Physics Department

Physics 233

Solar Neutrino Problem (SNP).

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Proton-proton cycle, chain of thermonuclear reactions that is the main source of the energy radiated by the Sun . Another sequence of thermonuclear reactions i.e. carbon cycle, contribute in the radiated energy. The energy of such nuclear reactions is carried off by gamma-ray photons (γ) and neutrinos (ν). The neutrinos produced can escape freely from the sun and carry away some of the energy released. This produces a flux of approximately 8×10^{10} neutrinos per square centimeter per second at Earth. These neutrinos can be detected on Earth using large underground detectors, and the flux measured to see if it agrees with theoretical calculations is roughly one-half of the flux expected from theory. The cause of the deficit was a mystery. This is the "**Solar Neutrino Problem**".

The **solar neutrino problem** concerned a large discrepancy between the flux of solar neutrinos as predicted from the Sun's luminosity and measured directly. The discrepancy was first observed in the mid**-1960s.**

In the late 1960s, **Ray Davis and John N.** Bahcall's Homestake Experiment was the first to measure the flux of neutrinos from the Sun and detect a deficit. The experiment used a chlorine-based detector. Many subsequent radiochemical and water Cherenkov detectors confirmed the deficit, including the Kamioka Observatory and Sudbury Neutrino Observatory. **So what are neutrinos in standard model of particle physics at then?**

Neutrinos are subatomic particles produced during nuclear fission and fusion processes. Like electrons (and muons and tauons), neutrinos are classified as leptons. There are three "flavours" of neutrinos: electron neutrinos, muon neutrinos, and tauon neutrinos. At that time it wasn't known whether neutrinos have either mass or magnetic moments but recent observations predicted that neutrinos have magnetic moment and so mass property that are too small making it hard to be detected.

The current understanding of the deficit of solar neutrinos detected by experiments on Earth is related to the fact that current neutrino detectors are sensitive only to electron neutrinos. **Pontecorvo** in 1967 proposed that neutrinos might oscillate, or change, flavors if a mass difference existed between the three varieties of neutrinos. The theory of how such oscillations might alter the flavor of a neutrino passing through matter along its path has been worked out by **Mikheyev, Smirnov and Wolfenstein** (1985) and is now referred to as the **"MSW effect".** It is likely that the electron neutrinos produced in the reactions in the Sun's core are altered as they travel to Earth and thus the number of them that we detect does not measure the true number emitted.

On June 18, 2001, a collaboration of Canadian, American, and British scientists made a dramatic announcement: they had solved the solar neutrino mystery. The international collaboration (led by **Arthur McDonald** of Ontario, Canada) reported the first solar neutrino results. The new detector was able to study in a different way the same higher-energy solar neutrinos that had been investigated previously in Japan with the Kamiokande and Super-Kamiokande ordinary-water detectors. The Canadian detector is called SNO for Solar Neutrino Observatory.

The solution of the mystery of the missing solar neutrinos is that neutrinos are not, in fact, missing. The previously uncounted neutrinos are changed from electron neutrinos into muon and tau neutrinos that are more difficult to detect. The muon and tau neutrinos were not detected by the Davis experiment with chlorine; they were not detected by the gallium experiments in Russia and in Italy; and they were not detected by the first SNO measurement. This lack of sensitivity to muon and tau neutrinos is the reason that these experiments seemed to suggest that most of the expected solar neutrinos were missing. On the other hand, the Kamiokande and Super-Kamiokande water experiments in Japan and the later SNO heavy water experiments had some sensitivity to muon and tau neutrinos in addition to their primary sensitivity to electron neutrinos. These water experiments revealed therefore larger fractions of the predicted solar neutrinos.

In recognition of the firm evidence provided by the 1998 and 2001 experiments "for neutrino oscillation", **Takaaki Kajita** from the Super-Kamiokande Observatory and **Arthur McDonald** from the Sudbury Neutrino Observatory (SNO) were awarded the 2015 **Nobel Prize for Physics**.

References:

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