# Neutrinos and Neutral Current Detectors

Neutrinos are light, barely massless, elementary particles that travel close to the speed of light. They are by-products of beta decay and are also the second most numerous particle in the universe. More importantly, they interact only weakly, making them difficult to detect. The standard solar model can estimatesthe flux of the neutrinos being produced in the sun, but experimental detection have fallen short of this value until recently. Since previous experiments detected only the electron flavor of the neutrino, this discrepancy is now attributed to neutrino oscillations from one flavor to another. The Sudbury Neutrino Observatory (SNO) made an effort to show this through experimental results. Neutral Current Detectors (NCDs) were utilized in the third phase of SNO to detect neutral current reactions occurring as a result of neutrino events. However, because of the makeup of these particular detectors, further study is needed to determine the exact transmission line properties of the NCDs.

Neutrinos were suggested to exist by the inconsistency between the model of beta decay and conservation of momentum. Using conservation of momentum, every electron or positron emitted from a particular beta decay would have identical momentum. However, when tested, a momentum spectrum was measured for the same beta decay process. This led to the hypothesis that an additional particle with almost undetectable mass and no charge was being emitted to take away some of the momentum from the reaction. Once postulated, they were found to only interact weakly and maximally violate parity, making them not only intriguing, but also the only known particle that could be a candidate for dark matter. Their ability to travel almost undetected and unhindered through matter gives them the potential of containing valuable information about the evolution and history of our universe. While neutrinos were theorized in order to solve one problem, once incorporated into the standard model of the sun, the experimentally detected neutrinos fell short of the expected value for neutrinos by a significant margin. Physicists attributed this to a new theory of neutrino flavor oscillations.

The Sudbury Neutrino Observatory sought to reconcile the difference between model and experiment by measuring neutrino oscillations in a consistent and reliable manner by measuring the flux, energy, and direction of solar neutrinos. They did this by creating a system that could measure all neutrino flavors whereas previous experiments had been able to measure only electron flavor neutrino. To do this, heavy water ($D_20$) was used in SNO so the extra neutron in deuterium could be utilized to facilitate detection of different neutrino reactions. The three reactions measured by SNO were elastic scattering, charged current reactions, and neutral current reactions. Neutrinos had previously been detected using only elastic scattering, which is significantly more sensitive to the electron flavor. By measuring all three reactions in three different phases, SNO was able to better show neutrino oscillations.

The heavy water used in SNO was contained in an acrylic tank and surrounded by light water. This setup was covered with photomultiplier tubes and built underground in a nickel mine. Photomultipliers were used in the first phase of SNO to detect all three reactions by detecting the photons given off by the reactions. Salt was added to the heavy water in the second phase to increase the neutron absorption cross-section of the system, improving the sensitivity to the neutral current reactions. The third and final phase used Neutral Current Detectors (NCDs) in an effort to improve results. Neutral Current Detectors are nickel proportional counters filled with Helium-3 with a copper wire running down the center. The Helium-3 has an even higher cross-section for neutron capture than salt and provided a separate means to detect neutrons, thereby separating the neutron signals from the electron signals.  Neutral current events are detected when the neutron captures onto a Helium-3 atom and releases a triton and a proton, which interacts with and sends a pulse down the copper wiring running down the NCD.

While the measurements obtained by SNO were improved by the introduction of NCDs, new errors were also introduced.  Because all material has some level of Uranium and Thorium, alpha particles were emitted from radioactive decay of the nickel on the outside of the NCDs.  The pulses created by these charged particles created significant background to the neutron signals.  To add to this, standard calculations for proportional counters cannot be used for these NCDs because of the ferromagnetic properties of the nickel.  These ferromagnetic properties affect the transmission line properties of the detector and attribute some sort of frequency dependence to its properties.

In an effort to understand this frequency dependence, we directly measured the transmission line properties at a set of varying frequencies.  Our initial results showed no coherent relationship between frequency and impedance.  We suspected our original setup was not obtaining the most accurate measurements, so we assembled a new measurement setup and obtained noticeably different results.  After additional research, we applied a correction, known as the open/short method, to our previous data and found it followed the data from the original set up almost exactly.  With confidence in our new correction method, data was taken for additional NCDs of two lengths and a combination of the two lengths.  These yielded erratic graphs with no relationship to frequency or to each other.  An additional correction, called the open/short/load method was applied to the data taken for the cable that connects the NCDs to the data acquisition system. When this failed to result in any conclusive relationship, we decided a closer look at the correction methods was needed. For further investigation, a cable of known impedance was measured and corrected with the open/short method and we found we can only reliably use this correction under 20 MHz. Using this new information about the correction method, we took data as precisely as possible and plotted the characteristic impedance up to 20 MHz. The resulting graph is significantly more coherent from previous graphs and behaves in a close-to-expected manner.

Despite the insight about the NCDs gained this summer, we did not conclude anything specific about the frequency dependence of the properties of these detectors. What we found was that the NCDs do not have constant impedance as assumed by the SNO experiment and their relationship with frequency is not a simple one. Most significantly we demonstrated the effectiveness of a particular correction as well as the limits of the correction method. However, to utilize these devices to their fullest potential, more data and research about the transmission line properties of these NCDS is required.

# References

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