CHAPTER II

SURVEY OF LITERATURE
In this Chapter we make a brief survey of the energy loss of electrons in their interaction with atoms in a condensed medium, with special reference to density effect and external bremsstrahlung in the optical region. In fact, the density effect discussed in literature so far does not take into account the type of effect we are studying, hence our survey is only qualitative. We mention the salient features of the interaction of beta particles with matter as we have used beta particles in our investigations. We describe the nature of polarisation of the medium in the case of a ferroelectric and indicate the relevance of the distinction between the electronic polarisability of the atoms and the polarisation in a crystalline medium which results from the lack of a centre of inversion symmetry in the charge distribution in the unit cell to density effect.

Interaction of Electrons with Matter

The mechanism by which electrons lose energy in a medium is well understood and has been treated theoretically. In fact, the topic is as old as atomic physics itself and is treated well in all standard text books and in many review articles. The quantum mechanical theory of the
average energy loss by excitation and ionization per unit path length of the electron in the medium was worked out by Bethe\(^9,10\) and also by Bloch\(^11\).

The Bethe-Bloch expression for the stopping power is

\[
\frac{dE}{dx} = \frac{2\pi e^4}{m_0 v^2} N Z \left[ \log \frac{m_0 v^2 E}{2 Z^2 (1 - \frac{v^2}{c^2})} - \left( 2\sqrt{1 - \beta^2} - 1 + \beta^2 \right) \log 2 \right] + 1 - \beta^2 + \frac{1}{8} (1 - \sqrt{1 - \beta^2})^2
\]

where

- \(N\) = number of atoms per unit volume in the target
- \(Z\) = atomic number of the target atoms
- \(I\) = geometric mean excitation and ionization potential of the target atom
- \(e\) = electron charge
- \(m_0\) = rest mass of the electron
- \(V\) = velocity of the incident electron
- \(E\) = kinetic energy of the incident electron

\[E = \frac{1}{2} m V^2\]
In the non-relativistic case we get

\[
- \frac{dE}{dx} = \frac{4\pi e^4}{m_0 v^2} E \ln \left( \frac{m_0 v^2}{I} \right)
\]

Here the mean excitation potential is defined by the relation

\[
3 \ln I = \sum_{n, l} f_{n, l} \ln \frac{\Lambda_{n, l}}{\Lambda_{n, l}}
\]

where \( f_{n, l} \) is the sum of the oscillator strengths for all electrons in the \( n, l \) shell and \( \Lambda_{n, l} \) is the mean excitation energy of the \( n, l \) shell. To a good approximation \( f_{n, l} \) may be put equal to unity and \( \Lambda_{n, l} \) equal to the ionisation potential.

Attempts have been made theoretically to calculate the value of \( I \) by using hydrogen-like wave functions\(^9,12\) and also by using the Thomas-Fermi model\(^11\). But it is found that empirically determined values of \( I \) obtained by substituting experimental values of stopping power into (2.1), give better overall agreement between theory and experiment. The evaluation of \( I \) from empirical data is
reviewed by Bethe and Ashkin\textsuperscript{2} and also by Allison and Marshaw\textsuperscript{13}. The "best values" of $I$ are compiled by Barke and Berger\textsuperscript{14}.

In the case of a compound, the mean energy loss is taken to be the sum of the losses in the constituent elements. That is, in the case of a compound we replace log $I$ by its value averaged over the constituent atoms. This Bragg's rule is generally valid but some noticeable discrepancies have been reported specially in the case of organic compounds\textsuperscript{15}. More important effect of condensed state of the material on the energy loss of a charged particle is the density effect.

As mentioned earlier, Swann\textsuperscript{16} pointed out that in the case of interaction of high energy electrons with atoms in a condensed medium, presence of intermediate atoms between the incident electron and the distant atom being excited, reduces the probability of energy transfer because of the atomic polarization of the intervening atoms. Fermi\textsuperscript{17} was the first to work out a detailed theory of density effect which has been further developed by Halpern and Hall\textsuperscript{18}, Budini\textsuperscript{19} and more extensively by Sternheimer in a series of papers\textsuperscript{20}. The density effect has been reviewed
from time to time. All these treatments take only atomic polarizability into account.

Electrons also lose energy through bremsstrahlung. Both classical and quantum mechanical theories of bremsstrahlung have been worked out. Explicit expressions for the cross section differential in photon energy and angle of emission obtained under different assumptions have been collected together and reviewed by Koch and Nuss.

Similarly, the theory of Cerenkov radiation was worked out by Frank and Pamm. In essence, if the velocity of the charged particle in a transparent medium of refractive index \( n \) is greater than \( c/n \) where \( c \) is the velocity of light in vacuum, light will be emitted mostly in the visible region. Though the radiation is limited to a cone, in the case of electrons which undergo multiple scattering in the medium, Cerenkov radiation is emitted in all directions.

Apart from Cerenkov radiation, radiation in the visible region is also emitted when an electron passes through an interface of two dielectric media. Theory of this transition radiation was worked out by Frank and
Ginzburg and has been subsequently developed by Ritchie and Eldridge. Boersch et al., Frank et al., Arakawa et al. and Dinsard have studied the transition radiation experimentally. The transition radiation increases with foil thickness only for foils of thickness less than 1 mg/cm² and remains constant beyond that, unlike bremsstrahlung radiation.

Interaction of Beta Particles with Matter

When one uses beta particles for studying the nature of interaction of electrons with matter one should take into account the continuous nature of beta spectrum. It is well-known that the beta spectrum leads to a linear plot, the well-known Fermi-Kurie plot, if the quantity \( \sqrt{N} \sqrt{G} \) is plotted against \( E \), where \( N \) is the number of beta particles of total energy \( W \) per unit energy interval, \( G \) is the modified Fermi function and \( E \) is the kinetic energy. The intercept in the end-point (kinetic) energy \( E_0 \) of the spectrum. It is also well-known that when there is a source straggling the spectrum leads to a straight line on the Konopinski-Shlenbeck plot, that is, if the quantity \( \sqrt{N} \sqrt{G} \) is plotted against \( E \). Needless to state that the \( N-G \) plot has no theoretical basis as was
known to yield better straight line than the F-K plot when there was more source straggling.

It is also well known that the intensity, \( I \), of beta particles transmitted through an absorber of thickness \( t \) decreases as

\[
I = I_0 \exp \left[ - \frac{\mu}{\rho}(\rho t) \right]
\]

where \( \mu/\rho \) is the mass attenuation coefficient, \( \rho \) is the density, and \( t \) the thickness of the absorber in cm. The quantity \( \mu/\rho \) is characteristic of the end-point energy, which indicates that the beta particles retain their spectral shape even after passing through an absorber.

Combining the linearity of F-K plot and the retention of the shape of the spectrum by beta particles transmitted through a small thickness of the absorber, one may determine the stopping power of electrons of the end-point energy. Recently, Molloni et al.\(^{32}\) and van de Geij \(^{33}\) have shown that even for an absorber of thickness up to 100 mg/cm\(^2\) the method gives stopping power of the medium in agreement with the one obtained by using the mono-chromatic electrons of energy equal to the end-point energy.
The external bremsstrahlung produced in an absorber sufficiently thick to stop all the beta particles, depends on the bremsstrahlung cross section integrated over the slowing down beta spectrum. It can be shown\(^1\) that the number of bremsstrahlung quanta emitted within an unit energy interval about energy \(E_1\) is given by

\[
N(E_i) = \frac{1.02 \times 10^7}{E_i} \int_{E_0}^{E_1} \frac{(E_i - E_0) N(E_i) dE_i}{N(E_i) dE_i}
\]

where \(k\) is a constant. The lower limit of the beta energy, \(E_1\), is equal to \(\beta\).

In the case of the bremsstrahlung in the optical region, \(E\) is about 5 eV and the range of beta energies contributing to bremsstrahlung would be much higher than this. So we may put the lower limit \(E_1\) to be equal to zero. However, we see that the number of quanta per unit wavelength interval would be proportional to \(1/\lambda\) and the intensity would be proportional to the atomic number.
Properties of Ferroelectrics

General feature of a ferroelectric substance is that their electric dipole moment is due to the absence of a common centre of symmetry for the positive and the negative charges in the unit cell. Above the Curie temperature the spontaneous polarization vanishes either due to displacive transition or due to order-disorder transition, accompanied by a change in crystal structure.  

In the case of TGS and RS the unit cell has a permanent dipole moment, and below the Curie temperature they are all oriented in one direction and above the Curie temperature they are oriented in random directions. On the other hand, in the case of BT the unit cell gets a dipole moment below the Curie temperature due to displacement of the constituent ions, and above the Curie temperature the unit cell ceases to have dipole moment.

However, the atomic polarizability of the constituent atoms is not much affected by the phase transition in both the types of transitions and so the density effect, as it is normally treated in literature is expected to be the same for both the phases. According to Sternheimer, this effect is estimated to be less than 1%. 