CHAPTER 1

INTRODUCTION

Interactions can be classified into one of the following groups, gravitational force, electromagnetic forces, weak interactions, QCD or strong force, and the particles are either leptons or quarks.

The leptons are identified by its characteristic of no strong interactions. They can be divided into two groups: the charged leptons and the neutral leptons or the neutrinos. The charged leptons can interact through weak and electromagnetic interactions. Neutrinos are uniquely different from the charged leptons in the sense that apart from being neutral, they can interact through weak interactions but do not experience electromagnetic interactions. There are six leptons, the electron (*e*), and the muon (μ) and the tau (τ) which are more massive then electron. The other three leptons are the neutrinos (ν), which have no electric charge and zero or very small mass. There is one type of neutrino corresponding to each type of electrically charged lepton. For each of the six leptons, there is an antilepton with equal mass and opposite charge, i.e. leptons appear in doublets, which are as follows:

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}.$$

The leptons have a generation structure since it is found that there is a sequence of increasing charged lepton masses and presumably also with their associated neutrinos. In any process involving leptons, the sum of each type of lepton number is apparently separately conserved.

One of the great achievements regarding interactions among particles is the unification of the electromagnetic and weak interactions into a single gauge theory, viz., the standard electroweak theory, or the Glashow-Weinberg-Salam (GWS) model [1]. The construction of the standard electroweak theory is based on an SU(2) x U(1) gauge theory where SU(2) and U(1) are the weak isospin and weak hypercharge groups respectively and this theory has already been proven to be renormalizable by 't Hooft [2]. Beta decay interactions can be described by the naive intermediate vector boson (IVB) model in which charged weak currents are mediated by massive vector bosons $W^{\pm}$. The naive IVB model is well behaved at low energies and to first order but not at high energies and high orders. Glashow produced a unified theory of the electromagnetic and weak interactions based upon the SU(2) x U(1) gauge theory. In this case there are four massless gauge bosons, the $W^{\pm}$ and W^3 of the SU(2) gauge field and a neutral B associated with the U(1) gauge field. Inserting a mass term by hand for these bosons would destroy the gauge symmetries and hence the renormalisability of the theory. Experiment would suggest that we have the weak interactions mediated by a triplet of massive bosons, the $W^{\pm}$ supplemented by a Z^0, to generate neutral currents, and a massless photon for electromagnetic interactions. Weinberg and Salam solved the problem of boson masses by employing the notion of spontaneous symmetry breaking. The spontaneous symmetry breaking occurs when a Lagragian density is invariant under a particular symmetry but the ground state or the vacuum is not.

The fermion masses are generated in the electroweak theory using the Higgs mechanism by coupling the fermion fields and the Higgs fields through Yukawa interactions. Leptons can exist in two helicity states; either left-handed or right-handed. The left-handed leptons are arranged in SU(2) doublets since charged weak currents contain only left-handed states, i.e. due to the vector-axial vector (V-A) structure of the currents while the right-handed leptons are SU(2) singlets because we want to avoid right-handed charged weak currents. Right-handed neutrinos are absent in the electroweak theory due to the fact that only left-handed neutrinos have been previously found to exist. The standard electroweak theory is so far the best theory we have to describe the weak interactions. The discoveries of the predicted neutral current in 1971 which is mediated by the Z^o boson and the $W^{\pm}$ bosons in 1983 [3] are great successes for this theory.

Although all available data seem to be consistent with the standard electroweak theory, there are a few undesirable features. Among them is the fact that the masses of the physical fermions cannot at all be predicted by the standard electroweak theory. The masses remain as undetermined parameters in the theory. Apart from the question of the fermion masses, the mass of the Higgs particle is also not predicted.

According to the standard electroweak theory, the neutrino is considered as a massless particle. This is due to the absence of the right-handed neutrino field which is imposed upon us by previous observations; that charged weak currents involve only left-handed fermions and only left-handed neutrinos are observed before in nature. The neutrino oscillations have become an interesting subject since the indication of the neutrino mass by the Super-Kamiokande experiment [4]. The implication of the oscillations is that a neutrino initially, say produced as an electron neutrino will after some time later converted into a different neutrino flavour, for example muon or tau neutrino. Then in these oscillations, separate lepton numbers are not conserved but the total lepton number is conserved.

In this thesis, we will calculate the total energy losses of the solar neutrinos in the electron neutrino-electron scattering. The effects of the neutrino oscillations are incorporated in the stopping power of matter equation through the survival probability of the electron neutrinos.

The organisation of the thesis is as follows. As neutrinos are the main subject of interest in this thesis, the physics of the neutrinos will be discussed in Chapter 2. This is followed by a discussion on the roles of solar neutrinos in Chapter 3. The standard solar model is discussed to understand the solar neutrino problem. The thermonuclear reactions in the sun emit a large flux of neutrinos. Due to its long mean free path, a neutrino is able to escape unhindered from the interior of stars and carry away large amount of energy. Since neutrino interact weakly with matter, they are very difficult to detect. Neutrino detectors especially chlorine are looked into. This will give us an overview of the solar neutrino problem and one of its solutions that is the neutrino oscillations. In Chapter 4, we will further discuss the effects of the neutrino oscillations due to the possibility of neutrino having finite, non-zero mass. Stopping power of matter on neutrinos will be discussed in Chapter 5.