Inelastic scattering of fast neutrons from excited states in $^{56}$Fe

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Setup at nELBE

- Target: cylinder of natural iron diameter 20 mm, thickness 8 mm
- HPGe detector at 125° to the neutron beam and a distance of 20 cm from the target
- Time difference between accelerator pulse and signal of the HPGe detector
  \( \Rightarrow \) time-of-flight of the incident neutrons
  \( \Rightarrow \) time resolution 10 ns
Neutron-scattering cross section

\[ \sigma = \frac{N_\gamma(E_n)}{\varepsilon_\gamma \Delta E_n} \cdot \left[ \frac{\Phi(E_n)}{\Delta E_\Phi} N_{at} \right]^{-1}. \]

\( N_\gamma(E_n) \) – number of events in the \( \gamma \) peak observed at a neutron energy \( E_n \).
\( \varepsilon_\gamma \) – efficiency of the HPGGe detector.
\( \Delta E_n \) – energy-bin width deduced from the gate width in the time-of-flight spectrum.
\( \Phi(E_n) \) – neutron fluence (time integral over the neutron-flux density) at \( E_n \).
\( \Delta E_\Phi \) – energy-bin width of the neutron fluence.
\( N_{at} \) – number of atoms per target area.
Excited states in $^{56}$Fe
Gamma-ray spectra at various neutron energies

\[ E_n = 8.168 \text{ MeV} \]
\[ E_n = 4.818 \text{ MeV} \]
\[ E_n = 1.472 \text{ MeV} \]
Cross section for inelastic scattering from $^{56}$Fe

$E_r = 847$ keV
Cross section for inelastic scattering from $^{56}\text{Fe}$
Cross section for inelastic scattering from $^{56}$Fe

![Graph showing cross section for inelastic scattering from $^{56}$Fe]
Cross section for inelastic scattering from $^{56}$Fe

Cross section for inelastic scattering from $^{56}$Fe

$E_\gamma = 1238$ keV

$^{56}$Fe(n,n')

$E_n$ (MeV) vs. $\sigma$ (b)
Cross section for inelastic scattering from $^{56}$Fe

![Graph showing inelastic scattering cross section for $^{56}$Fe](image)

$^{56}$Fe(n,n')

- $E_\gamma = 1238$ keV
- $E_\gamma = 1038$ keV
- $E_\gamma = 1303$ keV

$E_n$ (MeV) vs $\sigma$ (b)
Cross section for inelastic scattering from $^{56}$Fe

$^{56}$Fe(n,n')

$E_\gamma = 1238$ keV

$4^+_1$ state

Cross section for inelastic scattering from $^{56}$Fe
Cross section for inelastic scattering from $^{56}$Fe

$^{56}$Fe(n,n')

$2^+_1$ state

$4^+_1$ state

$6^+_1$ state

$E_n$ (MeV)

$\sigma$ (b)
Cross section for inelastic scattering from $^{56}$Fe

![Graph showing cross section for inelastic scattering from $^{56}$Fe vs. neutron energy $E_n$ (MeV). The graph includes data points for $^{56}$Fe(n,n$'$) with a $2^+_1$ state, and a plastic neutron detector and HPGe $\gamma$-ray detector.]
Cross section for inelastic scattering from $^{56}\text{Fe}$

$^{56}\text{Fe}(n,n')$

$2^+_1$ state

HPGe $\gamma$-ray detector

plastic neutron detector

$\sigma$ (b)

$E_n$ (MeV)
Multiple inelastic scattering from $^{56}\text{Fe}$

Excitation of $2^+$ states in two $^{56}\text{Fe}$ nuclei by one neutron and detection of the two 847 keV $\gamma$ rays at 125°.
Conclusions

- High-resolution measurement of $\gamma$ rays from states excited in inelastic neutron scattering.
- Determination of the cross section for individual excited states as a function of the neutron energy.
- Advantage of the measurement of $\gamma$ rays with an HPGe detector: measurement of the time-of-flight of the scattered neutrons not needed. Disadvantage: time resolution of 10 ns compared with 0.7 ns of the plastic scintillators used for the detection of scattered neutrons.
  ⇒ Fine structures of the cross sections may be washed out.