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Determination of fractional electron capture probabilities using Metallic Magnetic Calorimeters

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The measurements are the part of the European metrology research project MetroMMC, which started in 2018 for a duration of 3 years. This project concerns the development and use of MMC detectors and complementary detection techniques to understand the electron capture (EC) process in the decay and subsequent atomic relaxation processes in a few selected atomic nuclei. The goals of MetroMMC include:

- Measurement of fractional electron capture probabilities and absolute X-ray emission intensities.
- To improve theoretical models and calculations of the electron capture process and subsequent atomic relaxation.
- Validation of the theoretical data with the high-precision experimental data from this project.
- Six radionuclides that decay by EC have been selected for measurement within the project: Ca-41, Mn-54, Ni-59, Zn-65, Cd-109 and I-125.

- Low temperature energy dispersive cryogenic detectors.
- Measurement of energy of individual particles in the form of temperature change.
- Use of magnetization of paramagnetic sensor to monitor the temperature.
- Metallic host material for paramagnetic thermometer (Ag:Er).
- Nobel metals as absorber material (Au/Ag).
- High detection efficiency as the source is embedded in between two absorber halves resulting in 4π detection geometry.
- Low energy threshold and high energy resolution.

Metallic Magnetic Calorimeters (MMCs)

Fig.1: General working principle

Fig.2: Detector Holder

Fig.3: MMC and SQUID chips

Measurement of fractional electron capture probabilities for I-125

- It is of particular interest due to its use in nuclear medicine, target imaging and brachytherapy, → explicit knowledge about the decay data is necessary.
- It has a 100% electron capture decay via the first excited state of Te-125.
- Due to the 4π detection geometry, the binding energy of the captured electron released in the atomic rearrangement is integrated with the 35.49 γ de-excitation energy in the detector.

Source & Absorber Preparation:

Fig.1: PENELOPE simulated absorber-source geometry.

Fig.4: Autoradiographic image. The area from which source of required activity was taken.

Fig.5: Two absorber halves with the source in the middle.

Fig.6: Source placed on one half of absorber.

Fig.7: Absorber on M size MMC chip i.e. optimized for C_{abs} = 0.11 nJ/K.

- The source quality was further enhanced by repeated folding, laminating and annealing of the silver foil thus incorporating the I-125 in the volume.
- Direct diffusion welding of Ag on Au difficult → an intermediate Ag-Au alloy layer was used to bond the Ag source foil to the Au absorber material.

Total emission spectrum of I-125

Preliminary results: Peak area ratios corresponds to the fractional capture probabilities.

$P_L/P_K = 0.24109 (0.029)$, $P_M/P_K = 0.05779 (0.012)$, $P_N/P_K = 0.01462 (0.004)$
 $P_M/P_L = 0.23972 (0.403)$, $P_N/P_M = 0.25303 (0.311)$

The quoted uncertainties are composed of the statistical uncertainties related to the peak areas and an estimation of the uncertainty due to the data analysis including peak fitting.

Peaks	Energy (keV)
L ₁ without γ	4.97
Ag K _α esc. (γ+L)	15.51
Ag K _α esc. (γ+K)	18.31
K without γ	31.89
γ+N	35.78
γ+M	36.61
γ+L	40.55
Ag K _α esc. (γ+K)	42.60
Ag K _α esc. (γ+L)	45.31
γ+K	67.56

¹²⁵I characteristics:

- T_{1/2} = 59.38 days
- Allowed transition

Detector characteristics:

- Embedded source activity ~ 4 Bq
- Au absorber dimensions = (620 × 620 × 149) μm³
- Source dimensions = (260 × 260 × 6) μm³
- C_{abs} = 0.155 nJ/K at 20 mK

Mn-54 Electron Capture measurement

⁵⁴Mn decays by electron capture via an excited state (+2) of ⁵⁴Cr, which de-excites by the emission of a 835 keV γ to ⁵⁴Cr (+0). T_{1/2} = 312.19 d. It is used as an energy calibration source.

Source Preparation:

- Deposition by means of a micro-drop dispenser into gold nanofoam.
- Gold nanofoam made from Au-Ag alloy by wet chemical etching: 20% HNO₃, 55 °C, 2 h to remove Ag

Fig. 1: AgAu alloy foil diffusion welded (400 °C, 2 h) on Au foil.

Fig. 2: Some cracks present in Au nanofoam. Deposited source solution retracts into foam. No macroscopic crystallizations in the cracks.

Fig. 3: Absorbers glued on "XS" MMC chip, i.e. optimized for C_{abs} = 8 pJ/K @ 20 mK

Total emission spectrum of Mn-54

(Analysis ongoing)

M capture (80 eV)

L capture (700 eV)

K capture (6 keV)

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