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Abstract:

Two branches are observed feeding the 38^+ level of the yrast line in ^{158}Er. Two ~1.2 MeV cascade transitions constitute a fast (< 1 ps) collective component, probably with only minor changes in shape and structure from those at lower spin. Four slower γ rays (> 2 ps) suggest a transition to a different shape and structure, most likely to an oblate 46^+ state with all valence particles maximally aligned, a band termination.

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Calculations[1-3] predict that in the nucleus ^{158}Er oblate shapes will compete with prolate and triaxial ones along the yrast line near spin 50ħ. In fact, the first oblate shape predicted to be on the yrast line is the fully aligned 46^+ state; $\pi[(h_{11/2})^4]_{16}\nu[(f_{7/2})^3(h_{9/2})^3(i_{13/2})^2]_{30}$. Experimental evidence has recently been reported[4] for a change to oblate shape, however, at somewhat lower spin, ~40ħ. The present letter describes some of the first results obtained with HERA, the High Energy Resolution Array[5] at Berkeley, for the nucleus ^{158}Er. We find two branches feeding the 38^+ level; one is slow (> 2 psec), suggesting some population of the non-collective, oblate structures predicted, and the other is fast(< 1 psec), suggesting population also of the more collective prolate or triaxial structures.

The reaction used was 175 MeV ^{40}Ar + ^{122}Sn. The ^{40}Ar beam was provided by the 88-Inch Cyclotron of the Lawrence Berkeley Laboratory. Three targets were employed: a ~1 mg/cm^2 lead-backed target, a ~1 mg/cm^2 gold-backed one, and a target consisting of three self-supporting ^{122}Sn foils, each ~ 0.5 mg/cm^2 thick. The gamma rays were detected with 14 (for the lead-backed target) and 21 (for the unbacked and gold-backed targets) Compton-suppressed germanium detectors. With the 14 detectors about 2 x 10^8 double events were recorded; with 21 detectors the same number of triple events (corresponding to 6 x 10^8 doubles) were obtained per target.

A part of the spectrum (700-1400 keV) obtained with the unbacked targets in coincidence with the 1058 keV ($38^+ \rightarrow 36^+$) transition is shown in Fig. 1a. The region of the second (proton) backbend is seen and one can observe the marked drop in intensity for discrete lines above the 1058 keV gate. The five transitions observed in Ref. 4 of 827, 1031, 1203, 1210, and 1280 keV can be seen, and in addition there is a weak 971 keV line. Figure 1b shows the same region gated by the same transition, but for the gold-backed target; it is clear that the 1203-1210 keV lines are missing. We believe these are not observed because they are smeared out by Doppler shifts arising from: 1) the spread in velocity of the emitting nucleus as it slows down; and 2) the variety of detector angles relative to the beam direction. From range-energy data,[6] the mean time to slow the recoiling ^{158}Er nucleus in gold (lead) can be estimated to be around 0.5 (1.0) picosecond. For the 827, 971, 1031, and 1280 keV transitions to be sharp in Fig. 1b means that they must have been emitted after an interval (corresponding to their lifetime plus feeding time) 2-3 times longer than this. The fact that the 1200 keV lines disappear in Fig. 1b means that they have lifetimes (plus feeding times) shorter than the mean slowing time. If shorter than ~0.2 psec, they would be emitted before much slowing down occurred (i.e., at nearly full recoil velocity). In this case, a reasonably sharp line should appear in the summed spectrum from all the detectors after each one has been gain-adjusted for its full Doppler shift. We did not see 1200 keV lines in such a spectrum with the lead-backed target, suggesting a lifetime (plus feeding time) between 1 and 0.2 psec. However, at present we consider the lower limit to be tentative.

A spectrum like that shown in Fig. 1a is obtained if the 1017 keV ($36^+ \rightarrow 34^+$) transition is used as the gate, but with an additional weak 1276 keV line. Since this line did not appear with the 1058 keV ($38^+ \rightarrow 36^+$) gate, it must feed the 36^+ state directly. However, the other six γ rays of interest are in coincidence with the main sequence of the yrast band starting with the $38^+ \rightarrow 36^+$, 1058 keV transition. Figure 2a is a spectrum obtained with a gate on the 1280 keV transition (unbacked target) which shows that it is not in coincidence with the 1203 and 1210 keV transitions, but is in coincidence with the 827, 1031, and 971 keV gamma rays. Similarly, Fig. 2b, obtained from the sum of the gates on the 1203 and 1210 keV transitions, shows that the 1203 and 1210 keV gamma rays are not in coincidence with the 827, 971, 1031, and 1280 keV transitions but do feed in at the 38^+ level and are in coincidence with each other. Their relative intensities suggest that the 1203 keV line is the lower. The 971-1031-1280-827 keV cascade is ordered on the basis of relative intensities, though the nearly equally intense 827 and 1280 keV transitions might possibly be reversed. The gamma-gamma angular correlation data indicate that the 827 and 1280 keV lines are stretched E2 transitions, and suggest that the 1031 keV line is too. The other high-spin transitions were too weak to determine reliably, but we believe that the 971 keV line might well be a stretched E2 also. The top part of the level scheme determined here is shown in Fig. 4. It differs from that of Ref. 4 in that the 1200 keV γ rays feed the 38^+ rather than the 40^+ level. (This arrangement also removes an intensity imbalance noted in Ref. 4), and the 971 and 1276 keV transitions are added.

One of the two interesting results of these experiments is the identification of fast and slow feeding components into the 38^+ state of ^{158}Er. Such components have been seen separately in neighboring nuclei and have generally accepted interpretations. Among the Gd, Dy, Er, and Yb ($64 \leq Z \leq 70$) nuclei, those having neutron numbers between 82 and 88 generally have slow feeding times (> 1 psec). The reason is thought to be that they have regions of non-collective behavior (oblate or spherical shapes) along the decay pathways. Such regions have relatively slow transitions (of order single-particle strength or less) and no smooth decay pathways. In contrast, the well deformed rare-earth nuclei ($64 < Z < 74$; $90 < N < 110$) have fast feeding times (<< 1 psec), thought to be due to the presence of rotational bands. These bands provide smooth pathways of strongly enhanced E2 transitions, and thus provide for rapid de-excitation. It is therefore not so surprising that ^{158}Er, which lies on the boundary between these regions, would have both fast and slow feeding components. In fact, such a combination of feeding times has recently been inferred[7] from the decay curves of lower-lying states in recoil distance studies of the nearby nucleus, ^{154}Dy. The difference in the present case is that we have identified resolved lines in each of these two branches and have determined how they feed into the known yrast sequence.

It is perhaps worth noting that the delay in the slow branch is not likely to be due to the 827 keV transition alone, as it lies below the 1031 and 971 keV transitions, and probably the 1280 keV one, as well. Since all four lines are sharp in Fig. 1b, either the first (or all) is slow or the delay precedes them all. We can also try to infer a bit more about the fast 1200 keV lines. The 1 and 0.2 psec limits mentioned above refer to their combined lifetime and feeding time; the individual level lifetimes would have to be about a factor of two (on average) shorter. In a typical rotational band the correction due to feeding from higher states amounts to a factor of around 4 for such transition energies. If we take, rather arbitrarily then, a factor of 3 for the ratio of total time observed to lifetime, the above limits correspond to $B(E2)/B(E2)_{sp}$ values between 10 and 50 for the 1200 keV transitions. These are only estimated lower limits, but indicate appreciable collectivity in this branch. On the other hand, they are less than the 200 single-particle units characteristic of the low-spin regions of the well deformed nuclei and probably less than the values for the continuum γ-rays in

^{158}Er and other nearby Er nuclei.[8] One should remember that these 1200 keV γ-rays are very weak (1-2% of the $4^+ \rightarrow 2^+$ transition) and could represent somewhat slower links between faster decays at both higher and lower spins. Thus, they need not be similar to the average continuum γ-ray. On the other hand, the 1200 keV lifetimes are based on an assumed feeding correction and could be arbitrarily fast if all the delay is in the feeding. It will be interesting to measure the lifetimes of both the 1200 keV γ rays and the average continuum γ rays more accurately to see if a discrepancy really exists.

The other major point of interest in these results is the nature of the highest spin state found, that decaying by the 971 keV transition . If the 971 and 1031 keV lines are stretched E2 transitions, as we suspect, this state is the 46^+ one that is the maximally aligned state predicted by theory[1,2]; it is a band termination. That is, this state has all the valence particles aligned to their maximum spin, producing an oblate nucleus ($\gamma = 60°$). Higher spins would have to be made by core excitation or by promoting the valence particles to the next shell. Figure 4 gives the level energy (minus a rigid-rotor energy) vs spin plot for these high-spin states in ^{158}Er and shows the remarkable similarity for the levels of the slow branch to those of ^{156}Er (displaced 4 spin units with the two fewer neutrons), where the band termination has been seen[9] at 42^+. Both of these states lie unusually low, which shows the favorable energy of the maximally aligned states in this region of nuclei.

In conclusion, we feel that the observation of fast and slow feeding pathways in ^{158}Er is an exciting result. The data provide the best evidence to date that there is a change to oblate shapes at high spin for some states in ^{158}Er and very probably to the maximally aligned 46^+ state. At the same time, it shows that there are also decay pathways that do not go through such shapes. Perhaps most importantly, it gives us experimental access to study separately resolved lines associated with the two types of feeding.

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FIGURE CAPTIONS

Fig. 1 Coincident gamma-ray spectra from the reaction $^{122}Sn(^{40}Ar,4n)^{158}Er$.

a) Transitions in coincidence with a gate on the 1058 keV γ-ray depopulating the spin 38^+ level, self-supporting target.

b) Transitions in coincidence with the same gate as a), but gold-backed target.

Fig. 2 Coincident gamma-ray spectra obtained with the self-supporting target.

a) Spectrum in coincidence with the 1280 keV gamma-ray.

b) Sum of spectra with gates on the 1203 and 1210 keV gamma-rays.

Fig. 3 Top of the level scheme for the yrast band in ^{158}Er.

Fig. 4 Plot of level energy minus rigid-rotor rotational energy vs spin for yrast states in ^{156}Er, -•-, and ^{158}Er, -o-.

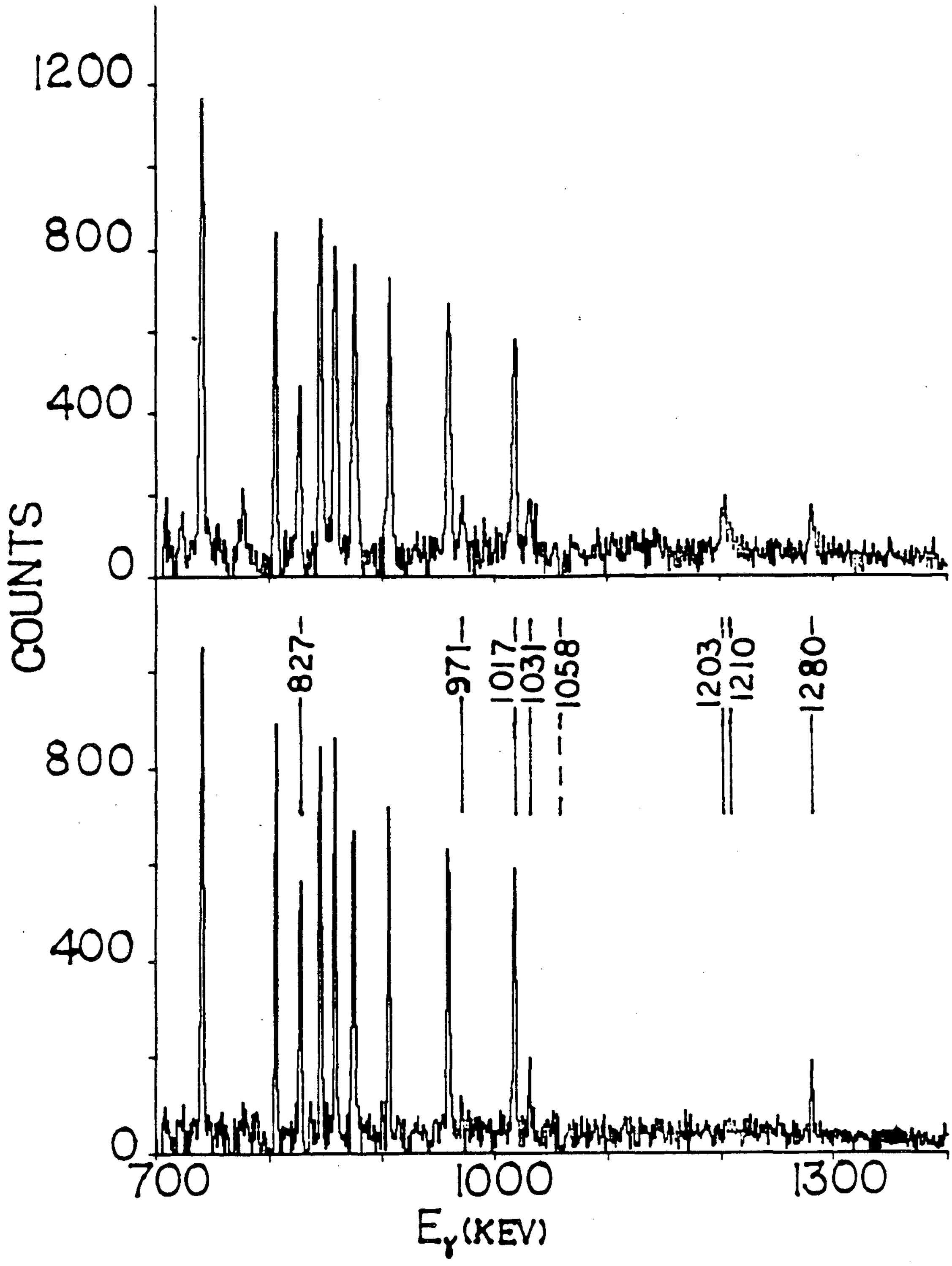


Fig. 1

XBL 855-2515

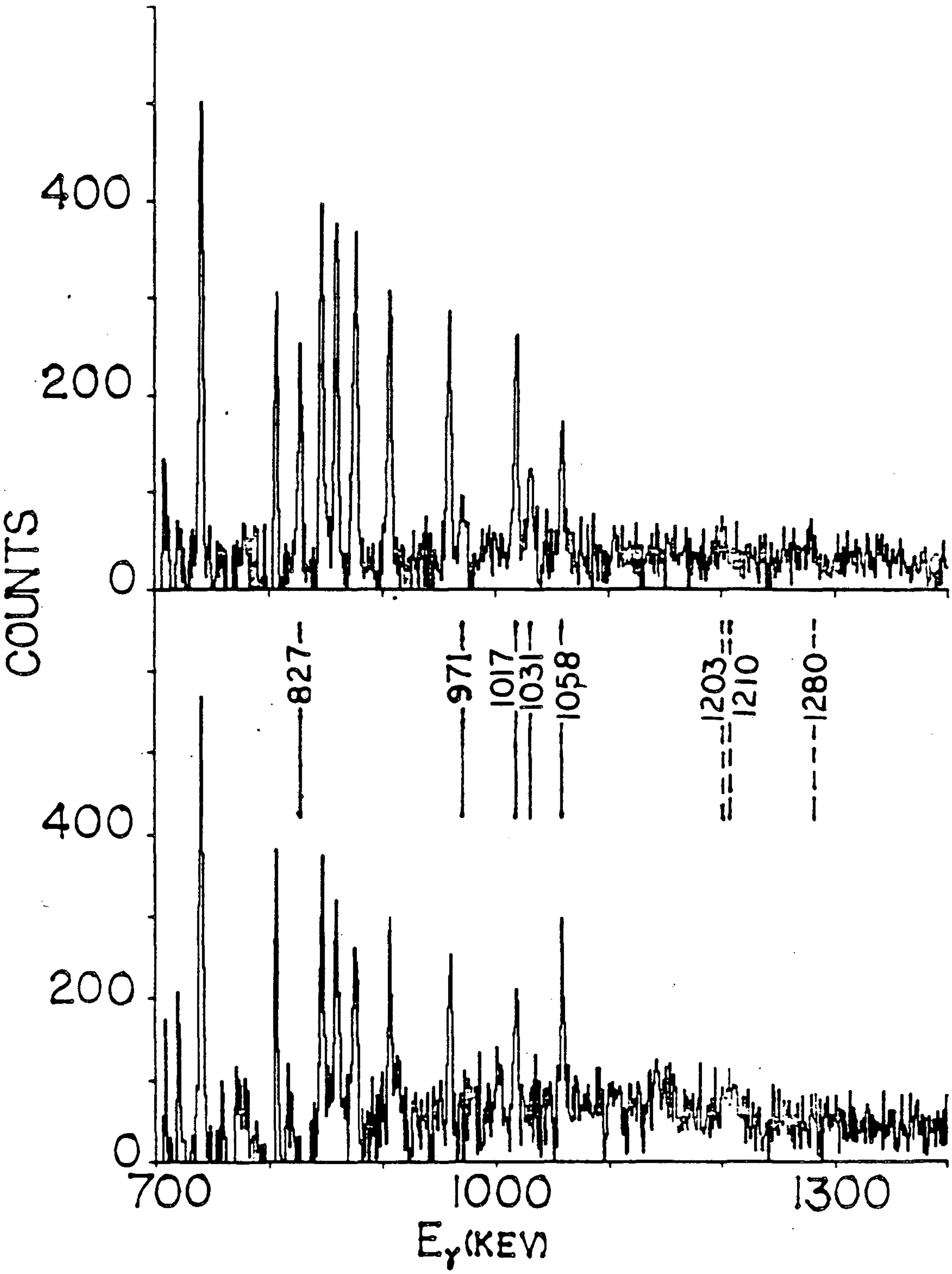
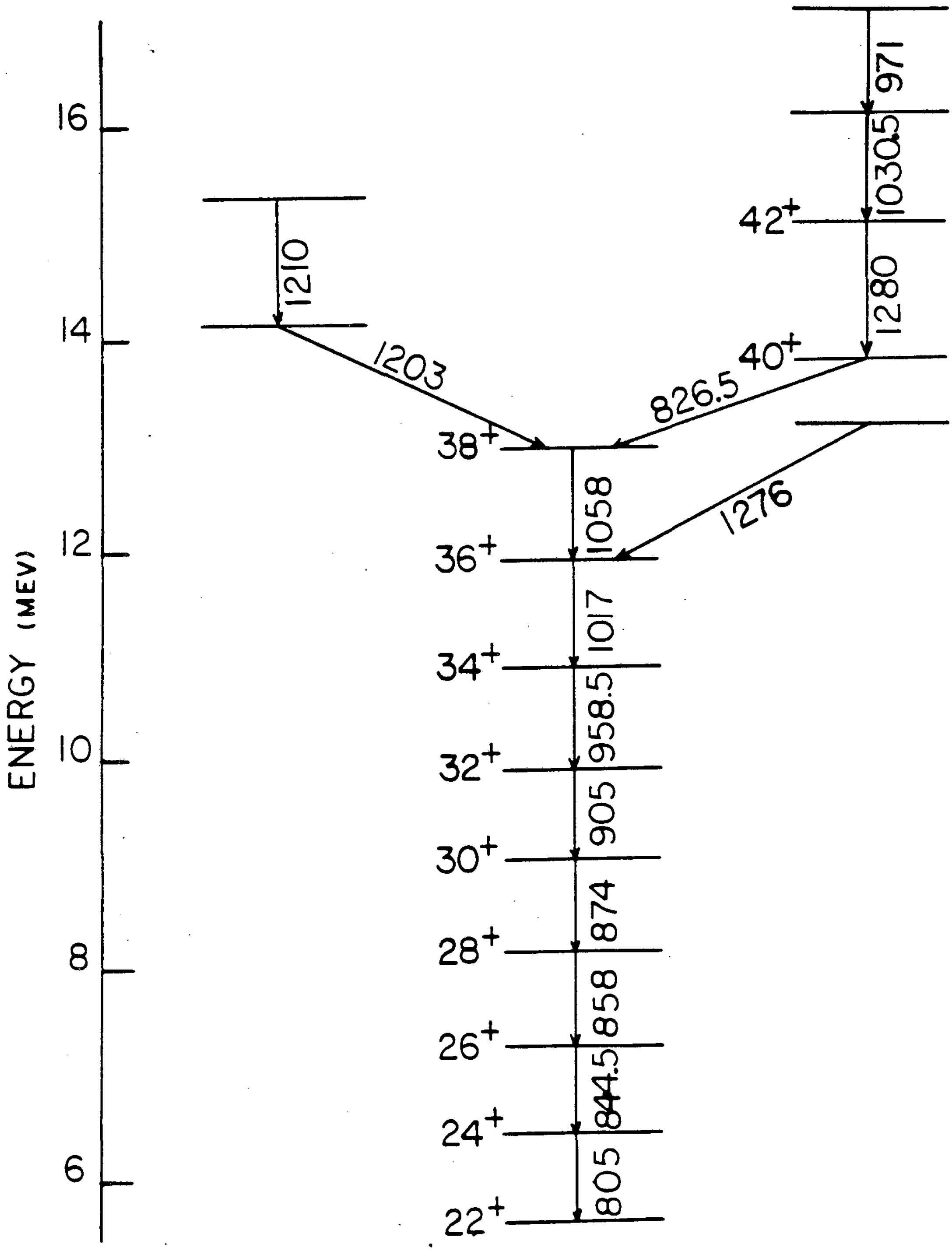


Fig. 2

XBL 855-2514



XBL 855-2513

Fig. 3

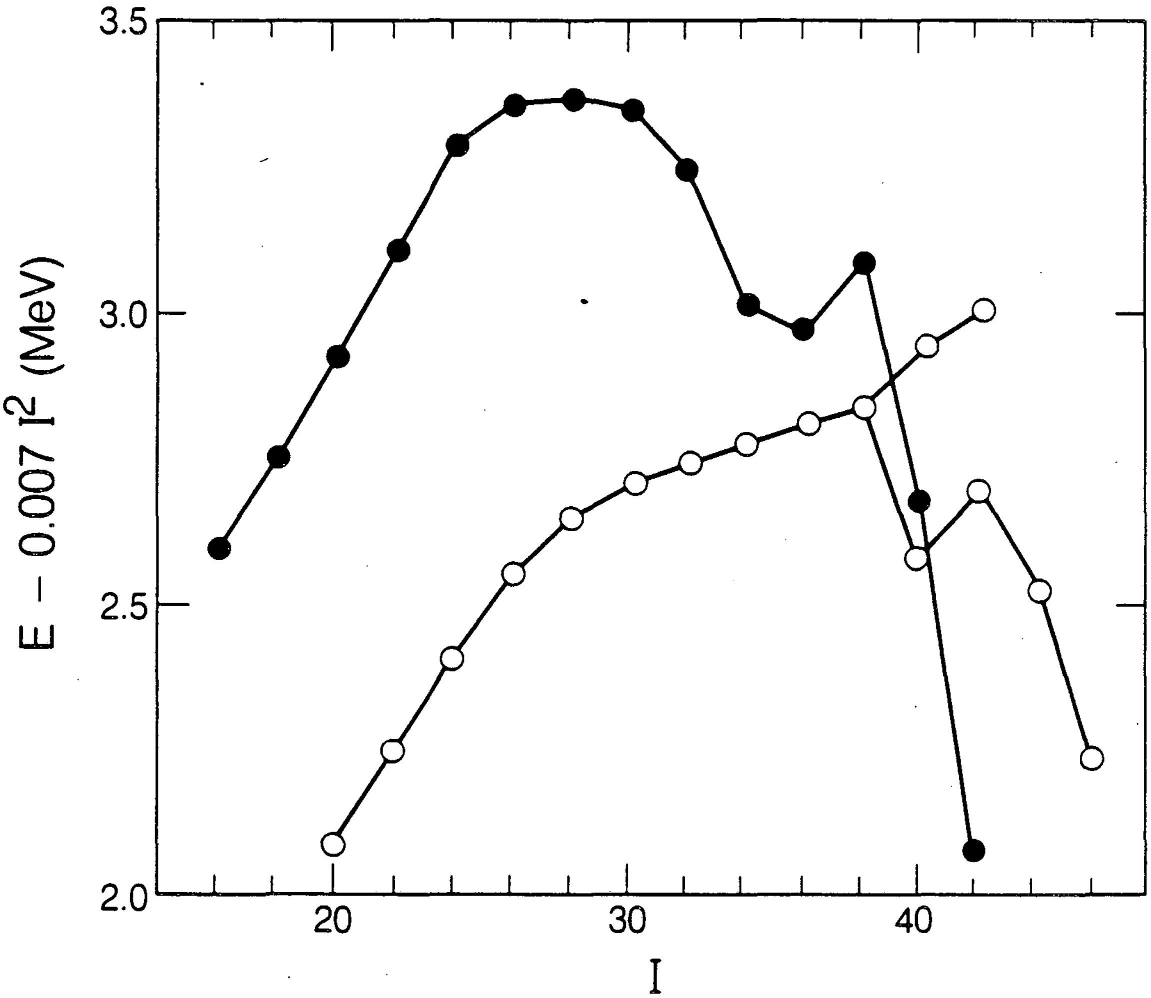


Fig. 4

XBL 858-8949