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NEUTRON-CAPTURE GAMMA-RAY SPECTRA OF THE TUNGSTEN ISOTOPES

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Abstract: The spectra of gamma radiation following reactor-neutron capture in separated tungsten isotopes have been measured with a three-crystal scintillation pair spectrometer as well as with a single-crystal scintillation counter, and with both in coincidence. Energies and intensities of the gamma rays from product nuclei ^{183}W, ^{184}W, ^{185}W and ^{187}W are reported. From those gamma rays identified as ground-state transitions, the neutron binding energies of these four isotopes respectively are deduced to be 6.10, 7 48, 5.86 and 5.34 MeV. The presence of considerable high-energy structure in each of the spectra indicates that direct capture and/or anomalous resonance capture processes may be of importance.

1. Introduction

The gamma ray spectrum following thermal-neutron capture in natural tungsten has been investigated by Kinsey *et al.* [1]) and by Groshev *et al.* [2]) using external conversion spectrometers. Trumpy [3]) investigated the circular polarisation of one gamma ray thought to be from ^{183}W following polarised neutron capture in natural tungsten. Because these experiments required large

TABLE 1

Capture cross sections, masses and isotopic constitution of the tungsten samples

Sample (Nominal)	σ (b)	Mass (g)	Constitution (%)				
			^{181}W	^{182}W	^{183}W	^{184}W	^{186}W
Natural	1.8	7.8	0.14	26.2	14.3	30.7	28.7
^{182}W	20.0	5.2	0.03	91.0	4.7	3.4	0.9
^{184}W	2.0	4.3	0 01	1.1	1.6	95.0	2.3
^{186}W	36.0	5.4	0.01	0.3	0.3	1.9	97.5

The isotopically enriched samples were in the form of tungsten oxide. Chemical impurities in each sample were less than 0.3 %.

samples, no separated-isotope studies were done. In the present work, natural tungsten in the form of metallic tungsten powder and ^{182}W, ^{184}W and ^{186}W in the form of isotopically enriched tungsten oxide, obtained through the

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Isotopes Loan Plan of the U.S.A.E.C., were irradiated in a neutron beam from the Ford Nuclear Reactor at the University of Michigan. The samples, whose isotopic abundance and cross sections are given in table 1, were placed in a total neutron beam of approximately 5×10^5 neutrons $\cdot$ cm^{-2} $\cdot$ sec^{-1}. The collimation and shielding, the geometrical arrangement and the resolution and efficiency of the three-crystal spectrometer have been reported previously [4]).

2. Procedure

The 3-crystal spectra were measured over a period of many days, with each spectrum being accumulated for four hours on a 256-channel analyser. Because photomultipliers drift in any intense radiation field [5]), the energy scale of each spectrum was adjusted according to a calibration curve obtained from a chlorine (n, γ) spectrum, which was taken after every second tungsten spectrum. For each sample, the fitted spectra were added together and the background was subtracted to give the spectra shown in fig. 1. The method of determining the background has been reported previously [4]). Essentially this consists of constructing a background spectrum appropriate to each sample out of measured background spectra representing separately the effects of background direct from the reactor, reactor gamma rays scattered by the sample, and capture gamma rays due to neutrons scattered by the sample.

A single-crystal scintillation spectrometer was used for energies below 2 MeV; in this case no intensities are quoted because of the intense background.

In order to help identify ground-state transitions, spectra were also measured with both spectrometers in coincidence. For the coincidence experiments, no energy discrimination was used either on the single counter or on the secondary counters of the three-crystal spectrometer.

The flux of neutrons falling in the capture-energy range was obtained as a by-product of subsidiary experiments done to determine the background components, and was also measured by activation of Au and Ir samples. This flux is $(3.4 \pm 1.5) \times 10^5$ neutrons $\cdot$ cm^{-2} $\cdot$ sec^{-1}.

3. Results

Table 2 lists the energies and intensities of the neutron-capture gamma rays observed with natural tungsten and with each of the separated isotope samples, together with the natural tungsten results of other groups. The energy scale is based on the energies of the chlorine capture gamma rays as given by Groshev *et al.* [2]). The intensities were calculated using the efficiency of the 3-crystal spectrometer, the previously determined monoenergetic line shape of the spectrometer, and neutron capture cross sections of 20, 2.0 and 36 b for ^{182}W, ^{184}W and ^{186}W, respectively. Values quoted in table 2 are *not* corrected for isotopic admixture. Note that the 7.48 MeV line which is prominent in natural

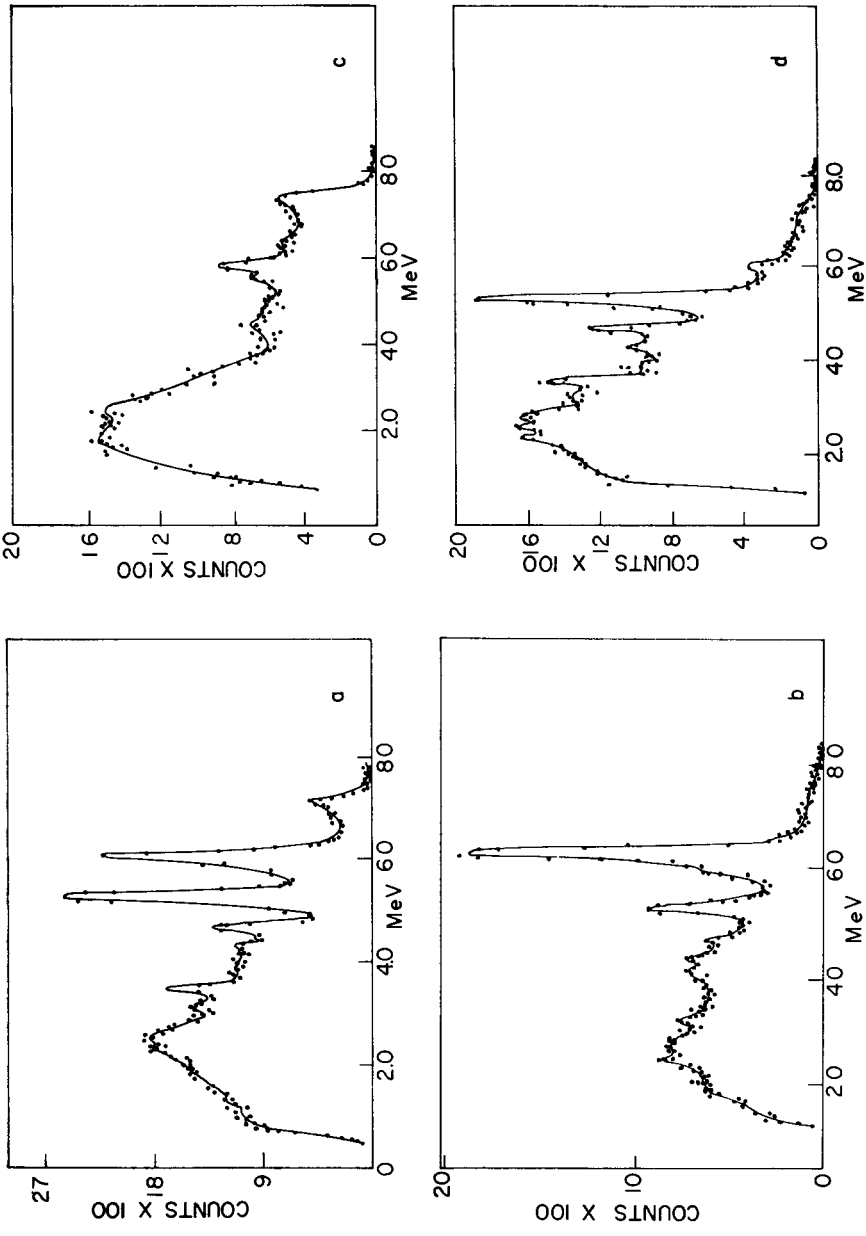

Fig. 1. Gamma ray spectra of tungsten measured with the three-crystal spectrometer (a) Natural tungsten sample (b) ^{182}W sample. (c) ^{184}W sample. (d) ^{186}W sample.

tungsten is weak or absent in the separated-isotope spectra. Hence this is assumed to be the ground-state transition in ^{184}W. (No sample of separated ^{183}W was available for this experiment.)

TABLE 2

Energies E of the neutron capture gamma rays (in MeV) and intensities I (in photons per 100 captures in the individual sample, with uncertainties in parentheses)

Present results							Groshev *et al.* [2])		Kinsey *et al.* [1])	
Nat. W	^{183}W		^{185}W		^{187}W		Nat. W		Nat. W	
E	E	I	E	I	E	I	E	I	E	I
7.48			7.49				7.43	0.5		
									6.73	0.1
6.38	6.35*		6.48*				6.42	0.4	6.40	0.3
							6.194	3.0	6.182	3.8
6.16	6.15	6(3)					6.15	2.0		
5.98			5.86	2(1)			6.03	0.65	6.02	0.3
	5.72*	1(0.8)					5.76	0.3	5.77	0.3
					5.34	3(2)	5.50	0.2		
5.26			5.40	1(0.6)	5.26	6(4)	5.33	2.5	5.30	2.4
							5.25	3.7	5.245	3.4
5.13	5.16	2(1)					5.17	1.8	5.14	2.3
					5.06	2(1.5)	5.08	0.5	4.94	0.6
							4.70	0.8		
4.62	4.56	1(0.8)	4.68	2(1)	4.73	5(3)	4.67	1.7	4.67	2.4
4.23	4.28	1(0.8)			4.31	4(3)	4.25	1.1		
	4.03	2(1.5)								
							3.86	0.6		
3.51					3.56	5(3)	3.57	2.1		
3.24	3.19*		3.28	5(3)			3.20	0.7		
					2.95					
2.76					2.76					
2.58			2.68*		2.54					
					1.03					
0.73	0.75				0.77					
0.63	0.63									
0.35	0.34		0.34							
0.20	0.20				0.24					

Unresolved lines are indicated by an asterisk (*).

4. Discussion

Natural tungsten and its isotopes have been studied by various techniques, such as mass spectroscopy, radioactive decay of neighbouring nuclei, and polarisation of capture radiation. Mass spectroscopic measurements by Johnson and Bhanot [6]) show that the binding energies should be 6.29 and 7.45 MeV for ^{183}W and ^{184}W, respectively. Martin [7]), using the Weizsäcker mass formula, found the binding energies to be 6.24, 7.45, 5.96 and 5.70 MeV for ^{183}W, ^{184}W,

^{185}W and ^{187}W, respectively. Using all existing data, Wapstra *et al.* [8]) found 6.19, 7.46, 6.8 and 3.4 MeV to be the binding energies of the same isotopes.

In the present work the binding energies of ^{183}W, ^{184}W, ^{185}W and ^{187}W are determined to be 6.10, 7.48, 5.86 and 5.34 MeV, respectively. There is some doubt about the binding energies of ^{185}W and ^{187}W. In ^{185}W, the spin change from the capture state to the ground state is large (3 or 4) so the ground state decay should be weak. Because the capture cross section of ^{184}W is small, the other isotopes in the sample contribute a line at 6.05 MeV, the line at 6.48 MeV and 50 % of the line at 7.49 MeV. However, the background has a high intensity near 7.5 MeV due to Pb and Li capture gamma rays. Thus the proportion of the line at 7.49 MeV which must be due to ^{185}W is of the order of the statistical uncertainty. The highest energy gamma ray which can definitely be attributed to ^{185}W is the one at 5.86 MeV, and as it is attenuated in the total-coincidence spectrum, this is interpreted as the ground-state transition.

In ^{186}W(n, γ)^{187}W, the spin change for the ground-state transition is 0 or 1 and this transition should be prominent. An intense doublet is found at 5.3 MeV, which is depressed in the total-coincidence spectrum. The upper member of this doublet, at 5.34 MeV, is taken to be the groud-state line.

All of the spectra have strong high-energy peaks which indicates that neutron capture takes place partly through the direct capture and/or anomalous resonance capture processes [9]). Either process requires a single-particle P state in the product nucleus, and according to the shell model a $3P_{\frac{3}{2}}$ neutron state would be available in any of the isotopes discussed. However, little more can be said as this is a region of large deformation.

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