MeV $\gamma$'s from Long Leaders in STP Air

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Outline

1. Introduction
2. Experimental setup
3. Results and discussion
4. Conclusions
5. Recommendations and outlook
1. Introduction

These phenomena are not well understood, especially the acceleration of electrons to produce high-energetic radiation.
Main objective:
Investigate the high-energy production related to lightning

- study on long laboratory produced sparks
- conditions for gamma production
- energies produced
- underlying mechanisms
2. Experimental setup

12 stage 2MV Marx generator

0.7 m spark
2. Experimental setup

Floor plan
2. Experimental setup

- LaBr$_3$ scintillator with PMT
  - 31 ns decay time (1/e)
  - 0.5 mm Al cover + 0.05 mm Al cabinet window
  - 1/e cutoff at 17 keV

- Dig. oscilloscope for HV and PMT signal + laptop storage.
  - 8 bit, max 2 Gs/s

- Calibration by 662 keV from $^{137}$Cs.
3. Results and discussion

Nal(Tl) response on $^{137}$Cs source
- Photo / Compton = 1 / 2.55
- Background low

![Graph showing Nal(Tl) response on $^{137}$Cs source]

- Photo
- Compton

7.8% FWHM
3. Results and discussion

Nal(Tl) detector response

Example of $\gamma$-pulse (Inverted)

![Graph showing the response of a Nal(Tl) detector to a $\gamma$-pulse.]

- Leader formation
- Discharge

Parameters:
- Voltage: 900 kV
- Energy: 566 keV
- Time: 0 to 5 microseconds
3. Results and discussion

\[ V_{\text{surge}} \approx 1\text{MV} \]
- space limitations

- In 100% of surges \( \gamma \)'s seen
  - about 75\% \( V_{\text{max}} \)
  - Very occasionally after \( V_{\text{max}} \)
  - \( \gamma \)'s related to leader formation
  - burst of \( \gamma \)'s up to or exceeding \( eV_{\text{max}} \) detected

\[ \text{Nal(Tl) detector response} \]
3. Results and discussion

NaI(Tl) detector response

Occasionally very energetic ones, exceeding $eV_{\text{max}}$

Overloaded > 1140 keV

Less detection with Negative discharges for NaI(Tl)
3. Results and discussion

LaBr₃(Ce) response on ¹³⁷Cs source

- Photo / Compton = 1 / 2.5
- Background low

Counts/sec

3.3 % FWHM
3. Results and discussion
LaBr3(Ce) detector response

Example of γ-pulse (inverted) with LaBr3 detector (70 cm gap)

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leader formation

discharge

840 kV
340 keV
95 keV

5.2 kA
3. Results and discussion

LaBr₃(Ce) detector response; Al-electrodes

Very often multiple intense $\gamma$-bursts detected (inverted)!

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877 keV
800 kV
416 keV
490 keV
With lead electrodes gamma energy seems to increase and γ’s occurred more frequently

3. Results and discussion
LaBr3(Ce) detector response; Pb-electrodes
3. Results and discussion

LaBr3(Ce) detector response

More intense γ’s with Negative discharges!

-900 kV

24.2 MeV

11.2 MeV

0.3 MeV

4.4 MeV

5 kA

MV (b), 5kA (g), 20MeV (k) and 20MeV (r)
3. Results and discussion

LaBr3(Ce) detector response

Fitting of detector’s signal using $^{137}$Cs-pulse

Energies [MeV]: 0.4694, 10.110, 3.0282, 21.0907, 3.1927, 6.8156, 3.6144, 1.4953, 3.8221, 2.6614
3. Results and discussion

LaBr₃(Ce) detector response; Negative discharges

Histogram of 42 negative discharges, $V_{\text{breakd}} \approx -900$ kV

42 Neg_discharges (Al electrodes)

228 bursts during 38 surges
3. Results and discussion

LaBr₃(Ce) detector response; Negative discharges

Histogram of 44 negative discharges, $V_{\text{breakd}} \approx -900$ kV
With 22 mm Al-absorber; 1/e cutoff $\approx 100$ keV

58 bursts during 22 surges
3. Results and discussion

LaBr₃(Ce) detector response; Negative discharges

Histogram of negative discharges without and with 22 mm Al-absorber; 1/e cutoff ≈ 100 keV

228 bursts during 38 surges

58 bursts during 22 surges
3. Results and discussion

LaBr3(Ce) detector response; with and without absorber

Histogram of negative discharges without and with 1.5 mm Pb-absorber (1/e cutoff ≈ 1.4 MeV)

30 Neg_discharges (Al electrodes) + 1.5mm Pb absorber (1/e cutoff = 1.4MeV)

213 bursts during 30 surges

94 bursts during 24 surges
3. Results and discussion

BaF2 detector response

Fast $\gamma$-pulse

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MV (b), 10 kA (g), kA (r) and 10 MeV (k)
3. Results and discussion

*BaF2 & LaBr3 detector response*

**BaF2 vs. LaBr3 γ-detection**

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- MV (b), 10 kA (g), 10 MeV (r), a.u. (k)
- Time [µsec.]

- 5.55 kA
- 7.05 MeV
- -915 kV
Localization (LaBr3)

- Positive discharge:
  Only $\gamma$-detection at anode!

- Negative discharge:
  $\gamma$-detection at anode and cathode as well as in air!
3. Results and discussion

Multi-angle measurement (2x LaBr3)

Floor plan 2

Marx Generator

EMC-cabinet 1

Scintillator & PMT

Al. window

0.9 m

1/e = 17 keV (cut-off energy)

EMC-cabinet 2

Scintillator & PMT

Al. window

0.9 m

1/e = 94 keV (cut-off energy)

7.80 m

1.25 m

0.7 m
3. Results and discussion

Multi-angle measurement (2x LaBr3)

Indication for pile-up

![Graph showing multi-angle measurement results](image)

- MV (b), 10 kA (g), kA (r) and 10 MeV (k)
- 180 keV
- 220 keV
- 240 keV
- > 6.9 MeV
- 5.36 kA
- -885 kV

Time [µsec.]
3. Results and discussion

Measurement on a wire-plate corona reactor

X-ray registered in wire-plate corona reactor.

No total breakdown needed!

Positive supply voltage:
- 65kV pulse + 20kV DC$_{\text{offset}}$
- 15/25ns rise/fall time

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3. Results and discussion

Run-away electrons?

Gurevich & Zybin:
Runaway region > 200keV for high in the atmosphere

Experiments (at STP):
In spite of an absorber with 1/e cutoff energy of ≈ 1.4 MeV high-energetic pulses are still detectable!
4. Conclusions

- More intense $\gamma$-burst with negative discharges (LaBr3)
- $\gamma$’s likely originate near the anode at streamer formation.
- Positive discharge $\rightarrow$ only $\gamma$-detection near anode. Negative discharge $\rightarrow$ $\gamma$-detection near electrodes as well as in air.
- No total breakdown needed for $\gamma$-production.
- Cosmic radiation as cause less probable because.
  - low background count rate
  - timing with the surge
5. Recommendations and outlook

- Investigation of difference in $\gamma$-production for positive and negative surges $\rightarrow$ need for fast current measurement!

- Role of humidity should be investigated more.

- Better conditioning Marx generator voltage waveform needed.

- Direct detection of fast particles.

- Variable gas conditions.

- Modeling work is needed.