Physics 531: Quantum Mechanics G. Duda

Creighton University Fall 2012

Project #2: The Solar Neutrino Problem

The Solar Neutrino Problem

The sun, due to nuclear fusion in its core, is an excellent source of neutrinos. However, early experiments conducted in the 1960s by Davis and Bachall and others (particularly the Homestake or Davis Experiment) found only approximately a third of the expected number of neutrinos as predicted by the standard solar model. This led to a rather interesting puzzle: does the sun put out fewer neutrinos than predicted or are we somehow missing neutrinos by the time they get to the Earth?

Stage 1 Research:

1. Familiarize yourself with neutrinos and the physics of neutrinos (i.e. weak interactions). How to neutrinos interact? What do they interact with and how?
2. How are neutrinos produced in the sun? What reactions produce neutrinos? With what energies?
3. Research the Standard Solar Model. How does this calculate the expected solar neutrino flux? What parameters does it depend on? Is this model considered reliable or are there potential sources of error?
4. Find references and papers from the neutrino detection experiments that showed a deficit in the expected number of neutrinos. What theories were proposed to explain this deficit?

Some good places to go for papers on the solar neutrino problem are the following. I would recommend using “solar neutrino problem” as a search topic.

1. Spires at SLAC: http://inspirebeta.net (inspire is the new version of spires)
2. The arXiv at Los Alamos (lanl.arXiv.org)
3. NASA Astrophysical Data System (NASA ADS: <http://adswww.harvard.edu/>)
4. Physics today
5. Scientific American
6. American Journal of Physics (http://ajp.aapt.org/)

**Stage 2**

Modern Understanding:

One scenario proposed which solves the solar neutrino problem is that neutrinos, created as electron neutrinos in the core of the sun through weak interactions, actually oscillate into different flavors as they travel to the earth. In other words, an electron neutrino changes into a muon or tau neutrino before reaching the Earth.

1. Think about this claim. How does it solve the solar neutrino problem? Why would such oscillated neutrinos not be detected in solar neutrino detection experiments?
2. What is the fundamental physics behind neutrino oscillations? How and why do they oscillate? How can this be explained with quantum mechanics?
3. What experimental evidence is there for neutrino oscillations? Does this agree with the theory? Are there conflicts between experiments?
4. What do these neutrino oscillation experiments measure about neutrinos? How many free parameters are there in models for neutrino oscillations?
5. Is the solar neutrino problem solved? Why or why not?

**Stage 3**

Calculation and Toy Model:

Develop a toy model for neutrino oscillations by only considering two types of neutrinos: electron and tau neutrinos. Suppose a neutrino is created through weak interactions as an electron neutrino. Calculate:

1. The probability that some time t later this neutrino will have oscillated into a muon neutrino.
2. The oscillation length for a 1 MeV neutrino vs. a 1 GeV neutrino.
3. Explain the fundamental parameters that your toy model depends on. Using data from neutrino experiments that examine electron neutrino to muon neutrino oscillations, estimate the values of your model parameters.
4. What can neutrino oscillation experiments tell us about neutrino masses? From the experimental data, what is Δm2 for muon and electron neutrinos?

Your project write-up should include the following information:

1. A historical section which details the solar neutrino problem (stage 1)
2. How neutrino oscillations solve this problem (stage 2)
3. Your toy-model calculations (from above)
4. A description of the full 3 neutrino oscillation model and a summary of the best experimental evidence for neutrino oscillations
5. Experimental constraints on the parameters of neutrino oscillation models