Study of L X-rays of bismuth induced by Pb-210 disintegration and by photoionization

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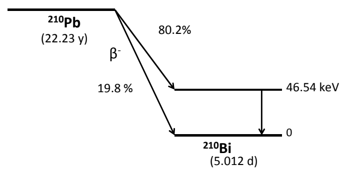
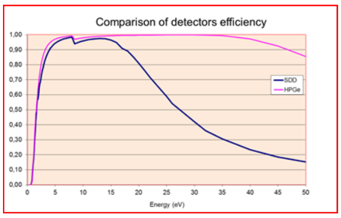
X-ray emission occurs consecutively to different ionization processes and the respective X-ray spectra have generally different shapes due to multiple ionizations introducing satellite lines: for L and higher shells, the relative X-ray intensities depend on the initial vacancies distribution between the sub-shells which itself depends on the ionization process. This study will give the opportunity to determine L fluorescence yields using two approaches and to examine the discrepancies observed in previous compilations, since methodological differences could be involved.

Bismuth X-rays: 2 ways of production

Radioactive decay:

^{210}Pb mainly disintegrates by beta minus emission to the excited level (46.34 keV) and to the ground state of ^{210}Bi.
The gamma transition between these two levels is highly converted in the L shell, thus leading to intense L X-rays.



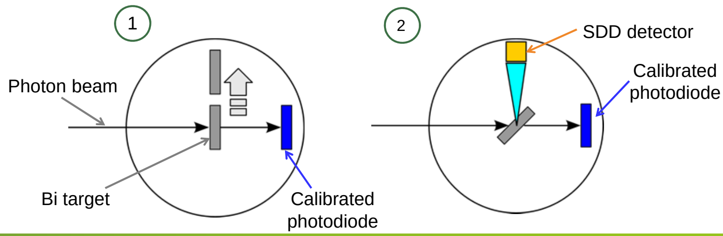


Radioactive point sources of ^{210}Pb were prepared and measured using accurately efficiency calibrated HPGe detector (FWHM = 115 eV at 5.9 keV).
Due to the high absorption coefficient of germanium, the detector efficiency remains high for both X- and gamma rays.

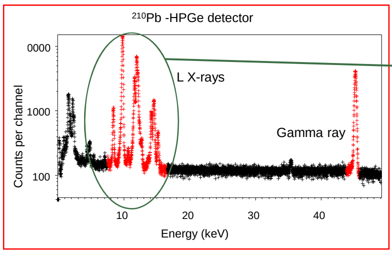
Photoionization on a pure Bi target:

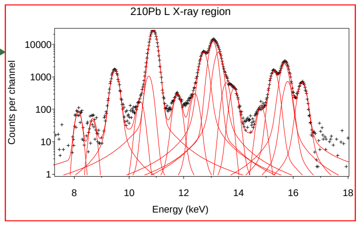
Highly pure monochromatic radiation is obtained with a double-crystal (Si 111) at the Metrology beamline of the synchrotron SOLEIL.
Measurement in two steps:

1. Transmission of the bismuth target measured under normal incidence using a calibrated photodiode.
2. The photon beam is incident at 45° on the bismuth target.
   The fluorescence spectrum is recorded by a silicon drift detector (SDD) (FWHM = 135 eV at 5.9 keV) installed at 45° from the target.
   The transmitted beam is simultaneously recorded by the photodiode, which provides the number of incident photons.



Radioactive decay





Spectrum processing using dedicated software (COLEGRAM), taking into account the detector response function and X-ray natural linewidths.

For each sub-shell, the partial L X-ray intensity ($I(X_i)$) is linked to the gamma-ray intensity ($I\gamma$), conversion coefficients (α_i), fluorescence yields (ω_i), and Coster Kronig transition probabilities (f_{ij}):

$$I(X_1) = I_\gamma \cdot \alpha_1 \cdot \omega_1$$

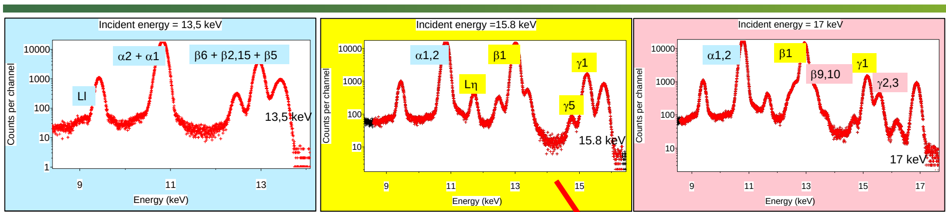
$$I(X_2) = I_\gamma \cdot (\alpha_2 + \alpha_1 \cdot f_{12}) \cdot \omega_2$$

$$I(X_3) = I_\gamma \cdot (\alpha_3 + \alpha_2 \cdot f_{23} + \alpha_1 (f_{13} + f_{12} \cdot f_{23})) \cdot \omega_3$$

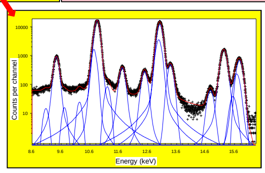
The L1 fluorescence yield can be directly derived, assuming α_1= 12.22 (18).
(Band et al., At. Data Nucl. Data Tables, 81, 1, 2002)

Preliminary result: ω_1= 0.114

Photoionization



Bi		L3	L2	L1
Z	Binding energy (keV)	13.4186	15.7111	16.3875
83	Natural width (eV)	6.27	6.22	12.3



Several incident energies have been used to successively ionize the three L sub-shells, making it possible to analyze the rearrangement spectra and to determine the X-ray intensities of the L1, L2 and L3 series.

For each group of lines, the partial fluorescence yield is:

$$\omega_i = \frac{4\pi}{\Omega} \frac{N_i}{\varepsilon_i} \frac{1}{I_p} \frac{1}{\tau_i} \frac{\mu_P + \mu_i}{1 - \exp(-(\mu_P + \mu_i) \cdot x)}$$

- N_i : counts in the group of peaks corresponding to L_i sub-shell
- ε_i : detection efficiency for L_i photons
- I_P : incident photon flux
- τ_i : ionization cross section in *i* sub-shell*
- μ_P and μ_i : mass attenuation coefficients* of Bi for the incident and the fluorescence energy
- x : target thickness
- Ω : detection solid angle

Preliminary results: ω_2= 0.388 and ω_3= 0.349

*XCOM database: *http://physics.nist.gov/PhysRefData/Xcom*

Work in progress

Next steps: Measurement of **Bi mass attenuation coefficients and ionization cross sections**.

Measurement of the ^{210}Pb radioactive source using a high-resolution cryogenic detector (magnetic metallic calorimeter). This cryogenic detector has an energy resolution (FWHM) of 30 eV across the whole energy range of analysis. Such a resolution allows the diagram and satellite lines to be clearly identified.
Finally X-ray intensities, L fluorescence yields and Coster Kronig transition probabilities should be derived with low associated uncertainties.

Acknowledgment

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