



“Physics in Canada”

Book Review

“La Physique au Canada”

Critique de livre

“**Experimental Studies of Neutrino Oscillations**”, by Kajita, Takaaki, World Scientific Publishing, 2016, pp. 108, ISBN 978-9814759267, price 26.12

Many years ago, I wrote an essay on the solar neutrino deficit problem as a requirement for an undergraduate course on Modern Physics. From that point on, I have maintained a hobbyist’s interest in neutrinos, and as an Ontario secondary school physics teacher, I have continued to entertain brief looks into the research conducted on the problem. As such, when I saw “Experimental Studies of Neutrino Oscillations” was available for review, I was excited at the possibility of reading research by 2015 Nobel laureate, Takaaki Kajita.

I feel it necessary to begin my review to emphasize that this book is not for someone without an understanding of the standard model, neutrino oscillations, or strong quantitative analyses. Dr. Kajita’s work is incredibly thorough, and the writing is technical, filled with acronyms and references that require the reader either to be *in-the-know*, or have a strong desire to complete additional research in order to be able to understand the main points, key findings, and their implications. Rather than written as a chaptered book - with a single thread to lead the reader from a “here is what we knew” to “here is what we know now” - this text is a compilation of seven previously published articles (from 2000 through 2009), to provide the reader information on research exploring neutrino oscillations at observatories predominantly located in Japan (such as the Super-Kamiokande), while expanding our understanding of detectors (e.g. Cherenkov), and solar and atmospheric neutrinos experiments. In addition, as scholarly articles follow a standard layout, the background information for many of the chapters is repetitive since the works are connected – and some more closely than others. With the above in mind, in the following paragraphs, I briefly summarize each chapter’s content, as I understand them.

The book begins with *Neutrino oscillations, discovery, current states and future directions*, which walks us through results gathered at Super-Kamiokande (1989), the Sudbury Neutrino Observatory [SNO] (2001) and the Kamioka Liquid Scintillator Antineutrino Detector (KamLAND), to provide evidence for solar neutrino oscillations, which parameters are considered, and the significance of the CHOOZ Antineutrino experiments. Originally published in 2009, Dr. Kajita also identifies future work proposed at the T2K (Tokai to Kamioka) and NOvA (NuMI Off-axis  $\nu_e$  Appearance) to be conducted this past decade. The remaining six chapters fill in background information necessary to have reached the findings shared in *Chapter 1*.

To this end, *Chapter 2* and *Chapter 3* explain some of the necessary background information about conducting neutrino oscillation research. *Future atmospheric neutrino experiments: the case of water Cherenkov detectors* (originally published in 2005), focused on Cherenkov detectors and how they are able to be used in atmospheric neutrino experiments (data on allowed parameter regions for atmospheric data on  $\sin^2 2\theta_{23}$  and  $\Delta m_{23}^2$  for different length

travelled per energy (L/E) values; oscillation probability for neutrinos passing through the earth as a function of zenith angle and energy). *The JHF-Kamioka neutrino project* (originally published in 2002) explains considerations and limitations of the JHF-Kamioka project (this project had a low event rate and required more study).

*Chapter 4* and *Chapter 5* expand our understanding of specific neutrino oscillations. *Solar and atmospheric neutrino results for Super Kamiokande* (originally published in 2002) confirms no day-night effects, and no energy spectrum distortions. From this study, it is established that  $\nu_e \rightarrow \nu_x$  (where x was either muon, tau or sterile) was disfavoured, but that  $\nu_\mu \rightarrow \nu_\tau$  (and not  $\nu_{sterile}$ ) did not contradict the data. Also, evidence of muons was observed as  $\nu_\mu$  passed through the Earth and interacted with rock to produce muons through charged current (CC) interactions (upward muons). *Neutrino oscillation experiments: Super-Kamiokande, K2K and the JPARC neutrino project* (originally published in 2004) begins from the analyses presented in *Chapter 3*, and proceeds with how  $\nu_\tau$  are recognized through their decay as a neutral current (NC) events. Dr. Kajita finishes this chapter writing about other projects at the time: MINOS (Main Injector Neutrino Oscillation Search) experiment, CNGS (CERN), and JPARC-Kamioka neutrino project (Japan Proton Accelerator Research Complex).

*Chapter 6* and *Chapter 7* provide additional information on specific neutrino experiments. *Present and Future Neutrino Oscillation Experiments* (originally published in 2004) clarifies our understanding for solar neutrinos, and that a Large Mixing Angle (LMA) solution is confirmed by data gathered at KamLAND. Observations gathered at the SNO when using *NaCl* confirmed that it is specifically the LMA-I solution that is favoured ( $\Delta m^2 \approx 7 \times 10^{-5} eV$ ). For Atmospheric neutrinos, the K2K experiments revealed some tau production. In the final chapter, *Solar and Atmospheric Neutrinos* (originally published in 2000), Dr. Kajita reiterates what we know about neutrino oscillation types, as well as the disfavoring of sterile neutrinos.

After reading the book, I am left wondering much about what the progress has been made with respect to neutrinos and how they can be used to understand the CP violation. Beginning in *Chapter 1*, Dr. Kajita identifies experiments using neutrino masses into neutrino oscillation probabilities would help researchers to better understand CP violation and baryon asymmetry. Again in *Chapter 5*, Dr. Kajita identifies that it is the JPARC-Kamioka neutrino project – under development at the time – that would be dedicated to exploring the CP Violation phase neutrino oscillation probabilities. At this point, there may be a sufficient amount of research which could be gathered by experts in the field to help others, like myself, understand this area.

For the high school teacher, the text provides background information to better understand some of the research into neutrino oscillations to give better context in discussing the 2015 Nobel Prize, but offers little to contribute to the teaching of the 2008 Ontario physics curricula as the text is well beyond the high school level. For the hobbyist, as with any scientific text, allow for time to think and come back to the information, and maybe to look up some additional background information – I found moving to some of the original publications was helpful to support my own learning.

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