

TEST OF COHERENT NEUTRINO DETECTION USING SAPPHIRE CRYSTALS

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ABSTRACT

An experiment to detect solar neutrinos using the method of Weber was undertaken. Two sapphire crystals of about 82 g each, along with compensating lead masses, were placed in a liquid-supported torsion balance (LSTB) in a symmetric configuration. If the sapphire has a sufficiently large coherent scattering cross section (proportional to the *square* of the number of scatterers) then the momentum transfer from solar neutrinos will produce an observable one day period in the angular position of the balance. To the limit of experimental sensitivity, no such effect was observed.

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INTRODUCTION

Joseph Weber has proposed that neutrino scattering from single crystals can give total cross sections proportional to the square of the number of scattering sites¹⁻⁴. This would produce enhancements of the cross section on the order of Avogadro's number for very modest sized crystals, making a table-top sized neutrino detector possible. The effect differs from ordinary coherent scattering of radiation in that the neutrinos have Compton wavelengths that are short compared to the crystal lattice spacing (for a discussion of long wavelength coherent scattering see ref. 5 page 683). Despite many theoretical arguments against the validity of this claim⁶⁻¹⁰, Weber has presented experimental results³ in apparent agreement with very large scattering cross sections for neutrinos from single crystals of sapphire (Al_2O_3). We decided that an attempt to reproduce his results was merited.

Weber published results for three types of experiments --detection of tritium β -decay neutrinos, nuclear reactor neutrinos, and solar neutrinos; all three utilizing a torsion balance as the detector. We pursued detection of neutrinos from the Sun using essentially the same method as Weber. The technique employs a torsion balance that holds test masses of lead and single-crystal sapphire. If the sapphire has a large scattering cross section and the lead has a negligible cross section then the solar neutrinos will impart momentum to one side of the torsion balance, producing a measurable torque. The torque changes sign as the earth rotates, and the 24 hour periodic motion that results is the solar neutrino signal.

Weber's results were for a torsion balance holding a 26 g sapphire crystal. With 65 days of data averaged together, the amplitude of the 24 h signal implied a force of $\sim 4.6 \times 10^{-6}$ dynes which he attributed to solar neutrinos. This is an astounding result in that if one assumes that all of the neutrinos that pass through the geometric cross section of this crystal are scattered through a random angle; and that the neutrino flux is that given by the standard solar model (see ref 11), then the maximum force on the crystal would be 5.3×10^{-6} dynes. The curve

designated "predicted signal" in Figure 2 was calculated for our experiment using the same assumptions. The curve is not a sinusoid due to the fact that the geometric cross section of the cylindrically shaped crystals changes throughout the day as the direction of the neutrinos changes. The maximum magnitude of the calculated force is $\sim 2 \times 10^{-5}$ dynes. Other methods for predicting the size of the effect give even larger forces. By simply scaling the results of Weber by the square of the mass for the two 82 g crystals used in this work, we calculate a force of 9×10^{-5} dynes for our torsion balance.

APPARATUS

The apparatus used for this work is a liquid-supported torsion balance (LSTB) that was developed at the Joint Institute for Laboratory Astrophysics (JILA) by Jim Faller and his students¹²⁻¹⁴. The LSTB shown in Figure 1 consists of an aluminum cylinder that floats in water that is kept at its temperature of maximum density (3.98°C). The water provides the support while the spherical and ovoid electrodes on the top of the LSTB are used to provide the centering force and the restoring torque. An optical lever, using four lenses mounted on the lid of the LSTB, provides for the detection of the angular position of the LSTB.

The test masses are two Pb/Al₂O₃ "sandwiches" and six gold-plated Pb cylinders each weighing about 510 g. The crystals themselves weigh 82 g each and are about 4.5 cm in diameter, 1.3 cm in height. The overall height of all eight masses is the same, with the crystal/lead masses having a larger diameter due to their lower density. The symmetric design is used to minimize the effect of gradients in the gravitational field. A calibration of the LSTB sensitivity to applied torques is done in the following way. First the oscillation period is measured for several different electrode voltages. This along with the moment of inertia about the vertical axis is used to calculate the torsion constant (the torque per unit angular displacement). The sensitivity is checked using the gravitational attraction of lead bricks placed near the apparatus. This produces an "order of

magnitude" response and demonstrates that the LSTB is moving freely. The gravitational torque has large uncertainties and cannot be used independently as a calibration.

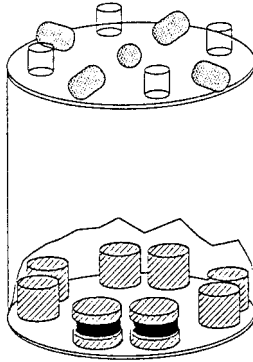


Fig. 1 A cutaway view showing the test masses inside of the LSTB. The sapphire is shown in black. On top are shown the lenses and the electrodes.

DATA

A data run consists of a computer reading multiple channels of an A/D data logger (optical lever output, thermistor resistances, magnetometer output, etc.) at one minute intervals. Ten minute averages are then stored on a disc. The signal is of the form of a 24 h periodic signal of the proper phase on the optical lever output voltage. This is converted into an angle using a calibration (done just prior to the experiment) and then into a torque using the torsion constant discussed above. Finally this is converted into a force using the length of the moment arm of the crystals about the vertical axis. A graph of the data time series is shown in Fig. 2 along with the predicted signal. A least-squares fit to a function of the form of the expected signal is performed. This functional form is just a cosine of the angle between the zenith and the direction to the Sun. This zenith angle is a fairly complicated function of the time of day and, of course, depends on the time of

year as well. An average of the least-squares fits for three such data runs gives the result of $-3.3 \pm 2.8 \times 10^{-8}$ dynes of extra force on the sapphire.

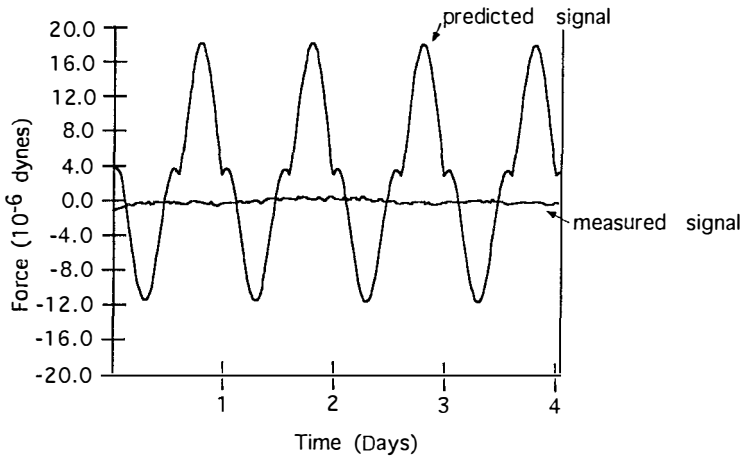


Fig. 2. This graph shows the data from one of the runs (starting at 17:30 EST on 7 Jan. 1993) along with the predicted signal based on the results of Weber. The angular position of the LSTB is converted into a force on the sapphire test masses.

EXPERIMENTAL UNCERTAINTIES

In an experiment of this nature the systematic errors must be dealt with very carefully. The fact that the signal has a period of 24 h presents difficulties in that many effects (e.g. temperature, tilts, motion of people) also occur with this period. The main sources of error considered are, gravity gradients, temperature fluctuations, magnetic field, and tilt. The temperature at various points on the apparatus, the tilt and the magnetic field were all monitored during the data runs in order to look for possible systematic errors.

The gravity multipole couplings are dealt with by first measuring the moments of the float by producing large gradients with nearby lead bricks. Then these moments are used with estimates of the local mass motions to give limits on

the torque produced by varying gravitational gradients. This error is estimated to be less than 0.5×10^{-8} dynes. The magnetic field on top of the LSTB tank was monitored with a three-axis flux-gate magnetometer, which combined with measurements of the torques produced by temporary large magnetic fields gave an estimated uncertainty of 0.2×10^{-8} dynes. The tilt was measured with a 2-axis electronic bubble level and in a similar manner the uncertainty was estimated to be 4.0×10^{-8} dynes. The temperature fluctuations at various points on the apparatus were monitored with thermistors, and combined with large artificial thermal gradients to make a worst-case estimate of the uncertainty as 4.0×10^{-7} dynes. The temperature fluctuation contribution dominates the systematic uncertainties, but this seems an overestimate as it is an order of magnitude larger than the "signal". However, temperature effects are very difficult to model and a less conservative estimate seemed unjustified.

An assumed feature of the coherent scattering is that the quality of the crystals is important for the effect. The more nearly perfect the crystals the better the coherence. We had our crystals tested by double crystal X-ray topography, by the same group at NIST that tested Weber's crystals, and they were found to be good single crystals with no extraordinary defects, comparable to his.

CONCLUSION

This experiment shows no observation of enhanced neutrino scattering cross sections for single crystals of sapphire. The extra force on the sapphire was $-0.3 \pm 4 \times 10^{-7}$ dynes, consistent with zero. The fraction of the predicted result is -0.002 ± 0.027 compared to 0.86 ± 0.26 observed by Weber. This uncertainty is obtained from his stated uncertainty in the solar neutrino flux³. A slightly different approach has also recently obtained a null result¹⁵.

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