CHARACTERISTICS AND FUNCTION OF AN ELECTRON ATTACHMENT SPECTROMETER: PULSE FORMATION TIME AND GAIN EFFECTS IN P-10 GAS

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An Electron Attachment Spectrometer (EAS) has been designed to measure electron attachment in air and other gases. The aim of the EAS is to observe how parameters such as the electric field, reduced electric field and type of gas can influence electron attachment. The overall objective of this work is to investigate if the gas-gain of a proportional counter can be optimized by minimizing electron attachment with oxygen to improve the measurement of tritium-in-air. Current research interests include the measurement of the time between the generation of the electron-ion pairs and arrival of the electrons at the wire anode. Additionally, the study of the multiplication properties of the detector as a function of pulse formation time, P-10 gas flow rate and electric field will be presented. The EAS is a cylinder with a length of approximately 92 mm and diameter of 41 mm comprised of cylindrical hollow brass electrodes and Teflon spacers. A uniform electric field within the tube is applied and guides electrons and/or ions towards their respective electrodes. A proportional counter with a 50 μm diameter wire anode is used to detect the electrons and/or ions created by an ^{241}Am source located at the opposite end.

Keywords: Proportional counters; electron attachment; gas multiplication.

1. Introduction

In the Canadian nuclear power industry, which is based on the use of pressurized heavy-water reactors, there is a need to monitor tritium-in-air against a background of gamma radiation and potentially other radionuclides. Tritium (^3H) is produced by the thermal

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neutron capture reaction with heavy water ($^2\text{H}(\text{n},\gamma)^3\text{H}$). The short range of ~ 6 mm in air, along with the low energy (18.6 keV max) of the beta particles emitted from tritium decay, creates a challenging detection environment, especially in air.¹ Additionally, the presence of oxygen, an electronegative gas, attracts electrons, making it challenging to detect the beta particles in the presence of air using detectors based on gas multiplication such as proportional counters or gas electron multipliers. Currently, commercial tritium-in-air personal monitors with acceptable sensitivity are not available. Research studies in this field have been conducted in the past using a double gas electron multiplier (DGEM) type device¹ and ionization chambers.²

In this article, the performance of a device based on gas-multiplication, such as a proportional counter, was investigated to observe electron transit time in P-10 gas under various conditions using an Electron Attachment Spectrometer (EAS). The EAS presented in this article is based on the operational principles of an Ion Mobility Spectrometer (IMS). An IMS is used to characterize gaseous ions by measuring the drift velocity of ions traveling in a uniform electric field within a drift region.³ The general geometry of an IMS is a hollow cylinder comprised of a series of ring electrodes separated by insulating rings. A voltage is applied along the length of the cylinder to generate a uniform electric field along the axis of the cylinder. Using the same methodology as the IMS, the EAS is designed to include a proportional counter device to measure the electrons after emerging from the drift region. The goal of the EAS is to measure the electron attachment in air and other gases. In this work, the detector design along with experimental results focusing on the multiplication and gain effects observed in P-10 gas by varying the electric field within the EAS are presented. These studies have provided operating conditions and signal expectations for the EAS in the presence of a common counting gas, P-10. From the results presented in this article, a starting point for additional measurements of signal intensity and drift time in the presence of fill gas mixtures containing P-10 and air, and other counting gases such as ArCO_2 , using the EAS will provide vital information of how electron attachment due to the presence of oxygen will affect the gas gain of the proportional counter and tritium detection.

2. Materials and Methods

The EAS is composed of cylindrical brass and Teflon pieces creating a hollow cylinder with a total length of ~ 92 mm and an outer diameter of 41 mm. Figure 1(a) is a cross-section of the EAS along the axis of the detector. The detector can be broken down into three sections: source holder/ionization region, drift region and collection region. The source holder is designed to contain an americium-241 (^{241}Am) alpha source and a surface barrier (SB) detector diametrically opposed. The ^{241}Am source is used to generate electron-ion pairs within the EAS, and the SB is used to detect the collimated alpha particles emitted by the ^{241}Am source. Figure 1(b) displays a cross-sectional view of the source holder showing the positions of the ^{241}Am source and SB detector. The drift region is composed of 5 brass rings with inner diameters of 25 mm and 37 mm as shown in Fig. 1(a). The thickness of the 25 mm diameter region of the brass rings is 2 mm. The Teflon

spacers between the brass rings also have an inner diameter of 37 mm and a thickness of 1.6 mm. The third region represents a proportional counter (PC) and is composed of a 50 μm diameter anode wire with a length of ~ 8 mm surrounded by a brass cylinder with an inner diameter of 37 mm and a length of 10 mm. An aperture grid is placed between the last brass ring and the anode wire to help guide the ions towards the center of the collection region.

Fig. 1. (a) Cross section of Electron Attachment Spectrometer (EAS). Resistors in series with the values listed in Table 1 were used to connect the nine electrodes (E). (b) Cross section of the source holder (SH) shown in (a). The dimensions of SH along with the ^{241}Am source and SB detector positions are also illustrated.

Table 1. An example of the voltage distribution to the nine electrodes (E) corresponding to Fig. 1 with $HV_{\text{EAS}} = -1500$ V applied to the Source Holder (E1). The resistor values listed were used between the adjacent electrodes (E) to divide the applied high voltage along the nine electrodes (i.e., a value of 270 k Ω was used between E2 and E3).

EAS Brass Electrode	Resistor (k Ω)	Voltage (V)
Source Holder (E1)	n/a	-1500
Brass Ring (E2)	0	-1500
Brass Ring 1 (E3)	270	-1265
Brass Ring 2 (E4)	270	-1029
Brass Ring 3 (E5)	270	-794
Brass Ring 4 (E6)	270	-558
Brass Ring 5 (E7)	270	-323
Aperture Grid (E8)	270	-87
Outer Cylinder (E9) ^a	100	0

^aOuter Cylinder (E9) is connected to ground.

In order to collect the generated electrons and negative ions, the ions must be guided towards the anode wire. A uniform electric field along the drift region is generated by connecting resistors in series to divide the applied high voltage (HV_{EAS}) within the drift region of the EAS. An additional resistor is used between the Aperture Grid (E8) and Outer Cylinder (E9) to guide the electrons to the collection region. Table 1 lists the resistor values and corresponding voltages applied to the brass electrodes when a HV_{EAS} of -1500 V is applied to the source holder.

Figure 2 is a schematic of the experimental setup. This setup was employed to measure the transit time (Δt) of electrons within the EAS and relative gain as a function of HV_{EAS} . The transit time represents the total travel time of the electrons from their location of origin within the source holder through the drift region and the pulse formation time within the collection region. The pulse formation time represents the avalanche formation time characteristic of proportional counters. See Ref. 4 for a description of an avalanche formation in proportional counters. The SB detector signal is used as a trigger to identify only EAS signals at the anode originating from collimated alpha particles. Without a trigger source, the origin of the detected signals cannot be distinguished. Using the setup shown in Fig. 2, the gate and delay generator (G & D) was used to vary the delay time of the SB signal arriving at the MCA gate. At each selected delay time, a pulse-height spectrum was collected and the count rate and spectrum peak channel were recorded. Given the measured count rate of the collimated alpha particles by the SB detector is ~ 1.7 cps, the corresponding peak transit time (PTT) was expected to occur when the anode count rate was maximum at ~ 1.7 cps. Using this experimental procedure, the peak transit time of electrons within the EAS as a function of HV_{EAS} in the

Fig. 2. Experimental setup used to measure the transit time of negative ions (electrons) within the EAS. The detected signals at the anode corresponded to the set delay time on the G & D relative to the alpha detection by the SB detector. MFC: Mass Flow Controller, HV: High Voltage, PreAmp: Preamplifier, Amp: Amplifier, G & D: Gate and Delay Generator, SB: Surface Barrier Detector, PC: Proportional Counter, MCA: Multichannel Analyzer. The oscilloscope was used as a visual check for the SB detector signal and the EAS anode signal.

presence of P-10 gas was measured. P-10 gas is composed of 90% argon and 10% methane. Using the PTT and known drift velocity of electrons in P-10 gas, the pulse formation time near the anode as a function of HV_{EAS} was calculated. The EAS was connected to a mass flow controller (TM Model 50 Mass Flow Controller, Sierra) at one end and open to the atmosphere at the other end. The mass flow controller (MFC) was used to set the flow rate of P-10 gas (50 scc/min) through the EAS.

Spectra were collected at each HV_{EAS} as a function of delay time set by the G & D using a spectrometer (UCS30 USB Computer Spectrometer, SPECTECH). Additional high voltage power supplies HV_{SB} and HV_{PC} were used to power the SB detector and anode within the EAS, respectively. The detected signals are connected to a preamplifier (PreAmp) followed by an amplifier (Amp) and additional relevant pulse processing as shown in Fig. 2. The oscilloscope was used as a visual check during experiments.

3. Results

The PTT in P-10 gas as a function of HV_{EAS} was determined for HV_{EAS} values ranging from -800 V to -2000 V. A series of spectra as a function of delay time were obtained at each HV_{EAS} . The total count rate and peak channel were recorded from each spectrum. The count rate is calculated by summing all the counts under the peak and dividing by the live time of the detector. The count rate was then plotted as a function of delay time, and the peak transit time was obtained by fitting the data to a Gaussian curve using Origin software. Figure 3(a) displays an example of a collected spectrum with $HV_{EAS} = -1500$ V and G & D delay time setting of 5 μ s. For this data, the count rate is 1.72 ± 0.03 cps and the peak channel (centroid) is 589 ± 28 . Figure 3(b) is a graph displaying the count rate as a function of delay time for $HV_{EAS} = -1500$ V. The PTT was obtained from the Gaussian fit parameter corresponding to the center of the curve. This procedure was repeated at all HV_{EAS} , and the corresponding PTT value for each HV_{EAS} was obtained.

Fig. 3. (a) Example of pulse height spectrum obtained with the EAS using $HV_{EAS} = -1500$ V and delay time of 5 μ s. The count rate and channel number corresponding to the centroid were recorded at each delay time. (b) The measured count rate in counts per second (cps) as a function of delay time obtained with $HV_{EAS} = -1500$ V.

3.1. Calculating the pulse formation time

In order to calculate the pulse formation time of the EAS, the drift time within the EAS drift region was subtracted from the PTT. The drift time within the EAS drift region was calculated by dividing the drift region length (5.8 ± 0.1 cm) by the drift velocity of electrons in P-10 gas obtained from Ref. 5. The drift velocity in P-10 gas ranged from 5.7 to 6.4 cm/ μ s for the HV_{EAS} range used in the experiments. Fig. 4 graphically displays the pulse formation time, PTT and drift time in P-10 gas as a function of HV_{EAS} .

Fig. 4. Pulse formation time in P-10 gas as a function of HV_{EAS} measured using the EAS. The peak transit time (PTT) and drift time are also displayed.

Fig. 5. (a) An example at $HV_{EAS} = -1500$ V of the line of best fit used to obtain the centroid channel number corresponding to the peak transit time shown in Fig. 4. The centroid channel number at each delay time was obtained from the pulse height spectrum (e.g., Fig. 3). (b) Gas-gain (represented by the centroid channel number at the peak transit time) of the EAS signal as a function of HV_{EAS} . A small decrease in gain is observed as the HV_{EAS} values become less negative.

3.2. Gas-gain in P-10 gas

The gas-gain in P-10 gas as a function of HV_{EAS} was also observed. Using a plot of the centroid of the collected pulse height spectrum (e.g., Fig. 3(a)) as a function of delay time, the centroid channel number corresponding to the peak transit time (PTT) was calculated. Figure 5(a) is an example of the plot of the centroid as a function of delay time obtained with $HV_{EAS} = -1500$ V. Using the line of best fit, the channel number corresponding to the peak transit time (PTT) was calculated. Figure 5(b) is a graph of the centroid channel number corresponding to the PTT values as a function HV_{EAS} . As expected, a very small decrease in gas-gain is observed as the electric field strength decreases (i.e., less negative HV_{EAS} values).

4. Discussion

The experimental setup shown in Fig. 2 was used to measure the pulse formation time in P-10 gas within the EAS. The pulse formation time measured indicates that the applied high voltage (HV_{EAS}) affects the electric field within the collection region, altering the pulse formation time. From Fig. 4, the effect on the pulse formation time appears greater in the HV_{EAS} range from -800 V to -1400 V, decreasing from 5 μ s to 3.5 μ s. The pulse formation time in the HV_{EAS} range from -1500 V to -2000 V appears to stabilize in the range of 3–3.4 μ s. At atmospheric pressure, the HV_{EAS} range used to investigate the transit time of the EAS is within the range of minimum electron attachment for oxygen.⁶ Since the ability to measure tritium-in-air is sensitive due to the presence of oxygen, being able to operate a gas detector at conditions of minimum electron attachment to oxygen will provide maximum detection efficiency for tritium-in-air. From the data presented in Figs. 4 and 5, the ideal and most stable operating conditions for the EAS with P-10 gas are in the HV_{EAS} range of -1500 V to -1800 V.

The experimental results presented provide a better understanding of the EAS function and operating conditions within ideal conditions for minimum electron attachment. Using these operating conditions, additional experiments will include the addition of controlled amounts of air to the P-10 gas within the EAS to investigate the effects on the electron transit time and loss of gain due to the presence of oxygen.

5. Conclusions

The function and characteristics of the EAS using P-10 gas were investigated and the results presented. The HV_{EAS} selected values within the range from -1500 V to -1800 V of the EAS are stable and within ideal reduced electric field (electric field strength per unit pressure) conditions for minimal electron attachment in oxygen. The findings presented in this work provide a solid foundation to further investigation of the effects of electron attachment in the presence of oxygen using the EAS and work towards designing and developing a gas based detector for measuring tritium-in-air.

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