conversion coefficient of the 82-kev transition, the $M1$ and $E2$ transition probabilities may be calculated. Compared to single-particle estimates, the $M1$ transition is retarded by a factor of $\sim$700 and the $E2$ transition is enhanced by a factor of $\sim$20. This is in agreement with the assignment of $d\frac{5}{2}$ to the 82-kev state and $g\frac{7}{2}$ to the ground state which would make an $M1$ transition l forbidden. The fact that the $E2$ transition is enhanced suggests that there is some cooperative phenomenon present in spite of the fact that Cs^{133} has an extremely small electric quadrupole moment. It is interesting to note that the enhanced $E2$ transitions are usually associated with nuclei which have large quadrupole moments, such as in the rare earth region where the quadrupole moments may be as much as a thousand times larger than the quadrupole moment of Cs^{133}.

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Total Neutron Cross Section for C^{12} from 500 kev to 1350 kev*

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The total neutron cross section of C^{12} has been measured in an effort to observe resonances corresponding to states recently reported in the $B^{11}(He^3,p)C^{13}$ reactions. No resonances were observed within the 5% accuracy of the measurement. Upper limits are set on the possible widths of the states.

THE results of recent measurements[1] of the proton energy spectrum from the reaction $B^{11}(He^3,p)C^{13}$ clearly indicate two weak proton groups that cannot be accounted for by known states in C^{13}. Although the possibility that the two proton groups may arise from the reaction $B^{11}(He^3,pn)C^{12}$ cannot be excluded, the data can be interpreted as indicating the existence of two previously undetected levels in C^{13} at excitation energies of 5.51 Mev and 6.10 Mev. Since these levels have not been observed in the total neutron cross-section measurements of C^{12}, it must be concluded that, if they exist, they are narrow states. The reported energy spread[2] in the earlier cross-section measurements was approximately 12–20 kev in the energy region of interest. To provide additional information concerning the existence of these states or to set upper limits on their widths, it was decided to repeat the measurements of the total neutron cross section of C^{12} with better energy resolution and with the greater sensitivity provided by the self-indication technique.[3]

Transmission measurements were made over a range of neutron energies that comfortably span the resonant energies suggested by $B^{11}(He^3,p)$ results. Neutrons were produced by the $Li(p,n)$ reaction. A fresh target was evaporated each day, and threshold curves were taken at the beginning and end of each day. The threshold curves indicate that the neutron energy spread was less than 5 kev over most of the range of neutron energies covered.[4] Transmission measurements were made at 1-kev intervals over each of two ranges of about 200 kev centered about the two expected resonant energies, and at 2-kev intervals elsewhere.

A single transmission sample was used throughout the experiment. It consisted of a cylinder of pile-grade graphite 1.5 in. in diameter and 0.9 in. thick. The detector sample was a flat plate of pile-grade graphite 3 in.×7 in.×$\frac{1}{2}$ in. thick.

Figure 1 shows the results of the total cross-section measurements. If they are observable, resonances should be found at neutron energies in the vicinity of 610 kev and 1250 kev. No resonance was detected with a peak height greater than 0.3 barn (5% transmission) above the smooth trend observed for the measured cross section. If one assumes a flat energy resolution

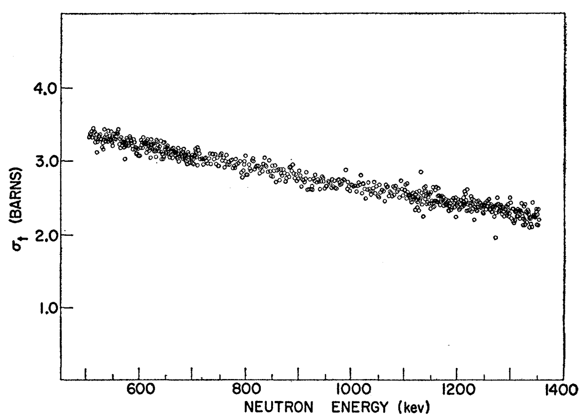

FIG. 1. Total neutron cross section of carbon as a function of neutron energy. Neutron energy spread was 5 kev or less for most of the points. The rms error in the values for the cross section is 2.7%.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
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TABLE I. Upper limit for widths of possible resonances of total spin J for a neutron energy of 1250 kev. The neutron energy spread Δ is taken as 5 kev. Resonances with widths greater than the values given would have been observed in the present experiment. For a neutron energy of 610 kev, Γ would be about half the tabulated values.

J	σ_R (barns)	$\Delta/\Gamma_{\max}$	$\Gamma_{\max}$ (ev)
1/2	2.5	16.5	303
3/2	5.0	35.5	141
5/2	7.5	55.0	91
7/2	10.0	83.5	60

function for incident neutron flux, one can place upper limits for the widths of the resonances if they exist. Table I gives, for various assumed J values, the maximum value for the width of a resonance not observable at a neutron energy of 1250 kev, i.e., one that would have resulted in a 5% dip in the transmission curve. The energy spread Δ has been taken as 5 kev. Since no resonance was observed near this energy, it is concluded that the postulated state in C^{13} must be narrower than the values given in Table I. At 610 kev the widths would be restricted to approximately one-half of the values shown in Table I.

Since some 660 points were taken in this experiment, and further since the results gave a smooth curve, a least-squares fit of the cross section by a function with only a few parameters gives a very accurate determination of the cross section in this region. The use of such a procedure[5] leads to the following power-series expansion for the cross section:

$$\sigma_T=4.710-(3.415)E+(1.649)E^2-(0.2606)E^4,$$

where E is in Mev, σ_T is in barns, and the value of the cross section at zero energy was taken to be 4.710 barns.[6] The rms error in this region is 0.075 barn or an average of 2.7%. While no data (other than the cross section at zero energy) below 500 kev were included in the fitting, the calculated curve lies within 3% of other measurements[2,6,7] from 1 to 500 kev.

For energies greater than 1400 kev the expansion quickly diverges from the measured cross-section values because of the large fourth-power term.

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[5] A least-squares-fitting program for use on the IBM-704 computer was supplied to us by J. E. Monahan of this laboratory.

[6] Comparison was made with the smooth curve through the experimental points given in *Neutron Cross Sections*, compiled by D. J. Hughes and R. Schwartz, Brookhaven National Laboratory Report BNL-325 (Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1958), second edition.

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Dynamic Orientation of Nuclei by Forbidden Transitions in Paramagnetic Resonance*

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Principally from the viewpoint of orienting radionuclei, this paper considers magnetically dilute paramagnetic ions in crystals for various cases in which there is a non-negligible radio-frequency transition probability for inducing a simultaneous flipping of an electron spin and a nuclear spin. These transitions, forbidden in zero order in high magnetic fields, may be provided by hyperfine interactions, and allow for direct dynamic nuclear orientation by applied rf fields. The transition probabilities are calculated for a general anisotropic spin Hamiltonian; thermal relaxation transitions are qualitatively discussed. The resulting steady-state dynamic nuclear polarization and alignment are calculated for the equalization of populations of pairs of levels by sufficient applied rf fields. The influence of various relaxation transitions is considered and it is noted that the nuclear orientation available through the forbidden transitions is considerably less sensitive to competing relaxation transitions than that obtained by saturation of the allowed transitions.

The general predictions are found to be in qualitative agreement with the results at Berkeley of Abraham and Kedzie using radionuclei.

The possibilities for dynamic alignment of radionuclei of diamagnetic atoms by forbidden transitions due to weak nuclear-electron dipolar coupling are also briefly discussed.

I. INTRODUCTION

OVERHAUSER[1] pointed out, and it was experimentally verified,[2] that the saturation of the paramagnetic resonance transitions of the conduction electrons in a metal could, through suitable hfs relaxation processes, lead to an appreciable nuclear polarization. This idea has been extended[3] to paramagnetic

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