A Gas Proportional Scintillation Counter with Krypton filling

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Introduction - GPSC

- Number of primary electrons proportional to the energy of the incident radiation.
- Electroluminescence (EL): excitation by electron impact. Number of VUV photons proportional to the number of primary electrons.
- Pulse amplitude proportional to the energy of the incident radiation.

J. M. F. dos Santos et al., X-Ray Spectrometry, 30 (2001) 373-381.
Motivation

Noble Gases have high photoionization cross sections and high electroluminescence yields

- Higher density and atomic number
- Lower ionization and excitation energies

What about Krypton?

- Radioactive ($^{85}\text{Kr}$) → Additional background
- Less dense than Xenon
- More expensive than Argon
- Cheaper than Xenon
- Denser than Argon
- Higher absorption cross section for X-rays in the 14 to 34 keV range
- Better position resolution values for X-rays in the 14 to 34 keV range

However...

Motivation

Noble Gases have high photoionization cross sections and high electroluminescence yields

- Higher density and atomic number
- Lower ionization and excitation energies
- Higher natural abundance
- Lowest cost

What about Krypton?

- Radioactive ($^{85}$Kr) → Additional background
- Less dense than Xenon
- More expensive than Argon
- Cheaper than Xenon
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Motivation

What about Krypton? (part 2)

A simulation toolkit for electroluminescence assessment in rare event experiments (C.A.B. Oliveira et al., 2011)

- Electroluminescence Yield – $Y$: number of photons emitted per primary electron;
- For Xe and Ar the electroluminescence yield is already well established;
- Xenon is the gas that gives the highest electroluminescence gains in the linear region, followed by krypton, argon and neon;
- No experimental data to backup the EL yield results obtained for krypton.

Experimental Setup

1. Absorption region: 2.5 cm
2. Scintillation region: 0.9 cm
3. 1.1 bar of Krypton
4. The Large Area Avalanche Photodiode (LAAPD) is a deep-UV enhanced series from Advanced Photonix Inc., with 16mm active diameter. It was biased at 1840V, corresponding to a gain of approximately 150.

Gas purified by St707 SAES getters, which were set to a stable temperature of about 150°C.

- Absorption region: 2.5 cm
- Scintillation region: 0.9 cm
- 1.1 bar of Krypton

The Large Area Avalanche Photodiode (LAAPD) is a deep-UV enhanced series from Advanced Photonix Inc., with 16mm active diameter. It was biased at 1840V, corresponding to a gain of approximately 150.
Experimental Results

Scintillation and Ionization thresholds

Energy Resolution (5.9 keV X-rays)

Electroluminescence Yield
Scintillation/Ionization thresholds and Energy Resolution

Drift electric field optimization

Amplitude and Energy Resolution as a function of the electric field in the scintillation region

- A value of $0.34 \text{ kV cm}^{-1} \text{ bar}^{-1}$ for the drift $E/p$ was chosen.
- **Scintillation threshold** $\cong 0.7 \text{ kV cm}^{-1} \text{ bar}^{-1}$
- **Ionization threshold** $> 3.3 \text{ kV cm}^{-1} \text{ bar}^{-1}$
- **Energy resolution values** $< 10\%$
Electroluminescence Yield - Method

(1) The full absorption of the 5.9 keV X-ray in the LAAPD will produce an average number of free electrons, \( N_{XR} \), given by:

\[
N_{XR} = \frac{E_{XR}}{W_{Si}} = \frac{5895 \text{ eV}}{3.62 \text{ eV}} \approx 1628 \text{ electrons}
\]

(2) The average number of VUV photons impinging the LAAPD for the scintillation pulses due to the 5.9-keV X-ray full-absorption in the gas is:

\[
N_{VUV,LAAPD} = \frac{A_{VUV}}{A_{dXR}} \times N_{XR} \frac{Q_E}{E}
\]

(3) The total number of VUV photons produced by the full absorption of the 5.9 keV X-ray in the detector is:

\[
N_{VUV,\text{total}} = \frac{N_{VUV,LAAPD}}{T \times \Omega_{\text{rel}}}
\]

- \( Q_E = 90\% \rightarrow \text{Quantum efficiency for 147 nm VUV photons} \)
- \( \Omega_{\text{rel}} \approx 0.215 \rightarrow \text{LAAPD relative solid angle} \)
- \( T = 84\% \rightarrow \text{Grid optical transparency} \)
- \( d = 0.9 \text{ cm} \rightarrow \text{EL gap} \)
- \( P = 1.1 \text{ bar} \rightarrow \text{Gas pressure} \)

(4) The average number of primary electrons produced in krypton by full absorption of the 5.9 keV X-ray is:

\[
N_e = \frac{E_{XR}}{W_{Kr}} = \frac{5895 \text{ eV}}{24 \text{ eV}} \approx 246 \text{ electrons}
\]

(5) Therefore, the **reduced EL yield** is given by:

\[
y = \frac{N_{VUV,\text{total}}}{p \cdot N_e \times d \times p}
\]
• The slope of the linear dependence corresponds to the scintillation amplification parameter, i.e., the number of photons produced per drifting electron and per volt.

• A value of about **117 photons/kV** was measured for reduced electric fields between 1.0 and 3.3 kV cm\(^{-1}\) bar\(^{-1}\).
• Absolute measurements of the electroluminescence yield obtained in a Kr GPSC are reported for the first time.

• The obtained experimental results are compatible with results from simulation available in the literature.

• The scintillation amplification parameter obtained in Kr, 117 photons/kV, is only about 15% lower than the one obtained in Xe, 137 photons/kV [1], and significantly higher than the one obtained in Ar, 81 photons/kV [2].

• An energy resolution below 10% FWHM was achieved for 5.9 keV X-rays. This result is worse than the one obtained with Xenon (8%), but better than the one obtained with Argon (12.5%) [3].

Thank you for your attention!

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