AN OVERVIEW OF NEUTRINO PROPERTIES

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ABSTRACT

Neutrinos are among the most abundant elementary particles in the universe. If we want to understand the Universe, then we need to know about the neutrinos. They are the second most abundant particles after photons. Though learning about the world of neutrinos is not so easy because their interaction with matter is extremely feeble. A brief review on the phenomenon of neutrino oscillation both in vacuum and in medium is studied here. In this work, I have discussed about neutrino experiments mostly natural and artificial neutrino experiments.
Marvelous results on neutrino oscillations in the last several years have triggered a lot of enthusiasm and interest in neutrinos, from experimental as well as theoretical point of view. One of the most important facts is that, neutrino physics is a data driven field - for several years now, new data are pouring at an outstanding rate. Our understanding of neutrinos has improved dramatically in the past ten years and there is no doubt that neutrino oscillation is an exclusive example of experimental evidence for physics beyond the Standard Model of particle physics.
Neutrino physics is a very intense field of research having implications in different branches of physics, such as high energy physics, quantum field theory, cosmology, astrophysics, nuclear physics and geophysics. Spectacular results on neutrino oscillations in the last several years have triggered a lot of interest in neutrinos, from experimental as well as theoretical point of view, and many future neutrino experiments are in preparation or under discussion to sharpen our understanding about these tiny particles. This work addresses several aspects of these issues.

Keyword : - Neutrinos, Natural, Physics, Data, Field etc.

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1. INTRODUCTION

The melodic portrayal of neutrinos by Dylan Casey in his tune "Neutrino of Love" is terrific. In fact, neutrinos are slippery, fickle, yet bulging. Despite this (or so!), After fifty years of its disclosure, even though it presents many mysteries and physicists face difficulties that need to be identified. Like electrons, they are basic particles. F. Rains would describe neutrinos as "... the smallest amount of reality at any point imagined by a person".
Neutrino material science (neutrino physics) is an extremely extraordinary and energetic field of research in high vitality physics, quantum field hypothesis, cosmology, astronomy, nuclear materials science and geophysics. The spectacular results on the most recent neutrino motions have elicited a great deal of enthusiasm and enthusiasm for neutrinos, as a mere hypothetical approach from testing. One of the most important certainties is that neutrino physics is an information-driven field - for quite a long time, now pouring new information at an extraordinary rate. Our understanding of neutrinos has improved greatly over the last ten years and there is no uncertainty that neutrino wavering molecules are an elite case of testing evidence for past physics of standard models of materials science. This achievement sets an unbelievable case of a guide in which both hypothetical understanding and test achievements are linked to the hip to provide the main evidence of the physical physics of the standard model's past. The progress came to an end in the 2002 Nobel Prize for Physics, which was awarded to two pioneers in neutrino physics. Masatoshi Koshiba was awarded a Supernova and Ray Davis Jr. Award for the recognition of neutrinos for the discovery of sun-oriented neutrinos (solar neutrinos).
Neutrino physics is currently set to move to the accuracy system. Accuracy neutrino assessments continue to be dynamic efforts to initiate the timing of science, which is likely to broaden the horizon of our insights about neutrinos. Various high-accuracy neutrinos have been investigated to improve our understanding of these particles.
This is an appropriate time to ask how the phenomenal systematic / proposed state-of-the-art analysis will perform in the coming decades to explain the idea of neutrinos and our push for new materials science. This asana is a push to examine parts of these issues.

2. NEUTRINO IN A NUTSHELL

Neutrinos are electrically neutral particles of spin with an extremely nominal mass approximately 5,00,000 times smaller than the mass of the electron, which itself is 2000 times smaller than the proton mass. There are at least three species (or flavors) of very mild neutrinos, νe, νμ and ν left, which are left-handed, and their antiparticles, eνe, μνμ and τντ, which are right-handed. After photons, neutrinos are the most bisexual particle in the Universe: each cubic meter of the Universe contains about 30 million neutrinos, remaining from the Big Bang, similar to the famous Bang Microwave Microwave Foundation. It also comes "unnoticed" from the farthest reaches of the universe, giving information about its source. The interaction of neutrinos is mediated by heavy W Z and Z0 bosons and accordingly at low energies they talk weakly with normal or normal matter and pass very much like light through a crystal, especially from Earth. If a target as large as Earth is placed in front of 100 billion neutrinos, only one of them is likely to interact with it. The average free passage of 1MeV neutrino in lead is about 1 light year! Therefore in this way, very large or huge detectors are required for neutrino detection / detection and in addition very intense neutrino beams are required.

3. NEUTRINO ODYSSEY/JOURNEY

Let us examine the inexplicable journey of manifestation in one of nature's most intriguing / elusive particles. In a letter to colleagues on 4 December 1930, Wolfgang Pauli [1] proposed the presence of neutrinos to ensure energy conservation in radioactive beta-decay. Following the revelation of neutrons by James Chadwick two years after the fact, it was first speculated that the molecule predicted by Pauli might be neutrons. Despite this, it was soon understood that Pauli's molecule must be much lighter than the neutron. In 1933, Enrico Fermi introduced the name neutrino, where he used the Italian syllable "-ino" to designate "smaller or smaller neutrons". In 1956, two decades after Pauli's letter proposed neutrinos, Clyde Cowan and Frederick Reinnes [2] observed antinutrinos (the antimatter partner of neutrinos) transmitted by the atom (nuclear reactor). This neutrino was later resolved as an associate of the electron. In 1969, neutrinos distributed by the sun's burn were distinguished by Ray Davis with an identifier / detector that relied on chlorine at an underground research center at the Homestake mine in the USA. This test reported that a large fraction of normal neutrinos had not been identified. It began with the long term "sunlight-based neutrino problem or solar neutrino problem". The elaboration that missing electron neutrinos may change in another way (unmarked for this test) was recommended long ago, although the absence of our insight into the sun-oriented or solar models on which normal neutrino rates were based was previously discussed. was spotted. An almost definitive explanation.

In 1987, neutrinos were identified from a supernova in the Large Magellanic Cloud. Just 19 occasions were observed [3–5] and they formed the standard image of the center-breaking (core-collapse) supernova. Recently, some examinations may confirm the presence of neutrino motions. In 1998, the super-commiocande experiment [6] expanded the evidence for oscillations of barometric neutrinos. This was an important point for neutrino physics.

4. ACCELERATOR AND REACTOR NEUTRINO EXPERIMENTS

In addition to the experiments measuring solar and atmospheric neutrinos, there are several terrestrial laboratory experiments for neutrino oscillation study in which neutrinos are produced either in accelerators or reactors. These experiments have the advantage of better control of the neutrino flux and therefore they play an essential role in precision measurement of neutrino oscillation parameters. In the following a short description of some of the most important accelerator and reactor experiments is given. For limited scope of the thesis, we confine to three neutrino-mixing only and hence the LSND experiment [40] is not taken into discussion.

CHOOZ Experiment

The CHOOZ experiment (1997-1998) looked for disappearance of electron neutrinos ν_e, i.e. $\bar{\nu_e} \rightarrow \bar{\nu_x}$ oscillation. Electron antineutrinos with a mean energy of a few MeV are produced in two nuclear reactors at the CHOOZ power station, and they were detected at about 1 km away from the neutrino source in a liquid scintillation detector via the inverse beta decay reaction, $\bar{\nu_e} + p \rightarrow n + e^+$. Due to its relatively long base-line, the experiment was sensitive to Δm^2 values down to atmospheric neutrino range.

The CHOOZ experiment [41] revealed an important fact that oscillations of electron neutrinos at the atmospheric scale of Δm^2 are small or zero. The parameter region $\sin^2 2\theta > 0.16 \text{ for } \Delta m^2 \geq 7 \times 10^{-4} eV^2$ is excluded [42]. Since the Kamiokande allowed region lies in the excluded area by the CHOOZ; the disappearance of muon neutrinos observed in

Kamiokande (and IMB, SK, Soudan-2) cannot be due to $\nu_\mu \rightarrow \nu_e$ transitions. The CHOOZ results put the constraint in the element U_{e3} of MNS mixing matrix as $U_{e3} < 0.16$ [42]. The results of the CHOOZ experiment were confirmed by the Palo Verde experiment [43]. In near future Double-CHOOZ [44] will be able to put the constraint on U_{e3} to the limit 0.025.

KamLAND Experiment

The Kamioka Liqiud-scintillator Anti-Neutrino Detector (KamLAND) is a very long base-line reactor disappearance experiment. It is a 1000 tons liquid scintillation detector, located at the old Kamiokande site, being exposed to a large flux of low energy electron antineutrinos, produced in several nuclear reactors at an average distance of 180Km. Again $\bar{\nu}_e$'s (with energies above 1.8MeV) are detected via the inverse ß-decay reaction $\bar{\nu}_e + p \rightarrow n + e^+$. Due to the long base-line, KamLAND is sensitive to small values of Δm^2 and it is able to provide a solar model independent test for the LMA solution of the solar neutrino problem. According to the KamLAND results [7], the ratio of the number of observed inverse ß-decay events to the expected number of events in the absence of neutrino oscillation is 0.611 ± 0.085 ± 0.041 for $\bar{\nu}_e$ energies 3.4MeV, This rules out the no-oscillation hypothesis at 99.95% C.L. Also the observed energy spectrum shows a distortion which is consistent at 93% C.L. with the expected spectrum in case of neutrino oscillations. The KamLAND results [7] exclude all oscillation solutions but LMA MSW solution and are therefore in good agreement with the recent solar neutrino results which favor the LMA solution to the solar neutrino problem.

K2K experiment

The KEK to Kamioka (K2K) [42, 45] is the first working accelerator based long-baseline (LBL) experiment. The neutrino beam, produced in the synchrotron accelerator at KEK and detected at SK, consists of 98% pure muon neutrinos with the mean energy of 1.3GeV. Therefore, K2K is sensitive to the same Δm^2 region as the atmospheric neutrino experiments. This experiment is to test the oscillation solution for the atmospheric neutrino problem and to determine more precisely the oscillation parameters. According to the K2K-I and K2K-II data (0.89 x 10^{20} p. o. t. in total) [45], 107 beams induced neutrino events have been detected in SK detector whereas the expected number in the absence of neutrino oscillations is 151^{+12}_{-10}. The observed neutrino spectrum shows a distortion expected from neutrino oscillation effects. K2K results are consistent with the parameter values corresponding to the atmospheric neutrino oscillations.

MINOS

$(\nu_\mu + \bar{\nu}_\mu)$ MINOS [46] is an accelerator based long-baseline experiment, in which a neutrino beam with 98.5% and a mean energy of 3GeV is produced at Fermi-lab and observed at the MINOS detector in the Soudan mine at a distance of 735 km.

For the first data [47] (0.93 x 10^{20} p. o. t.), 92 events have been detected, whereas **177±11** ν_μ events with E < 10GeV were expected. This provides an 5.0σ evidence for disappearance. The values of the oscillation parameters from MINOS are consistent with those from K2K, as well as

from SK atmospheric data. The impact of the data from MINOS in global analysis [48] is that the best fit value for $\Delta m^2 32$ is shifted from $2.2 \times 10^{-3}\ eV^2$ or SK+K2K to. $2.5 \times 10^{-3}\ eV^2$ MINOS improves the lower bound from $1.4 \times 10^{-3} ev^2$ for K2K+SK to $1.9 \times 10^{-3} eV^2$ at 3σ. There is no change in θ_{23} due to MINOS.

The OPERA [49] and ICARUS [50] experiments belonging to the CERN to Gran Sasso program [51], are aimed at a direct measurement of $\nu_\mu \rightarrow \nu_\tau$ oscillation over a long baseline of about 730Km.

Future accelerator experiments

The accelerator based neutrino experiments discussed above, belong to the first generation long baseline accelerator experiments dedicated for precise measurement of oscillation parameters $\Delta m^2_{21}, \Delta m^2_{32}, \theta_{12}$ and θ_{23} within $\sim 10-20\%$ accuracy. There are proposals for second generation accelerator experiments [52] which can measure with better precision the solar and atmospheric oscillation parameters, determination of the value of the mixing angle θ_{13}, possibility to determine the sign of Δm^2_{32} via MSW matter effects, and finally observe the leptonic CP violation, using neutrino beams with higher intensity: super-beams, beta-beams and neutrino factory beams and neutrino factory.

5. NEUTRINO OSCILLATION IN VACUUM

It is a quantum mechanical behavior in which neutrinos change flavor as it propagates. There is now strong evidence for neutrino oscillations from all the neutrino experiments [17]. This information has opened a new physics of massive and mixed neutrinos beyond the Standard Model (SM) of particle physics. The idea of neutrino oscillation was first introduced by Pontecorvo [18]. The essence of this effect is very simple and can be demonstrated theoretically using the principles of quantum mechanics. We consider a two-level quantum system. If the system is in one of its stationary states |Ψi> (eigenstates of the Hamiltonian); it will remain in this state, and time evolution of the wave function is that it just picks up a phase factor: $|\Psi_i(t)\rangle = e^{iE_i t}|\Psi_i(0)\rangle$.

If, however, a state is prepared which is not one of the eigenstates of the Hamiltonian of the system, the probability to find the system in this state will oscillate in time with frequency W21= E2-El, where E2 and El are the energy eigenvalues.

In the case of neutrino oscillations, neutrinos are produced by the charged current weak interactions and therefore are weak eigenstate neutrinos ve, vμ and vɽ. However, the neutrino mass matrix in this flavor basis is not diagonal. This means that the mass eigenstate neutrinos v1, v2 and v3 are in general different from the flavor eigenstates. Therefore the probability of finding a neutrino created in a given flavor state to be in the same state (or any other flavor state) oscillates with time.

6. NEUTRINO: "NU" HORIZONS

We live in an exciting time when the light of new discoveries is breaking apart our long-held picture of the Standard Model. This revolution began in part with the widely confirmed assertion that neutrinos have mass, and it will continue to be waged by upcoming neutrino experiments. Spectacular results from a series of experiments over the last four decades [6,8,11,17–19,31,36,76–79] have firmly established the phenomenon of neutrino oscillation and paved the way for the "golden" age of neutrino physics. Since neutrino oscillations can occur only if there is a mass difference between at least two neutrinos, an observation of this effect proves that at least one non-zero neutrino mass exists.

Neutrinos are strictly massless in the Standard Model of particle physics and the finite neutrino masses required by the experimental data provide the first hint for physics beyond the Standard Model, and make an extension of the theory necessary. No doubt that this has put the Standard Model in a paradoxical situation. Moreover, the fact that neutrino masses are so tiny (very much smaller than that of any other known fermion) should find an explanation in the new theory.

Recent discoveries on neutrinos might provide unique information on a more complete theory of elementary particles. The sensitivity of neutrino experiments to very tiny mass scales might provide the scope to learn something about physics at very high energy scales (i.e., at very small distances), which will never be accessible in particle accelerator experiments. Therefore, information from neutrinos is complementary to the one from accelerator experiments, and it may provide a key to a so-called Grand Unified Theory, in which the electromagnetic, the weak and the strong interactions are unified to one fundamental force.

Another puzzle of modern physics is the origin of matter. In the so-called Leptogenesis mechanism the origin of matter in the very first moments after the Big Bang is related to neutrinos. In that theory the small asymmetry between matter and anti-matter is generated by processes involving neutrinos in the early stage of the Universe. In this way a theory of neutrino may even provide the reason for our existence. Neutrinos have played a key role in shaping the Universe as we see today. We have just started our journey in the mysterious world of neutrinos, a tiny creature of Nature. A long journey is waiting for us ahead and many experimental approaches are required to get the full view. In the near future, the Large Hadron Collider (LHC) will start its quest for Higgs and it is expected that the LHC will explore the mechanism of electroweak symmetry breaking and provide clues of new heavy degrees of freedom. This will certainly boost up the future road map of the neutrino physics programme and it is for sure that neutrino physics, a bit player on the physics stage in yesteryears, has now donned a central role and will play a crucial part in the high energy physics programme.

CONCLUSIONS

Neutrino physics is traversing through an exciting phase with lots of new data making this field more interesting. There is an excellent progress in our understanding of the neutrinos over the last ten years or so, thanks to the experiments on neutrino oscillations which confirm the fact that neutrinos have a tiny, but non-zero, mass quite against the expectations of our best theory- the Standard Model. We have now a rough picture of the parameters governing three-flavor oscillations and we are all set to move into the precision regime. There is no doubt that the use of artificial neutrino sources is mandatory in the era of high precision experiments. In this direction the beta-beam is a recently proposed technique of producing a pure, intense and collimated beam of νe or $\bar{\nu} e$ through the beta-decay of completely ionized radioactive ions. My thesis sheds light on the neutrino oscillations and neutrino experiments.

After that we move to the artificial sources and here we discussed accelerator and reactor neutrino experiments such as CHOOZ, K2K, KamLAND and MINOS. These all experimental detectors are of great importance in neutrino physics.

The study of neutrinos has always landed up with lots of surprises. So we can expect further surprises in store and, obviously, beta-beams can play a leading role in this direction. This thesis work is an effort to judge the expected performance of a beta-beam neutrino source in the future progress of neutrino physics and also for the hunt for signals of non-standard new physics. We hope that this work will provide a boost to the detailed and thorough R&D of the novel beta-beam neutrino source in future.

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