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THE ROTATIONAL STATES OF ¹⁸⁴Os, ¹⁸⁶Os and ¹⁸⁸Os

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Abstract

Gamma rays following the ($^4\text{He}, 2n$) reactions, leading to the nuclei ^{184}Os , ^{186}Os and ^{188}Os , have been studied. Unambiguous assignments have been made for the $6+$ states, strong assignments for the $8+$ states and tentative assignments for the $10+$ states of the ground state rotational bands in these nuclei.

1. Introduction

New data on the ground state rotational bands of ^{184}Os , ^{186}Os and ^{188}Os have been obtained from studies of the gamma rays following the reactions $^{182}\text{W}(^4\text{He}, 2n)^{184}\text{Os}$, $^{184}\text{W}(^4\text{He}, 2n)^{186}\text{Os}$ and $^{186}\text{W}(^4\text{He}, 2n)^{188}\text{Os}$. The angular distributions of the gamma rays at 27 MeV bombarding energy and, in one case, their excitation functions were measured. The method of measurement is fully described in the preceding paper¹⁾. The spectra of the gamma rays from these reactions, taken with Ge-Li counters, are shown in fig. 1. We give here a brief discussion of the results obtained from each of the three osmium nuclei.

2. The Nucleus ^{186}Os .

The levels in ^{186}Os have been investigated by Emery et al.²⁾ and by Harmatz and Handley³⁾ from the decay of ^{186}Ir . The rotational states of the ground state band have been well established up to the 6^+ state. A 584.4 keV gamma ray has been assigned by Emery et al. as the $8 \rightarrow 6$ transition, but the evidence for this assignment is weak. Sakai et al.⁴⁾ and Ejiri et al.⁵⁾ have studied the conversion electrons in ^{186}Os through the $^{187}\text{Re}(p, 2n)^{186}\text{Os}$ reaction. They found a transition of 589 ± 3 keV, which they identified with the 584.4 keV transition of Emery et al. and also assigned it to the $8 \rightarrow 6$ transition. Yamazaki and Hendrie⁶⁾ have studied gamma rays from the same reaction and assigned a 585 keV gamma ray to this same transition. Lark and Morinaga⁷⁾ investigated the rotational levels in ^{186}Os through the $^{186}\text{W}(^4\text{He}, 4n)^{186}\text{Os}$ reaction, observing the gamma rays with NaI detectors. Their assignment of the various transitions was based purely on the systematics. Because of the poor resolution of NaI detectors and the large numbers of strong non-rotational transitions in this region (see

fig. 1), their evidence can not be considered very reliable. However, they assigned a gamma ray of energy 550 ± 7 keV to the $8 \rightarrow 6$ transition.

In our measurements on the gamma rays from the $^{184}\text{W}({}^4\text{He}, 2n)^{186}\text{Os}$ reaction we also saw a gamma ray of energy 584.4 keV and we measured its angular distribution. We obtained values of $A_2 = 0.17 \pm 0.08$ and $A_4 = 0.05 \pm 0.09$. These values are not very precise, but they are consistent with the 584.4 keV transition being a stretched E2 transition, which it must be if it is the $8 \rightarrow 6$ transition. Further, we observed a gamma ray of 551.8 keV energy, which had an intensity comparable to that of the 584.4 keV gamma ray. The angular distribution of the 551.8 keV gamma ray, with $A_2 = 0.22 \pm 0.09$ and $A_4 = -0.14 \pm 0.09$, is consistent with that of a stretched E2 transition. This gamma ray was not seen in the $^{187}\text{Re}(p, 2n)^{186}\text{Os}$ reaction.

On the above evidence alone it would be possible to assign either the 584.4 keV, or the 551.8 keV gamma ray to the $8 \rightarrow 6$ transition. We shall demonstrate here, considering first experimental evidence and then the systematics of rotational states in osmium nuclei, that the 551.8 keV gamma ray is likely to be the correct assignment.

The excitation functions of the $2 \rightarrow 0$, $4 \rightarrow 2$, 584.4 keV and 551.8 keV transitions relative to that for the $6 \rightarrow 4$ transition, are shown in fig. 2. It can be seen that the yields of the $2 \rightarrow 0$ and $4 \rightarrow 2$ gamma rays decrease with increasing bombarding energy, relative to the yield of the $6 \rightarrow 4$ transition. Such behaviour is generally observed in $({}^4\text{He}, 2n)$ reactions, which occur at bombarding energies only a little above the potential barrier for the incident helium ions. From the discussion of the reaction mechanism in the

previous paper¹), one can see qualitatively the main reason for this. When the target has spin zero, as here, a significant yield of gamma rays from a final state of spin I will be expected only if a sizeable fraction of the total reaction cross section corresponds to incoming angular momenta l of about I or greater. Since with increasing bombarding energy above the potential barrier, the cross sections for high l values increase relatively more rapidly than those for low l values, it will be expected that the yields of gamma rays from final states of high I will increase relatively more rapidly than those of low I . Figure 3 shows theoretical cross sections for forming particle stable states in ^{186}Os with spin greater than I , divided by the cross sections for spin greater than six, as functions of incident energy. These curves were calculated with the computer program mentioned in the preceding paper. It can be seen that the behaviour of these curves is similar to that observed in our experiment. Referring again to fig. 2, one can see that the excitation function of the 584.4 keV gamma ray is similar to that for the $4 \rightarrow 2$ and $2 \rightarrow 0$ transitions, that is, like a gamma ray arising from a state of spin less than six. On the other hand, the 551.8 keV gamma ray has an excitation function which could be consistent with a rise in its relative cross section with energy, as expected for a gamma ray from a state of spin 8.

A second piece of evidence, for the assignment of the 551.8 keV gamma ray to the $8 \rightarrow 6$ transition, comes from a comparison of the $^{187}\text{Re}(p,2n)^{186}\text{Os}$ data with those from the $^{184}\text{W}(^4\text{He},2n)^{186}\text{Os}$ reaction. The 584.4 keV gamma ray was seen in both $(p,2n)$ and $(^4\text{He},2n)$ reactions, whereas the 551.8 keV gamma ray was seen only in the $(^4\text{He},2n)$ experiment. Table 1 shows the relative intensities of the various transitions observed in both types of reaction. As expected

the high angular momentum states are relatively more populated in the ($^4\text{He}, 2n$) reaction. Nevertheless the intensity of 584.4 keV transition relative to that of the $4 \rightarrow 2$ transition is approximately the same for both reactions. Thus again the evidence suggests that the 584.4 keV gamma ray comes from a state having relatively low angular momentum and the 551.8 keV gamma ray from one having rather high angular momentum.

The third piece of evidence, supporting the assignment of the 551.8 keV gamma ray to the $8 \rightarrow 6$ transition, arises from the systematics of the rotational states of the osmium nuclei, shown in fig. 4. This type of plot shows up deviations from systematic behaviour very sensitively, since it removes the general $I(I + 1)$ energy dependence of the levels of spin I . We have plotted the ratio of successive rotational constants A_I against the intermediate spin I . The quantity A_I is defined by

$$A_I = h^2/2J_I = \frac{\Delta E(I \rightarrow I - 2)}{4I - 2}$$

It is very apparent that the energy of 584.4 keV for the $8 \rightarrow 6$ transition in ^{186}Os fits very badly indeed with the systematics, whereas 551.8 keV fits in very well (the $8 \rightarrow 6$ transition corresponds to intermediate spin six in fig. 4). Although no one piece of evidence in itself is entirely conclusive, we feel that these three taken together suggest strongly that the 551.8 keV gamma ray does rise from the $8 \rightarrow 6$ transition and that the 584.4 keV gamma ray has previously been incorrectly assigned.

Harmatz and Handley³) have given an alternative assignment for the 584.4 keV transition, based on energy sums only. This assignment, to a transition

from a $4+$ state at 1352 keV to the $2+$ state at 767 keV, would not be in conflict with the data reported here.

Emery et al.²⁾, from their experiment on the decay of 15.8 hour ^{186}Ir , have concluded that the spin of ^{186}Ir is 7. This conclusion appears to depend strongly on the assumption that the 584.4 keV gamma ray arises from the $8+$ state. If, as seems likely, this assumption is incorrect, then the possibility of spin 6 for the ground state of ^{186}Ir cannot be excluded.

We observed another gamma ray of energy 647.6 ± 0.5 keV, which might be very tentatively assigned to the $10 \rightarrow 8$ transition. Its angular distribution coefficients, $A_2 = 0.55 \pm 0.3$ and $A_4 = -0.3 \pm 0.3$, are consistent with it being a stretched E2 transition and its energy fits very well with the systematics, as shown in fig. 4. Its excitation function, shown in fig. 2, was measured, but the results are not precise enough to draw any firm conclusions. The intensity of this gamma ray is nearly equal to that of the 551.8 keV transition, whereas one might have expected the $10 \rightarrow 8$ transition to be rather weaker.

3. The Nucleus ^{184}Os

The states up to $8+$ of the ground state rotational band in ^{184}Os have been assigned by Sakai et al.⁴⁾ and by Yamazaki and Hendrie⁶⁾ from (p,2n) experiments and up to the $10+$ state by Lark and Morinaga⁷⁾ from a ($^4\text{He}, 4n$) experiment. The same objections apply to the Lark and Morinaga data as previously noted. Sakai et al. give 504 ± 4 keV and Yamazaki and Hendrie give 504 keV for the energy of the $8 \rightarrow 6$ transition. In the (p,2n) experiment this transition has approximately the same intensity relative to that of the $6 \rightarrow 4$

transition, as does the 584 keV transition in ^{186}Os . In view of our remarks on the ^{186}Os case, we would like to point out that the difference between their value of 504 keV and ours of 500.7 ± 0.4 keV for the 8 \rightarrow 6 transition may be significant. It is possible that the 8 \rightarrow 6 transition is very weak in the (p,2n) reaction and that the 504 keV transition is not seen in our ($^4\text{He},2n$) experiment, because it is masked by the strong 500.7 keV transition. A gamma ray of 596.6 ± 1 keV might be assigned tentatively to the 10 \rightarrow 8 transition. Its values for $A_2 = 0.20 \pm 0.1$ and $A_4 = -0.06 \pm 0.1$ are not very precise, but are probably not inconsistent with the value of $A_2 \sim 0.32$, expected for the 10 \rightarrow 8 transition, from those for the 8 \rightarrow 6 and 6 \rightarrow 4 transitions in this nucleus. It should be remarked that the peak corresponding to this gamma ray is broad. Its energy is in good accord with the systematics, as can be seen from fig. 4.

4. The Nucleus ^{188}Os

Apart from the work of Lark and Morinaga⁷⁾ the levels in the ground state rotational band of ^{188}Os have been given only up to the 4+ state^{3,8)}. We find gamma rays of 461.9 ± 0.3 keV and 573.8 ± 0.4 keV, whose angular distributions are consistent with those expected for the 6 \rightarrow 4 and 8 \rightarrow 6 transitions. These energies are not in agreement with those of 470 ± 7 and 640 ± 10 keV, given by Lark and Morinaga. Another gamma ray of 655.9 ± 1 keV energy might be very tentatively assigned to the 10 \rightarrow 8 transition, on the basis of systematics only. A point corresponding to this is shown in fig. 4.

5. Conclusion

The energies which seem to us to be most likely for the members of the ground state rotational bands in the three osmium isotopes are shown in table 2. We feel that the assignments up to the 6^+ states are likely to be good, those for the 8^+ states are fairly good and those for the 10^+ states very tentative.

Many rotational states so far have been assigned purely on the basis of energy-level systematics. Though this may often be a useful procedure, it must be remembered that in doing this one is often assuming what one is setting out to prove. Clearly, it is a particularly dangerous practice in the osmium region, where the level density is rather high at fairly low excitation energy and many strong transitions are seen both in the reaction experiments and in radioactive decay. Angular distribution measurements are an additional tool in identifying the rotational transitions, since they must have angular distributions characteristic of stretched E2 transitions. In this paper we have confined our attention to gamma rays which satisfy this criterion, though others which do not were also seen. However, the identification of a transition as being of stretched E2 character is not sufficient in itself to conclude that the transition is rotational, as the example in ^{186}Os shows. Clearly, stretched E2 transitions can occur between non-rotational states as well. We have demonstrated that excitation function measurements can provide additional evidence regarding the spins of the decaying states. However, in order to make more reliable assignments for the higher rotational transitions, it will be necessary to perform coincidence measurements.

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Figure Captions

- Fig. 1. Gamma ray spectra from the bombardment of ^{182}W , ^{184}W and ^{186}W with 27 MeV ^4He ions.
- Fig. 2. Relative excitation functions of gamma rays seen in the $^{184}\text{W}(^4\text{He},2n)^{186}\text{Os}$ reaction. The full lines have no theoretical significance.
- Fig. 3. Calculated cross sections for forming particle stable states in ^{186}Os with spin greater than I, relative to those for forming states with spin greater than six.
- Fig. 4. Systematics of rotational state energies in osmium nuclei. Data were obtained from the present work and the following references: Ref. 9) ^{182}Os , Ref. 2) ^{186}Os , Ref. 8) ^{188}Os , Ref. 3) ^{190}Os .

Table 1

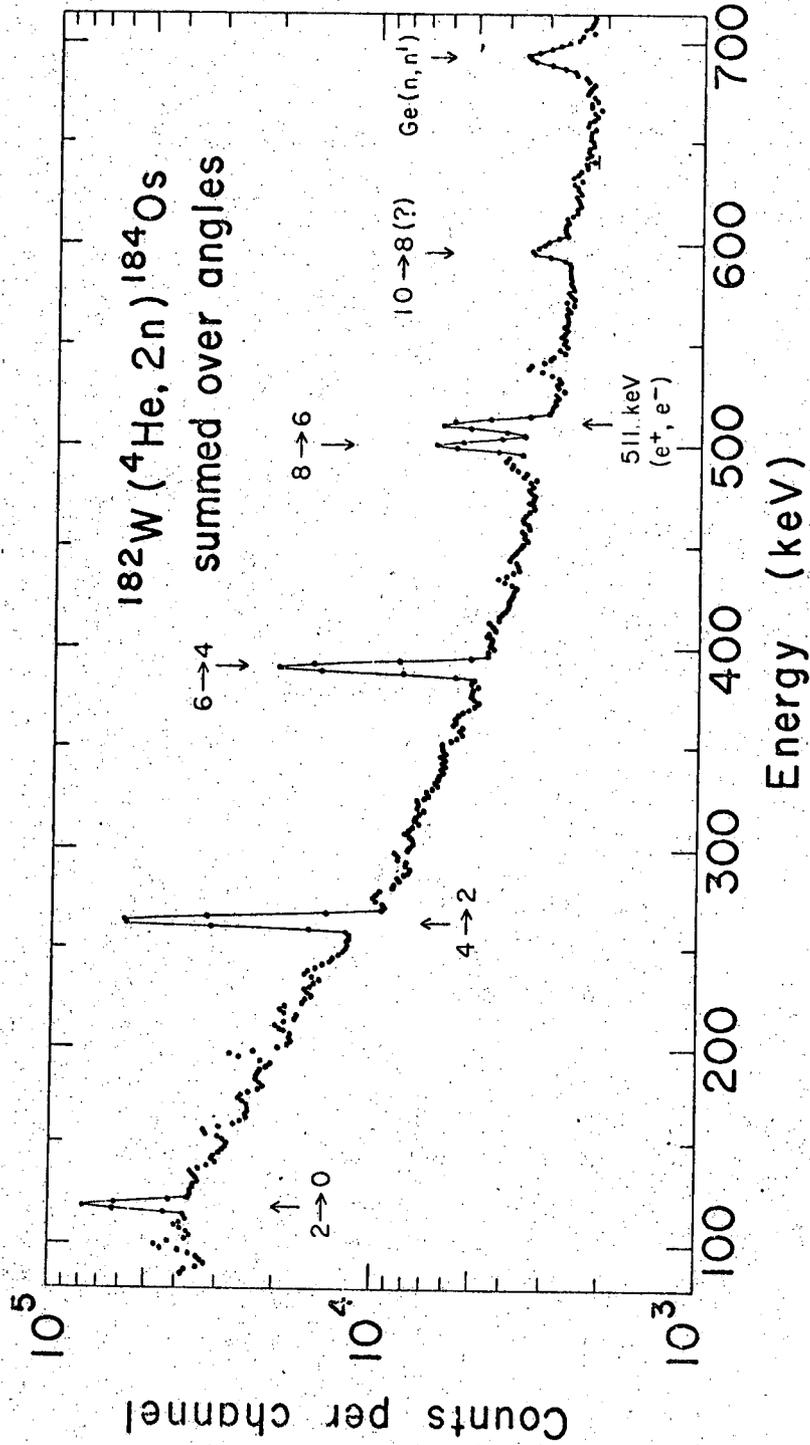
Relative intensities of transitions in ^{186}Os observed in two reactions. Those for the 551.8 keV transition were estimated from the published spectra for the $^{187}\text{Re} + p$ reaction^{5,6}). *Assuming E2.

Reaction	type of observation	2→0	4→2	6→4	551.8	584.4
$^{187}\text{Re} + 14 \text{ MeV } p$	conv. el.	270	100	39	< 6*	27
	gamma rays				< 8	24
$^{182}\text{W} + 27 \text{ MeV } ^4\text{He}$	gamma rays	175	100	46	16	20

Table 2

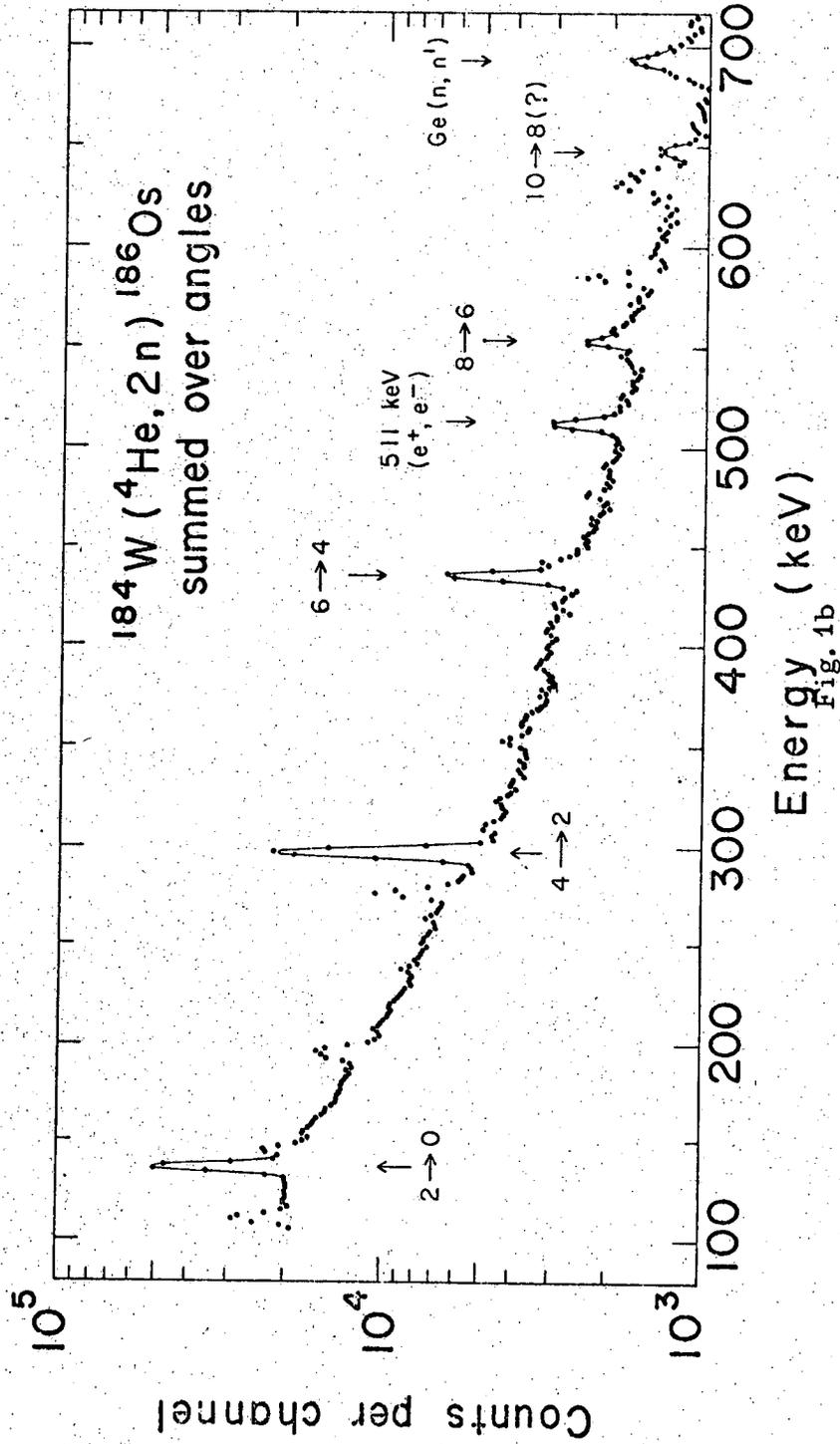
Energies of rotational states. The data for the 2+, 4+ and 6+ states of ^{186}Os are taken from ref. 2) and those for the 2+ and 4+ states of ^{188}Os from ref. 8). The brackets round the 10+ transitions indicate that these assignments are tentative.

	^{184}Os	^{186}Os	^{188}Os
2+	119.8 ± 0.3	137.15 ± 0.03	155.03 ± 0.03
4+	383.6 ± 0.4	433.90 ± 0.06	477.94 ± 0.05
6+	773.9 ± 0.6	868.7 ± 0.1	939.8 ± 0.3
8+	1274.6 ± 0.7	1420.5 ± 0.3	1513.6 ± 0.5
10+	(1871.2 ± 1.2)	(2068.1 ± 0.6)	(2169.5 ± 1.1)

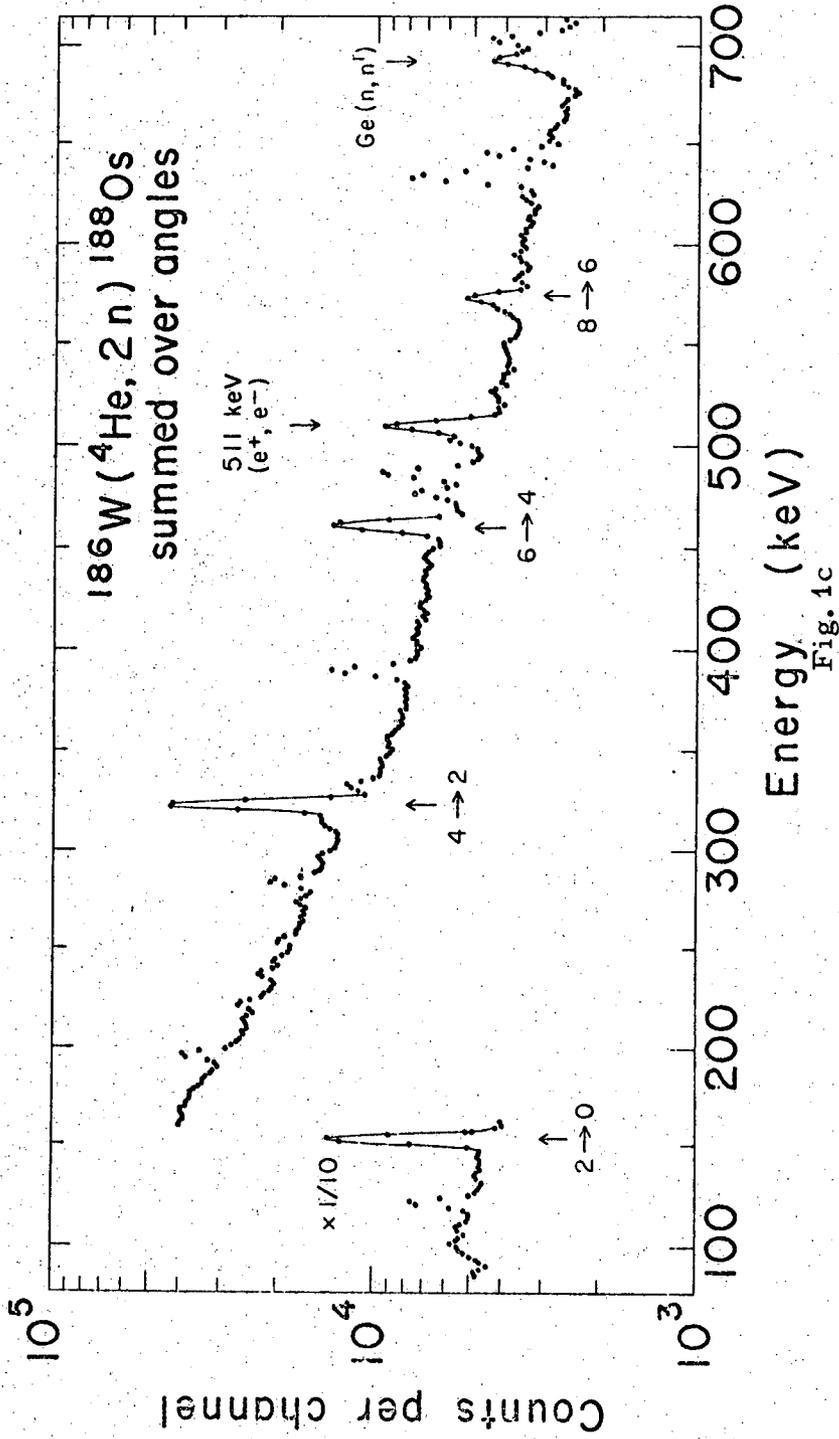


NUB 13607

Fig. 1a



NUB 1362



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Fig. 1c

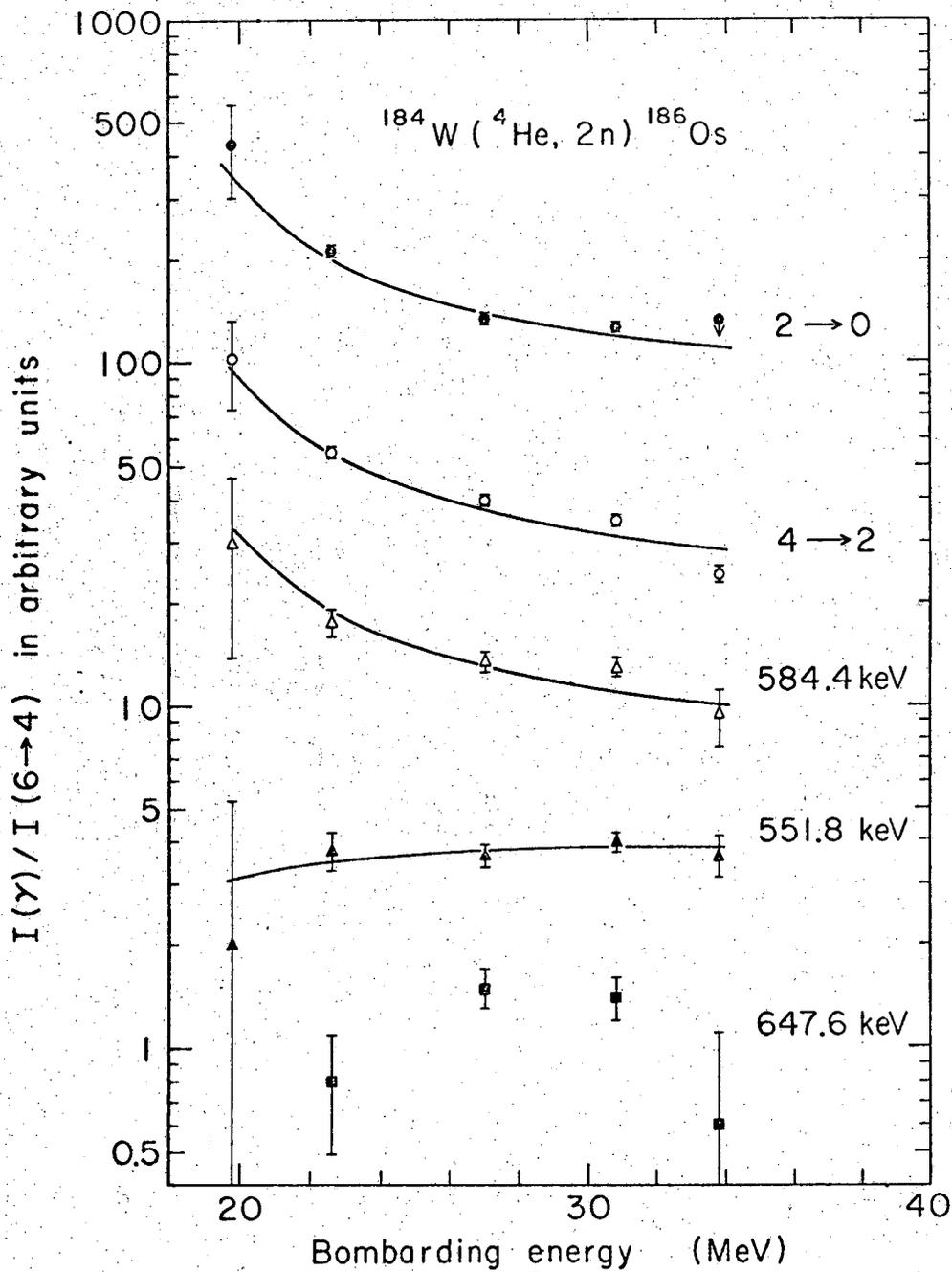
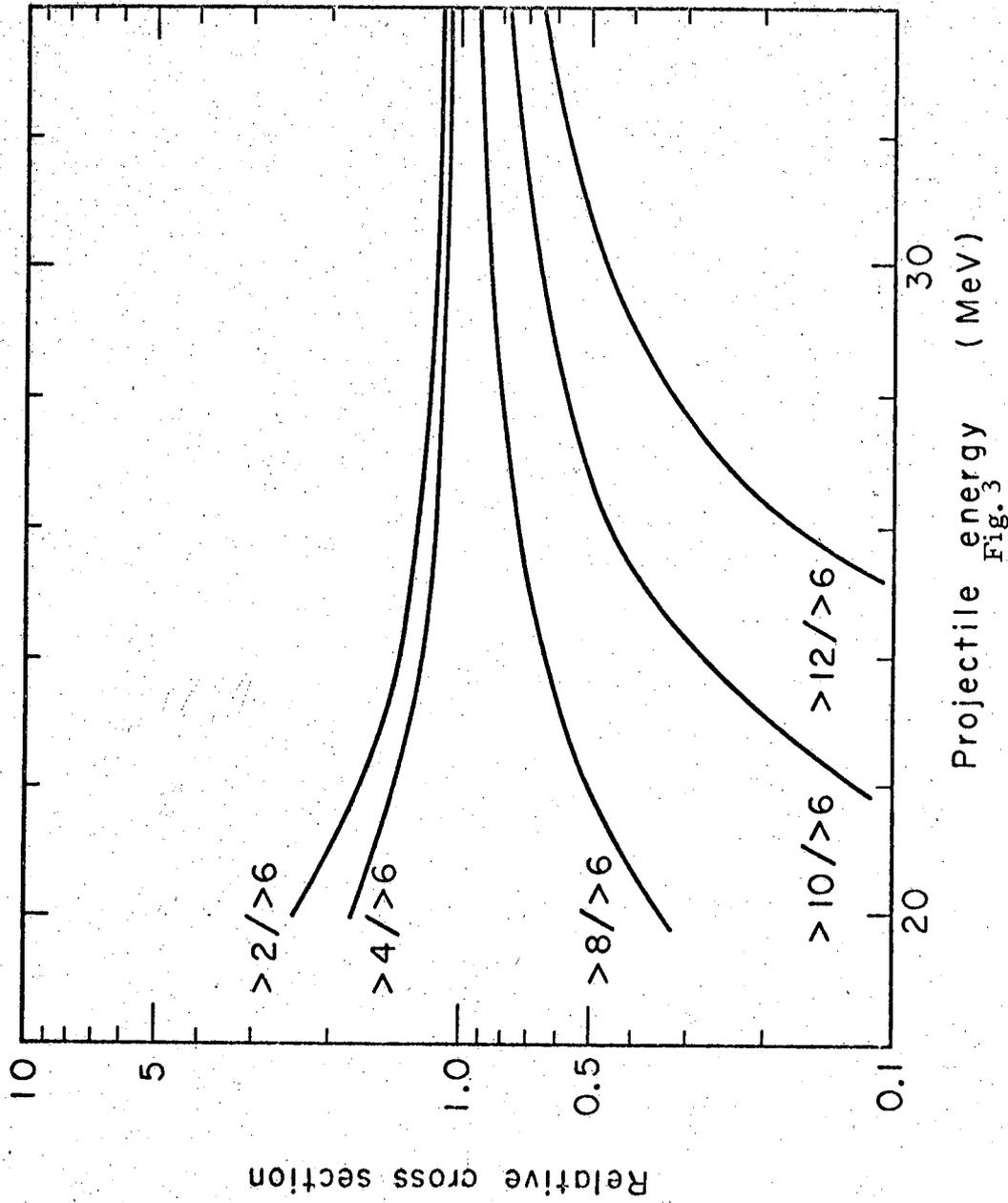


Fig. 2



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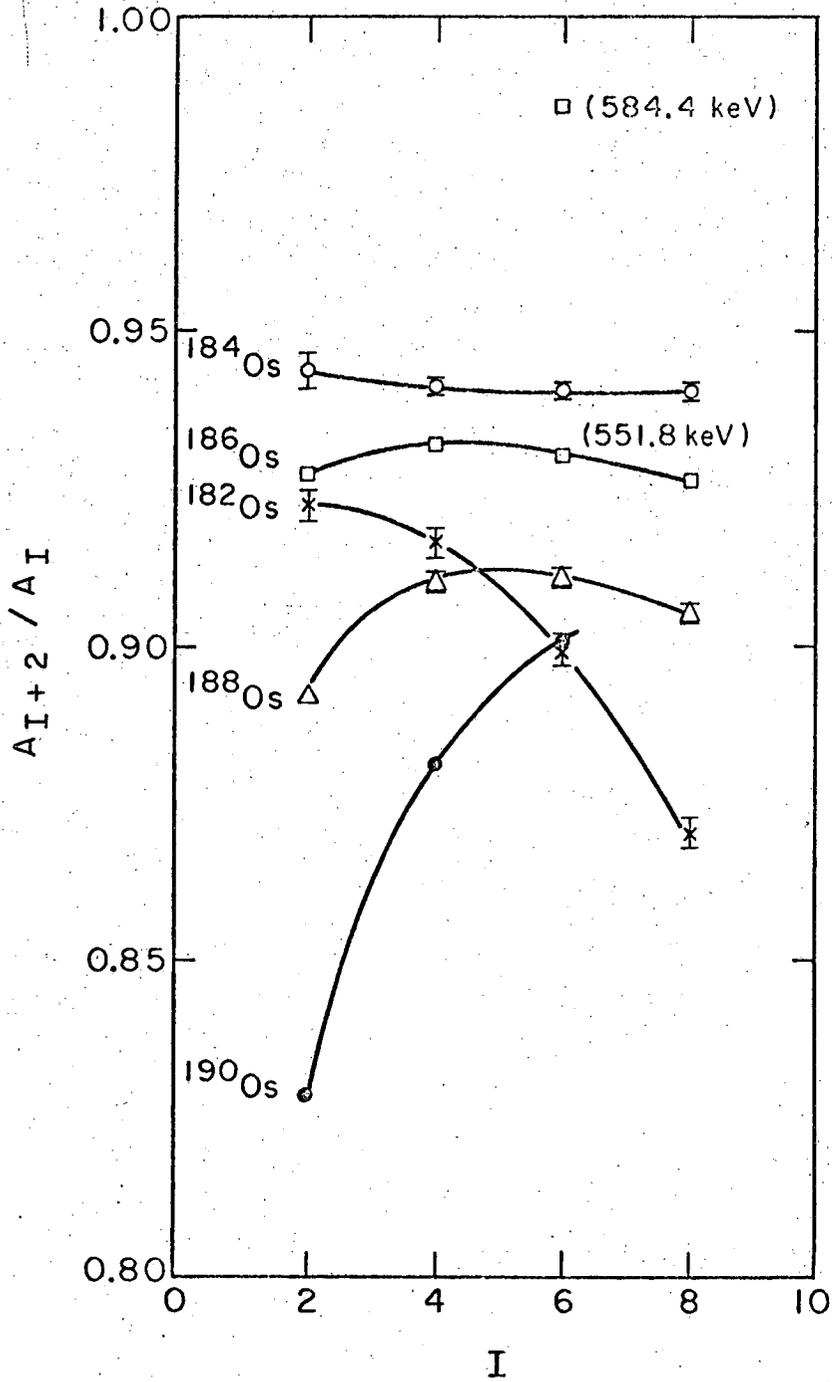


Fig. 4

MUB-13600

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