to work well for the three-body bound-state problem, at least, for the molecular-type potential used in this paper.

While many properties of ^{12}C are adequately explained by the three-boson model, there are some which clearly have not been well-fitted in this work. The octupole 3^- was obtained too low in energy and we feel this should be investigated further by constructing other phase equivalent potentials and using them in the 3-boson problem. Similar comments apply to the charge form factor.

ACKNOWLEDGMENT

The authors wish to thank Professor N. de Takacsy for many helpful discussions. We are indebted to Professor A. Arima for a comment. We wish to thank Professor B. Margolis for support and encouragement.

*Supported in part by the N.R.C. of Canada and in part by the Quebec Department of Education.

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PHYSICAL REVIEW C VOLUME 7, NUMBER 5 MAY 1973

Neutron Capture in Fluorine Below 1500 keV*

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(Received 11 December 1972)

Neutron time-of-flight radiative capture data taken at the Oak Ridge electron linear accelerator have been analyzed for single-level resonance parameters. Eleven resonances were found, with parameters as indicated, listing E_0 (keV), J value assumed, and Γ_γ (eV) in order: 27.07 (2) 1.4 ± 0.3, 48.7 (1) 1.7 ± 0.4, 97.0 (1) $\leq 6.0 \pm 1.8$, 269 (2) 3.5 ± 0.8, 270 (1) ≤ 4.4, 386 (1) $\geq 7 \pm 2$, 490.5 (0) $\geq 10 \pm 3$, 595 (2) $\geq 7 \pm 2$, 1460 (1) $\geq 11 \pm 3$. Values of total width were also found for these resonances. Two resonances are very narrow and their capture areas yield estimates of $g\Gamma_n$. At 43.5 keV, $g\Gamma_n = 0.086 \pm 0.02$ eV if $J \geq 1$ or $\Gamma_n = 0.42 \pm 0.1$ eV if $J = 0$, and, at 173.5 keV, $g\Gamma_n = 0.35 \pm 0.10$ eV. The increase of nearly an order of magnitude in radiative width with increasing energy up to 600 keV is notable. Twelve large resonances between 1600 and 5000 keV were not analyzed for capture because of detector sensitivity to the inelastic scattering channels which open in that energy region.

I. INTRODUCTION

Resonance neutron capture by fluorine has been studied previously by activation,[1] liquid scintillator tank,[2] and sodium iodide scintillation spectrometer.[3] The activation method, when applicable, has advantages in signal-to-background ratio but suffers from the modest energy resolution of the available monoenergetic source reactions at the intensities required. In the present work a general purpose neutron-capture detector was used, based on fluorocarbon liquid scintillators with

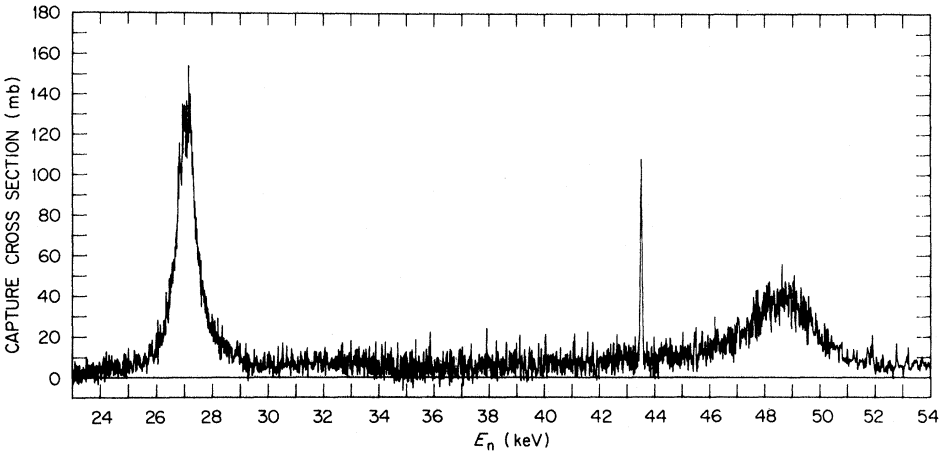

FIG. 1. Measured $^{19}F(n,\gamma)$ capture yield for a $2.6\times 5.2\times 0.67$-cm $(CF_2)_n$ sample (0.0337×10^{24} atoms/cm^2 ^{19}F). Environmental backgrounds and backgrounds due to nonresonant scattering from the sample have been subtracted. Mid-channel data points are connected by straight lines to preserve the experimental resolution in the plots. Statistical deviations below zero are not significant. The parameters of Table I indicate lower limits to the cross section due to tails of the analyzed resonances. The $1/v$ extrapolation of the thermal cross section, for example, provides a lower limit to at least 538 keV and probably much further because of s-wave levels beyond the 270 keV not included in our analysis.

pulse-height weighting.[4] The neutron time-of-flight resolution permitted the identification of narrow resonances not seen in the earlier work. The results for the well-known resonances near 27 and 49 keV agree well with the earlier studies.

II. EXPERIMENT

Neutron capture by a fluorine sample represents a unique challenge with our detection system[4] because the scintillation detectors contain much more fluorine than the sample. The very small probability of neutron capture by fluorine, of course, was one of the original reasons for choosing a C_6F_6 based γ detector.[5] Fortunately the energy loss for a neutron scattered from sample to detector (3 to 16%) is much larger than the neutron energy resolution (roughly 0.2%) and thereby allows separation of the effect by time of flight. The effect of scattered neutrons was investigated quantitatively using the off-resonance response to ^{208}Pb[6] and carbon samples.

The detector pulse-height bias serves to eliminate response to the ^{19}F 110- and 197-keV inelastic levels in both sample and detector. This bias leads to an implicit extrapolation to zero pulse height of all neutron-capture spectra. In particular, the fluorine-capture γ-ray pulse-height spectrum is assumed to have the same shape below 153 keV (bias) as that from the 4.9-eV neutron-capture resonance in gold. As the detector response is dominated by the Compton process and the weighted spectra have only about 3.6% of their area below this bias, the extrapolation can hardly introduce an uncertainty as large as 1%.

The detector and ^6Li neutron monitor[7] efficiency was normalized at the 4.9-eV gold resonance using a 0.005-cm-thick sample to saturate the resonance.

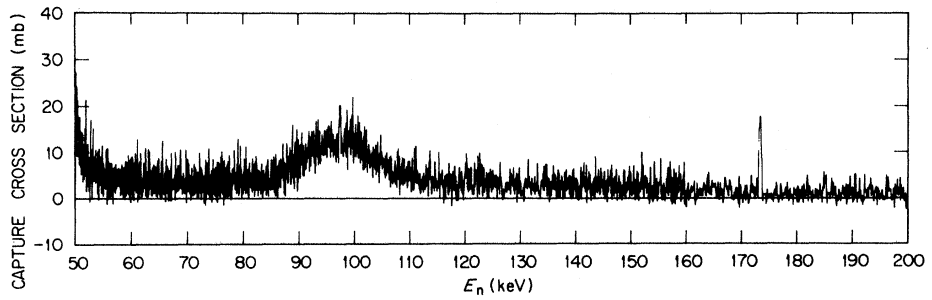

FIG. 2. See caption for Fig. 1.

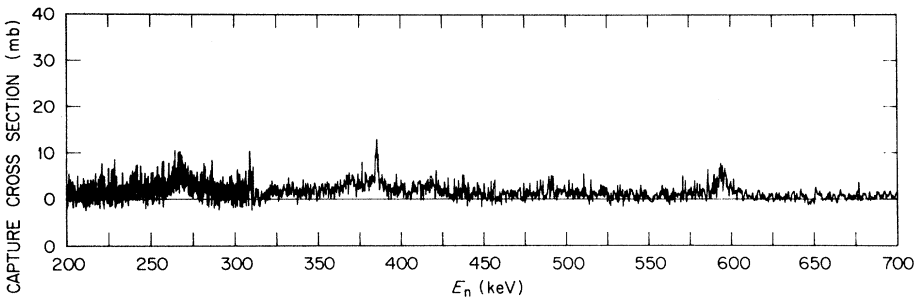

FIG. 3. See caption for Fig. 1.

The Au line shape was computed with a Monte Carlo code.[8] The ^{6}Li glass scintillator efficiency at higher energies and the perturbation of the transmitted flux were calculated as indicated.[4,6]

III. RESULTS

The γ-energy yields from $E_n = 23$ keV to $E_n = 700$ keV are shown in the three figures. The resonance parameter information extracted from the yields is presented in Tables I and II. In the latter, resonances from $E_n = 1500$ to 5000 keV are identified primarily from their inelastic neutron yields to the fourth and fifth levels of ^{19}F near 1500 keV. Further analysis with bias raised to eliminate this reaction is probably not warranted as the capture yield suggested by the activation work[1] is only of the order of 0.1 mb, probably indistinguishable above our present backgrounds.

The resonances up to 200 keV have been analyzed with two exit channels as has indeed been traditional for all fluorine resonances.[1] Although inelastic scattering to the first two levels (110 and 197 keV) is not observed directly, it is seen (and corrected for) in the scattered neutron background and through competition with resonance capture.

Resonance self-protection factors for the finite sample thickness were computed by numerical integration using the complex error function for most resonances, where multiple scattering within the resonances was unimportant. For the 97-keV resonance, the width is comparable to the average energy loss on scattering and a Monte Carlo calculation[8] was used to relate the yield to the parameters.

Near 270 keV a very strong peak is reported[9,10]

TABLE I. Derived resonance capture parameters and comparison with earlier work: Gabbard (Ref. 1), Block (Ref. 2) and Nyström (Ref. 3). Indicated errors are intended to include both systematic and statistical errors at the 2 standard deviation level.

			^{19}F + n resonance parameters				
Peak E_n(lab) (keV)	Assumed J^π	Assumed l	Observed Γ (keV)	Derived Γ_γ (or Γ_n) (eV)	Gabbard Γ_γ (eV)	Nyström Γ_γ (eV)	Block Γ_γ (eV)
27.07 ± 0.05	2^-	1	0.355 ± 0.03	1.4 ± 0.3	1.1	1.4 ± 0.3	1.3 ± 0.2
43.5 ± 0.1	≥1		<0.08	$g\Gamma_n = 0.86 \pm 0.02$			
	0			$\Gamma_n = 0.42 \pm 0.1$			
48.7 ± 0.3	1^-	1	1.96 ± 0.3	1.7 ± 0.4	1.6	1.5 ± 0.3	1.6 ± 0.2
97.0 ± 0.5	1^-	1	13.5 ± 1.5	6.0[a] ± 1.8	2.2		4.2 ± 1.1 (for $J = 1$)
173.5 ± 0.9			≤0.6	$g\Gamma_n = 0.35 \pm 0.1$	($g\Gamma_\gamma = 0.44$)		
269 ± 1	2	1	10 ± 2	3.5 ± 0.8	3.9		
(270 ± 8)	1	0		(≤4.4 from thermal capture)			
386 ± 1	1^-	1	5 ± 1	≥7 ± 2	($g\Gamma_\gamma = 1.8$)		
(490.5 ± 1)	0^-		(2.4 ± 0.6)	≥(10 ± 3)	1.9		
595 ± 2	2		8 ± 1	≥7 ± 2	8.1		
(1295 ± 12)	1^-	1	(50 ± 10)	(≥9.6 ± 4)	8.6		
1460 ± 3	1	≥1	14 ± 2	≥11 ± 3			

[a] May include two resonances.

TABLE II. Additional resonances from 1500 to 5000 keV seen prominently via $^{19}F(n,n')\gamma$ reactions.

Additional prominent inelastic peaks in $^{19}F+n$			
E_n(lab) (keV)	Γ(lab) (keV)	E_n(lab) (keV)	Γ(lab) (keV)
1645	15	3400	35
1916	28	3475	≤30
2240	45	3620	120
2465	75	4240	90
3075	120	4620	200
3215	80	4900	≤50

in the inelastic cross section with a "width" of at least 50 keV. In capture we see a 10-keV-wide peak with only a faint suggestion of an underlying broader peak. The large inelastic peak can probably be understood in terms of two resonances near the same energy with opposite parity ($l=0$ and 1, respectively). If all the thermal cross section is attributed to the broader $l=0$ resonance and the yield to the first inelastic level is maximized, one obtains a quite reasonable radiative width of 4.4 eV. Of course, some fraction of the thermal yield can be attributed to a bound level or levels with $J^\pi = 0^+$ or 1^+.

Broad levels near 420 and 490 keV appear likely but a quantitative analysis of capture area has not been attempted in view of the background uncertainty.

In the group of levels from 27 to 595 keV (6628 to 7167 keV excitation in ^{20}F) the radiative width appears to increase nearly an order of magnitude with increasing excitation. In the next two levels measured, after a gap of 665 keV, no further increase is evident. The earlier activation study[1] reported three levels in the gap with radiation widths near 3 eV which, however, should be a lower limit in view of inelastic competition.

With so few levels found it is probably best to hope for their future accommodation to a detailed shell model rather than to compute strength functions or speculate on doorway states.

The infinite dilution resonance integral (including the $1/v$ term) computed from Table I is 23 ± 5 mb. This is in good agreement with the reported value 25 ± 5 mb.[11] Likewise the Maxwellian average $[\sigma\times v]/v_T = 7.6$ mb for $kT = 30$ keV.[12]

*Research sponsored by the U.S. Atomic Energy Commission under contract with the Union Carbide Corporation.

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