and Itoh, Kumakhov and coworkers and Bonderup et al. A somewhat different approach to the calculation of axial dechanneling has been given by Elleegaard and Lassen. Making some simplifying assumptions, the authors derived a formula which gave a good fit to their experimental data. They assumed angular distribution of the beam inside the crystal to have the Gaussian form

\[
P_{\text{ms}}(\varphi) \, 2\pi d\varphi = (2\pi d\varphi/n^2) \exp (-\varphi^2/n^2) \tag{1.15}
\]

and with \( n^2 = (x/L_\perp)^2 \) ...

\[
\tag{1.16}
\]
where \( L_1 \) is a constant equal to depth required for \( \Omega^2 \) to grow as large as \( \psi^2 \), \( \phi \) is the instantaneous angle between particle trajectory and axis, \( P_{ms}(\phi) \) is the multiple scattering distribution and \( \Omega \) is the rms multiple scattering angle. The dechanneled fraction is then assumed to be

\[
1 - f_{ch}(x) = \int_{\psi_1}^{\infty} P_{ms}(\phi) 2\pi \phi d\phi = \exp \left( -\frac{\psi^2}{\Omega^2} \right) = \exp \left( -\frac{L_1}{x} \right) \quad \ldots \quad (1.17)
\]

For planar dechanneling, considerations apply similar to those already discussed for the axial case. A diffusion model for the escape of particles from planar channels was developed by Feldman et al \(^{67} \) and Thompson \(^{67} \). Feldman et al were able to obtain good fits to a variety of experimental data on planar dechanneling. For depths greater than a few microns the calculated expression for the channelled fraction becomes approximately

\[
f_{ch}(x) = \text{const.} \exp \left( -0.693x/x_{1/2} \right) \quad \ldots \quad (1.18)
\]

where \( x_{1/2} \) the half thickness for dechanneling, is proportional to \( \psi_c^2/D \), \( D \) being a diffusion constant.

The dechanneled fraction has been calculated from above theory for a few ions and targets and along different axes or planes \(^{65,68,69} \) and the results agree well with the experimental data. To develop a similar theory for electron dechanneling the quantum effects \(^{70,71} \) should be taken into account. Since then
major experimental and theoretical efforts in the field of radiation study were devoted to dechanneling measurements.

A possible perturbation of the transverse energy results from imperfections in lattice e.g. displaced atoms, foreign atoms, dislocations, subgrains, and other boundaries, region damaged by radiation or deformed by elastic strains. Morita and Sizmann divided the process of defect induced dechanneling into instantaneous and delayed dechanneling, the former referring to dechanneling due to single large angle scattering event while the latter refers to successive small angle deflections resulting in loss of alignment of the projectile leading to dechanneling. These authors found that delayed dechanneling is much more effective than instantaneous dechanneling. This happens because the fraction of particles which can directly hit the imperfection to be deflected by large angles is small compared to the majority of remaining particles which can undergo small deflections successively and hence contribute to delayed dechanneling. Dechanneling by defects may be classified in another way. When the projectile directly hits the defect or is scattered in the potential field of the defect and the trajectory is modified as a consequence, the dechanneling is said to be of obstruction type. The atoms in interstitial sites cause obstruction type of dechanneling. If on the other hand, the defect gives rise to distortion in a certain region of the crystal disturbing the regularity of the material in that region
the dechanneling is of distortion type. The dislocations are
the most important type of defects causing distortion dechannel-
ing. Very frequently the dechanneling caused by the defects is
neither purely of the obstruction type nor of the distortion
type but rather a combination of both, termed as composite
dechanneling. The examples of defects are voids, gas bubbles etc.
A channeled particle can experience instantaneous dechanneling
on a defect or with a greater probability it can have delayed
dechanneling which on the average is likely to increase the
transverse energy of the projectile. It is felt that lattice
vacancies may likewise manifest themselves as scattering centers
and dechannel the incident charged particles.

Joussett et al\textsuperscript{62,83} studied the dechanneling of $\alpha$-particles
by hydrogen and carbon interstitials in Rl-crystals using
Rutherford scattering from impurities. Quéré and co-workers\textsuperscript{84-86}
extensively studied dechanneling from dislocations with the
assumption of a 'dechanneling cylinder' around dislocation line.
A large number of theoretical and experimental studies\textsuperscript{87-96} of
defect induced dechanneling of positively charged particles
have been accumulated in recent years. The scattering of electron
from defects and disorder in thin crystals was studied by sev-
eral authors\textsuperscript{97-99} using dynamical diffraction theory in electron
microscopy. Dechanneling of electrons by vacancies produced by
thermal treatment was also studied by Basu et al\textsuperscript{100}. 
In certain transmission experiments with thick crystal foils a fraction of randomly incident beam is observed to emerge as channeled projectiles\textsuperscript{101}. Such feeding-in of random particles is only possible via scattering at lattice imperfections. The experiment on the measurements of defect enhanced dechanneling of particles in crystal may be used to estimate the spatial distribution of lattice defects\textsuperscript{102}. Dechanneling experiments are useful in the semi-qualitative determination\textsuperscript{103} of defect concentrations.

It is known that a crystal when heat treated and subsequently quenched, produces lattice vacancies and interstitial atoms. In case of ionic crystals like sodium chloride or potassium chloride, the defects that are produced are mostly Schottky type of defects or vacancies. This is one of the aims of the present investigation to observe the range profile of the charged particles while moving through the defect inundated crystals. Alternatively, such an investigation may provide a simple means to have an idea of the energy-loss of the charged particles either light or heavy. Alkali halides are the simplest type of ionic crystals and are easily obtained in the form of large single crystals. They are transparent in the entire visible range of electromagnetic wave. These crystals are insulators with large energy gap of the order of 10 eV. Their optical spectra corresponding to the transition of electron from the valence band to the conduction band lie in the ultraviolet region.
One or more peaks due to absorptions by excitons are formed in the long-wavelength side of the ionization levels. New absorption bands\textsuperscript{104} can be created by irradiation of the crystal by ionizing radiation e.g. x-rays and \( \gamma \)-rays and by charged particles. Some of these bands are due to holes or electrons trapped at defects in the crystals and are known as color-center bands.

There is a number of review articles\textsuperscript{104-106} on the nature of color-centers, their optical, electrical and other properties. Of the various color centers, F-centers formed by trapping of electron in the anion vacancy is the simplest and most stable. So it has been the focal point of the color-center research. According to Tibbs\textsuperscript{107} F-band corresponds to \( {1s-2p} \) transition of F-center electron. A number of color centers giving rise to optical transition bands on the long wavelength side of the F-band received far less attention than F-band. These centers M, R and N are F-aggregate centers because they are found to bear genetic relationship to the F-center.

A number of workers\textsuperscript{108-112} studied the mechanism of formation of color-centers by ionizing radiation and by other energetic particles. To create an F-center some amount of energy is required. This energy of F-center formation known as efficiency of F-center formation (\( \eta = n_i E_i / n_F \), where \( n_i \) and \( n_F \) are the number of incident particles per cm\(^2\) and number of F-centers produced per cm\(^2\) respectively and \( E_i \) is the energy of the incident particles), has been estimated by many authors\textsuperscript{108-110}.
Rabin and Klick have shown that the F-center formation energy is of the order of several KeV. According to Varley model of F-center formation, the energy required to form an F-center should be independent of the energy of the ionizing radiation. The experimental results of Hermann and Pinnard support the Varley mechanism. Experiments of Porreca show that the energy of F-center formation depends on the energy of radiation (for high energies) and support Ritz model.

Charged particles while passing through alkali halide crystals lose energy and form F-center along their path. Thus in the crystals irradiated with charged particles the depth of coloration may be considered as the depth of penetration of the particles in the matrix. Choudhury et al. studied the electron ranges in crystalline solids (like NaCl and KCl) by observing the number of F-centers formed by the incident electrons along their path. The method has also been applied by Mukherjee et al. and Basu et al. for various related measurement of channeling and dechanneling phenomena. Similar measurements of depth of coloration of proton and helium ions of energy between 300 KeV and 1.7 MeV in alkali halides were made by Hehl et al.

The purpose of the present work is to investigate the influence of lattice defects on the channeling and energy loss of α-particles and electrons in alkali halide crystals. To produce lattice defects, external impurities like Mg$^{2+}$ has been incorporated into the crystals. A number of cation vacancies
equal to that of impurity concentration are produced to maintain the electrical neutrality of the crystal. Lattice vacancies can be produced in a crystal by quenching it from a high temperature to room temperature. The quenched crystal retains the vacancies of the higher temperature\textsuperscript{116,117}. Among the lattice vacancies Schottky type vacancies are predominant in alkali halide crystals\textsuperscript{116}. The number of Schottky pairs at a temperature $T(K)$ is given by

$$n = n_0 \exp \left(-\frac{W_s}{2kT}\right) \quad \ldots \quad (1.19)$$

where $n_0$ is the total number of ion pairs, $W_s$ is the energy required to produce a Schottky pair and $k$ is the Boltzmann constant. The value of $W_s$ for NaCl and KCl crystals varies between 1.9 and 2.1 eV. Since the quenched crystals are known to retain the vacancies of the higher temperature, it is felt that if the impurity-doped crystals are quenched from a high temperature, the thermally produced vacancies may have a chance to interact with the impurities. It is presumed that the range of charged particles in such specimens may be different because of the interactions of two different type of defects. With this aim an experiment has been conducted to observe the mode of electron channeling in the quenched and impurity doped crystals. This investigation could help to generate new idea as to the production of different defect structures in crystals. Regarding other features of the present investigations, it is felt convenient
to undertake calculations as to find theoretically the range 
\[ R = \int_0^\infty \frac{dE}{(dE/dx)} \] of \( \alpha \)-particles in undoped crystals.

The introduction of a point defect induces displacement of the lattice atoms which surround it. When the symmetry of the lattice thus lowered, the induced displacements are said to result in a distortion of the lattice. Lattice distortion can be of elastic and electrostatic origin. Because of the relaxation and distortion of the lattice around a defect, there is an associated strain energy. The elastic interaction varies as \( r^{-3} \) where \( r \) is the position vector of the observation point. In case of charged defects in alkali halide crystals there is an associated coulomb energy which varies as \( r^{-1} \). The long range character of distortion around a charged defect mainly results from coulomb interaction. Hall showed that such distortion has a high degree of anisotropy and in an otherwise perfect lattice they may disturb the channel potential.

When the lattice defects are small in number they are distributed over larger region and are treated as singular defects. As the number of defects increases they tend to pair. A defect that induces a lattice compression will tend to pair with a defect that induces a lattice expansion. On the other hand a charged defect forms a pair with a charged defect of opposite sign. When the concentration of a particular type of defect is large, they tend to form clusters. The concentration of clusters at a temperature \( T(K) \) is given by.
\[ C_n = A_n C_1^n \exp \left( \frac{B_n}{KT} \right) \]  \hfill (1.20)

where \( A_n \) is a geometrical factor, \( B_n \) is the binding energy of the defect complex and \( C_1 \) is the concentration of singular defect.

The singular defects and clusters are expected to behave differently in crystal lattice as scattering centers to the motion of charged particles through the crystal. The coulomb field of a singular defect is very much reduced when they form clusters\(^\text{118}\). Again, when many singular defects form cluster, they may arrange themselves regularly over the lattice so that the anisotropic strains of one annul to a great extent those of the other and the crystal is little affected\(^\text{122}\).

The process of disappearence of defects occurs in materials containing defects in concentration larger than the thermodynamic equilibrium concentration. Thermodynamic driving forces reduce the concentration of defects to the equilibrium concentration, characteristic of the material and of the temperature\(^\text{123}\). On quenching from a high temperature to a low temperature a large supersaturation of single vacancies are produced. They disappear by migration to grain-boundaries, dislocations, voids etc. or by spontaneous nucleation of secondary defects\(^\text{124-126}\). High temperature quenching (above 600\(^\circ\)C) produces a number of dislocations and divacancy clusters\(^\text{127,128}\) which further enhance the disappearence of singular defects.
It has been shown that for low temperature of quench the super-saturation of vacancies is not sufficient for the formation of loops etc. while above some critical temperature of quenching loops are formed appreciably. Consequently the crystals are expected to be fairly transparent to the particle beam below a certain temperature of quench and above that temperature the process through which the particle range changes with the temperature of heat treatment is in course of investigation. Some additional specimens doped with known concentration of impurities were studied with a view to observe dechanneling of α-particles due to both distortion and obstruction effects of the impurities embedded in the crystals. Such a study is important from theoretical and experimental points of view but attracted limited attention only.

These are the considerations which led to undertake a systematic investigation on the energy-loss of charged particles (α-particles and electrons) in different crystallographic directions of pure and impurity-doped sodium chloride and potassium chloride crystals.
SCOPE AND CONTENT OF THE PRESENT WORK

Alkali halides are transparent over a wide range of wavelengths from 200 nm to 15 nm, new absorption bands or color centers as they are termed may be created by irradiating the crystals with ionizing radiations like α-particles or electrons. The color centers that are produced at the expense of energy from the incident particles along their path are used to determine their range in the corresponding medium. The problem was undertaken with a view to observe the anisotropy in range of α-particles and electrons in cubic ionic crystals ultimately leading to problems of channeling and dechanneling of the particles. Since it is difficult to make thin crystalline wafers of NaCl and KCl to within desired accuracy, the transmission technique cannot be applied efficiently for the purpose. Consequently a simple method as to observe the F-center distribution was undertaken at various depths below the irradiated samples.

In order to measure the depth of coloration the optical density due to F-centers was observed at different depths below the crystals cut along <100> and <110> directions. Attempts have been made to evaluate the energy loss value theoretically and compared with the corresponding experimentally observed values. The efficiency of F-center formation by α-particles or electrons has been estimated in all cases, because this is an
important factor to have a proper understanding of the mechanism of energy loss in the medium.

The influence of lattice defects (Schottky defects or foreign impurities) on the F-center production has been studied. The channel potential $U(r)$ is naturally expected to change when these defects are incorporated in the matrix, causing thereby a change in the depth of penetration of the particles. The ranges of $\alpha$-particles (between 40 MeV and 50 MeV) in NaCl and KCl crystals, heat treated at various temperatures (from 300K to 973K) have been observed through F-coloration depth. The range indicates a relation with the temperature of heat treatment i.e. with the vacancy creation and dissolution in the crystals. In case of impurity doped crystals (Mg and Al), the range is found to be shorter than that of pure crystals. The efficiency of F-center formation is found to be independent of orientation and concentration of both type of impurities in the crystals.

It is interesting to know how the different species of defects interact in an ionic crystal. In course of this investigation, the electron range (50 KeV) has been estimated in doped NaCl crystals quenched from different temperatures. The results are fascinating and attempts have been made to interpret them in terms of recent observations.
The present investigation comprises the following experimental works:

1) Arrangement for crystal growing, cutting and surface preparation of crystals by wet cut technique.

2) Production of F-centers by irradiation with α-particles of energy between 28 MeV and 50 MeV in pure and defect induced crystal of NaCl and KCl at room temperature.

3) Production of F-centers by irradiation with 50 KeV electrons in pure and impurity doped crystals quenched from different temperatures to room temperature.

4) Arrangement for the photoelectric scanning of the F-absorption spectra.

5) Estimation of the depth of penetration of charged particles in the crystals by surface stripping technique.