Spinning out of Control: Exploring Angular Momentum in Nuclear Fission

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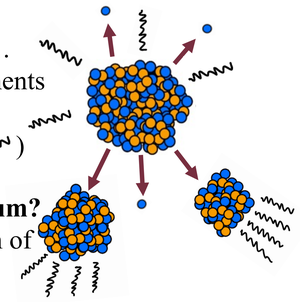
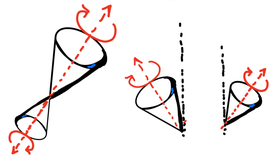
Background

What is Nuclear Fission?
Splitting of a nucleus into…
1. Two "Spinning" Fragments
2. 2-3 Neutrons ( )
3. Gamma Radiation ( )
4. & More!

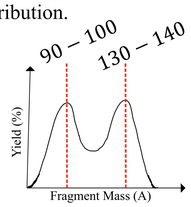


What is angular momentum?
1. A metric for the motion of spinning objects.
2. A conserved quantity!



LEFT: Spinning top analogy describing angular momentum of a fissioning system. BELOW: Generic fission fragment mass distribution.

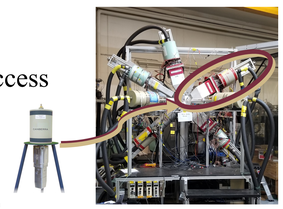
What's so interesting about fission?
1. "Two-hump" mass distribution.
2. Apparent lack of angular correlation between fission fragments[2].



Methods

Reaction of interest:
$^{209}_{83}\mathrm{Bi} + {}^{14}_{6}\mathrm{C} \longrightarrow {}^{223}_{89}\mathrm{Ac} \longrightarrow$ Fission

How are we studying it?
Gamma ray spectroscopy.
Gamma rays allow us to access level properties:
1. Excitation Energy
2. Angular Momentum



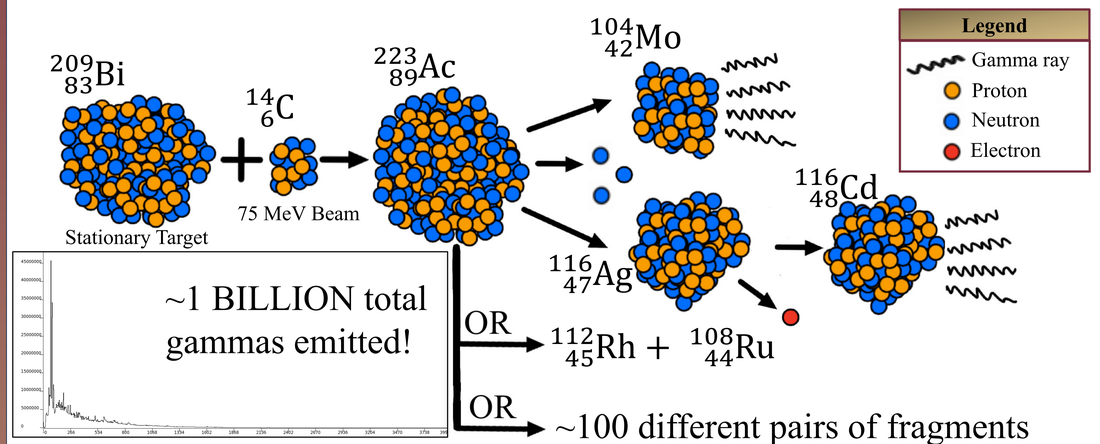
ABOVE: Gamma-ray Array @ FSU's John D. Fox Laboratory.

How are the gamma rays detected?
Arrangement of 7 single- crystal and 3 Clover™ Germanium detectors.

Gamma Ray Energy → Energy Spectrum → Fission Fragment Mass

Gamma Ray Momentum → Angular Correlations → Fission Fragment Momentum

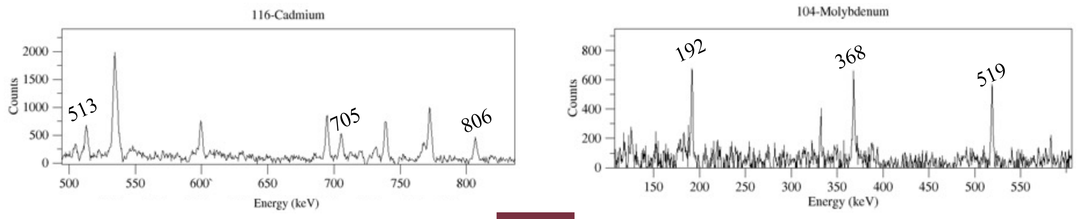
Findings



ABOVE: Counts vs. Energy (keV) gamma ray spectrum for all gamma rays emitted by the $^{209}_{83}\mathrm{Bi} + {}^{14}_{6}\mathrm{C} \longrightarrow {}^{223}_{89}\mathrm{Ac} \longrightarrow$ Fission system.

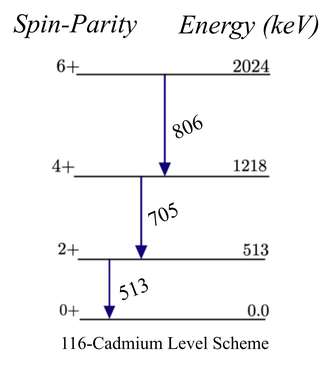
Create a gamma-gamma "coincidence" spectrum

"Coincident" gammas
=
Emitted within same 10^{-6} s
=
From the same fragment!



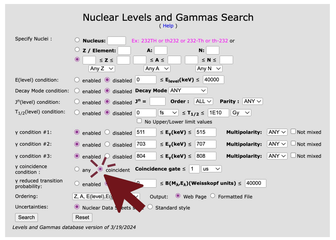
Translate coincident gammas to a characteristic level scheme

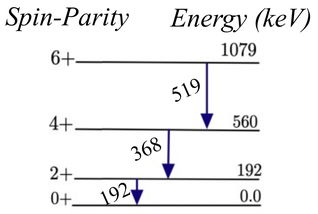
WWW.NNDC.BNL.GOV
Evaluated Nuclear Structure Data Files Library[1].



116-Cadmium Level Scheme

Gamma Ray
Energy Level

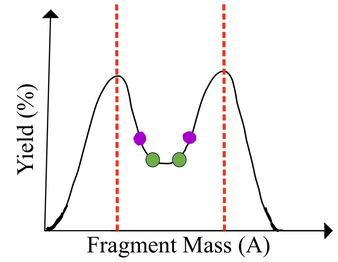




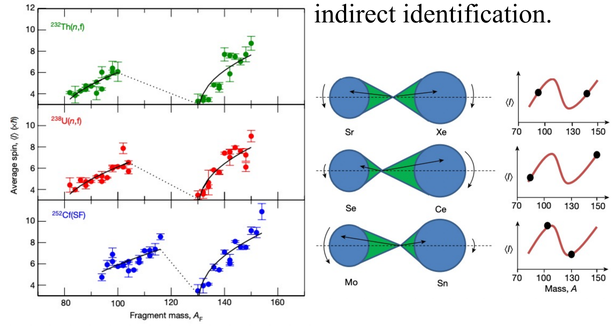
104-Molybdenum Level Scheme

Discussion

Goals:
1. Identify all fragment pairs to produce yield vs. fragment mass plot.
2. Develop familiarity with gamma-ray spectroscopy to apply to analysis of different reaction types.



Obstacle:
Fission fragments were not directly detected. Only gamma rays were used for indirect identification.



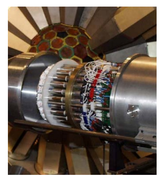
ABOVE LEFT: Average spin distribution vs. mass of fission fragments results from *Nature* article. RIGHT: Figure modeling torque of the fragments as the fission nucleus splits from *Nature* article. [2]

Next Steps

$^{252}_{98}\mathrm{Cf} \longrightarrow$ Spontaneous Fission!

Why study spontaneous fission?
Spontaneous fission systems have no energy or angular momentum contribution from an incident particle.
RIGHT: Gammasphere + HERCULES at Argonne National Laboratory used to collect fission fragment and gamma-ray data.

IDEA Grants



[1] National Nuclear Data Center, https://www.nndc.bnl.gov/nudat/ [2] Wilson, J.N., Thisse, D., Lebois, M. *et al.* Angular momentum generation in nuclear fission. *Nature* **590**, 566–570 (2021). https://doi.org/10.1038/s41586-021-03304-w