

Neutrino: Detection And Helicity Measurement

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“ Neutrino: Detection And Helicity Measurement”

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Abstract

The properties of neutrino, detection of neutrino, helicity and experimental determination of helicity are discussed here. Main points on which this project work give focuses are the interaction of neutrino with matter, neutrino reaction cross section, mean free path of neutrino, neutrino helicity and experimental measurement of helicity. Experimental detection of neutrino will be discussed on the basis of Cowan and F. Rein's experiment.

Declaration

This project work is my original work, has not been presented for a degree in any other university and that all the sources of material used for the project work have been dually acknowledged.

Name: Gemechuu Gudeta

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Place and time of submission: Addis Ababa University, July 2010.

This project work have been submitted for examination with my approval as
university advisor,

Name: Pr. A.K. Chaubey

Signature:

Chapter One

Introduction

1.1 Brief History of Neutrinos

The idea of the neutrino came to life in 1930 by J.W. Pauli as an attempt to explain the continuous spectrum of β - decay and solve the problem of non-conservation of momentum and energy in radioactive decays. It was Wolfgang Pauli who set the gears in motion when he suggested the existence of a weakly interacting neutral particle with the same spin as an electron and very little or no rest mass. This strange proposal was put forth in a self-proclaimed “desperate” attempt to keep the law of energy conservation intact in nuclear beta decay ($n \rightarrow p + e^- + \nu_e$). The outgoing electron in the decay was observed to have a continuous energy spectrum, rather than the distinct energy that is dictated by momentum and energy conservation in a two-body decay. The only logical conclusion was that another particle was involved in the decay. This particle would have to interact with matter extremely weakly in order to explain why it had not been observed in experiments.

Fermi formulated a theory for calculating the simultaneous emission of an electron with a neutrino, so including Pauli’s hypothetical particle, at Solvay conference in Bruxelles in October 1933 Pauli said about this particle: *“... their mass can not be very much more than the electron mass. In order to distinguish them from heavy neutrons, mister Fermi has proposed to name them neutrinos. It is possible that the proper mass of neutrino be zero... It seems to me plausible that neutrinos have a spin 1/2... We know nothing about the interaction of neutrinos with other particles of matter and with photons: the hypothesis that they have a magnetic moment seems to me not funded at all”*. In 1933 it was shown that the neutrino mass was very much lower than electron mass; in the same year the discovery of the positron and the beta plus radioactivity confirmed the neutrino idea.

Fermi assumed the neutrino hypothesis to formulate a theory of weak interactions. This theory gave a great deal of credibility to the neutrino hypothesis, but it became necessary to find a concrete proof of the existence of neutrinos. The problem was that neutrinos could penetrate several light years of ordinary matter before interacting. It became clear that large detectors were needed to overcome the neutrino interaction probability. In 1955 at Los Alamos, Reine's and Cowan provided the first experimental evidence of neutrino-induced interactions by searching successfully for distinct experimental signature in inverse beta decay ($\bar{\nu}_e + p \rightarrow n + e^+$). They used an intense flux of anti-neutrinos from a nuclear reactor; the neutrinos interacted in a target made of ~ 200 lt of water and cadmium chloride dissolved in it. The detection of anti- ν_e was made through the inverse β^- decay reaction $\bar{\nu}_e + p \rightarrow n + e^+$. The predicted cross section for the reaction was $6 \times 10^{-44} \text{ cm}^2$ and they measured $6.3 \times 10^{-44} \text{ cm}^2$.

In addition to the electron neutrino ν_e produced in nuclear beta decay, the existence of two other flavors of neutrino have been verified in the years since. Lederman, chwartz, and Steinberger discovered in 1963 that the neutrino from pion decay (the muon neutrino ν_μ) was distinct from the electron neutrino.[6] Tau neutrinos were then discovered by the DONUT experiment at Fermilab in 2000. In 1973 neutral currents(neutrino interactions in which a neutrino is not trans- formed into an electron or a muon) were discovered at CERN and confirmed at Fermilab.

In 1978 in e^+, e^- collisions at SLAC was found the evidence for the τ - lepton to which a third neutrino ν_τ might be associated. The indirect evidence of ν_τ came in the study of the Zboson decay width at the $e^+ e^-$ LEP collider which provided a strong indication for the existence of three and only three families of neutrinos . The direct observation of the ν_τ was made only in 2001 at Fermilab in the DONUT experiment .

After discovery of these particles, the next obvious step was to measure their masses. Experiments which have directly searched for neutrino masses have only been able to set upper limits. The current bounds are:

$$\begin{aligned}m_{\nu_e} &< 3\text{eV}/c^2, \\m_{\nu_\mu} &< 0.19\text{MeV}/c^2, \text{ and} \\m_{\nu_\tau} &< 18.2\text{MeV}/c^2.\end{aligned}$$

Since the ν_e is consistent with the massless particle Pauli proposed, massless neutrinos were added to the growing “standard” list of particles.[2,3,8]

The experimental studies of neutrino properties contributed to formulate the Standard Model (SM) of strong and electroweak interactions of Glashow, Weinberg and Salam, which describes the experimental results obtained till now. The studies of solar and atmospheric neutrinos proved the existence of neutrino oscillations, thus neutrinos must have non zero masses.

Chapter Two

Beta decay and neutrino hypotheses

2.1. An historic introduction

Radioactivity was discovered in 1896 by Becquerel and it became clear within a few years that decaying nuclei could emit three types of radiation, called α , β and γ rays. The emission of ordinary electron from nucleus was among the earliest observed radiative decay phenomena. The inverse process, capture by a nucleus of an electron from its atomic orbit was observed in 1938. Joliet's-Curie in 1934 first observed the related process of positive electron (positron) emission on radioactive decay. These three nuclear processes are closely related and are grouped under β -decay. [2, 4, 8]

The most common and basic β -decay process is the conversion of proton into a neutron or of neutron into proton. In a nucleolus, β -decay change both Z and N by one unit.

$$Z \rightarrow Z \pm 1 \text{ or } Z \rightarrow Z \pm 1 \text{ (-1 or +1)}.$$

$$A(Z,N) \rightarrow A(Z+1,N-1) + e^-$$

$$A(Z,N) \rightarrow A(Z-1,N+1) + e^+ \tag{2.1a}$$

Beta minus (β^-) are produced by decay of n into proton and β^+ are produced by the decay proton into neutron. Neutrons are unstable particles and nearly all in about 10 minutes by being converted to protons. β -decay process is nuclear process.

$$n \rightarrow p + e^- + \dots \tag{2.1b}$$

$$p \rightarrow n + e^+ + \dots \tag{2.1c}$$

$$p + e^- \rightarrow n + \dots \tag{2.1d}$$

the processes 2.1c and 2.1d occurs only for protons bound in the nucleus. The above process is not complete [1]. An outstanding puzzle was related to the beta-decay process. The continuous energy distribution of beta decay electrons was a confusing experimental result in the 1920s. An example of such a beta spectrum is shown in figure 1.1.

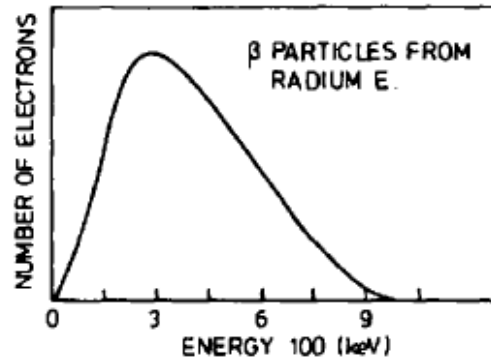


Figure 2.1. Simple example of a beta spectrum. This figure is taken from Basic ideas and concepts in nuclear physics K. Heyde(1999).

Experimentally it is shown that the energy distribution extends from zero to an upper limit (the endpoint energy) which is equal to the energy difference between the quantized initial and final nuclear states. The spectrum of emitted β expected is:

$$E = {}_Z m c^2 - {}_{Z+1} m c^2 - m_0 c^2 = \text{constant for one element.}$$

Experiment show that the energy is continuous from the minimum to maximum(endpoint)energy as shown in fig 2.2. If β - decay were,like α -decay, we would expect all of the β - particles to have a unique energy, but virtually all of the emitted particles have a small energy.

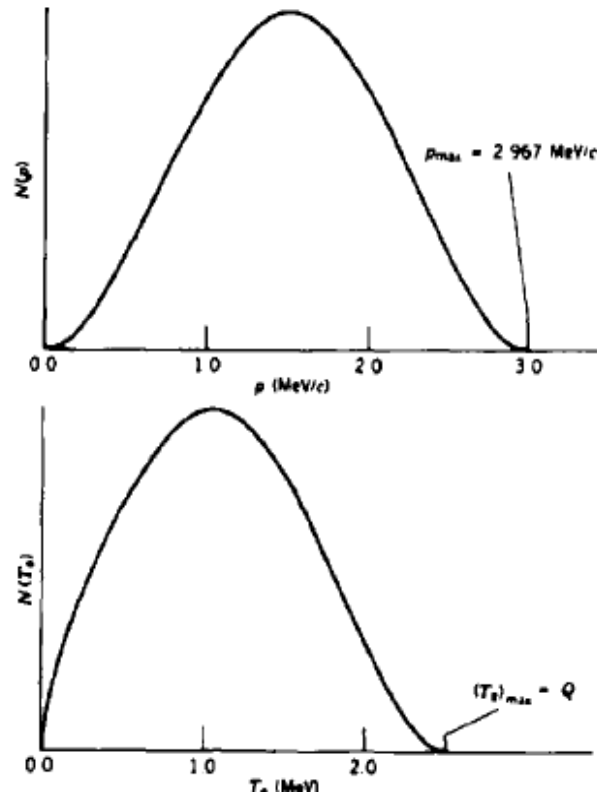


Figure 2.2. Electron energy and momentum distributions in beta-decay. These distributions are for a decay with $Q_\beta = 2.5 \text{ MeV}$. (Taken from Karen, introductory Nuclear Physics 1987 John Wiley & Sons).

It appears that in β^- decay the law of conservation of energy is violated although the maximum energy of the distribution corresponds to that expected from the mass difference of the parent and daughter. $E_\beta = E_{max}$ at end point, whereas at any other points $E_\beta \neq E_{max}$ indicating the missing energy and also violation of energy conservation law.

In addition to a possible violation of energy conservation law by all electrons except with maximum energy, there also appear to be violation of the conservation of angular momentum. For instance in a decay of the type.

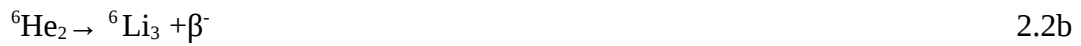


would therefore require integral angular momentum, in contradiction to have single value. Also the law of conservation of spin angular momentum is violated.[2]

$$n \rightarrow p + \beta^- + E_\beta$$

$$\frac{1}{2}\hbar = \frac{1}{2}\hbar + \frac{1}{2}\hbar \text{ which implies that } 1 \text{ or } 0 .$$

Linear momentum conservation violation takes place in an experiment from cloud chamber photograph from beta decay of



in which the momentum vector of the final product clearly do not add up to zero, as they should. The decay process is a three body particle system. According to this, a three body particle system the resultant linear momentum will have many values represented by the diagonals where as the initial momentum is only in one direction.[2,3]

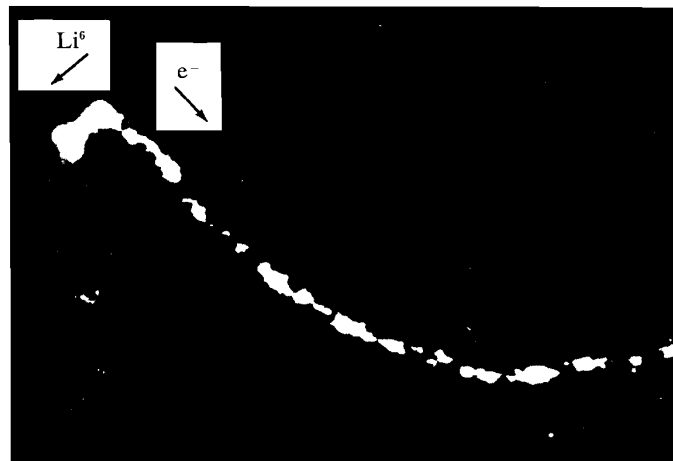


Figure 2.3. Recoil of a Li nucleus following the beta decay of ${}^6\text{He}$. The lithium ion is at the left-hand side and the electron is the curved track. The photograph was taken in a low pressure cloud chamber (Taken from K. Heyde 2nd ed, 1999).

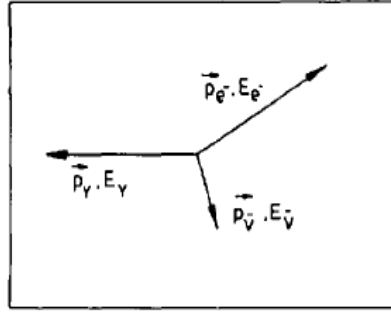


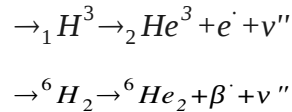
Figure 2.4. The energy and linear momenta (E_{e^-} , P_{e^-}), ($E_{\nu e^-}$, $P_{\nu e^-}$), (E_Y , P_Y) for the electron, anti- neutrino and recoiling nucleus in the β^- -decay of a nucleus(taken from K. Heyde 2nd ed,1999).

$$W = T - m_o c^2 \tag{2.3a}$$

and

$$W = T, \text{ if } m_o = 0$$

The beta decay in equation (1) and equation (2) would then become:



the positron or electron kinetic energy T_e becomes :

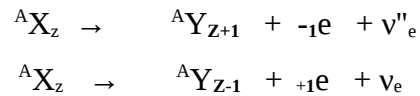
$$T_e = m'_p - (m'_o + m_o) c^2 - W_\nu \tag{2.3b}$$

where W_ν -is energy carried by neutrino or anti-neutrino. Therefore ,even though the mass difference for a given decay is fixed ,the electron can have a continuous energy distribution and the conservation law becomes valid.

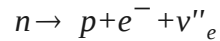
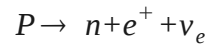
All difficulties concerning the conservation law in beta decay were overcome by the neutrino hypothesis of Pauli(1933). Pauli suggested the existence of a new, very light uncharged and penetrating particle, named as the neutrino. According to Pauli the neutrino carries the ‘missing’ energy. Conservation of electric charge requires the neutrino to be electrically

neutral(zero charge) and angular momentum conservation and spin statistics considerations in the decay process require the neutrino to behave like a fermion of spin $\frac{1}{2}$, he assigned zero or nearly zero mass(experimentally the mass is known to be $\frac{1}{2000}$ of electron mass) for mass energy balance of beta decay.

Experiment shows that in beta-decay processes, two different types of particles(neutrinos) can be emitted. These are called the neutrino (ν) and anti neutrino ($\bar{\nu}$). An anti-neutrino and neutrino differ in only helicity and nature of interaction they make with nucleon during direct and inverse beta decay process. Experiment show that neutrino is left handed where as anti-neutrino is right handed or have different helicity. Neutrino is particle emitted in β^+ decay and the anti neutrino is emitted in β^- decay. Incorporating the neutrino hypotheses we can write the equation of β decay as;



and



The above β^- decay process of equation 2.4 satisfies the basic conservation.⁽¹⁾

In 1934 Fermi developed a successful theory of beta decay based on Pauli neutrino hypothesis .The transition rate can then be determined from Fermi golden rule to determine beta spectrum shape and to estimate neutrino mass. Transition probability λ for any transition depends on level density "n" and also on $\rho = dn/dE$ which is density of state. It is determined from;

$$\lambda = 2 \frac{\pi}{\hbar} |H_{fi}|^2 \frac{dn}{dE_o}, \text{ where } E_o = E_e + E_\nu \quad \text{Fermi golden rule} \quad 2.5$$

$$\lambda = p(dp_e) dp_e = \text{the probability that electron of momentum in between } p_e \text{ and } p_e + dp_e \text{ is emitted.} \quad 2.6$$

$$\text{where, } |H_{fi}| = \frac{g}{V} |\psi_f M \Psi_i| = \frac{g}{V} |M_{fi}| \quad 2.7$$

Where M_{if} -matrix element of interaction. Evaluating both $|M_{fi}|$ and dn/dE_o (density of state) as well using Fermi coulomb correction

$$F(Z, E_e) = 2\pi \frac{\eta}{(1 - e^{-\pi\eta})} \quad 2.8$$

$$p(p_e) dp_e = C p_e^2 F(Z, E_e) (E_o - E_e)^2 |M_{if}|^2 dp_e \quad 2.9$$

$$\lambda(p_e) dp_e = |M_{if}|^2 \frac{1}{2\pi^3 \hbar^7 C^3} F(Z, p_e) p_e^2 (E_o - E_e)^2 \left[\frac{(1 - m_\nu^2 C^4)}{(E_o - E_e)^2} \right]^{1/2} dp_e \quad 2.10$$

$$\lambda(p_e) dp_e = C p_e^2 F(Z, E_e) (E_o - E_e)^2 |M_{if}|^2 dp_e \quad 2.11$$

$$\lambda(p_e) dp_e = |M_{if}|^2 \frac{1}{2\pi^3 \hbar^7 C^3} F(Z, p_e) p_e^2 (E_o - E_e)^2 \left[\frac{(1 - m_\nu^2 C^4)}{(E_o - E_e)^2} \right]^{1/2} dp_e \quad 2.12$$

The expression (12) vanishes for $p_e = 0$ and $p_e = p_{\max}$, corresponding to a decay in which the electron carries all the energy, i.e. $E_e = E_{\max}$. In figure 2.5, we show the momentum and kinetic energy ($E_e = T_e - m_0 c^2$) spectra for electrons and positrons emitted in the decay of ^{64}Cu Evans 1955 (Taken from K. Heyde 1998).

It is interesting to study the influence of the neutrino mass m , on the beta spectrum shape. Therefore, slightly change the representation of the electron decay into what is called a

Fermi-Kurie plot. If the matrix element $|M_{if}|$ is totally independent of p_{e^-} and for vanishing neutrino mass m , the quantity on the left-hand side of the expression.

$$\left[\frac{\lambda(p_e)}{C p_e^2 F(Z, E_e) |M_{if}|^2} \right]^{1/2} \alpha (E - E_e) \quad 2.13$$

should vary linearly with the total (or kinetic) electron energy.

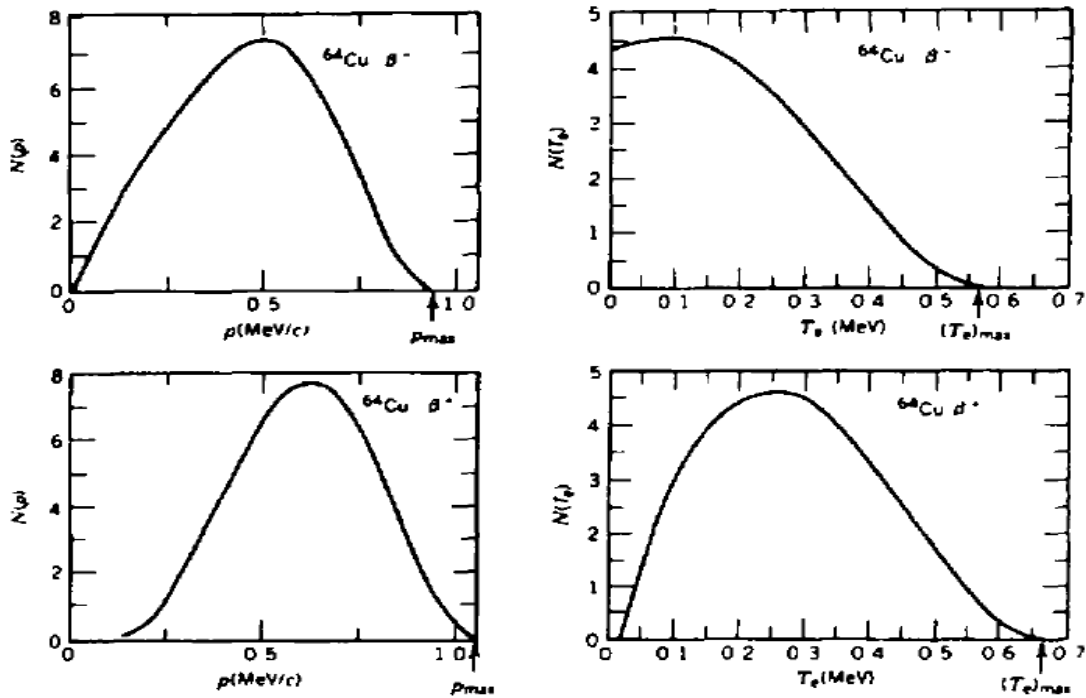


Figure 2.5, Momentum and kinetic energy distributions of electrons and positrons emitted in the decay of a ^{64}Cu . A comparison with figure 2.4, illustrates the differences that arise from the Coulomb interactions within the daughter nucleus for electron and positron decay. (Taken from Karen, introductory Nuclear Physics 1987 John Wiley & Sons).

The intercept with the energy (or momentum) axis is a convenient way to determine the decay endpoint energy (and so the Q-value). Fermi kurie plot fig 2.6. experimental plot help to estimate the neutrino mass and give the end point energy.

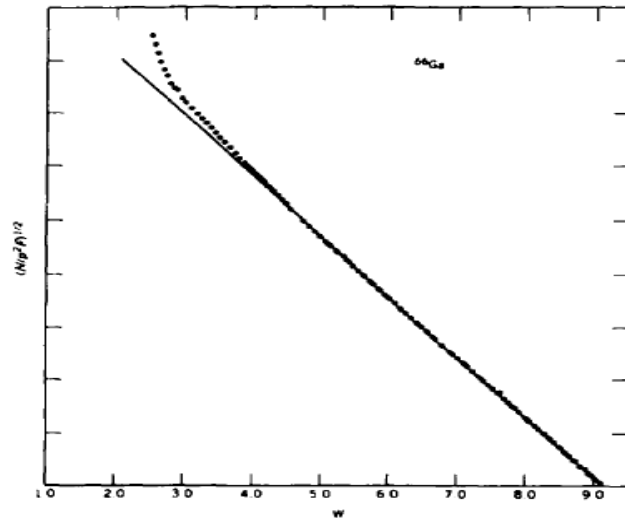


Figure 2.6. Fermi-Kurie plot for the allowed 0^- to 0^+ beta-decay in ^{66}Ga . The horizontal axis gives the relativistic total energy $E_{e^-} = T_{e^-} + m_0c^2$ in units of m_0c^2 (called w). The deviations, for small energies, from a straight line arise from low-energy electron scattering within the radioactive source (from Camp and Langer 1963)(Taken from K. S. Krane,1987).

If the neutrino mass is assumed to be small but non-zero, interesting deviations from a straight line appear as exemplified for tritium β^- -decay with $m_{\nu_e} = 0$ and $m_{\nu_e} = 30\text{eV}$. A vertical asymptomatic limit appears now at the maximum electron energy for $m_{\nu_e} = 30\text{eV}$ as illustrated in figure (2.8) The analytical study of the Fermi-Kurie plot can be carried out by using equation (13), which contains small, but specific corrections implied by a neutrino mass.

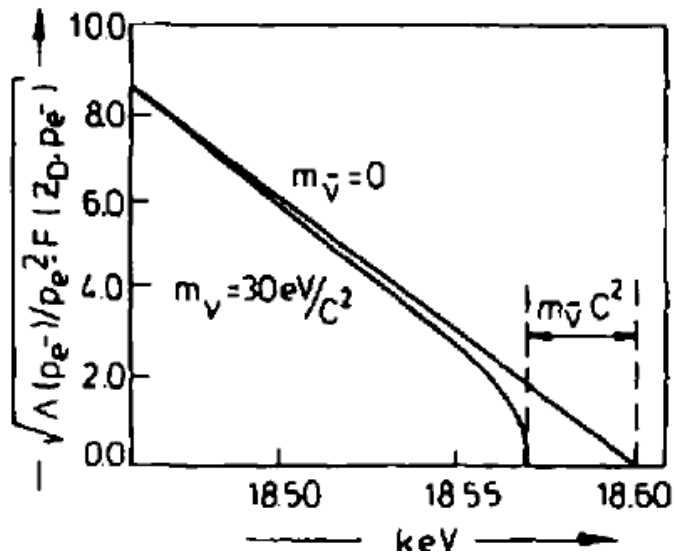


Figure (2.7) Illustration of the Fermi-Kurie plot for ${}^3\text{H}$ beta-decay to ${}^3\text{He}$, in the hypothetical case of decay with a non-vanishing neutrino mass of $m_{\nu}c^2 = 30\text{eV}$ and the zero-mass situation $m_{\nu}c^2 = 0\text{eV}$ (Taken from K. Heyde 2nd ed, 1999).

2.2. GENERAL PROPERTIES OF NEUTRINO

Neutrinos are electrically neutral particles of spin $\frac{1}{2}$ (fermions) that is, spin $\frac{1}{2}$ leptons which are one of the three classes of elementary particles. Neutrinos family of leptons-(light weight) have zero or slightly zero mass. They have no strong interactions. All leptons have weak interaction. Leptons which carry electric charge also show electromagnetic interaction. There are six types of leptons and they occur in pairs which are called generation.

$$\begin{array}{ccc} \nu_e & \nu_\mu & \nu_\tau \\ e^- & \mu^- & \tau^- \end{array}$$

Each generation comprise a charged lepton which are electrically charged e^- , and a neutral neutrino. The three charged leptons are (e, μ, τ) electron, and two heavier particles, muon(mu) and tauon(tau). The associated neutrinos are electron neutrinos (ν_e), mu neutrinos(ν_μ) and tau neutrinos(ν_τ) respectively. In addition to lepton there are six corresponding anti-leptons(electron anti-neutrino, muon anti-neutrino and tauon anti-neutrino).[1, 2, 5, 11]

$$\begin{array}{ccc} \bar{\nu}_e & \bar{\nu}_\mu & \bar{\nu}_\tau \\ e^+ & \mu^+ & \tau^+ \end{array}$$

In general, there are three known types (flavors) of neutrinos: electron neutrino ν_e , muon neutrino ν_μ and tauon neutrino ν_τ , named after their partner leptons in the standard model (as shown in table 2.1). The current best measurement of the number of neutrino types comes from observing the decay of the Z boson. This particle can decay into any light neutrino and its anti-neutrino, and the more types of light neutrinos available, the shorter the lifetime of the Z boson. Measurements of the Z lifetime have shown that the number of light neutrino types is three. The correspondence between the six quarks in the standard model and the six leptons, among them the three neutrinos, suggests to physicists' intuition that there should be exactly three types of neutrino. However, actual proof that there are only three kinds of neutrinos remains an elusive goal of particle physics.[2,3,5,8 7]

Table 2:1 lepton generation

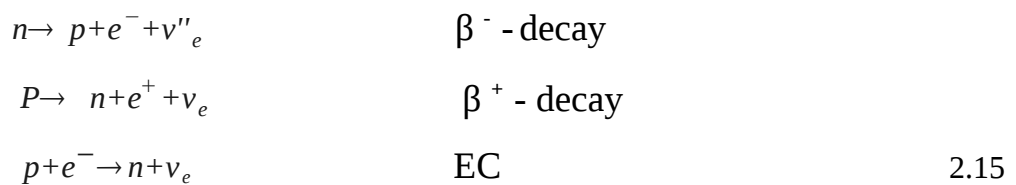
	fermion	symbol
Generation 1	Electron neutrino	ν_e
	Electron anti-neutrino	$\bar{\nu}_e$
Generation 2	Muon neutrino	ν_μ
	muon anti-neutrino	$\bar{\nu}_\mu$
Generation 3	Tauon neutrino	ν_τ
	Tauon anti-neutrino	$\bar{\nu}_\tau$

Neglecting gravity, the charged lepton interact via electromagnetic and weak forces, where as for the neutrinos, only weak interaction has been observed. There are three flavors (species) of very light neutrinos electron neutrino, muon neutrino and tau neutrino, which are left handed, and their anti-neutrinos electron anti neutrino, muon anti neutrino and tau anti-neutrino which are right handed.

Electron type neutrinos are produced in nuclear beta -decay (β^\pm).



The beta decay process is accompanied by the emission of electron, neutrino and electron anti-neutrino.



The neutrinos can also be produced in muon decay process as:

$$\begin{aligned} \mu^\pm &\rightarrow e^\pm + \nu_\mu \nu_\mu'' + \nu_e \nu_e'' ; \text{ that is} \\ \mu^+ &\rightarrow e^+ + \nu_\mu + \nu_e \\ \mu^- &\rightarrow e^- + \nu_\mu'' + \nu_e'' \end{aligned} \quad 2.16$$

Tauon decay process is given as :

$$\begin{aligned} \tau^+ &\rightarrow \mu^+ + \nu_\mu + \nu_\tau \\ \tau^- &\rightarrow e^- + \nu_\mu'' + \nu_\tau'' \\ &\rightarrow \nu + \text{hadrons} \end{aligned} \quad 2.17$$

Neutrinos of the third type tauon neutrinos have not been experimentally detected. while π^\pm meson(bosons) decay as :

$$\begin{aligned} \pi^+ &\rightarrow \mu^+ + \nu_\mu \\ \pi^- &\rightarrow \mu^- + \nu_\mu'' \end{aligned} \quad 2.18$$

accompanied by formation of muon neutrino and anti-neutrino.

Therefore, electron neutrino and anti-neutrino($\nu_e \nu_e''$) always participate in interaction together with electron and positron ,where muon neutrino and anti-neutrinos are accompanied by muon in all interaction. Thus it is forbidden to exchange electron neutrino by muon neutrino and muon anti-neutrino by electron anti-neutrinos.

Experimentally it was shown that ;

$$n \rightarrow p + e^- + \nu_\mu'' , \quad p \rightarrow n + e^+ + \nu_\mu$$

Similarly , the converse processes;

$$n + \mu \neq p + e^- , \quad p + \nu_\mu \neq n + e^- \text{ are also forbidden . Experiment shows that this}$$

process can only be accompanied by the formation of muon.

$$\begin{aligned}
 n + \nu_{\mu} &\rightarrow p + \mu^{-}, \\
 p + \bar{\nu}_{\mu} &\rightarrow n + \mu^{-},
 \end{aligned}
 \tag{2.19}$$

Thus neutrino and anti-neutrino are different particles in handedness (or in their helicity).

The nearly zero mass, zero charge and that it interacts extremely weakly with matter of neutrino makes neutrino difficult to detect. The neutrinos and anti-neutrinos are uncharged (as uncharged point particles, have vanishing magnetic moment). They are thus immune from electromagnetic interaction, which is often used to distinguish particles from anti-particles. It is difficult to catch the elusive neutrino as a result of its small interaction cross section.

Neutron decay and other beta decay events produce electron anti-neutrinos. Those anti-neutrinos should interact with protons to produce neutrons and positrons. [3,4, 5,6]

Table 2.2, Properties of leptons:all have spin $\frac{1}{2}$ and masses are given units of Mev/c^2 ; the antiparticles(not shown) have the same masses as their associated particles; but the electron charge lepton numbers are reversed in sign.[1, 2,3, 5 ,8]

Name and symbol	mass	Q	Le	Ln	Lt	Life time (s)	Main decay
Electron e-	0.511 Mev/c^2	-1	1	0	0	stable	none
Electron neutrino ν_e	< 2.2 Mev/c^2	0	1	0	0	Stable	none
muon(mu) μ	105.7 Mev/c^2	-1	0	1	0	2.197x10 ⁻⁶ s	e-, ν^e , ν ,n (100)
Muon neutrino (ν_μ)	<0.19 Mev/c^2	0	0	1	0	stable	none
Tauon (τ)	1777 Mev/c^2	-1	0	0	1	2.906x10 ⁻¹³ s	μ^- , ν_μ , ν_e (17.4). e-, ν_e , ν_τ (17.8) ν_τ + hadrons(~64)
Taoun neutrino (ν_τ)	<18.2 Mev/c^2	0	0	0	1	stable	none

L=1 for leptons , L= -1 for anti-leptons and L= 0 for others

2.3. The neutrino mass

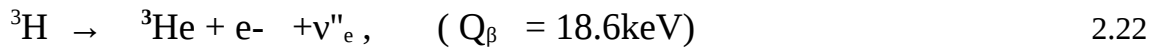
Fermi theory is based on the assumption that the rest mass of neutrino is zero. It should be clear by now that a knowledge of the neutrino mass, if different from zero, is a fundamental problem in nuclear and particle physics. We have also recognized that a precise knowledge, with an upper and lower limit is a very difficult experimental problem. One of the most straight forward methods relies on scrutinizing the beta spectrum shape (or the Fermi-Kurie plot) at and near the maximum electron energy.[2] The β - spectrum shape is given as;

$$\lambda(p_e) dp_e = |M_{if}|^2 \frac{1}{2\pi^3 \hbar^7 C^3} F(Z, p_e) p_e^2 (E_o - E_e)^2 \left\{ \frac{(1 - m_v^2 C^4)}{(E_o - E_e)^2} \right\}^{1/2} dp_e \quad 2.20$$

or transforming to the electron energy E_e is given as:

$$\lambda(E_e) dE_e = \frac{|M_{if}|^2}{2\pi^3 \hbar^7 C^3} F(Z, p_e) p_e E_e (E_o - E_e)^2 \left[\frac{(1 - m_v^2 C^4)}{(E_o - E_e)^2} \right]^{1/2} dE_e \quad 2.21$$

The effect of a finite, but small neutrino mass will be best observed for beta-decay processes with a very small Q value. The β -decay of tritium (^3H) is an appropriate candidate for such search since



because of the relatively very low Q_β - value and the possibility of detailed calculations of the electron wave function in the resulting ^3He ion.

In figure (2,8), illustrate some of the more precise experimental results (left-hand side) for the Fermi-Kurie plot obtained by Bergkvist (1972) are consistent with a zero mass, indicating an upper limit of about 60eV. The more recent data of Lubimov (1980) seem to indicate a non-zero rest mass of about 30eV, (while others suggest an upper limit of about 20eV) with error limits between 14 eV and 46 eV. These measurements have been criticized since, the small

effect one is searching for, requires the utmost care in extracting a finite neutrino mass and many corrections are necessary.

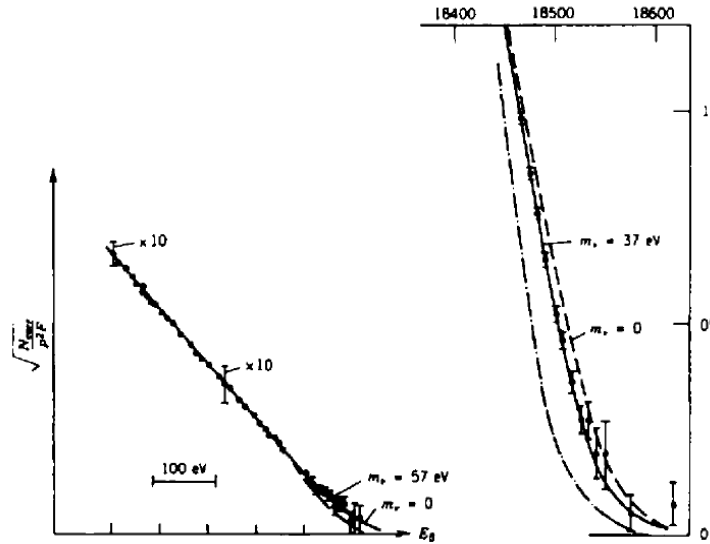


Figure 2.8. Fermi-Kurie plots of tritium beta-decay. The data (left) are from Bergkvist (1972) and are consistent with a zero mass, indicating an upper limit of 57 eV. The more recent data (right) by Lubimov (1980) seem to indicate a non-zero neutrino mass of about 30eV (Taken from K.Heyde 2nd ed,1999).

The more recent data from Kundig et al (1986) have better statistics and the analysis yields, including systematic errors (figure 2.8.),

$$m_e c^2 \leq 18 \text{ eV} .$$

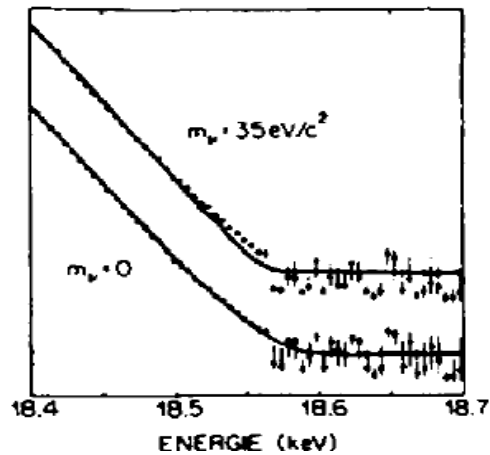


Figure 2.9: Upper end of the electron spectrum for the Kundig data. The solid lines indicate fits with neutrino masses of $m_{\nu}=0$ and $35\text{eV}/c^2$. The non-zero mass indicates a fit with net deviation from the data (taken from Kundig et al 1986). (Taken from K. Heyde 2nd ed,1999).

Why is the need for all this effort? One of the main reasons why all this effort is related to testing models of the universe. The original Big Bang theory predicts that the universe should contain neutrinos with a concentration of about $\beta \approx 10^8/\text{m}^3$. If these particles have a finite but small rest mass, this matter content might be large enough to make our universe collapse under the force of gravity. The limit on neutrino mass for this condition may be as low as 5eV. Precise answers are therefore very important and have an immediate bearing on our basic understanding of profound questions in cosmology.[1,5,8]

Recently, on the occasion of the 1987A supernova that was first seen on 23rd February of that year in the Large Magellanic Cloud, optical signals as well as neutrino signals were detected at the same time. They had been traveling through space for 170,000 years and the neutrinos were recorded on earth about three hours before arrival of the optical signal. The neutrino emission spectrum is expected to be a thermal spectrum corresponding to a temperature of about 5MeV and the neutrinos corresponding to a different energy $E_{\nu e}$ spread

out over a certain time span in their motion from the star towards the Earth. This effect was observed by the experimental groups: a burst of neutrino events with energies of 10 MeV over a timespan of about 10 s (figure: 2.10) .[3, 5,8]

The mass-dependence of the neutrino is contained in the following expressions: for a relativistic particle, moving with almost the speed of light one obtains the velocity(V_{ν}):

$$V_{\nu} = \frac{c}{\left[1 + \left(\frac{m_{\nu}^2 c^2}{p_{\nu}^2} \right) \right]^{1/2}}$$

$$V_{\nu} \approx c - \frac{m_{\nu}^2 c^3}{2p_{\nu}^2}$$

$$V_{\nu} \approx c - \frac{m_{\nu}^2 c^5}{2E_{\nu}^2} \tag{2.23}$$

The arrival time of high-energy neutrinos will be earlier than for the low-energy neutrinos, i.e.

$$\frac{\delta t}{t} \sim \frac{\delta V}{V} = \frac{m_{\nu}^2 c^4}{E_{\nu}^2} \frac{\delta E}{E_{\nu}} \tag{2.24}$$

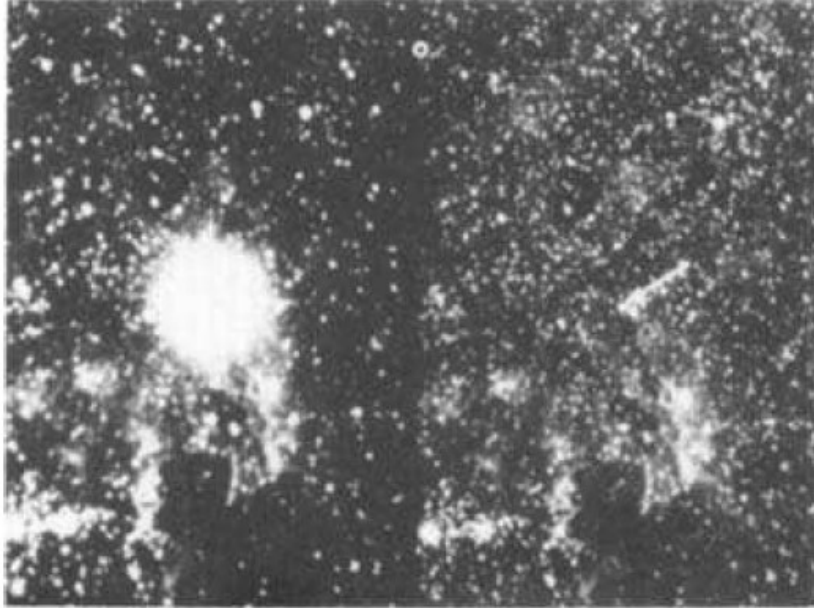


Figure 2.10 . Supernovae 1987 shown (before and after) the explosion which appeared on the night of 27 February 1987 in the Large Magellenic Cloud. This SN 1987a event is about 170000 light years distant and was used to obtain estimates on the emitted neutrino energy and on the possible neutrino mass. (Taken from Holstein 1989, Weak Interactions in Nuclei, 1989 Princeton University Press.(Taken from K. Heyde 2nd ed,1999).

The recorded events, seen by the Kamiokande detector and IBM group, have an energy spread $E \sim 10$ MeV and the neutrinos arrive over a time span $t \sim 10$ s. So, we simply deduce.

$$M_{\nu} c^2 \leq E_{\nu} \left(\frac{\delta t}{t} \frac{E}{\delta E} \right)^{1/2}$$

$$\leq 10\text{Mev} \left(\frac{10\text{s}}{10^{13}\text{s}} \right)^{1/2}$$

$$\leq 10\text{ev} \tag{2.25}$$

Using a more careful model for time and energy distribution, one obtains as a relativistic limit.

$$M_\nu c^2 \leq 20\text{ev}$$

A recent review on various direct neutrino mass measurements has been given by Robertson and Knapp (1988).[1]

Similar experiment from the Mainz tritium β -decay spectrometer experiment is appropriately corrected for experimental resolution, results in an upper limit on the mass of the ν_e of $m_{\bar{\nu}_e} c^2 < 3 \text{ eV}$.

Experiments which have directly searched for neutrino masses have only been able to set upper limits. The current bounds are:

$$m_{\nu_e} < 3\text{eV}/c^2 ,$$

$$m_{\nu_\mu} < 0.19 \text{ MV}/c^2 , \text{ and}$$

$$m_{\nu_\tau} < 18.2 \text{ MeV}/c^2 .$$

As an average neutrino mass from Troistk neutrino mass experimentally given for all run is: [5, 9, 11,12]

$$m_{\nu_e} < 2.5\text{eV}/c^2$$

Chapter Three

Interaction of neutrino with matter and Its helicity

3.1. Interaction of Neutrino with matter

The neutrino is one of the most pervasive forms of matter in the universe, yet is also one of the most elusive. We have seen that it has no electric charge, little or no mass and behaves like a fermion with intrinsic spin $\hbar/2$. The neutrino was suggested by Pauli to solve a number of problems related to standard beta-decay processes. In this section we concentrate on a number of properties related to the neutrino (namely interaction with matter, neutrino mass, double beta-decay and different types of neutrinos).

After Fermi theory of beta decay, Bethe and Peierls pointed out the possibility of inverse beta-decay. Here, the nucleus captures a neutrino or anti neutrino and ejects an electron or positron. These processes can be depicted as:



The cross-sections for such inverse processes are expected to be extremely small because of the characteristic weakness of the beta interaction.

Let us consider the inverse of the neutron decay process, i.e;

$\bar{\nu} + p \rightarrow n + e^+$, which satisfies the conservation of leptons but

$\nu + p \rightarrow n + e^-$, does not conserve lepton number and is an absolutely forbidden process.

The failure to observe such a reaction is one of the best indicators that neutrinos and anti-neutrinos are really different particles. The neutrinos and anti-neutrinos are uncharged (as uncharged point particles, have vanishing magnetic moment). They are thus immune from electromagnetic interaction, which is often used to distinguish particles from anti-particles. It

is difficult to catch the elusive neutrino as a result of its small interaction cross section . To understand this let us consider the cross section for the reaction given bellow.

$$\nu'' + p \rightarrow n + e^- \quad \text{as;}$$

$$\sigma = \frac{\text{probability pertarget atom for the reaction to occur}}{\text{incident flux of } \nu''}$$

$$\lambda = \frac{2\pi}{\hbar} |M_{if}|^2 \frac{dn}{dE} \quad 3.2$$

the incident flux $\nu'' = c/V$ implying that ;

$$\sigma = \frac{\frac{2\pi}{\hbar} \frac{g^2}{V^2} |M_{if}|^2 \frac{4\pi p^2 dpV}{h^3 dE}}{c/V} \quad 3.3$$

Where $\frac{dp}{dE} = \frac{E}{c^2 p}$ gives

$$\sigma = \frac{2\pi}{\hbar c} g^2 |M_{if}|^2 \left(\frac{4\pi p E}{c^2 h^3} \right) \quad 3.4$$

Taking $g^2 |M_{if}|^2 = g^2 f(1+y^2) = 5.6g^2$ and, $g = 0.88 \times 10^{-4} \text{mev} f^3$; $1f = 10^{-15} \text{m}$.

Choosing an incident anti-neutrino energy of 2.5Mev, some what above the minimum energy of 1.8Mev needed to incident the reaction (because $m_p c^2 < m_n c^2$ we must supply the additional needed mass energy through the incident anti-neutrinos), and thus the electron energy is 1.21Mev. Putting all these values in equation 3.4 the resultant cross section becomes;

$$\sigma = 1.2 \times 10^{-19} \text{b} ; \text{where b -barn and } 1\text{b} = 10^{-28} \text{m}^2$$

$$\sigma = 1.2 \times 10^{-43} \text{cm}^2$$

Therefore, neutrino reaction cross-section is of the order of 10^{-43}cm^2 . This is incredibly small cross section (compared with the low energy nucleon-nucleon scattering cross section of 20b!) by evaluating the probability for a neutrino to be captured in passing through a typical solid, which contains of the order of 10^{24} proton per cm^3 . The neutrino has a reaction cross

section of about 10^{-43}cm^2 for each proton it encounter, and as is passing through 1cm^3 of a material a neutrino will encounter about 10^{24} protons. The net reaction probability is: $(10^{-43}\text{cm}^2)(10^{24}\text{cm}^{-3})= 10^{-19}\text{cm}^{-1}$; that is, the reaction probability is 10^{-19} for each cm of material through which neutrino passes. We can calculate the neutrino mean free path that is the distance that the neutrino mass passes through a material before being captured or before making reaction. [3, 5]

3.2. Neutrino mean free path

Mean free path is the distance that the neutrino mass passes through a material before being captured or before making reaction. The relation between cross section and mean free path is given as:

$$l = \frac{1}{n\sigma}$$

, n = number of nuclei per cross section,
 σ – neutrino reaction crosssection ,
 $n\sigma$ – the interaction probability .

$$l = 1/(10^{-43}\text{cm}^2)(10^{24}\text{cm}^{-3}) = (1/10^{-19})\text{cm} = 10^{19}\text{cm} = 10 \text{ light years} .$$

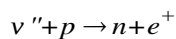
Therefore, to have a reasonable probability to be captured, the neutrino must pass through about 10^{19}cm of material, or about 10 light years. It is not wondering that it took 25 years to find it one! [3, 6, 8]

3.3. Experimental Detection of Neutrino

In 1930 Wolfgang Pauli proposed a solution to the missing energy in nuclear beta decays, namely that it was carried by a neutral particle. Enrico Fermi in 1933 named the particle the "neutrino" and formulated a theory for calculating the simultaneous emission of an electron with a neutrino. The zero charge, zero rest mass and that it interact extremely weakly with matter make the neutrino the most difficult particle to detect. The basic problem in detection was that the neutrinos could penetrate several light years depth of ordinary matter before they would be stopped.

The actual experimental detection of neutrino was done through an ingenious and pain taking series of experiment carried out in 1950s by F. Reine and Cowan. Pauli postulated the neutrino to satisfy the conservation law, verification of these laws does not give independent proof of the existences of neutrino. F. Reine and Cowan provide direct, independent proof of the existence of neutrino. The detection of the neutrino was as the initiator of the inverse-beta decay reaction of:

anti-neutrino + proton \rightarrow neutron + positron.



Proton is bombarded with anti neutrino is expected that they emit positron to become neutron. As a source of anti-neutrino they used a 1Gw nuclear reactor (since the neutron reach fission products under go negative beta decay and consequently emit anti-neutrino)to observe the reaction. Reine's and Cowan experiment at Savannah River Plant near Augusta, Georgia where they had better shielding against cosmic rays. This shielded location was 11m from the reactor and 12 m underground. The reactor average emission rate is about 6ν per fission, and the net flux of anti-neutrino was 10^{13} neutrino per cm per sec ($10^{13}\nu/\text{cm}/\text{sec}$). The target was water with CdCl_2 dissolved in it. The experimental arrangement is schematically shown in fig:3.1.

The proton for the reaction are provided by water (containing about 10^{28} proton per cm) in to which some cdcl_2 compound had been introduced. Cd has a large cross section (probability)

of capturing thermal neutrinos. The detector contained 200 liters of water with up to 40 kg of dissolved CdCl_2 . The water tanks were sandwiched between two scintillator layers which contained 110 5" photo multipliers each. I and II in the form of tank are liquid scintillation detectors, each contains 400 liters of liquid scintillator solution.

To establish the reaction $\bar{\nu} + p \rightarrow n + e^+$ the following events must be identified:

1) An anti-neutrino from the reactor interact with a proton in the water tank. The capture of anti-neutrino by a proton gives a neutron and positron.

2) The positron produced in the capture reaction quickly annihilates with an electron of the surrounding material within about 10^{-9} sec ($e^- + e^+ \rightarrow \gamma + \gamma$) in scintillator resulting two gamma rays of 0.511MeV each emitted in opposite directions (gives flash). The two gamma rays carry an energy equal to the electron rest mass 0.511MeV. These rays can be detected by the liquid scintillation marked I and II. Cowan and Reine observed this annihilation radiations which follows very quickly (in an interval of about 10^{-9} sec) the emission of positron.

3) The neutron diffuses through the solution (water with dissolved CdCl_2) and slow down through the collision with proton and it is then captured in the Cd nuclei, which has a large neutron-capture cross section by the reaction $\text{Cd}(n, \gamma)\text{Cd}^*$. That is following the neutron capture, ^{114}Cd is left in a highly excited state, which quickly emits 9.1MeV γ -ray. This capture of neutron process takes about 10^{-5} sec.

The characteristic signal of a neutrino is thus a light signal from the positron annihilation radiation (0.511MeV photon) followed 10^{-6} sec later (the time necessary for the neutron to be slowed and captured) by the 9.1MeV neutron capture γ -ray. Cowan and Reine succeeded in establishing the characteristic sequence of the above events.

Thus sequentially the positron was detected by its slowing down and annihilating with an electron producing two 0.511MeV gamma rays in opposite directions. The characteristic signal of a neutrino is thus a light signal from the positron annihilation radiation. The pair of gamma rays was detected in time coincidence in liquid scintillator above and below the water by photomultiplier tubes detecting the scintillation light. The neutron was also slowed by the water (through the collision with proton) and captured by the cadmium microseconds after the positron capture. In the capture several gamma rays were emitted which were also detected in the scintillator as a delayed coincidence after the positron's annihilation gamma ray detection.

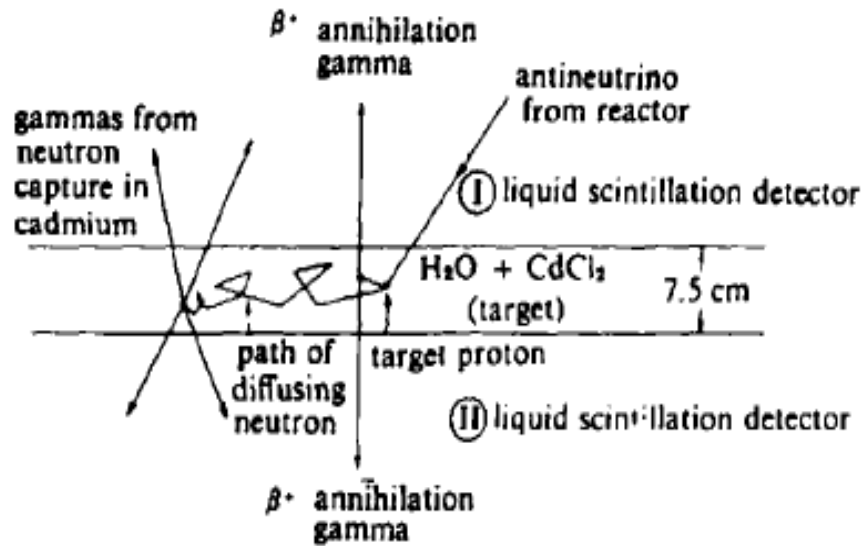
They delayed the annihilation pulse so that it could be displayed at the beginning of the oscilloscope trace. A delay of about 30×10^{-6} sec was required. An electronic circuit was gated for about 20×10^{-6} sec so that it was able to accept a neutron pulse triggered by capture gamma ray viewed by photomultiplier tube (PM Tube).

The oscilloscope was photographed each time the sequence of annihilation gamma ray pulse and neutron pulse was displayed Fig 3.1. This shows acceptable sequence of events, every time the oscilloscope was triggered. Cowan and Reine were able to record about 30 events per hour. They had predicted a cross-section for the reaction to be about $6 \times 10^{-44} \text{ cm}^2$ and their measured cross-section was $6.3 \times 10^{-44} \text{ cm}^2$.

To check their result they used water with out any CdCl_2 in it and found that the neutron pulses due to the gamma rays disappeared. Also when the nuclear reactor was shut down they found that the events mentioned above could not be observed.

Finally they concluded that the observed sequence of events are sufficiently characteristics to establish the interaction $\nu'' + p \rightarrow n + e^+$.

Conclusively Cowan and Reine experiment proved the existence of neutrino and following which the conclusion was inescapable the neutrino is a real particle, and not just a figment of Pauli's and Fermi's fertile imagination.



Fig;3.1. Cowan and Reine neutrino detection experiment schematic diagram of arrangement (Taken from K. Heyde). I and II are liquid scintillation detector. An anti-neutrino from a reactor produces a neutron and a positron. The positron is detected via its annihilation radiation. The neutron is moderated and detected via the capture gamma-ray.

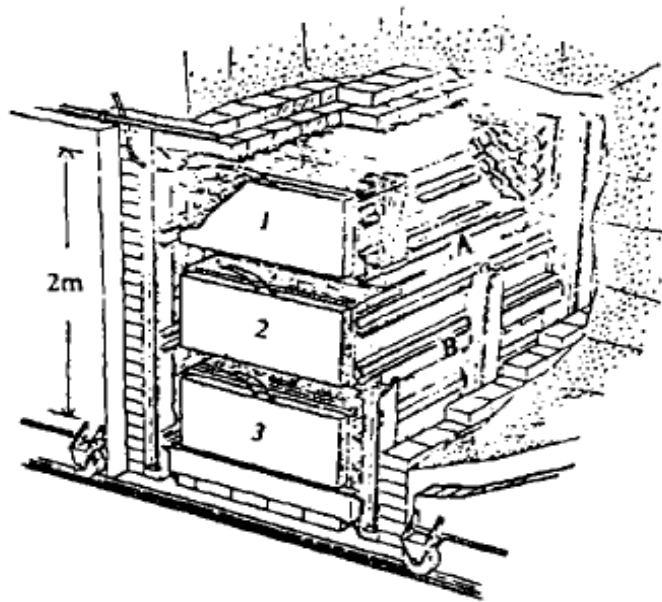


Fig: 3. 2. The detector set-up of Cowan and Reine neutrino detection. The detector tanks 1, and 3 each contains 400liters of liquid scintillator solution. They were viewed by 1105-inch photomultiplier tubes. The tank in between A and B contained 200 liters of water- CdCl_2 target. (Taken from K.Heyde).

Annihilation gamma-ray
gamma ray

Neutrino pulse due to capture

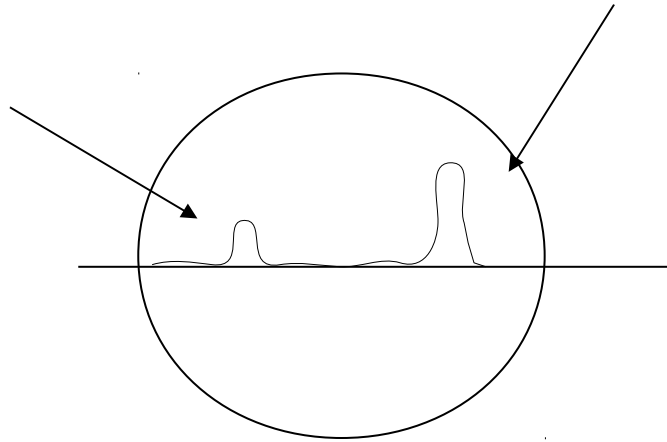
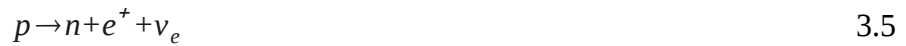


Fig:3.3.Triggered pulse due to positron annihilation and neutron capture. This sequence establishes direct neutrino interaction which is given by equation $\bar{\nu} + p \rightarrow n + e^+$.

3.4. Neutrino helicity and experimental determination of helicity

Neutron decay and other beta decay events produce electron anti-neutrinos. Those anti-neutrinos should interact with protons to produce neutrons and positrons. The reaction



transforms nuclear proton to neutron by beta plus decay, while process



transform neutron into proton by beta minus decay process. The inverse beta decay for equation(3.5) is allowed for $\bar{\nu}$ as;

$\nu'' + p \rightarrow n + e^+$, similarly, the inverse beta decay of equation (3.6) is allowed ,i.e

$$\nu + n \rightarrow p + e^-$$

since $\nu_e \neq \nu''_e$ the processes, $\nu + p \rightarrow n + e^+$ and $\nu''_e + n \rightarrow p + e^-$ are forbidden.

Experimental investigation of these provides the existence of ν_e and ν''_e confirmed that they are of different nature. To demonstrate the ν''_e capture by neutron is not possible, related experiment was done by Davis and co-workers in 1955. They used a large tank of Ccl_4 in an attempt to observe:



If neutrino and ant-neutrinos are identical then the reaction given by equation (32) is the inverse of ;



Thus, if ${}_{17}^{37}\text{Cl}$ is bombarded with anti-neutrino assume to get ${}_{18}^{37}\text{Ar}$. By purging the tank periodically and searching for the presence of radioactive ${}_{18}^{37}\text{Ar}$ in the removed gas Davids showed that ${}_{18}^{37}\text{Ar}$ was not produced. He was able to conclude that the reaction was not observed, indicating that ν and ν'' are different particles.^(5,6,8,10)

How ever, according to Davids conclusion ν and ν'' are different yet have not specified the fundamental properties that distinguishes neutrino from ant-neutrino. Experimentally there is one property :all ant-neutrinos have their spin vector($s_{\nu''}$) parallel to their momentum vector ($p_{\nu''}$), while all neutrinos(ν) have spin opposite to momentum. They exhibit a :''handedness'' similar to a screw. In other word, neutrino is a left handed particle while anti neutrino is a right handed particle, the only process that occur in nature. This property is said to be helicity. [1,6,7]

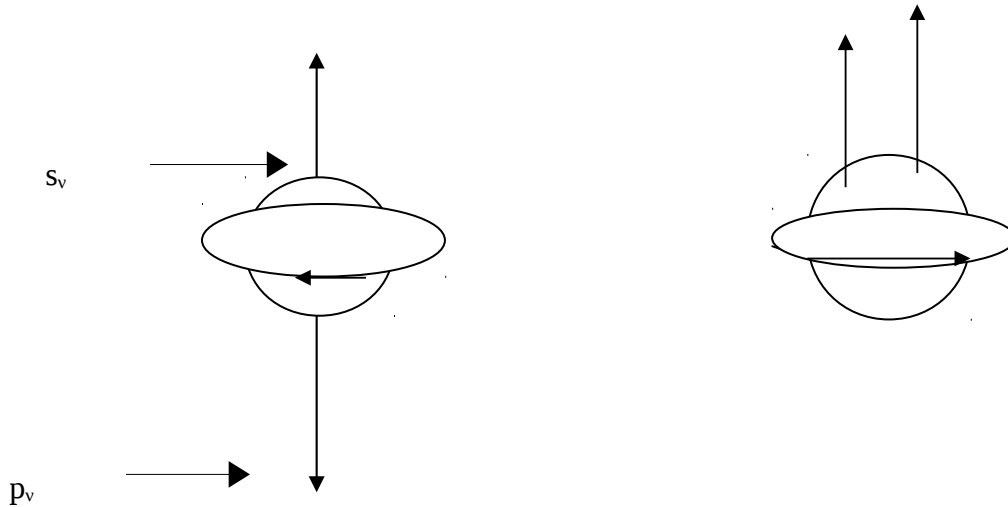


Fig 3.4 a) for neutrino, s_v is anti parallel to p_v

b) for anti-neutrino s_v is parallel to p_v

Helicity(h) is defined as:

$$h = \frac{s \cdot p}{|s||p|}, \text{ s -spin of the particle}$$

p- momentum

h- has the value +1 for anti-neutrino and -1 for the neutrino. (It is often said that this helicity property for anti-neutrino is "right handed" and neutrino is "left handed" because the precision of s about p traces out pattern analogous to the threads of a right handed screw for anti-neutrino and of left handed screw for neutrino). Electrons from beta decay have similar property, with $h = -v/c$ for e^- and $h = +v/c$ for e^+ , but this is not an intrinsic of all e^+ and e^- , only those emitted in beta decay. Electron in atoms have not definite helicities, no do positrons that originate from pair production ($\gamma \rightarrow e^+ + e^-$). All neutrinos and anti-neutrinos, however have helicity. It is this helicity property that causes the anti-neutrino capture process $\bar{\nu} + {}^{37}\text{Cl} \rightarrow {}^{37}\text{Ar} + e^-$ to be forbidden and that of the parity non-conservation in beta decay (in weak interaction) process.

3.5. Experimental determination of neutrino helicity.

A direct measurement of neutrino helicity was carried out in an elegant experiment by G. Goldberg and coworkers in 1958. The experimental set-up is shown in fig:3.5. The radioactive source consists of $^{152}\text{Eu}_{63}$ (europium) whose simplified decay pattern is shown in fig:3.6. Neutrinos are emitted from ^{152}Eu as a result of e- capture, while the γ ray is emitted as a result of the E_1 -transition of the daughter nucleus ^{152}Sm . Magnetized iron is used for determining the circular polarization of gamma ray, and a lead filter protects the detector from direct beams. The annular scatterer is made of Sm_2O_3 .

The basic ideas underlying the experiment was described as follows. Suppose that neutrinos that are formed during the K-capture of an electron by the formed ^{152}Sm nucleus (the transition energy 0.9mev) flies up ward. In this case the daughter nucleus ^{152}Sm will move down-ward with a recoil energy of

$$T_{nuc} = \frac{E_o^2}{2m_{nuc} c^2} \approx 3\text{ev}$$

Further assuming that the daughter nucleus formed in an excited state with an excitation energy equal to E_o , and is de- excited while moving by emitting a gamma-ray in the direction of its motion (down ward).

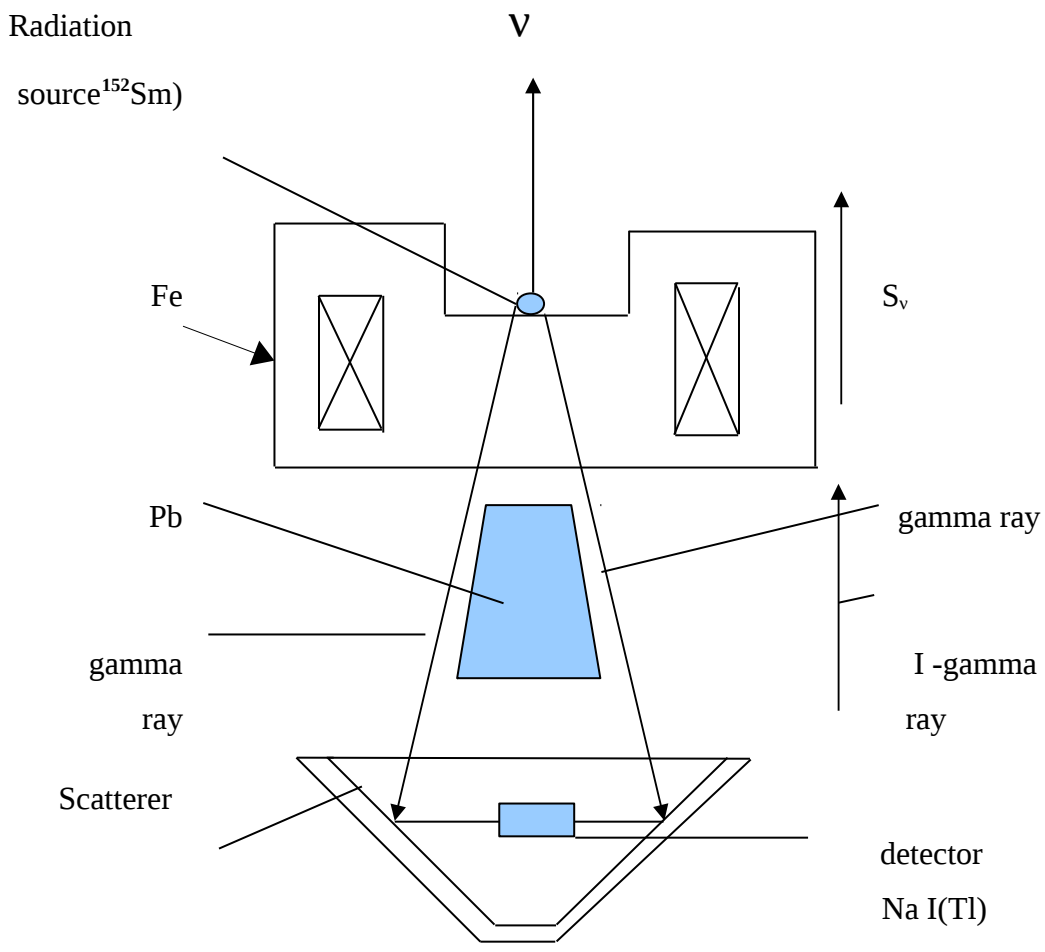


Fig:3.5.Experimental set up for helicity measurement .

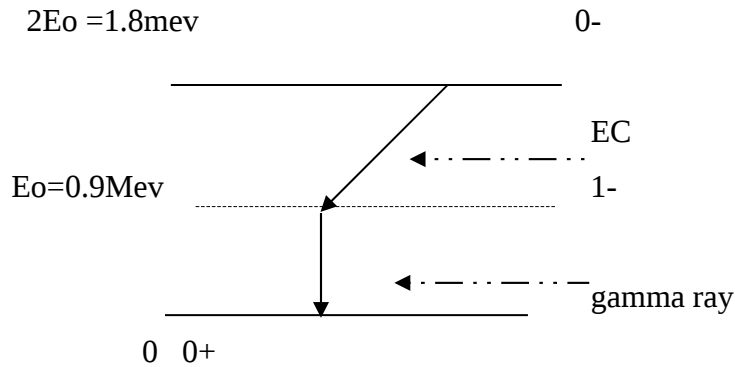


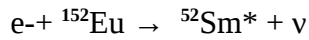
Fig:3.6;the simplified decay pattern for ^{152}Sm

It is clear from the law of conservation of energy and momentum conservation that after receiving the second (equal and opposite) recoil energy $T'_{nuc} = T_{nuc}$, the Sm nucleus comes to halt, while a gamma ray "acquire" its energy and is emitted with an energy ;

$$W = E_o + T'_{nuc} = E_o + \frac{E_o^2}{M_{nuc} c^2}$$

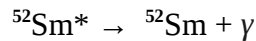
It is known that gamma ray with such an energy must undergo resonance interaction with ^{152}Sm nuclei in the ground state. Thus resonance scattering of gamma ray is investigated in Goldberg's experiment without the application of the Mössbauer effect. Obviously the resonance scattering of this type can be observed only for the above mentioned process (when the neutrino flies upwards, while the Sm nucleus and gamma ray flies downwards the gamma quantum being emitted from the moving nucleus) and $T_{nuc} = T'_{nuc}$. In fact, the energy of electron capture for the $^{152}\text{Eu}_{63}$ nucleus (0.9mev) is slightly different from the excitation energy of the ^{152}Sm nucleus (0.961). Hence, $T_{nuc} = 2.88\text{ev} \neq T'_{nuc} = 3.28\text{Mev}$. This difference is naturalized by a small deviation from the vertical for the direction of the gamma quantum motion as shown in Fig:3.5. above. [3,5,10]

By using the law of conservation of angular momentum the above process is analyzed. It follows from the e-capture scheme ;



$1/2 + 0 \rightarrow 1 + 1/2$; that the neutrino spin and angular momentum of the excited state of ${}^{52}\text{Sm}^*$ nucleus must be oriented in opposite directions. since their momenta are also oppositely oriented, the sign of longitudinal polarization of the nucleus must be the same as the sign of neutrino helicity.

From the gamma transition scheme



$$1 \rightarrow 0 + 1,$$

it follows that the sign of circular polarization of gamma ray must be the same as the sign of longitudinal polarization of the nucleus. That is as that of neutrino helicity.

Thus, the helicity of neutrino can be determined from the sign of circular polarization of gamma ray. The neutrino helicity is found to be negative. No direct experiment were carried out to determine the sign of anti neutrino helicity, but all other experimental data indicate that it must be positive. Thus, for all electron leptons (e^- , e^+ , ν_e , $\bar{\nu}_e$), the sign of their helicity is opposite to the sign of lepton charge(table 3.1)[6,7]

Table:3.1

Particle	Lepton charge L_e	Longitudinal polarization $p/ p $	Particle	Lepton charge L_e	Longitudinal polarization $p/ p $
e^-	+1	$-\nu/c$	ν_e	+1	-1
e^+	-1	$+\nu/c$	$\bar{\nu}_e$	-1	+1

Chapter Four

Conclusion

The main aim of this project work gives focuses on properties and mass of neutrino, interaction of neutrino with matter, cross section, mean free path, experimental detection of neutrino, helicity and helicity measurement. Generally, we conclude the main concepts as follows.

The neutrino is one of the most pervasive forms of matter in the universe, and the most elusive. It has no electric charge, little or no mass and behaves like a fermion with intrinsic spin $\hbar/2$, travels nearly at the speed of light.

There are three types, or "flavors", of neutrinos: Electron neutrinos, muon neutrinos and tauon neutrinos; each type also has a corresponding antiparticle called anti neutrinos. Interactions involving neutrinos are mediated by the weak interaction.

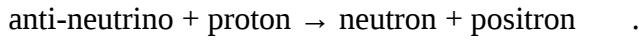
The neutrino was suggested by Pauli to solve a number of problems related to standard beta-decay processes. All difficulties concerning the conservation law in beta decay were overcome by the neutrino hypothesis of Pauli(1933).

Fermi formulated a theory for calculating the simultaneous emission of an electron with a neutrino based on Pauli's hypothetical particle.

The shape of experimental kurie plot near $T_{e(\max)}$ has also been used to set an upper limit to the neutrino mass. Experiments which have directly searched for neutrino masses have only been able to set upper limits. The current bounds are: $m_{\nu_e} < 3\text{eV}/c^2$, $m_{\nu_\mu} < 0.19\text{ MeV}/c^2$, and $m_{\nu_\tau} < 18.2\text{ MeV}/c^2$.

The zero charge, zero rest mass and that it interact extremely weakly with matter make the neutrino the most difficult particle to detect. Neutrinos could penetrate several light years depth of ordinary matter before they would be stopped. The neutrino reaction cross-section $= 1.2 \times 10^{-43} \text{cm}^2$ which is of the order of 10^{-43}cm^2 which is incredibly small cross section. Its mean free path $l = 1/(10^{-43} \text{cm}^2)(10^{24} \text{cm}^{-3}) = (1/10^{-19}) \text{cm} = 10^{19} \text{cm} = 10 \text{ light years}$.

The actual experimental detection of neutrino was done in 1950s by F. Reine and Cowan . F. Reine and Cowan provide direct, independent proof of the existence of neutrino. The detection of the neutrino was as the initiator of the inverse-beta decay reaction of:



The characteristic signal of a neutrino is thus a light signal from the positron annihilation radiation followed by the neutron capture γ -ray. Cowan and Reine succeeded in establishing the characteristic sequence.

Thus sequentially the positron was detected by its slowing down and annihilating with an electron producing two gamma rays in opposite directions. The characteristic signal of a neutrino is thus a light signal from the positron annihilation radiation.

Conclusively Cowan and Reine experiment proved the existence of neutrino and following which the conclusion was inescapable the neutrino is a real particle, and not just a figment of Pauli's and Fermi's fertile imagination.

Experimentally David proved that ν and $\bar{\nu}$ are different and not specified the fundamental properties that distinguishes neutrino from ant-neutrino. Experimentally:all ant-neutrinos have their spin parallel to their momentum, while all neutrinos(ν) have spin opposite to momentum. They exhibit a "handedness" neutrino is a left handed particle while anti neutrino is a right handed particle. This property is said to be helicity.

A direct measurement of neutrino helicity was carried out in an elegant experiment by G,Goldberg and coworkers in 1958 indicated that the neutrino helicity is negative. No direct experiment were carried out to determine the sign of anti neutrino helicity,but all experimental data indicate that it must be positive.

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