Solar Neutrinos

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What are Neutrinos?

- Neutrinos are chargeless, nearly massless particles
- Most abundant particle in the Universe
- Interact with matter via weak nuclear force
  - Nearly transparent to matter
- Only known type of particle that can escape from the sun's core without interacting
- Hypothesized in 1930
  - Beta decay

$$n \rightarrow p + e^{-} + energy$$

How are neutrinos made?

- The sun, and all other stars, shine due to nuclear fusion reactions happening at the core

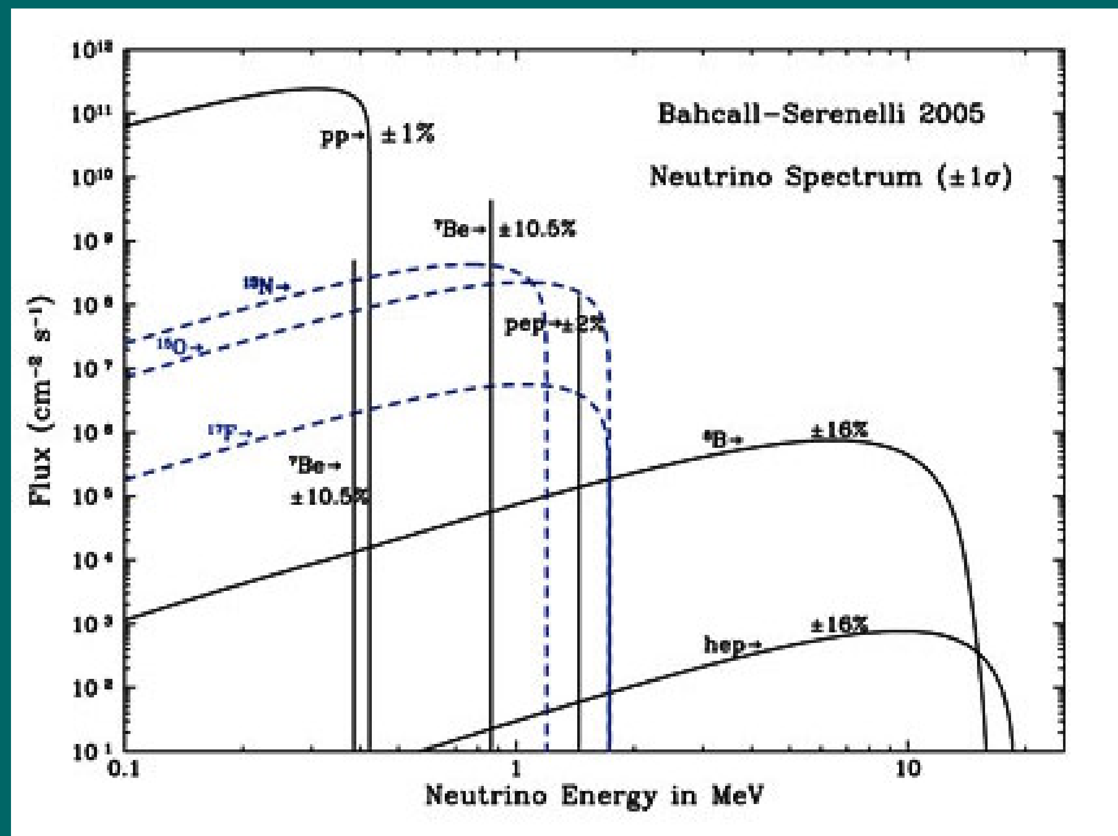
$$p + p \rightarrow d + e^{+} + \upsilon_e$$

$$p + e^{-} + p \rightarrow d + \upsilon_e$$

$$^{3}He + p \rightarrow {}^{4}He + e^{+} + \upsilon_e$$

$$^{7}Be + e^{-} \rightarrow {}^{7}Li + \upsilon_e$$

$$^{8}B \rightarrow {}^{8}Be + e^{+} + \upsilon_e$$



First experiment

- Raymond Davis Jr., Homestake Mine in SD, 1964
- Based on reverse beta decay of chlorine atoms

$$\upsilon + {}^{37}Cl \rightarrow {}^{37}Ar + e^{-}$$

- 470 metric tons of perchloroethylene solution ~10^{30} atoms Cl
- Saw atom decays once every few days
  - About half of what the solar model predicted
- Cl has too high of an energy threshold for neutrinos in sun's primary proton-proton reactions
  - Detects only neutrinos with higher energy; those from Be and B decays

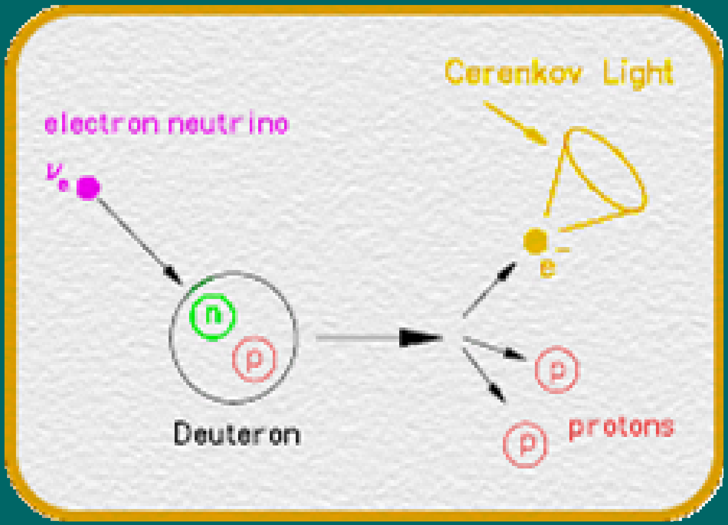
SNO experiment

- Sudbury Neutrino Observatory
- Detects all three types of neutrinos using heavy water (D_20)
  - can separately observe electron neutrinos and all types of neutrinos
  - Measures flux, energy, and direction of electron neutrinos produced by sun
  - From flux and shape of the energy spectrums they can determine how strongly the flavours mix

Neutrino Interactions in D_20

- Charged current reaction
  - When electron neutrino approaches deuterium, W is exchanged
  - electron is ejected at the speed of light (which is faster than the speed of light in water)
    - Gives off shockwave of light called Cherenkov Radiation
    - Detected by photomultiplier tubes (PMT)
      - Patterns can be related to energies of the neutrinos and their angular distribution
  - Standard solar model predicts ~ 30 charged current events/day

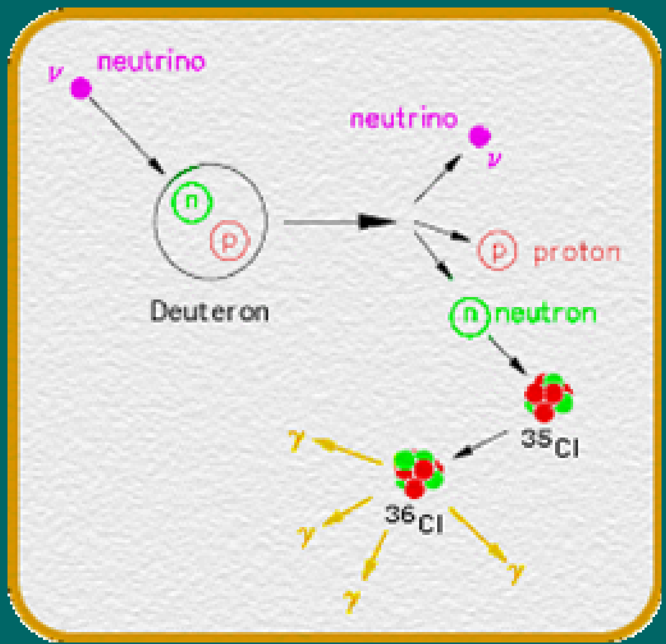
$$\upsilon_e + d \rightarrow p + p + e^-$$



Neutrino Interactions in D_2O

- Neutral Current Reaction
  - Z boson is exchanged
    - When neutron captured by another nucleus, gamma rays are emitted and can be detected
  - Equally sensitive to all types of neutrinos
    - 3-He proportional counters hung in grid within D_2O
    - 35-Cl can be added to NaCl
      - High absorption cross-section for thermo neutrons
  - Standard solar model predicts ~30 neutral current events/day

$$\upsilon + d \rightarrow \upsilon + p + n$$

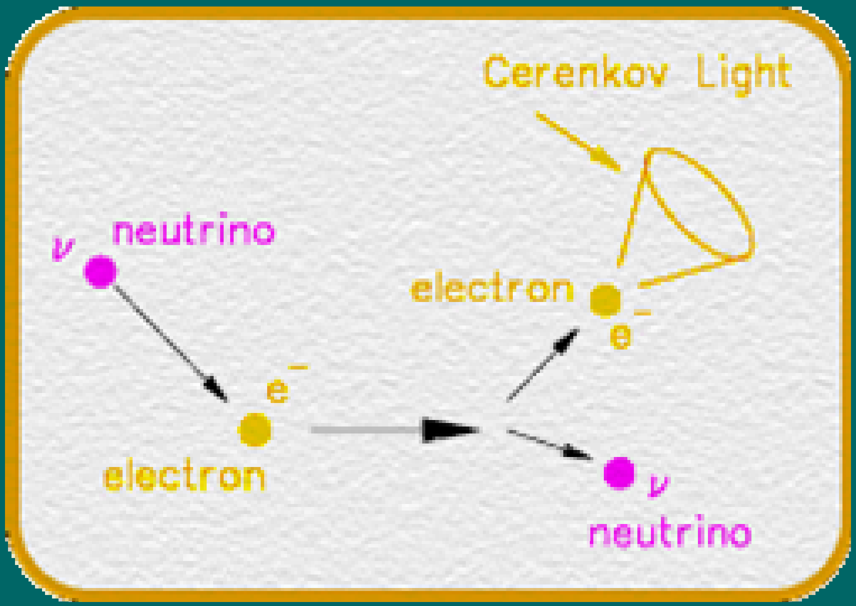


Neutrino Interactions in D_2O

- Electron Scattering

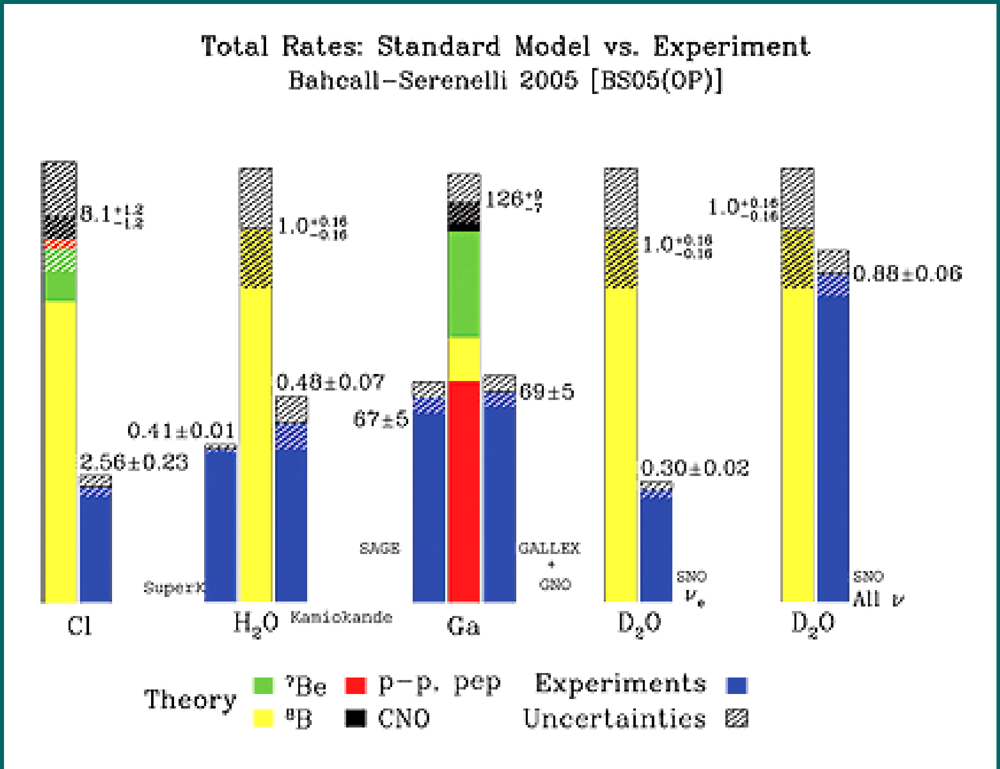
$$e^- + \upsilon \rightarrow e^- + \upsilon$$

  - Not unique to heavy water
  - Sensitive to all neutrinos, but electron neutrinos are more likely by a factor of 6
  - Little spectral information gained
  - Good directional information
  - Standard solar model predicts ~ 3 events/day



Results of SNO Experiments

- Problem - Flux of electron neutrinos is still too low
  - Total flux of neutrinos agrees with standard solar model
- Solutions
  - Solar solution – problem with solar model
    - Much investigation has found that our current model is very accurate
  - Neutrino solution – problem with our theory of neutrinos



Neutrino Solutions

- There were three solutions considered:
  1. Irregular neutrino emission spectra or other beta decay oddities
  2. Neutrino oscillations
  3. Irregular neutrino interactions with detectors
- 1 and 3 have been tested extensively in labs
- 2 involves neutrino travel across astronomical distances
  - Supported by reports that anomalies occur during travel of terrestrial distances

Neutrino Oscillations

- Superposition – a mixture of states
  - Behave as the K^0 meson - produced in a weak-interaction eigenstate (flavor), but travel in a mass eigenstate
  - interact with our detectors as a mixture of two or more flavors
- Good data fit:
  - 100% electron-neutrino leaves sun, and ends up a mix of ~ 40% electron-neutrino and ~60% some other neutrinos
- Neutrinos occupy corresponding place in lepton families as to K^0 and B^0 constituent quarks in quark families
- Process can only occur if neutrinos have mass

Neutrinos in Standard model	Mass
Electron neutrino	< 2.5 eV
Electron antineutrino	< 2.5 eV
Muon neutrino	< 170 keV
Muon antineutrino	< 170 keV
Tau neutrino	< 18 MeV
Tau antineutrino	< 18 MeV

Questions?

Sources

- SNO homepage http://www.sno.phy.queensu.ca/
- Talk Origins http://www.talkorigins.org/faqs/faq-solar.html
- John Bahcall homepage http://www.sns.ias.edu/~jnb/
- Bahcall, John. “How Uncertain are Solar Neutrino Predictions?” Physics Letters B. vol. 443 p. 1, 1998.
- Bahcall, John. “Where do we stand with solar neutrino oscillations?” Physical Review D. vol. 58, 1998