STM JOURNALS
Research & Reviews: Journal of Physics
ISSN: 2278-2265(online), ISSN: 2347-9973(print)
Volume 4, Issue 2
www.stmjournals.com

A Review of the Use of Super Kamiokande to Determine Atmospheric Neutrino Oscillations

A. Bala*
Department of Physics, Usmanu Danfodiyo University, Sokoto, Nigeria

Abstract
Super Kamiokande is a large water Cherenkov detectors situated at kamioka town in Japan. It was commissioned in 1996 and data taken began since then. The sole aim of this detector is to study atmospheric neutrinos, solar neutrinos, sterile neutrinos search for proton decays and other astrophysical sources. Lots of significant progress has been made during recent years in understanding of neutrino oscillation. This paper reports some findings of atmospheric neutrino oscillation using data taken from super kamiokande and other detectors of similar purpose. It also highlights some of the future projects based on this research area.

Keywords: *Kamiokande, neutrino, atmospheric, oscillation*

****Author for Correspondence*** E-mail: abkwashabawa@gmail.com

INTRODUCTION

Neutrino Physics is one of the widely growing areas in elementary particle physics. Neutrinos were formally assumed to have no mass (Standard model). Several experimental observations have shown that these neutrinos has nonzero mass and they undergo flavour oscillation. The study of atmospheric neutrinos has provided more information towards the better understanding of elementary particles in modern particle physics. Understanding of neutrino mass requires a better understanding of their oscillation [1].

Recent experimental results of data taking from super kamiokande have given a detailed analysis of two flavour oscillations. The oscillation probability depends on the distance travelled by the neutrino, the neutrino initial flavour as well as the energy of that neutrino. The probability of a neutrino produce in flavour v_a to be observed in another flavour say v_b after travelling a distance L is given by [1–4] as;

$$P\left(v_a \rightarrow v_b\right) = \sin^2 2\theta \sin^2\left(1.27\Delta m^2 L\right)/E_v$$

Where, E_v is the neutrino energy (GeV), Θ is the mixing angle and Δm^2 is the mass squared difference of the neutrino eigenstates.

In this review I will report some recent results of atmospheric neutrinos oscillations from sets of data taken from super kamiokande and other related detectors. A brief description of the super kamiokande and mode of formation of these atmospheric neutrinos will be given.

BACKGROUND THEORY

Cherenkov Detectors

These types of detectors employ Cherenkov radiation in detecting a particle. They have a wide range of applications such as fast particle counters, hadronic particle identification and tracking detectors used in event reconstruction. Example of such detectors is the large water detectors like the super kamiokande. These detectors according to Beringer [5], utilizes the properties of Cherenkov radiation such as:

- The prompt emission of a light pulse;
- The existence of a velocity threshold for radiation;
- The dependence of the Cherenkov cone half angle.

These detectors can be classified as either imaging or threshold types, depending on whether or not they use Cherenkov angle information

Cherenkov Radiation

Cherenkov radiation is an electromagnetic radiation emitted when a charged particle like electron passes through a dielectric medium at a speed greater than the phase velocity of light in that medium. The phenomenon was discovered by Pavel Alekseyevich Cherenkov in 1935 during his PhD studies on luminescence [6]. He observed a strange phenomenon which he described as a weak bluish light induced from by gamma-radiation in a pure sulphuric acid. His supervisor proposed that the observed phenomenon by Cherenkov is a distinct one, he therefore, forward the result to Frank and Tamm. They formulated a theoretical explanation of the result and conclude that the observed asymmetry of this light indicates the reality of the radiation observed, a theory was therefore, developed to describe this phenomenon [7].

SUPER KAMIOKANDE

Super kamiokande is a large water Cherenkov detector located in Kamioka town in Japan. It was commissioned and data taking began since 1996 [8]. The scientific aim of this large water detector is to study atmospheric neutrinos, solar neutrinos, sterile neutrinos, search for proton decays and other many astrophysical sources.

It is a cylindrical shaped detector having a height of 41 m and a diameter of about 39 m. It is 50,000 ton tank of water; this detector is located approximately 1000 m underground. The water in the tank acts as both the target for the atmospheric neutrinos, and the detecting medium for the byproducts of neutrinos interactions. The large tank of this detector is divided into two: the inner detector (ID) and the outer detector (OD). The wall of the inner detector is lined with 11146 photomultiplier tubes, whereas, the outer detector contains about 1885 photomultiplier tubes. This detector exploits a phenomenon kwon as Cherenkov radiation to detect high energy particles from neutrino interactions. The average energies super kamiokande is capable of measuring ranges from a few hundred MeV to a few GeV. The observed zenith angle distribution of the charged particles is link to the neutrino path length, this neutrino path lengths are the depth of the atmosphere approximately equals to 10 km [8].

When these atmospheric neutrinos interact with water molecules in the detector, a bluish Cherenkov light is transmitted through the highly pure water of the tank. This light produce eventually falls onto the wall of the detector which is covered with photomultiplier tubes. Each of these photomultiplier tubes is sensitive to illumination by a single photon of light which travels at speed greater than that of light in vacuum. Each of these photomultiplier tubes is capable of measuring the amount of light reaching it, as well as the time of arrival of each photon. This measurement is then collected by an external circuit and from that the energy and the starting point of each neutrino can be reconstructed (Figure 1).

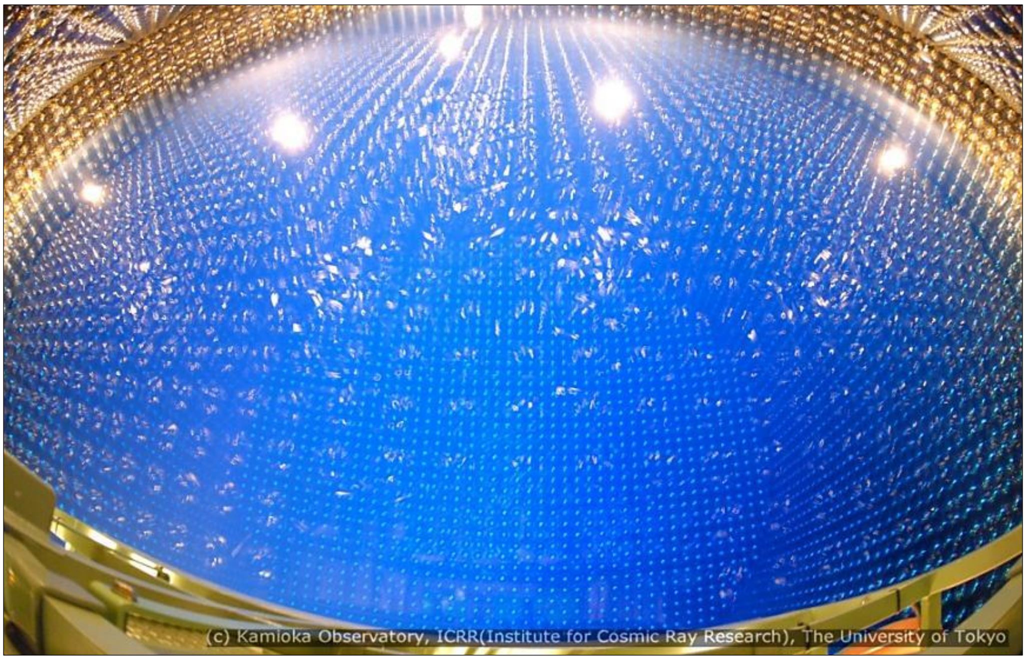

Fig. 1: *Internal View of a Super kamiokande [9].*

Events are observed in super kamiokande in three different ways: they are observed as fully contained (FC), this is when all the energy is deposited inside the inner super kamiokande detector. Events are considered partially contained (PC) if some high energy muons exits the inner detector, depositing some energy in the outer detector and are called upward going muons when the energy enters from below and deposit light in both the inner and the outer detectors.

Photomultiplier Tube

A photomultiplier tube is a device that creates an electric charge in proportion to the amount of light energy that it receives. The operation of the photomultiplier tube is dependent upon an important physical phenomenon known as PHOTOELECTRIC EFFECT [5]. When light enters a photomultiplier tube, the light passes through the output window. This light excites an electron in the photocathode and photoelectrons are emitted into the vacuum. The photoelectrons are then been accelerated and guided towards the first dynode by a focusing electrode, at this point they get multiplied by means of secondary electron emission. This multiplication process is repeated throughout the successive dynodes usually 8 to 19, depending on the mode of production. The final multiplied electrons collected by the last dynode are then collected by an external circuit. Below is a schematic picture of a photomultiplier tube (Figure 2).

ATMOSPHERIC NEUTRINOS

Generally, neutrino happens to be the most weakly interacting fundamental particles. Unlike electron and proton, neutrinos have no charge. This makes them so hard to detect. Atmospheric neutrinos are produce by the decay of particles when primary cosmic rays interact with earth atmosphere (air nucleus). When cosmic rays interact with this air nuclear, kaons and pions are produced, they both decays after travelling 3.7 and 7.8 m, respectively to muons [11]. These muons after also travelling some distance about 658 m decays to neutrinos and anti-neutrinos. Atmospheric neutrinos are the second most abundant particles in the universe after light (Figure 3). They are similar to the more familiar electron, with no electric charge. Because of this neutral nature of atmospheric neutrinos, they are not affected by electromagnetic forces which act on electrons; they are only affected by a weak sub atomic force of much shorter range than electromagnetic force. Their nature allows them to travel through great distance in matter without being deflected or absorbed. Apart from being neutral, handedness also gives neutrinos a unique property from other fundamental particle. A left handed particle will have a right handed mirror image; the case is not so neutrinos. A left handed neutrino has a left handed mirror image.

Atmospheric Neutrinos Interaction

In super kamiokande, atmospheric neutrinos interact in different ways. They undergo charged current interaction which is sometimes referred to as Quasi-elastic interaction [12]. In this mode of interaction, the neutrino converts into the equivalent charged lepton. Example is the inverse beta decay,

$$\bar{\upsilon}_e + p \rightarrow n + e^+$$

where, an electron anti neutrino scatters a proton to produce a neutron and a charged lepton (positron).

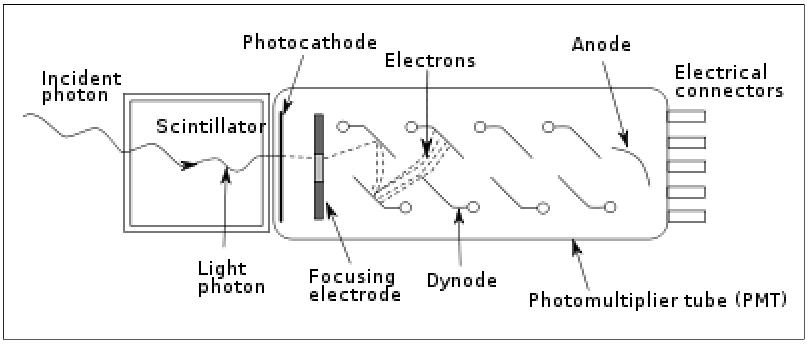

Fig. 2: *A Photomultiplier Tube [10].*

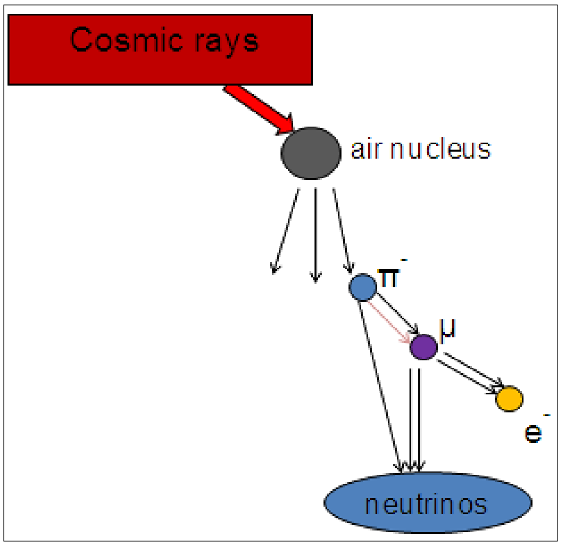

Fig. 3: *Sketch of how Neutrinos are formed.*

This interaction is of great importance in oscillation experiments, due to some reasons as highlighted by [12].

- It has the best major of the neutrino energy.
- Charged current interaction is about constant around a few GeV, thus can be used to measure neutrino flux.
- Also in some experiments using neutrinos energies below a GeV, charged current interaction is the dominant part of the cross section.

Atmospheric neutrinos also undergo neutral current interaction. In this interaction, the neutrino remains as a neutrino by transferring all of its energy and momentum to whatever particle it interacts with, e.g. neutrino electron scattering.

$\upsilon + e \rightarrow \upsilon + e$

Neutrino Oscillations

Observation of atmospheric neutrino oscillation began in 1986 when the IBM proton decay detector recorded too few stopping muons less than the expected number to be produced by atmospheric muon neutrinos [13]. In 1988 the kamioka group suggested that this could be best explained as neutrino oscillations (Figure 4).

In 2011, a Monte Carlo events corresponding to 500 years exposures of each run period was used to fit against the data taken from Super Kamiokande I, II and III. The best fit to the data was found at $\Delta m^2_{23} = 2.1 \times 10^{-3} eV^2$ and $\sin^2 2\theta_{23} = 1.0$. Similar analysis were made to determine the neutrino oscillation ($v_\mu \leftrightarrow v_e$) and ($v_\mu \leftrightarrow v_\tau$) using a chi-square comparative method of the data from super kamiokande and a monte carlo simulation. The best fit to the oscillation of muon neutrinos to a tau neutrino was observed at $\sin^2 2\theta_{23} = 1.0$ and $\Delta m^2_{23} = 2.2 \times 10^{-3} eV^2$ [2].

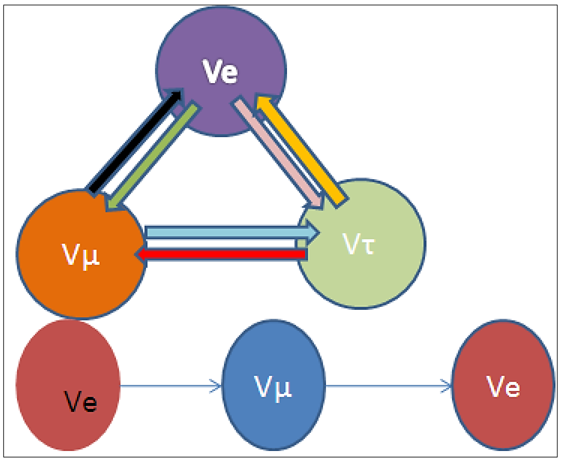

Fig. 4: *Images showing how One Neutrino Type can Oscillate into Other Flavour Type.*

Another analysis to determine the three flavour neutrino oscillation was made with an assumption of one mass scale dominance of the data from super kamiokande, combining the fully contained events, the partially contained events and the upward-going muon data set. The mass square difference, the mixing angle θ_{23} and θ_{13} were found to be 2.5 x $10^{-3} eV^2$, 0.5 and 0.0 at 90% confidence level [14].

Detailed explanation were given in [2] about the disappearance of the muon neutrinos in accelerator and atmospheric measurement which was best described by the oscillation of muon neutrinos into a tau neutrino. The observation of this tau neutrino is difficult due to its high production threshold about 3.5GeV. The best explanation could be that this tau decays into final states with multi particles producing Cherenkov light.

Apart from super kamiokande, there are other detectors and method used in the observation of atmospheric neutrinos. ANTYRES telescope is one of such detector; it is located about 40 km off the French coast [3]. About 2 km depth into the sea, it is also designed to measure and search for astrophysical sources but at high energy threshold of TeV to PeV. Unlike the super kamiokande, it has 885 photomultiplier tubes. This detector like super kamiokande is located in a relatively far under water to reduce the background due to intense flux of the down-going muons present at the ground level. The result obtained from this telescope was in full agreement with other results obtained from super kamiokande [2], MINOS [4] and Ice Cube [15,16]. The first oscillation maximum in this this experiment for upward going muons was found around 24GeV (E_v) [3].

In a recent result from MINOS experiment, in the combined analysis to determine the oscillation of muon neutrino into electron neutrino as well as the disappearance of tau neutrinos, using some set of data taking from accelerator and atmospheric neutrinos. The first mixing angle, the second mixing angle and the mass squared-difference were reported to be 0.61, 0.0238 and 2.35 x $10^{-3}eV^2$ [4]. In this experiment, a more significant value of the second mixing angle θ_{13} was obtained compared to the result obtained in [8].

FUTURE PROJECTS

A next generation underground water Cherenkov detector called Hyper Kamiokande has been proposed. This detector will serve as a far detector of a long baseline neutrino oscillation, experiment and as proton decay measuring detector, atmospheric and solar neutrinos and neutrinos from other astrophysical origin. The fudicial volume of this detector is about 20 times larger than that of the existing super kamiokande. The inner region of this detector will be viewed by 99,000 20-inch photomultiplier tubes; this number is about nine times the number of photomultiplier tubes in the existing type. Other projects include Indian-based Observatory (INO) in Indian and Large underground Observatory for Proton decay, Neutrino Astrophysics and CP Violation [17].

CONCLUSION

Results presented has shown that neutrinos undergoes flavour oscillation, i.e., a neutrino can be produced in one flavour type and then been observed in another flavour type. This phenomenon provides clear evidence that neutrino has mass not as predicted by the standard model.

REFERENCES

1. Takaaki K, 2004, Atmospheric Neutrinos, *New J Phys*. 2004; 6: 1–35p. DOI: 10.1088/1367-2630/6/1/194
2. Wendell R., Atmospheric Neutrino Oscillations and the Search for Appearance at Super-Kamiokande: *Nucl Phys B - Proceedings Supplements*, 2011; 218: 309–313p.
3. Kouchner A.A. Collaboration, 2014, Recent Results from the ANTARES Neutrino Telescope: *Braz J Phys*. 2014; 44: 550–559p.
4. Adamson P. Combine Analysis of Muon Neutrino Disappearance and Muon to Electron Neutrino Appearance in MINOS Using Accelerator and Atmospheric Neutrinos</article-title>: *Phys Rev Lett*. 2014; 112: 191801p.
5. Beringer J. Particle Data Group. *Phys Rev*. D86, 010001 (2012) and 2013 Partial Update for the 2014 Edition. 2012.
6. Engelfried J. Cherenkov light imaging—Fundamentals and recent developments: *Nucl Instrum Meth A*. 2011; 639:1–6p.
7. Cherenkova EP. The Discovery of the Cherenkov Radiation: Nuclear Instruments and Methods in Physics Research Section A: *Accelerators, Spectrometers, Detectors and Associated Equipment*. 2008; 595: 8–11p.
8. Fukuda S, *et al*. The Super-Kamiokande Detector: *Nucl Instrum Meth A*. 2003; 501: 418–462p.
9. Available at: www.learner.org-500x335-search by image.
10. Hamamatsu Photons: characteristics and Uses of Photomultiplier Tubes No. 79-57-03(1982)
11. Kudenko YG. T2K Observation of Muon-to-electron Neutrino Oscillations: *Phys Uspekhi*. 2013; 56: 1120–1125p.
12. Gaisser TK. Neutrino Oscillations: The 2007 Benjamin Franklin Medal in Physics Presented to Arthur McDonald and Yoji Totsuka: *J Franklin Inst*. 2011; 348: 453–458p.

13. Ransome RD. Neutrino Interaction, *Physics in Collision*. Vancouver, BC Canada, 2011, 1–8p.
14. Hosaka J., *et al.* Three Flavour Neutrino Oscillation Analysis of Atmospheric Neutrinos in Super-Kamiokande: *Phys Rev D*. 2006; 74: 032002p.
15. Mase K. The Latest IceCube Results: *Nucl Instrum Meth A.* 2014; 766: 43–47p.
16. Odrowski S, Recent Results from the Icecube Neutrino Telescope, for the IceCube Collaboration, *International Symposium on Multiparticle Dynamics*, Kielce, Poland, 2012, 687–693p.
17. Available at: www.nu.to.infn.it

Cite this Article

Bala A, A Review of the Use of Super Kamiokande to Determine Atmospheric Neutrino Oscillations, *Research & Reviews: Journal of Physics (RRJoPHY)* 2015; 4(2): 19–24p.