L X-ray intensities of Np from ^{241}Am disintegration using a metallic magnetic calorimeter (MMC)

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Interest of ^{241}Am L X-ray intensities:

- ^{241}Am is widely used for efficiency calibration of semiconductor (SC) spectrometers (γ-ray at 59.5 keV and X-rays between 11 and 23 keV);
- L X-ray intensities are used to balance the nuclear decay scheme because numerous γ transitions are anomalous;
- X-ray intensities are important atomic fundamental parameters (FPs).

Difficulties to calculate the X-ray intensities:

X-ray emissions of ^{241}Am depend both on:
- Nuclear FPs (γ transition probabilities, ICCs);
- Atomic FPs (CK probabilities, ωL, transition rates).

However, ^{241}Am have many anomalous γ transitions and ICCs

Difficulties to measure these intensities:

Measured values of intensities with SC spectrometers:
- Their FWHM energy resolution is too large to separate the peaks lying between 11 and 23 keV,
- Their efficiency varies of ~ 10% between 11 and 23 keV.

➡ The use of ultra high energy resolution MMC will provide new data for radionuclide data evaluation, calculations and for users.

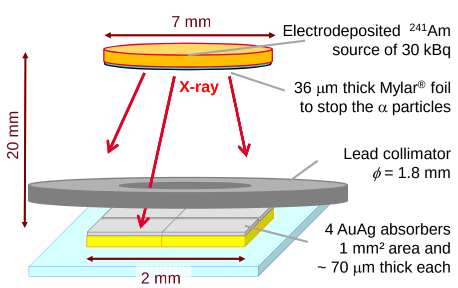
X-ray intensities by EDXRS with Metallic Magnetic Calorimeter (MMC)

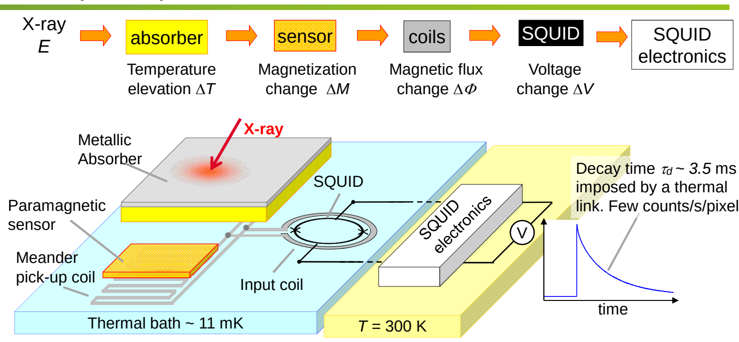
$$I(E) = \frac{N(E)}{\varepsilon_i(E)} \cdot \frac{I(\gamma)\cdot\varepsilon_i(\gamma)}{N(\gamma)}$$

I: Photon emission intensity
N: Number of counts in the full energy peak

ε_i: intrinsic detection efficiency (determined by Monte Carlo simulations)

γ: γ-ray at 59.54 keV is used as a reference line





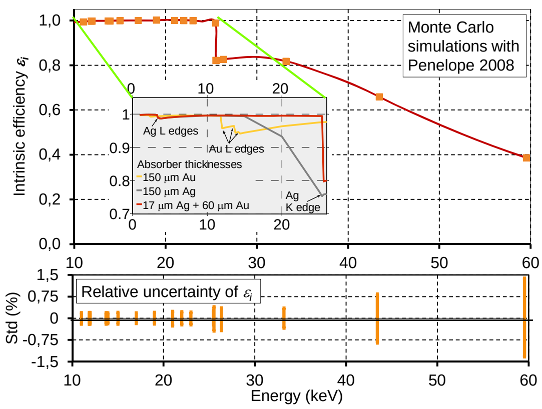
Energy resolution of MMCs

- Statistical fluctuations:
  - For SC spectrometers ~ 3 eV are required to create an electron-hole pair → FWHM ~120 eV at 6 keV.
  - For MMCs, only ~ 5 μeV are required to thermally excite a state. → energy resolution not limited by statistical fluctuations but by the signal/noise ratio.
- Signal : $\Delta V \propto \Delta T = \frac{E}{C(T)}$

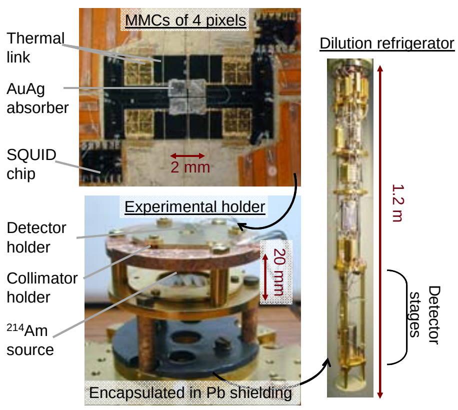
  →Low temperature *T* required < 50 mK to minimize the detector heat capacity *C*.
- Noise : $\text{Thermal noise} \propto \sqrt{4k_B \cdot T^2 \cdot C(T_0)}$; $\text{SQUID noise} \propto T$

→ At low temperature high energy resolution achievable (**ΔE_{FWHM} = 27 eV below 60 keV).**

Detection efficiency of AuAg Absorber

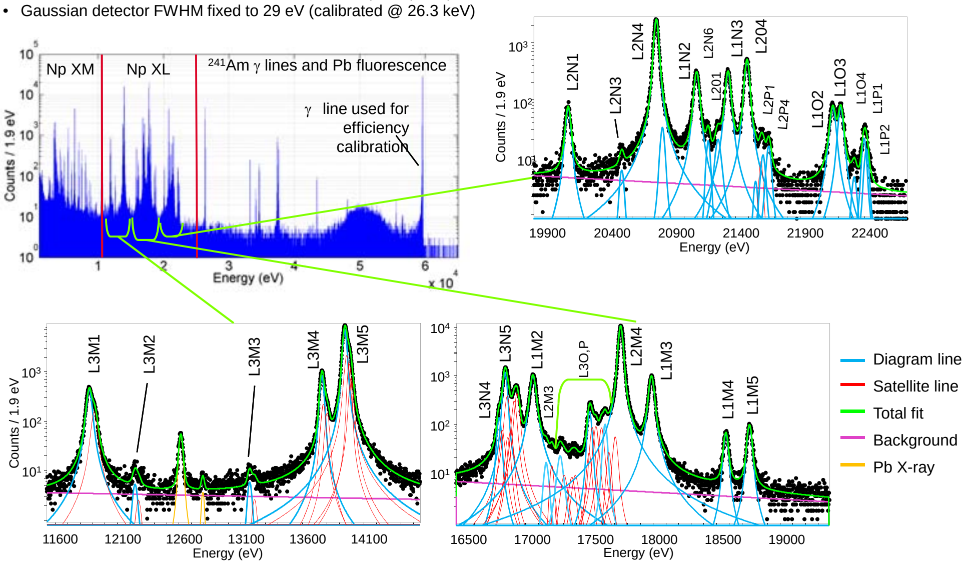


Experimental set-up



Energy spectrum analysis

- Full energy peaks fitted with Voigt functions.
- Lorentzian widths fixed with values from J.L. Campbell (2001).
- Gaussian detector FWHM fixed to 29 eV (calibrated @ 26.3 keV)



Results

X-ray Transition	Energy (eV)	Present work: Intrinsic Efficiency	Present work: I(E) (%)	Present work: I(E) (%) (sum)	M.C. Lépy measurement (2008): I(E) (%)	M.C. Lépy measurement (2008): I(E) (%) (sum)	E. Schönfeld calculation (2001): I(E) (%)
L3M1 (Ll)	11870.9	0.9964 (20)	**0.929 (14)**		**0.837 (9)**		**0.842 (27)**
L3M2	12242.0	0.9972 (20)	**0.0114 (5)**		**0.0260 (5)**		
L3M3	13171.7	0.9975 (20)	**0.01036 (40)**		**0.0199 (5)**		
L3M4 (Lα2)	13757.3	0.9977 (19)	**1.281 (20)**	**13.36 (22)**	**1.398 (15)**	**13.00 (13)**	**1.37 (5)**
L3M5 (Lα1)	13942.8	0.9973 (19)	**12.08 (20)**		**11.60 (12)**		**12.00 (40)**
L2M1 (Lη)	15858.5	0.9993 (20)	**0.393 (6)**		**0.404 (5)**		**0.383 (16)**
L3N1	16110.3	0.9994 (19)	**0.236 (5)**		**0.2480 (30)**		**0.218 (20)**
L3N4 (Lβ2)	16793.1	0.9999 (19)	**2.993 (40)**		**0.3390 (40)**	**2.790 (30)**	**2.93 (10)**
L3N5	16839.3				**2.451 (26)**		
L1M2 (Lβ4)	17058.7	0.9999 (19)	**1.596 (24)**		**1.736 (18)**		**1.74 (8)**
L2M3	17162.8	1.0000 (19)	**0.01952 (38)**	**0.627 (10)**			
L3N7	17207.0	1.0001 (19)	**0.0971 (22)**		**0.594 (6)**		
L3O1	17272.0	1.0001 (19)					**0.639 (20)**
L3O4…P5	17504.1	1.0003 (19)	**0.510 (8)**				
L2M4 (Lβ1)	17747.7	1.0005 (19)	**11.71 (18)**		**11.83 (12)**		**13.4 (6)**
L2M5	17936.0	1.0006 (19)	**0.01349 (32)**	**1.353 (20)**	**1.310 (13)**		**1.48 (7)**
L1M3 (Lβ3)	17989.6	1.0006 (19)	**1.340 (20)**				
L1M4	18574.3	1.0010 (20)	**0.0740 (11)**		**0.0540 (10)**		
L1M5	18759.9	1.0011 (20)	**0.1108 (17)**		**0.0470 (10)**		
L2N1	20099.0	1.0005 (22)	**0.0972 (15)**		**0.0870 (10)**		**0.106 (5)**
L2N3	20514.8	1.0002 (23)	**0.00697 (25)**				
L2N4 (Lγ1)	20783.1	1.0000 (23)	**2.844 (43)**		**2.940 (30)**		**3.19 (13)**
L2N5	20830.5	1.0000 (23)	**0.0365 (6)**		**0.467 (5)**		**0.481 (21)**
L1N2 (Lγ2)	21096.1	0.9998 (24)	**0.424 (6)**				
L2N6	21186.0	0.9998 (24)	**0.01892 (35)**				
L2O1	21262.3	0.9998 (23)	**0.0336 (6)**	**0.455 (6)**	**0.520 (6)**	**1.087 (12)**	**1.160 (40)**
L1N3	21339.9	0.9998 (23)	**0.421 (6)**				
L2O4	21487	0.9997 (23)	**0.615 (9)**		**0.567 (6)**		
L2O7,P1,N4,N5	21603.4	0.9997 (23)	**0.0448 (13)**				
L1O2	22152.9	0.9995 (23)	**0.1160 (18)**	**0.2187 (34)**	**0.1730 (20)**	**0.2420 (28)**	**0.236 (10)**
L1O3	22213.8	0.9994 (23)	**0.1027 (16)**				
L1O4,.5	22319.0	0.9993 (22)	**0.00600 (27)**	**0.0454 (25)**	**0.0690 (10)**		
L1P2	22395.1	0.9992 (22)	**0.0236 (13)**				
L1P3,.5	22413.5	0.9992 (22)	**0.0158 (13)**				

γ–ray transition	Energy (eV)	Intrinsic Efficiency	I(E) (%)	I(E) (%) [Nucleide database]
γ2-1	26344.6	0.8254 (29)	**2.384 (37)**	**2.31 (8)**
γ1-0	33196.7	0.8171 (29)	**0.1195 (19)**	**0.1215 (28)**
γ4-2	43418.3	0.658 (6)	**0.0664 (13)**	**0.0669 (29)**
γ6-4	55540.7	0.453 (5)	**0.0212 (9)**	**0.0181 (18)**
γ2-0	59540.9	0.385 (5)	**Reference line**	35.92 (17)

Uncertainties dominated by the absorber thickness uncertainties (required for the Monte Carlo simulation of the intrinsic detection efficiency) or by the counting statistics.

Conclusions

New intensities for 34 L X-ray transitions with a high energy resolution MMC:

→ Many peaks well separated
→ Satellite lines observed and analysed

→ Lower systematic errors due to the fitting procedure,
→ More confident data.