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THE FISSION OF ^{238}U FOLLOWING INELASTIC SCATTERING OF ^{6}Li

A. C. Shotter, C. K. Gelbke, T. C. Awes, B. B. Back,
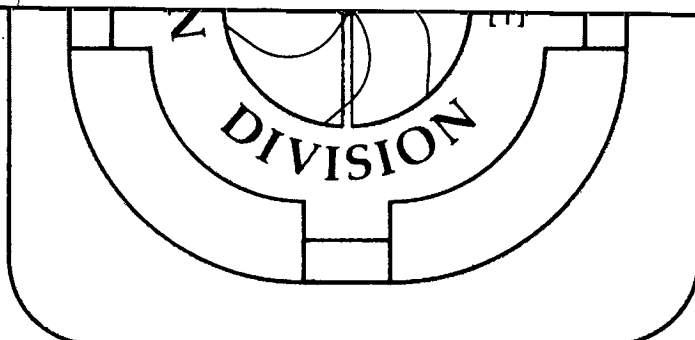J. Mahoney, T. J. M. Symons and D. K. Scott

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DISCLAIMER

OBSERVATION OF ISOSCALAR GIANT RESONANCE STRUCTURE IN THE FISSION OF ^{238}U FOLLOWING INELASTIC SCATTERING OF ^{6}Li[*]

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Abstract:

Resonance structures are observed in the region of
the isoscalar giant quadrupole resonance for the reaction
$^{238}U(^{6}Li, ^{6}Li',f)$ at 150 MeV. The ratio between the fission
probabilities for resonance to compound nucleus components
appears to be greater than the recently reported value from
(α,α') scattering.

Several experiments have been undertaken to investigate the decay
modes of the isoscalar giant quadrupole resonance in the actinide nuclei.
Electron scattering and photo absorption have provided indirect evidence
that the fission probability for the quadrupole resonance is greater than
for the dipole resonance.[1] A recent study[2] of the ($\alpha,\alpha'f$) reaction on ^{232}Th
and ^{238}U targets arrived at the conclusion that the fission decay of the
giant quadrupole resonance is inhibited by at least a factor of five as
compared to the fission decay of the continuum since no resonance
structure was observed in this channel. We report here the
measurement of the fission decay of ^{238}U induced by the inelastic
scattering of ^{6}Li where clear resonance structure is observed in the
fission channel.

Self-supporting metallic ^{238}U targets of 0.5 mg/cm^2 thickness were
bombarded with 150 MeV ^{6}Li^{3+} ions from the 88-Inch Cyclotron of the Lawrence
Berkeley Laboratory. The experiment was performed in two parts. First,
singles spectra of inelastically scattered ^{6}Li nuclei were measured with
a magnetic spectrograph; this avoids the background problems
due to nuclear reactions in solid state detectors.
Second, inelastic ^{6}Li spectra corresponding to coincidences between ^{6}Li
nuclei and fission fragments were measured with the experimental arrangement
shown in fig. 1. The fission fragments were detected with large area
parallel plate proportional detectors A, B and the ^{6}Li nuclei were detected
with a solid state telescope placed either in (I) or out (O) of the
horizontal plane. Solid state detectors could be used for this part of
the experiment since the coincidence requirement considerably reduces the
background.

An example of a singles [6]Li spectrum taken at 16° with the magnetic spectrograph is shown in fig. 2; the contributions from carbon and oxygen were measured in separate experiments and have been subtracted in fig. 2. It was discovered that the shape of the energy spectrum did not change significantly over the range of angles subtended by the solid state tele- scope used for the coincidence experiment. The spectrum shows a clear giant resonant structure centered around 10.5 MeV with a F.W.H.M. width of 7 MeV. The peak of this structure is close to the value of $63\,A^{-1/3}$ expected for the isoscaler giant quadrupole resonance. However, the width of this structure is considerably broader than expected for the giant quadrupole resonance, which may indicate that several different multipolarities contribute to the observed structure.[3,4]

Energy spectra of inelastically scattered [6]Li nuclei observed in coincidence with fission fragments are shown in fig. 3 for various detector geometries (for notation, the symbol A·$\overline{B}$ denotes an event in detector A and no event in detector B; see also fig. 1). The sharp peak observed at 6.1 MeV is due to the fact that the neutron channel opens up at an excita- tion energy only slightly higher than the fission barrier. At the location of this peak the angular distribution of the fission fragments is highly anisotropic with respect to the recoil direction of the target nucleus,[5] whereas at higher excitation energies the angular distributions are nearly isotropic. This change in anisotropy is clearly evident from the figure if one notes that, for the in-plane geometry, the detector combination A·$\overline{B}$ selects events close to the recoil axis, whereas the combinations B·A and B·$\overline{A}$ correspond to fission fragments emitted at increasing angles with respect to the recoil direction (the mean value of this angle for each detector configuration is shown in the figure). The rise in the fission yields at

about 12 and 17 MeV excitation energies corresponds to second and third

chance fission, i.e. fission after the evaporation of one and two

neutrons, respectively; in fig. 3, arrows mark the predicted thresholds.

The structure located around 9.5 MeV between the first and second chance

peaks has not been previously observed. Due to the large anisotropy of

the fission fragment angular distribution close to the fission barrier,

this structure is difficult to identify if fission fragments are detected

close to the recoil direction of the target nucleus (see fig. 3a).

It is most unlikely that this structure could be due to excited states

of ^{6}Li, since the only possible candidate is the T=1 state at 3.56 MeV

which will only be weakly excited since this involves an isospin flip.

The coincidence spectrum corresponding to the sum of all

out-of-plane data and the in-plane data for the combination $B \cdot \bar{A}$ is shown

in fig. 4a. For comparison, the solid curve shown in this figure repre-

sents the singles spectrum shown in fig. 2. Clearly, a one-to-one

correspondence cannot be established between the spectral shapes in the

energy region around 10 MeV, since the structure in the coincidence

spectrum peaks at a lower excitation energy with a narrower width than the

structure observed in the singles spectrum. This difference becomes more

apparent in fig. 4b which shows the ratio of these coincidence and

singles spectra. The ratio varies strongly as a function of excitation

energy of the ^{238}U target nucleus.

An attempt to extract relative fission probabilities from our

measurements is presented in fig. 4c. The data points of this figure were

derived from those of fig. 4b by applying corrections to take account of

the incomplete angular range of the fission detectors used to measure

the coincidence spectrum fig. 4a. These corrections have been performed by

assuming fission angular distributions similar to those of ref. 5; they

are of the order of 60% at the fission threshold and smaller than 10%

above 9 MeV excitation energy. Also in fig. 4c, the fission probabilities

for ^{238}U deduced[6,7] from the reactions ^{236}U(t,pf) and ^{238}U(γ,f) are shown

as solid lines. Our data points in this figure have been normalized at

6.1 MeV to the (t,p) data; this is done for diagramatic comparison

purposes only and cannot be considered as a reliable normalisation.

From our experiment

we cannot estimate the fission probability from our experiments to better

than 50%. This large uncertainty arises from the difficulties in normal-

izing data from two experiments using completely different techniques, in

particular the tight geometry of the coincidence experiment combined with

the rather steep angular distributions means the normalization is very

sensitive to small variations of beam spot position.

It is evident that the energy dependence of the fission probabil-

ities for the charged particle induced fission is very similar below about

8.5 MeV. Unfortunately, no data on charged particle induced fission of ^{238}U

are published for excitation energies above this energy. It should, however,

be noted that the rise of the fission probability in the region of the

second and third chance fission is very similar for the ^{6}Li-induced reaction

and the photo-fission.

The results from this experiment are different from those obtained using the (α,α') reaction reported in ref. 2, since clear resonant structures are observed in the present coincidence spectra. It is not clear whether this difference could be due to the excitation of different states in the two reactions, or due to the detection of fission fragments preferentially in the recoil direction of the target nucleus reported in ref. 2, where structure may be obscured by the strong peak at the fission threshold. The absence of resonance structure reported in ref. 2. leads to the conclusion that the fission probability of the giant quadrupole resonance is smaller by at least a factor of 5 compared to that of the continuum. From our data we feel we cannot deduce the fission probability with any confidence because the identification of resonance and background is highly uncertain for the coincidence spectrum. Nevertheless by adopting the extreme simplification of defining a smooth background (see dashed lines in . fig. 4a) we find that the resonant structure observed in the coincidence spectra has to be associated with an integral fission probability of at least half the value of the fission probability of the underlying continuum. This value was deduced by taking a ratio of areas above and below the dashed lines in fig. 4a. for the singles and coincidence spectra. It should be kept in mind, however, that such a choice of background for the coincidence spectrum would mean that the ratio of the fission probabilities between the resonance structure and background would vary between 1.3 to 0. for the energy range 7.5 to 11.5

MeV, and be 0 for the remaining resonace region between 11.5 and 17.5 MeV, which is clearly unreasonable. We therefore, feel that this simple choice of background for the coincidence spectrum represents an upper limit and, consequently, the quoted ratios of fission probabilities should be taken as lower limits, with the probable values being considerably above these limits. The division between resonance and compound nucleus contributions is therefore likely to be lower than drawn in Fig. 4a, and so would lead to a higher value than 1/2 quoted above for the ratio between fission probabilities for the resonance to compound nucleus components.

The fission probability varies strongly over the energy region of the resonance structure observed in the singles spectra. For excitation energies above about 13 MeV this energy dependence is mainly due to the occurence of second and third chance fission. Additional structure might be caused by the contribution of several multipolarities[3,4] to the resonanct structure and the splitting of the quadrupole resonance[8] into its K = 0, 1 and 2 components. It is possible that different fission probabilities have to be associated with these various contributions. To pursue further this interesting question it will be necessary to compare directly, the fission probabilities for a reaction condition in which the resonance is strongly excited with a reaction condition where it is only weakly excited over an extended energy range.

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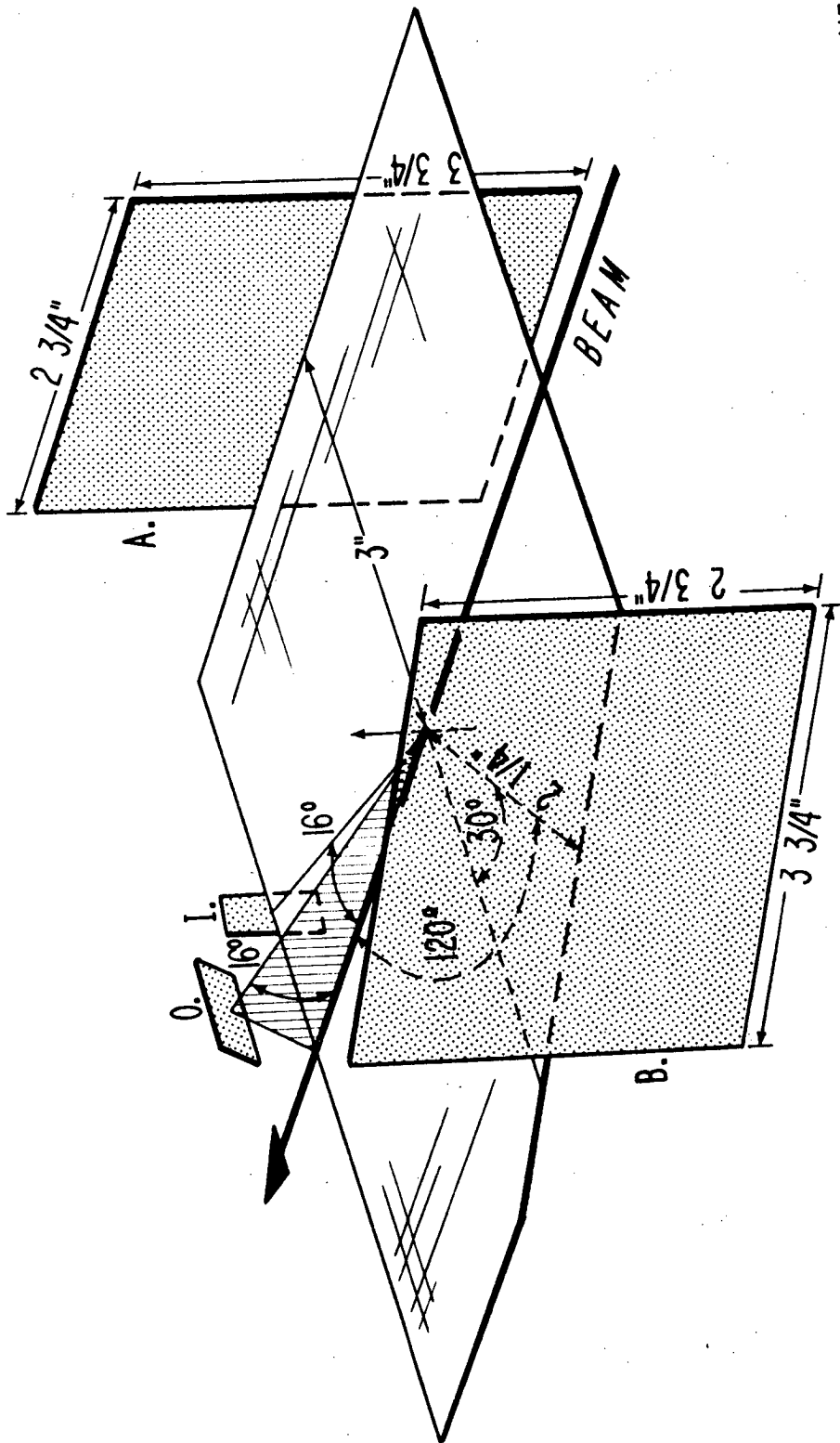
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FIGURE CAPTIONS

Fig. 1. Experimental layout for the coincidence experiment.

Fig. 2. Energy spectrum measured by the magnetic spectrograph at a

scattering angle of 16°.

Fig. 3. Coincidence energy spectra for different detector configura-

tions. The notations "in" and "out" of plane, refer to the ^{6}Li tele-

scope (see fig. 1.). Θ_f is the mean angle between the recoiling ^{238}U

nucleus and the fission detector.

Fig. 4. Comparison between the singles and coincidence energy spectra.

Amended fig. 3. caption.

Coincidence energy spectra for different detector

configurations. a) Li telescope in plane, fission detector

configuration A·$\overline{B}$, which corresponds to a mean angle between

the recoiling ^{238}U nucleus and the fission detector, $\Theta_f \approx 0°$

(A and B refer to the fission detectors shown in fig. 1.).

b) Li telescope in plane; fission detector B·A, and $\Theta_f \approx 20°$.

c) Li telescope in plane; fission detector B·$\overline{A}$, and $\Theta_f \approx 65°$.

d) Li telescope out of plane, fission detector B, and

$\Theta_f \approx 90°$. e) Li telescope out of plane; fission detector A

and $\Theta_f \approx 90°$.

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Fig. 1

Fig. 2
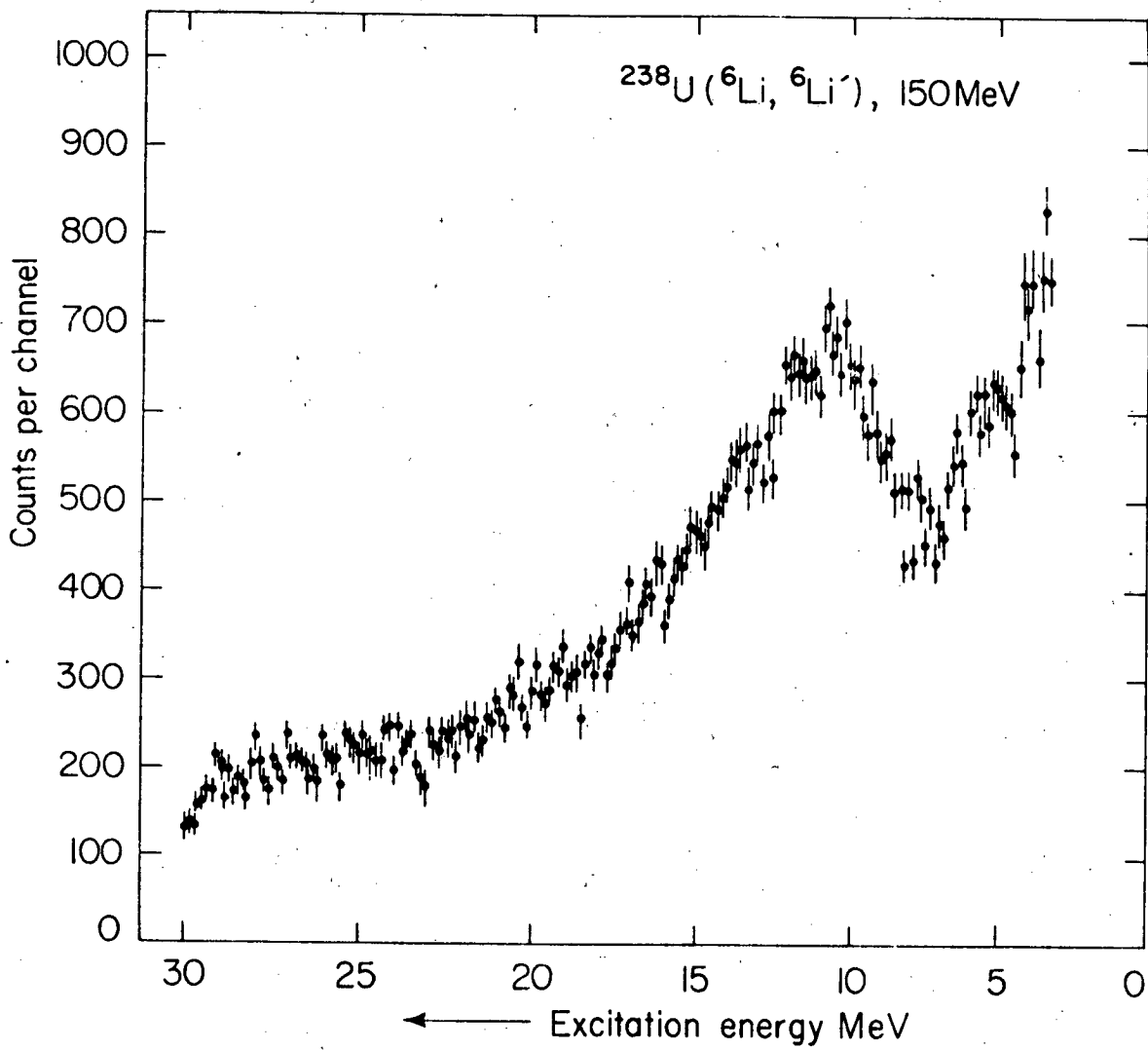
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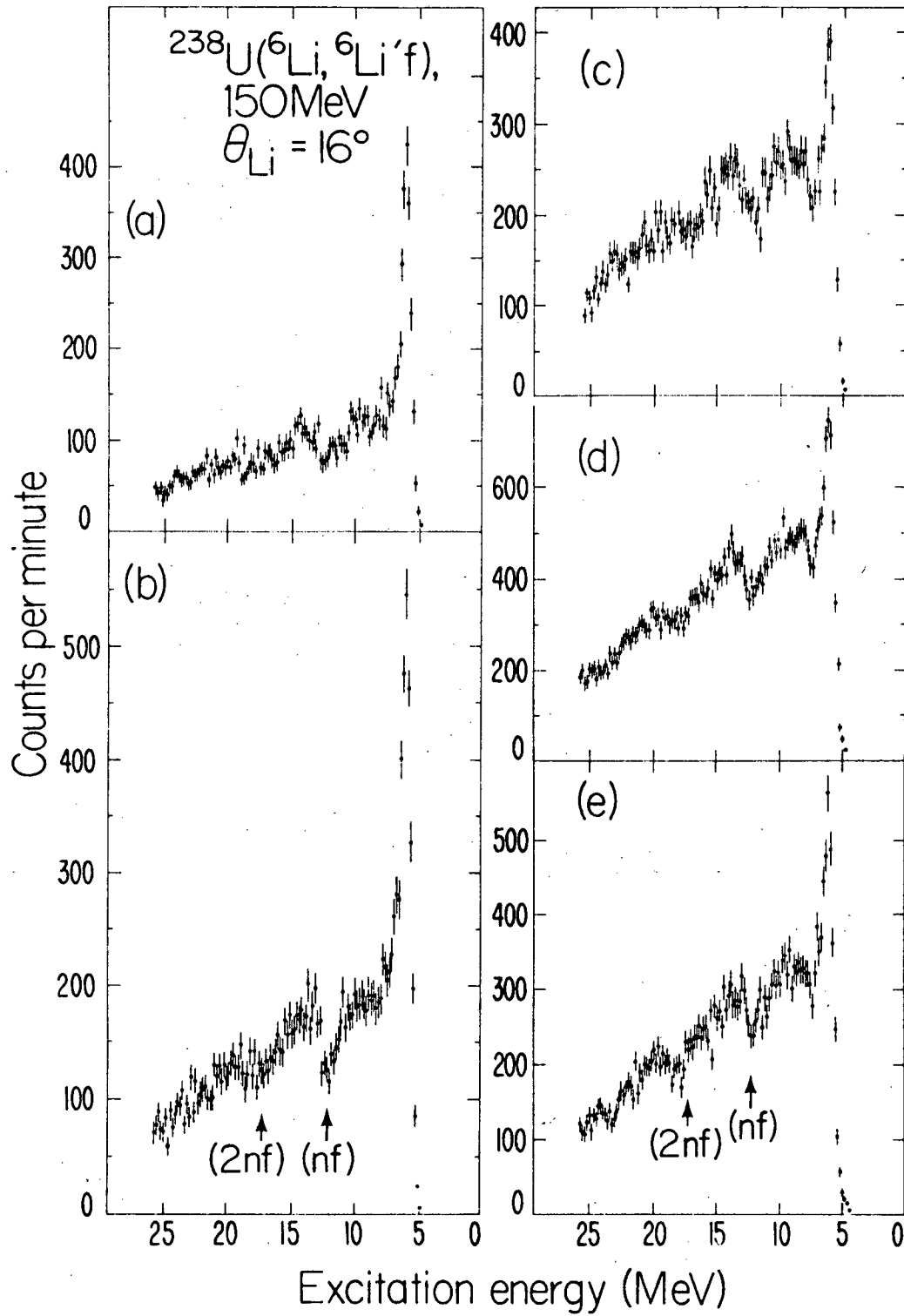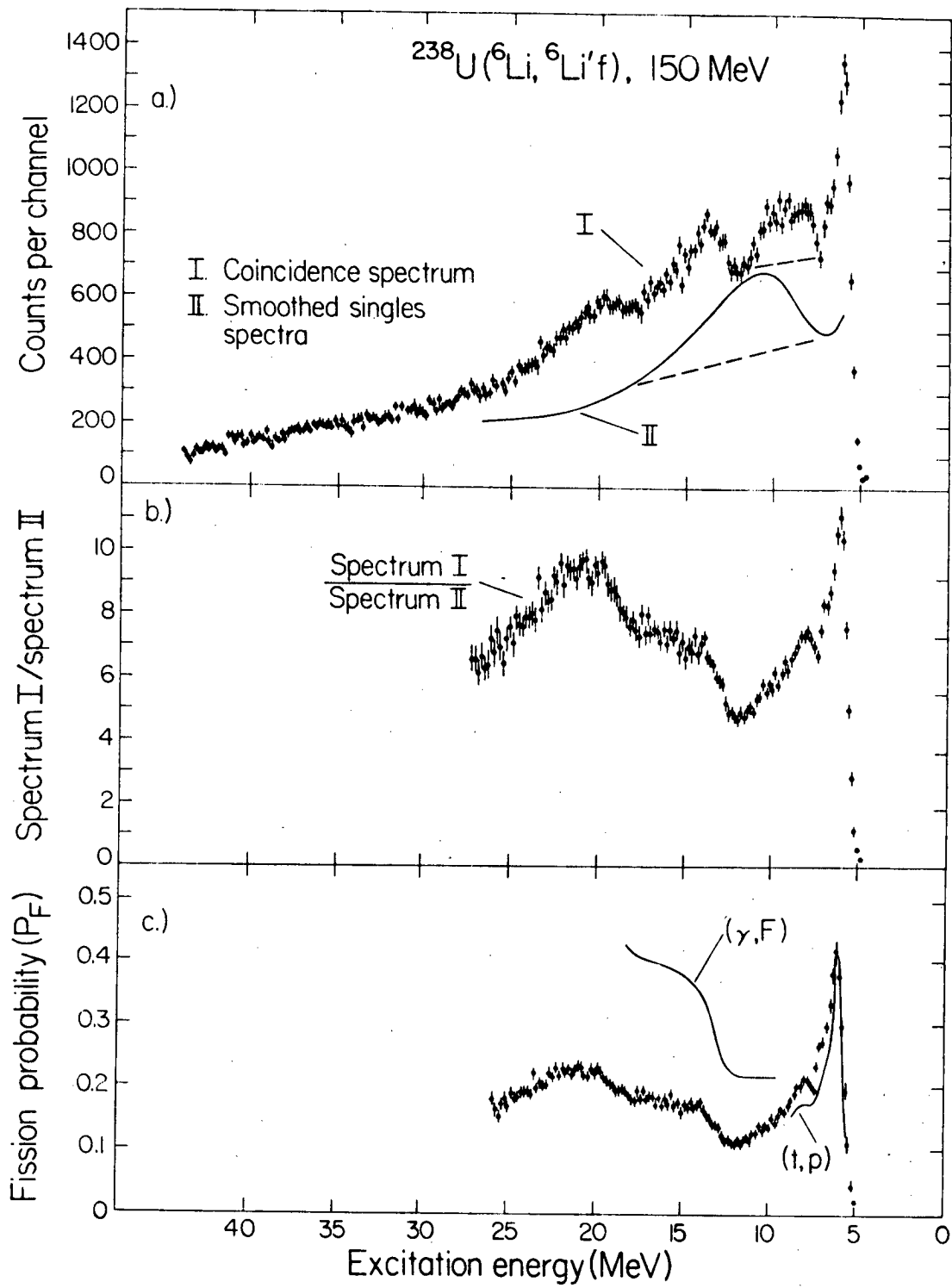Fig. 3

Fig. 4

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