Light nuclides observed in the fission and fragmentation of $^{238}$U

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OUTLOOK

1) Experiment: $^{238}$U $\rightarrow$ p + Ti at 1 A·GeV

2) The tool: the FRS at GSI

3) Four new (preliminary) results:

Fission of $^{238}$U in $^{238}$U $\rightarrow$ p
- extremes of fission

Fragmentation of $^{238}$U in $^{238}$U $\rightarrow$ Ti
- velocity of the light residues
- N/Z of the light residues
- even-odd structure in N=Z nuclei
THE EXPERIMENT: 1 A·GeV $^{238}$U $\rightarrow$ H$_2$

AIM: to measure the formation cross sections of residues in the reaction $p + ^{238}$U at 1 GeV.

Advantages of the inverse kinematics:
- complete identification
- knowledge of the kinematics

Disadvantage:
- I need a H$_2$ target

So, actually I have to perform two experiments:

Where can I perform such experiments?

I need 1 A·GeV $^{238}$U beam
- a recoil separator
THE FRAGMENT SEPARATOR AT GSI

- identification of Z from IC: \( \Delta E \propto Z^2 \)

- identification of A/Z from time and position:

\[
\frac{A}{Z} = \frac{m_0}{e} \frac{B\rho}{c\beta\gamma}
\]

\( \beta = \frac{v}{c} \) with \( v = \frac{s}{ToF} \)

- once nuclides are identified (i.e. A and Z are integer numbers), velocity is calculated from \( B\rho \):

\[
\gamma v = B\rho \frac{Z \cdot e}{A \cdot m_0}
\]

very precise evaluation!
FEATURES OF THE FRS

- full identification \((A, Z)\)

- **absolute velocity** - extremely precise (from \(B\rho\); \(B\rho\) resolution \(\sim 3 \cdot 10^{-4}\))

NO SUCH AN ACCURATE INFORMATION BEFORE!

- limited acceptance in magnetic rigidity: needs to combine several \(B\rho\) settings to cover all \(A/Z\) and velocities,

- limited angular acceptance: only a part of the real production is measured.
OUR DATA: 1 A GeV $^{238}$U \rightarrow H_2 ( + Ti )

A, Z, $\nu$ \rightarrow VELOCITY SPECTRUM FOR EVERY ISOTOPE

All isotopes of one element: potassium

What do we learn from these pictures?
REACTION MECHANISM

- Fission due to the interaction with $H$
- Fragmentation due to the interaction with $Ti$

238U + $p$ → fission

238U + Ti → fragmentation

$^{238}\text{U}$

$^{42}\text{K}$

$v_{\text{long}}$

Beam frame

Lab. frame

$V_{\text{transv}}$

$V_{\text{transv}}$

$V_{\text{long}}$

FISSION

FRAGMENTATION

Fission due to the interaction with $H$

Fragmentation due to the interaction with $Ti$
1\textsuperscript{st} RESULT: $^{238}\text{U} + p$ (fission)
Extremely asymmetric fission

Lines: calculated velocities of fission fragments from the compound nucleus $Z = 84, A = 214$

(*) H.-J. Kluge, ISOLDE user's guide, CERN 86-05 (1986)
2\textsuperscript{nd} RESULT: $^{238}\text{U} + \text{Ti}$ (fragmentation)

Velocity of light residues

symmetry line for fission products, i.e.
average velocity of the compound nucleus

Mean Velocity in Centre of Mass

Projectile = $^{238}\text{U}$ 1 A GeV

Primary BEAM

Ti target

Pb target
$3^{rd}$ RESULT: $^{238}\text{U} + \text{Ti}$ (fragmentation)

Mean N/Z of fragments

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**stability line**

EPAX, projectile = Au
EPAX, projectile = Fe

- 800 A·MeV Au + p
- 414 A·MeV Fe + p
- 750 A·MeV U + Pb
- 1000 A·MeV U + Pb
- 1000 A·MeV U + Ti
4\textsuperscript{th} RESULT: $^{238}\text{U} + \text{Ti}$ (fragmentation)
Even-odd structure in N=Z nuclei

\begin{itemize}
    \item \textbf{In contradiction to theoretical expectations:}
    \end{itemize}

"The combined pairing effects in binding energies and level densities cancel in such a way that evaporation cross sections become approximately independent of pairing effects"

(T. Ericson, Advances in Physics 9 (1960) page 471)
Conclusions

LIGHT NUCLIDES FROM 1 A·GeV $^{238}$U + p and Ti

The apparatus:
FRS allows full (A, Z) identification and very precise determination of the velocity of produced residues

→ formation cross section for every isotope, with its velocity distribution

Four new aspects of the physics of the two reactions:

$^{238}$U + p
- extremely asymmetric fission (down to $Z_{\text{frag}}=10$)

$^{238}$U + Ti
- acceleration of light residues
- deviation of the N/Z of fragments from the asymptotic value
- unexplained even-odd structure in N=Z nuclei