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VUV EMISSION AND BREAKDOWN IN PARALLEL-PLATE CHAMBERS

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Abstract

The emission of vacuum ultraviolet (VUV) light by the electron avalanches is responsible for the photon feedback in gaseous detectors, worsening their performance at high gains. It is also generally assumed that there is a connection between breakdown and photon feedback in these detectors. We measured the VUV light emission from the avalanches in a parallel-plate avalanche chamber (PPAC) in the spectral region 120–170 nm. The radiation was detected by a photosensitive wire chamber coupled to the PPAC through an UV-transparent window. By choosing the gas filling of the wire chamber several spectral bands could be selected, suggesting an identification of the emission origin. The breakdown limit of the PPAC was simultaneously measured and found to be fairly independent of the measured VUV emission. The results obtained provide a guide to the selection of gaseous mixtures for practical use in photon-counting detectors, minimizing the photon feedback.

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1. INTRODUCTION

Single- and two-step parallel-plate avalanche chambers have found a wide range of application in imaging chambers, fast Ring Imaging Cherenkov (RICH) counters, BaF₂ calorimeters, etc. [1]–[4]. Advantages of this type of chamber are the simplicity of construction and the possibility of gating and operation at high gas gains of 10⁶ or more. The main limitation comes from secondary processes such as photon feedback and sparking. This problem was studied by some authors for single-wire counters and for multiwire proportional chamber (MWPC) geometries (see, for example, Refs. [5], [6]) and is understood quite well; the vacuum ultraviolet (VUV) emission, feedback and sparking being strongly connected.

The situation in the parallel-plate avalanche chamber (PPAC) is completely different:

- i) In PPACs there is a high electric field near the cathode, which strongly increases the probability of electron extraction [5], i.e. photon and ion feedback.
- ii) Compared to the MWPC, the PPAC operates at much lower electric field in the gas-amplification region, which strongly changes the avalanche emission spectrum responsible for feedback [7].

In this work we make a systematic study of the VUV emission together with some measurements of the breakdown limit in order to understand the physics involved and optimize the geometry and gas composition of PPACs.

2. THE EXPERIMENTAL SET-UP

The experimental set-up is presented in Fig. 1. It contains two independent gas detectors: a PPAC and a photosensitive wire chamber, separated by a 4 mm thick CaF₂ window. The detector frames were made of high-grade fibreglass¹⁾, and the sides opposite to the CaF₂ window are closed by Mylar windows 50 μ m thick.

The PPAC has a 10 $\times$ 10 cm² active surface and consists of 3 parallel electrodes (50 μ m crossed-wire meshes at 500 μ m pitch), separated by 1.1 and 0.4 cm gaps, which define respectively the drift and amplification regions. The anode mesh of the amplifying gap is in contact with the CaF₂ window. The MWPC has anode wires of 30 μ m diameter at a 2 mm pitch; cathode planes are also made with meshes (of the same kind as described above), placed 5 mm apart from the anode. A third mesh plane is placed 1 cm apart from the upper cathode plane, defining the MWPC conversion gap, this mesh also being in contact with the CaF₂ window.

The detectors are fed by separate gas systems and can work with different gas mixtures at atmospheric pressure. The MWPC was flushed, for most measurements, by a mixture of argon and triethylamine (TEA) vapour. In the PPAC we used several mixtures of noble gases with TEA, CH₄, and C₂H₆. The partial pressure of the TEA vapour in the gas could be regulated between 1 and 50 Torr.

The avalanches in the PPAC were initiated by 5.5 MeV α particles from a ²⁴¹Am source. A collimator selects the α tracks almost perpendicular to the electrodes, and a small area on the Mylar window was removed and covered by a 6 μ m thick Hostaphan foil to let the α particles through. The average primary charge yield is estimated to be 5 $\times$ 10⁴ electrons for the α particles in Ar gas and 5 $\times$ 10³ in He gas.

Signals from both detectors were recorded by charge-sensitive amplifiers and sent in parallel to an oscilloscope, a pulse-height analyser, and a scaler. The gain in the MWPC

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could be calibrated by direct exposure to either a ^{55}Fe source or a VUV mercury lamp producing single photoelectrons. The PPAC charge amplifier had a long time constant ($50\ \mu\text{s}$) in order to extend the integration to the ion component of the PPAC signal, thus integrating the total charge in the avalanche (N_e). It was calibrated by direct injection of a square current pulse on the chamber anode.

The photoelectron yield in the MWPC (N_{pe}) was estimated by comparing the pulse height from the calibrating ^{55}Fe source with the pulses observed in coincidence with the PPAC avalanches. Using this method, pulses corresponding to the detection of between a few and $\sim 10^5$ photoelectrons could be measured. When the number of photoelectrons was smaller the voltage applied on the MWPC was increased strongly in order to operate in a saturated mode, where we were able to record single photoelectrons under the conditions of a good counting plateau. In this case, we measured not the pulse amplitude but the fraction of pulses from the MWPC in coincidence with the pulses from the PPAC. After statistical treatment this method allows an estimation of the average number of photoelectrons created in the MWPC per avalanche in the PPAC. The conversion from detected photoelectrons to the number of photons emitted over the full solid angle was done assuming a geometrical acceptance of 20% and an average quantum efficiency of 10%.

The measurements were made at a total collected charge of between 10^7 and 5×10^7 electrons. Within this interval the measured intensity of VUV light is proportional to the charge with good accuracy.

3. THE VUV LIGHT EMISSION

The installation described above allows the measurement of the number of VUV photons emitted by the avalanches in the PPAC with different gas mixtures for wavelengths between 120 and 170 nm. The lower boundary of spectral sensitivity is determined by the CaF_2 window transmission cut-off (120 nm) and the upper boundary is set by the TEA ionization threshold at 170 nm (see Fig. 2).

This spectral region is of course very narrow, but in what concerns the photon feedback processes this may not be a limitation. Most hydrocarbons (e.g. CH_4) absorb strongly at wavelengths shorter than 140 nm, making it unlikely that shorter wavelengths reach the cathode electrodes and extract electrons there. Because the quantum efficiency of metals strongly increases with photon energy, the most active band for photon feedback will be just below the gas-absorption threshold — the region we are measuring.

Using the methods described above, measurements of the number of photoelectrons released in the MWPC per electron in the PPAC (N_{pe}/N_e) were made for different gas mixtures in the PPAC: several noble gases with TEA vapour, CH_4 , and C_2H_6 . Results obtained with mixtures of noble gases with TEA vapour are presented in Fig. 3a. A decrease of the VUV emission intensity with increasing TEA partial pressure is apparent, as well as an increase with the atomic weight of the noble gas. For comparison, in the same figure are given the intensities of the TEA emission peaked at 280 nm, this data being taken from Ref. [8]. The intensity of this emission is independent of TEA concentration for $p_{\text{TEA}} > 1$ Torr, and is many orders of magnitude higher than VUV emission. Figure 3b shows the results for the mixtures of noble gases with CH_4 and C_2H_6 . One can see the same tendency as described above: the VUV emission drops with increasing concentration of the quencher and increases with the weight of the noble gas. These mixtures show a much larger VUV emission than those containing TEA.

It could be that not all detected photoelectrons are due to ionization of the gas molecules; the photoelectric effect on the cathode surfaces of the wire chamber may also contribute. To estimate this effect we made some control measurements in which the wire chamber was filled with a mixture of Ar + CH₄ without any trace of TEA vapour. The radiation, passing through the CaF₂ window, cannot ionize this gas and photoelectrons can be created only on the mesh surfaces. As a further check we have measured the delay of the signals from the wire chamber with respect to the PPAC, the results being consistent with an electron production on the cathode surface. Results of this measurement are also indicated in Fig. 3. Clearly the contribution of the surface effect is negligibly small in all cases and therefore the main response comes from the photoionization of the TEA vapour.

In a second series of experiments we tried to estimate roughly the spectral region of emitted VUV photons by introducing additional gases into the Ar + TEA mixture in the MWPC. The additional gases will compete with TEA for the absorption of photons in their respective absorption bands, reducing the quantum efficiency of the gas in these bands. In this way, the extra gases introduced in the MWPC play the role of gas filters, cutting different spectral parts of the VUV emission of the avalanches. In Fig. 4 are given the transmission curves for different gases at atmospheric pressure, showing the well-defined cut-off edges. Most of our measurements were done with CH₄ as a gas filter, which allows cut-off of the quantum efficiency of the MWPC gas in the region 120–140 nm. By comparison with the measured emission in the full sensitive range (120–170 nm) the relative contribution of the 120–140 nm region can then be estimated.

This method was verified using Ar₂⁺ emission from the PPAC, with a known spectrum, peaked at 120 nm (see for example Ref. [9] and Fig. 2). We measured the variation of the photoelectron yield as a function of the CH₄ concentration in the MWPC gas and found that for a partial pressure larger than 90 Torr the photoelectron yield becomes independent of the concentration, corresponding to an almost total absorption by the CH₄ of the photons on its absorption band ($\lambda < 140$ nm). The CH₄ concentration in the wire chamber was normally kept at 160 Torr during all gas filter measurements. In order to have the cleanest possible Ar gas in the PPAC the measurements were done at high flux (500–700 cm³/s). The test measurement of Ar₂⁺ emission with a CH₄ gas filter show that about 70–80% of the emission from the avalanches is in the region 120–140 nm and 20–30% in the region 140–170 nm, in agreement with the expectations (see Fig. 2).

After verification of this method the same gas-filter measurements were performed for some other mixtures in the PPAC: Ar and He plus TEA or CH₄, and also Xe + TEA. All the measurements concerning mixtures containing hydrocarbons gave the same results: with an accuracy of $\sim 20\%$ all VUV emission recorded was concentrated in the spectral region 140–170 nm.

4. BREAKDOWN LIMIT

The occurrence of breakdown sets the most severe operational limitation for PPACs, and in order to improve the operating characteristics of these detectors it would be useful to understand the physics involved in the process. Breakdown in PPACs is sometimes thought to be connected with photon feedback, so we measured the maximum operating gain of the PPAC described above, simultaneously with the VUV emission measurements, in order to find some correlation.

The experimental results obtained indicate that, within a factor of 2, a total charge limit of 10⁸ electrons is found for a 2 orders of magnitude range in quencher pressure, five

different gas compositions (indicated above), and primary charges ranging from 220 to 5×10^4 electrons (so the gas gain varies by about two orders of magnitude). These results strongly suggest a breakdown mechanism dominated by the total amount of charge in the avalanches and, unlike VUV emission, largely independent of the gas composition, for the gases studied, and the chamber gain (see discussion).

5. DISCUSSION

5.1 VUV emission

In principle, the VUV emission from the PPAC avalanches could be due to one or more of the following processes: excimer emission of the noble gas, molecular emission of the additive gas, or fragment emission from dissociative recombination processes of the additive gas.

To make the discussion clearer we have also given in Fig. 2, the TEA absorption cross-section and quantum efficiency and possible C^* and H^* lines from dissociative recombination of the hydrocarbon gases. Some prominent N^* lines were also included because the TEA molecule includes a nitrogen atom.

Our results allow us to put forward a hypothesis about the origin of the emission. For example, in the case of an Ar + TEA mixture in the PPAC we can assume that the molecular emission of TEA cannot ionize TEA molecules in the MWPC. On the other hand, the measurements with the CH_4 gas filter show that the first and second continua of Ar^* emission (which exist mainly below 140 nm) do not contribute noticeably, so the observed emission can be either third Ar_2^* emission at $\lambda > 140$ nm [10] or fragment emission of TEA, which leads to the emission of atomic lines: C^* , H^* , N^* , etc. The third continuum of argon corresponds to transitions between the highest levels of Ar_2^* molecules and cannot be excited separately from the second continuum, so it cannot contribute noticeably in a situation where the second continuum does not appear — the case of our experiment. We should note that the excitation of the third continuum, requiring higher kinetic energy of the impact electrons, was never observed in gas scintillation counters [9]. On the other hand, fragment emission has been clearly seen in gas mixtures containing hydrocarbons, by other authors (see for example Ref. [11]) and it explains very well the feedback mechanism in some detectors [12]. We can conclude from this that probably fragment emission gives the main contribution for the observed VUV emission in Ar + TEA gas. This conclusion is immediate for the case of He + TEA and He + CH_4 , since it is practically impossible to excite the He_2^* continuum under the conditions of a gas avalanche [13]. For the other mixtures (Ar + CH_4 and Ar + C_2H_6) the VUV emission was also concentrated in the region $\lambda > 140$ nm, and we assume that also in this case the fragment emission dominates.

From Fig. 2 one can see that the measured VUV emission always drops with the additive gas concentration and increases with the atomic weight of the noble gas. A certain absorption of VUV light in the PPAC gas on its trajectory to the window certainly should be considered, but it cannot explain the observed behaviour. The gas-filter measurements show that the emission spectrum is concentrated in the region $\lambda > 140$ nm, and for this region the TEA absorption coefficient is less than $0.8 \text{ (cm Torr)}^{-1}$. For our geometry and typical gain the electron multiplication mean free path is about 200 μm , and we can assume this to be the characteristic distance from the window at which most photons are emitted, if the electron multiplication proceeds until a wire is reached. In the extreme case of 60 Torr of TEA the photon absorption length will be around 200 μm , indicating that we can neglect absorption for smaller concentration of quencher. Therefore the observed

decline of VUV emission with concentration must have another origin.

It is well known that in any kind of discharge (including avalanches) the high energy tail of the electron energy distribution (responsible for the excitation and ionization processes) is strongly suppressed above the first excitation level [14]. In the case of mixtures with molecular additives, with low rotational and vibrational excitation levels, this suppression appears above a few eV. The number of energetic electrons, responsible for fragment excitation, will then decrease with the concentration of the quenching gas in agreement with the observations.

The number of these energetic electrons will normally also increase with the electron temperature. It is possible that the electron temperature in avalanches (for a given concentration of quencher and for a fixed ratio E/p) increases with the atomic weight of the noble gas, owing to there being less electron energy losses in elastic collisions. In our case, operating at almost constant gain, the applied E/p increases with the atomic weight of the noble gas. This effect can explain the observed increase of the emission with the atomic weight of the noble gas. On the other hand, for the heavy gases, Kr and Xe, there may exist a contribution from their excimer emission, which emits only for $\lambda < 140$ nm.

5.2 Breakdown limit

We studied gases having widely differing properties concerning emission and absorption spectra, photosensitive thresholds, etc. It would be reasonable to expect large variations in the efficiency of any breakdown process based on photon emission and absorption, resulting in variable breakdown limits. We made some measurements and calculations, showing that, on the contrary, the breakdown limit (total charge in the avalanche for a given spark probability per avalanche) remains constant over a wide variety of gas fillings, unlike VUV emission. These results indicate a space-charge dominated mechanism for breakdown; the electrical charges created by the avalanche distort the local electric field, enhancing the local gain and light production. This effect can be relatively independent of the light emission and absorption characteristics of the gases.

Owing to lack of space we cannot present these results here and they will be published later, together with a systematic study of the breakdown phenomena in PPACs [15], [16].

6. CONCLUSIONS

We measured the VUV light emission from the electron avalanches in a PPAC in the band 120–170 nm. Several mixtures of noble gases with CH_4 , C_2H_6 , and TEA were covered. The emission always decreases with increasing quencher concentration and increases with the atomic weight of the noble gas. The emission of gases containing different quenchers may differ by several orders of magnitude.

By using CH_4 as a gas filter we could separate the sensitive band into two sub-bands: 120–140 and 140–170 nm. For mixtures containing hydrocarbons the emission is concentrated in the band 140–170 nm, whilst for pure Ar the emission is concentrated in the 120–140 nm band as should be expected from argon excimer emission. These results suggest that for the mixtures containing hydrocarbons the emission is mainly due to fragment emission and not to noble-gas excimer or molecular emission.

We measured simultaneously the maximum gain of the PPAC (limited by the onset of breakdown) in order to find some correlation between breakdown and VUV emission. We found a charge limit of 10^8 electrons which seems to be fairly independent of the gas

composition and chamber gain.

6.1 Application to detectors

Results obtained in this work are useful in the optimization of the PPACs' gas composition in order to minimize photon feedback. A He + TEA + CH₄ gas mixture, which has reduced VUV emission was successfully used in a BaF₂ calorimeter with a CsI photocathode [17] The efficiency of CsI to VUV emission is now up to 40% at 193 nm, but in gases with small VUV emission one succeeds in working at gas gains up to 10⁵.

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REFERENCES

- [1] P. Astier et al., IEEE Trans. Nucl. Sci. **NS-36** (1989) 300.
- [2] V. Peskov et al., Nucl. Instrum. Methods **A283** (1989) 786.
- [3] M. Izycki, et al., A large multistep avalanche chamber, description and performance, these Proceedings.
- [4] R. Bouclier et al., preprint CERN-PPE/90-140 (1990), to be published in Nucl. Instrum. Methods.
- [5] V. Peskov, Sov. Phys. Tech. Phys. **20** (1975) 791 and **22** (1977) 335.
- [6] T.J. Sumner et al., Nucl. Instrum. Methods **244** (1984) 477.
- [7] G.D. Bogomolov et al., Instrum. Exp. Tech. **21** (1978) 639, and G. Charpak, preprint CERN-EP/83-62 (1983);
G. Charpak and W. Dominik, unpublished data, July 1983.
- [8] V. Peskov et al., Nucl. Instrum. Methods **A277** (1989) 547.
- [9] M. Saletet et al., Portugalia Phys. **11** (1980) 53.
- [10] G.S. Hurst et al., Phys. Rev. **178** (1969) 4.
- [11] T.J. Sumner et al., IEEE Trans. Nucl. Sci. **NS-29** (1982) 1410.
- [12] R. Arnold et al., Nucl. Instrum. Methods **A270** (1988) 255.
- [13] A.E. Zaidel et al., VUV spectroscopy (in Russian) (Nauka, Moscow, 1967).
- [14] Y.P. Raizer, Principles of modern physics of gas discharge processes (in Russian) (Nauka, Moscow, 1980).
- [15] P. Fonte, V. Peskov and F. Sauli, Feedback and breakdown in parallel-plate chambers, in preparation.
- [16] P. Fonte et al., Model of proportional to streamer transition in parallel-plate detectors, in preparation.
- [17] G. Charpak et al., Liquid photocathodes for fast detectors, these Proceedings.
- [18] R.A. Holroyd et al., Measurement of the quantum efficiency of TMAE and TEA from threshold to 120 nm, Contributed paper No. 6408, 23rd Conf. on High Energy Physics, Berkeley, Calif., 1986, ed. S.C. Loken (World Scientific, Singapore, 1987).
- [19] G.V. Marr, Photoionization processes in gases (Academic Press, New York, 1967).
- [20] P.J.M. van der Burgt et al., J. Phys. Chem. Ref. Data, **18** (1989) 1757.

FIGURE CAPTIONS

Fig. 1 : Schematic view of the device.

Fig. 2 : Several parameters of interest for the interpretation of VUV measurements. The quantum efficiencies Q of the TEA vapour [18] alone and multiplied by the window transmission can be read in the left scale. The absorption coefficients A of TEA vapour and CH_4 [19] can be read in the scale to the right. The Ar_2^* second-continuum emission [9] is in arbitrary units. The atomic lines are represented according to the scale of their relative cross-sections for 100 eV electron impact on CH_4 gas, following Ref. [20] [Those lines marked (c) were taken at 200 eV.] The cross-section for the H Lyman- α line is $9 \times 10^{18} \text{ cm}^2$; all carbon line cross-sections have been multiplied by 10 in order to make them visible.

Fig. 3 : a) Normalized VUV light emission between 120 and 170 nm (points connected by dotted lines) as a function of TEA concentration; for comparison the intensity of the broad, longer wavelength, TEA molecular emission peaked at 280 nm is also shown (from Ref. [8]). b) Similar measurements for mixtures of noble gases with CH_4 and C_2H_6 . The errors can be estimated from the dispersion of the data points. Measurements corresponding to pure noble gases have been plotted at 0.15 Torr for convenience of representation, and those points measured through the counting method are represented by the solid circles and solid upright triangles.

Fig. 4 : Transmission curves for several hydrocarbons.

Fig. 1

Fig. 2

Fig. 3

Fig. 4