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AD-A179 700

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release, distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 87-0366

6a. NAME OF PERFORMING ORGANIZATION: University of Maryland Physics Department

6b. OFFICE SYMBOL (If applicable):

7a. NAME OF MONITORING ORGANIZATION: Air Force Office of Scientific Research

6c. ADDRESS (City, State and ZIP Code): College Park, Maryland 20742

7b. ADDRESS (City, State and ZIP Code): AFOSR-NP, Building 410, Bolling AFB, Washington, D.C. 20332-6448

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AFOSR

8b. OFFICE SYMBOL (If applicable): NP

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F49620-84-C-0087

8c. ADDRESS (City, State and ZIP Code): Defense Advanced Research Projects Agency, 1400 Wilson Boulevard, Arlington, Virginia 22209

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2309	A1	

11. TITLE (Include Security Classification): "New Method in Elementary Particle Detection" (U)

12. PERSONAL AUTHOR(S): J. Weber

13a. TYPE OF REPORT: Final

13b. TIME COVERED: FROM Aug. 1984 TO Dec. 1986

14. DATE OF REPORT (Yr., Mo., Day): March 31, 1987

15. PAGE COUNT: 11

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number):

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Total cross sections are measured for coherent elastic scattering of antineutrinos from a reactor, incident on a single crystal of sapphire, with a mass of 100 grams. The cross section is 2.7 cm^2 ± .24. (Reprints)

sq. cm. / +or-

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☒ DTIC USERS ☒

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: John F. Prince

22b. TELEPHONE NUMBER (Include Area Code): 301-454-3527/714-856-7231

22c. OFFICE SYMBOL: NP

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AFOSR-TR- 87-0366

New Method in Elementary Particle Detection

Sponsored by

Advanced Research Projects Agency (DOD)

ARPA Order No. 4099

Project A.O. 2309

Monitored by AFOSR/NP Under Contract

#F49620-84-C-0087

Final Report

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

Abstract

Total cross sections are measured for coherent elastic scattering of antineutrinos from a reactor, incident on a single crystal of sapphire, with a mass of 100 grams. The cross section is 2.7 $cm^2 \pm$ .24.

Introduction

A new method[1] for observation of neutrinos and antineutrinos employs tightly coupled scatterers in a nearly perfect crystal. Total cross sections are proportional to the square of the number of scatterers.

Published theory[1] makes the assumption that the crystal is "infinitely stiff." Available crystals have stiffness described in a quantitative way by their Debye temperatures.

The "infinite stiffness" implies that available crystals will have the predicted cross section for low energy neutrinos. An earlier investigation employed 12 kilovolt antineutrinos from a tritium source. This report summarizes observations for 1.6 MeV antineutrinos from a nuclear reactor.

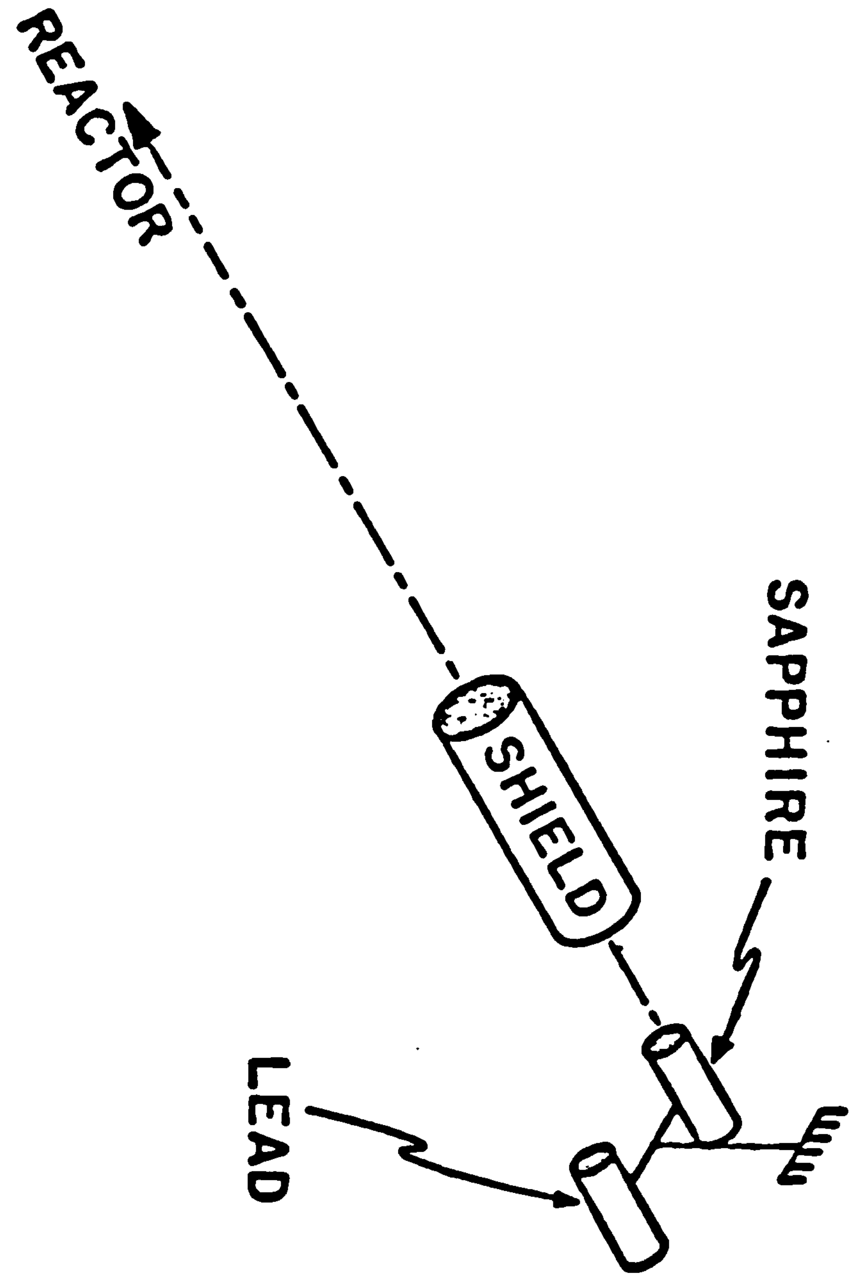

FIGURE 1

Observations

The torsion balance arrangement shown in Figure 1 was employed. A 100 gram sapphire crystal was on one side, and a 100 gram lead mass on the other side of the balance.

An AC bridge was employed for sensing and measurements. The bridge is balanced for the equilibrium position of the torsion balance. A force applied to one of the masses will rotate the torsion balance, producing an error voltage from the AC bridge. This voltage is amplified and employed to produce electrostatic forces to restore the torsion balance to equilibrium, by a closed loop servosystem. In final equilibrium, the force resulting from elastic scattering of antineutrinos is therefore balanced by an electrical force. The servosystem integrator output measures the elastic scattering force. The system is calibrated by moving a lead brick into position and measuring the servovoltage for the known gravitational interaction between lead brick and torsion balance.

The nuclear reactor is normally on for about 40 days, then off for about one week. In order to obtain sufficient data for a reasonably precise value of the cross section, it was necessary to switch the antineutrinos on and off a large number of times.

If the large cross sections predicted by the theory are correct, a large sapphire crystal should serve as a shield for antineutrinos. The switching process is carried out by moving the shield in the line of sight between reactor and torsion balance.

At first no magnetic tape - data acquisition system was available. A series of human observer hand operated observations was performed in the following way. With reactor on, the shield was placed in a fixed position in the line of sight. Servovoltage measurements were made with a high impedance voltmeter. Voltages were read and recorded, in ink, in a bound notebook. Similar measurements of servovoltage were made with shield removed. The procedure was repeated, with reactor off.

Torsion balance calibration was performed, when the reactor was off, by moving a lead brick close to one of the torsion balance masses, again recording servovoltage outputs.

About 5000 measurements were made, employing these procedures.

Eventually a magnetic tape - data acquisition system became available. Measurements were then carried out in the following way. The shield was driven up, then down, continuously by a motor. Synchronization voltages were written on one channel of the magnetic tape. The servosystem voltage was recorded on a separate channel. The system was left operating for more than a week, at a time when the reactor was expected to be changed from on to off or vice versa, about the middle of the recording period. Magnetic tapes were read "blind" by our computer programmer. The signal average with reactor off was then subtracted from the signal average with reactor on. In this way gravitational and magnetic forces associated with the shield were subtracted out. Figure 2 shows the effect, therefore, of reactor alone.

It was discovered that collimation was important because relatively small changes could have a large effect on the fraction of the cycle that occultation was occurring.

As an additional check, the magnetic tape - data acquisition

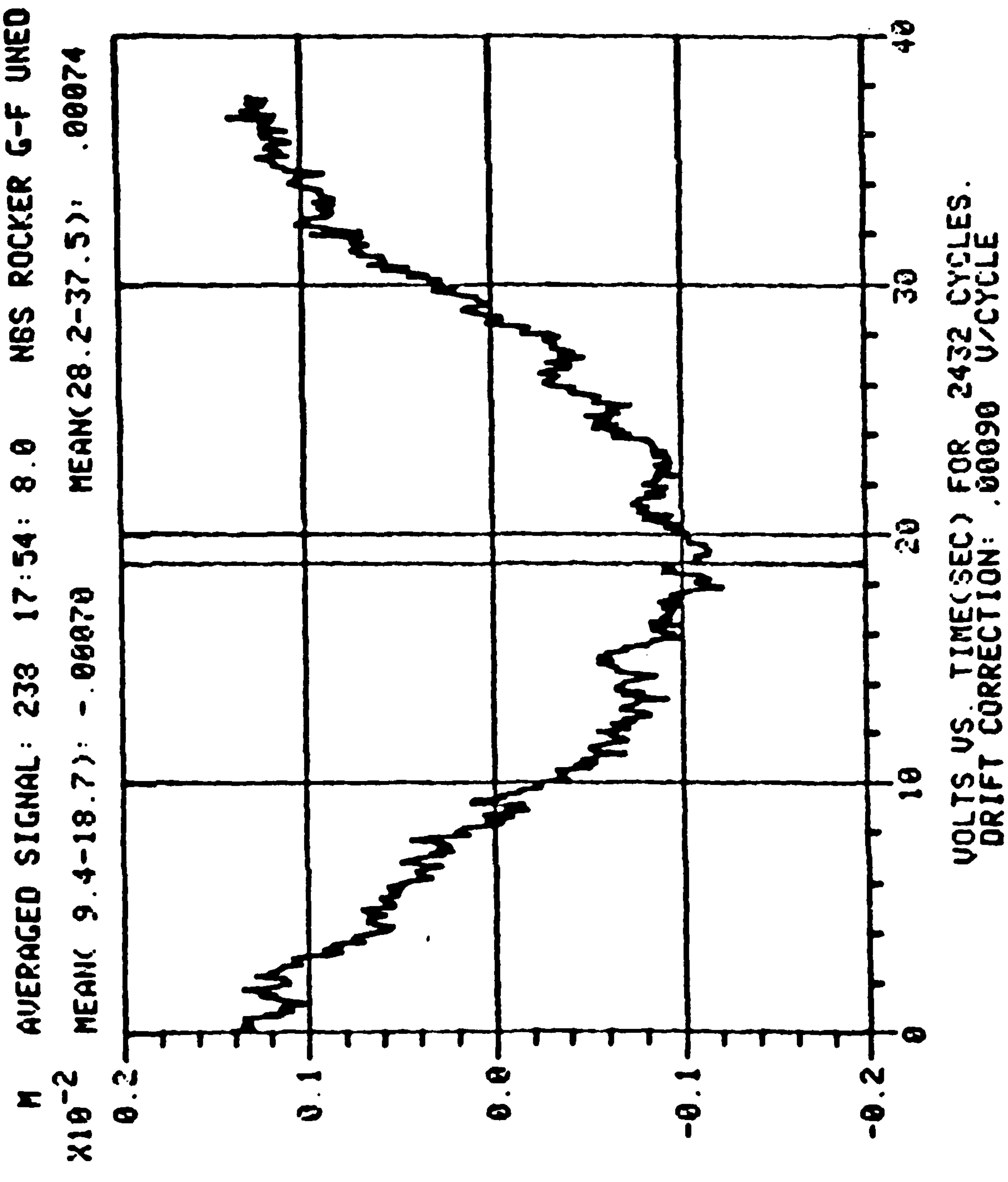
M
AVERAGED SIGNAL: 233 17:54: 8.0 NBS ROCKER G-F UNED
MEAN(9.4-18.7): -.00070 MEAN(28.2-37.5): .00074
X10^-2
0.2
0.1
0.0
-0.1
-0.2
0
10
20
30
40
VOLTS VS. TIME(SEC) FOR 2432 CYCLES.
DRIFT CORRECTION: .00090 V/CYCLE

FIGURE 2

system was employed in the following way. The motor was controlled manually, and employed to move the shield into the occulting position. Data were recorded on magnetic tape. Then the motor was again operated to move the shield as far as possible away from the occulting position. Servosystem voltages were again recorded on magnetic tape. Procedures were repeated with reactor off, and with lead bricks for calibration. The magnetic tapes were read "blind."

Let us define an elastic scattering cross section for incident particles with average momentum $\langle p \rangle$ by σ_p for incident flux ϕ. A force F is measured

$$F = \phi \langle p \rangle \sigma_p$$

For these experiments the result is

$$\sigma_p = 2.7\ \text{cm}^2 \pm .24$$

Low Temperature Inelastic Scattering

An alternative method for antineutrino detection consists of observation of energy transfer from the incident antineutrinos to the spin quantum states of the nuclei of a crystal. Observations of this were in reasonable agreement with theoretical predictions. It was planned to purchase a gas handling system for a large dilution refrigerator insert, and emplace the complete system at the National Bureau of Standards. Unavailablility of funds, ($100,000) for the gas handling system led to a decision to concentrate the effort on the elastic scattering room temperature observations.

Fluid Supported Torsion Balance

The wire supported torsion balance employed for the present experiments responds to seismic excitation. The noise background considerably exceeds the thermal fluctuation limits.

Dr. J. Faller[2] has suggested that a fluid be employed to float relatively large masses, and has claimed a considerable reduction in background noise. His design did not employ any wire at all. Centering was accomplished by electrostatic forces exerted on electrodes near the center of the floating structure.

We designed and constructed two systems, following Faller's suggestions. The performance was relatively poor. Limitations of time, and funds led to the decision to employ the wire supported (Cavendish) type of torsion balance for cross section measurements.

Substantial improvement in fluid supported torsion balance operation resulted from removal of the electrostatic restoring system and replacing it by a wire - so that the fluid buoyancy reduced the support wire stress to a few per cent of the value without the fluid.

Solar Neutrinos

A torsion balance similar to the one at the reactor was employed to carry out a search for solar neutrinos. A 24 hour effect was searched for as the sun apparently rotates around the balance. At this time a positive result has been obtained, consistent with the assumption that about 7×10^{10} neutrinos per cm^2 per second, with energy about 0.4 MeV are incident on the torsion balance. This is tentative, because search for systematic errors is continuing.

Conclusion

Large cross sections are observed for solar and reactor antineutrinos incident on nearly perfect crystals, with high Debye temperatures.

1. J. WEBER FOUNDATIONS OF PHYSICS, Vol. 14, 12, 1185-1209, Dec. 1984.
   PHYSICAL REVIEW C Vol. 31, 4, 1468-1475.
2. J. FALLER Proceedings of the Second Marcel Grossmann Meeting, Trieste, Italy, 1979, North Holland Publishing Company.