Design and Initial Testing of an Electron Attachment Spectrometer

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Abstract

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, type of gas and pressure 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. The EAS is a cylinder with a length of approximately 92 mm and diameter of 41 mm. The EAS contains a series of hollow cylindrical brass electrodes separated by hollow cylindrical Teflon spacers. A voltage difference is applied along the length of the EAS to generate a uniform electric field within the tube and to guide electrons and/or ions towards their respective electrodes. A 50 μm diameter wire anode surrounded by a brass cylinder with an inner diameter of 37 mm is used to detect the electrons and/or ions as they drift along the length of the EAS. An Am-241 source is used to generate electron-ion pairs at one end of the EAS tube and the electrons or negative ions are then drifted by the electric field and detected by the wire anode at the opposite end. A surface barrier detector is also used to detect the alpha particles emitted by the Am-241 source and to provide a trigger signal to measure the time between the generation of the electron-ion pairs and the arrival of the electrons at the wire anode. A simulation of the ion trajectories within the EAS was also conducted to ensure the voltages applied to the electrodes focus the electrons onto the wire anode using the software SIMION® (Version 8.0).

Introduction

The Electron Attachment Spectrometer (EAS) presented in this article is based on an Ion Mobility Spectrometer (IMS). An IMS is used to characterize gaseous ions by measuring the drift velocity of ions travelling in a uniform electric field within a drift region (1). 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 goal of the EAS is to measure the electron attachment with oxygen in the present of air and other gases. The IMS was modified by removing some of its components and redesigning of the source holder to allow for the insertion of an Americium (Am-241) alpha source and a surface barrier (SB) detector. Additionally, the original anode was replaced with a 50 μm wire to create a proportional counter (PC) for the detection of the generated electrons by the alpha source.

The aim of the EAS is to measure the electron attachment in air and other gases and to also observe how electron attachment is affected by the applied electric field, type of gas and gas pressure. The main objective of this research is to investigate if a PC can be used to measure tritium in air. Figure 1 is a graph of the probability of electron attachment in oxygen (O_2) as a function of the reduced field (E/p) (2). (Where E is the electric field and p is the pressure in mmHg.)

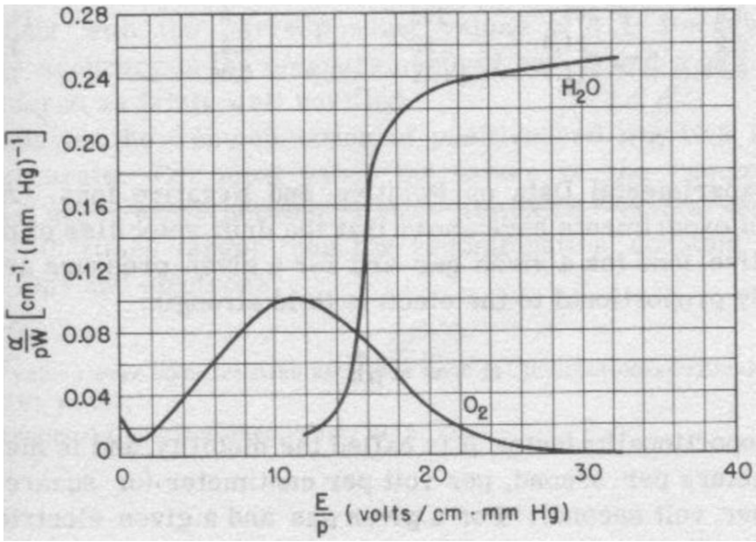

Figure 1: Probability of electron attachment in oxygen (O_2) and water (H_2O) as a function of reduced field (E/p).

From the graph, a minimum of electron attachment in O_2 occurs between 0 and 2 V/cm/mmHg. Given our interest in minimizing electron attachment at atmospheric pressure (760 mmHg) an electric field along the drift tube of 200 V/cm is within this range. In the work presented here the design of the EAS is described along with the generation of ions using an Am-241 source. Additionally, a simulation of the EAS using the SIMION® software is presented.

Experimental Design and Setup

Detector Design

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 2 is a cross-section of the EAS along the diameter of the detector. The detector can be broken down into three sections: (i) source holder/ionization region, (ii) drift region and (iii) collection region. The source holder is designed to insert an Americium-241 (Am-241) alpha source and a surface barrier (SB) detector across from each other. The Am-241 source is used to generate electron-ion pairs within the EAS and the SB is used to detect the alpha particles emitted by the Am-241 source. Figure 3 is a schematic diagram of the source holder displaying the position of the Am-241 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 Figure 2. The thickness of the 25 mm diameter 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 50 μm anode wire surrounded by a brass cylinder with an inner diameter of 37 mm. An aperture grid is placed between the last brass ring and the anode wire to help guide the ions toward the center of the collection region.

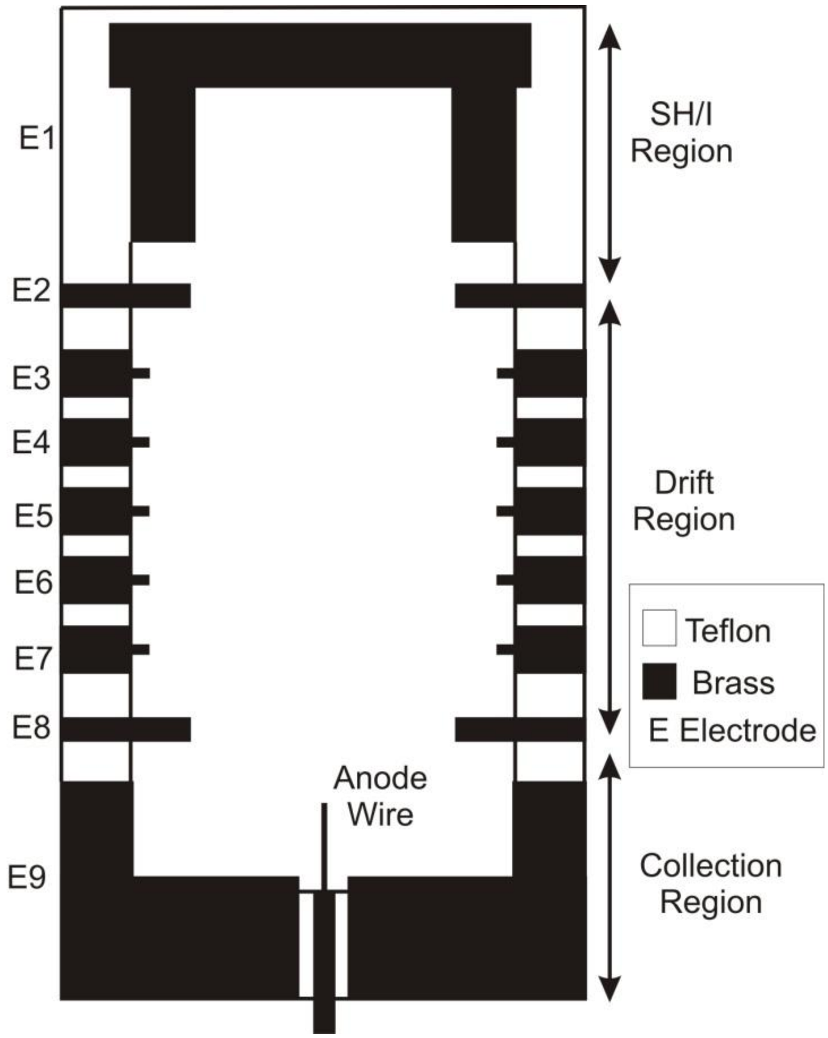

Figure 2: Cross section of EAS. Resistors with values as listed in Table 1 were used to connect the 9 electrodes (E).

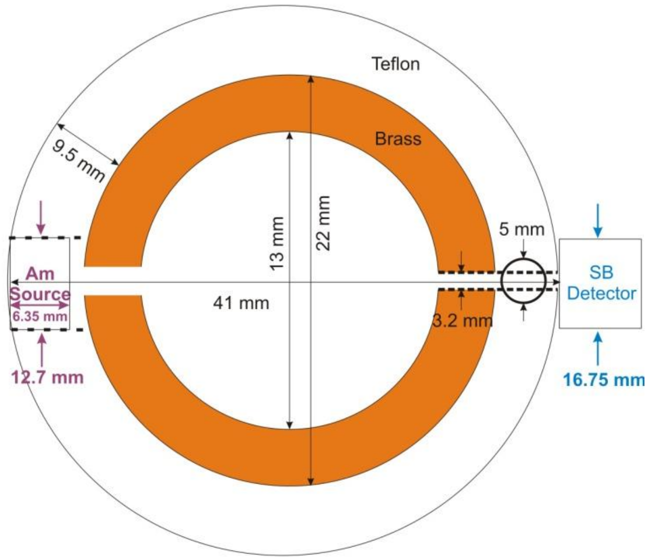

Figure 3: Cross section of the source holder (SH) shown in Figure 2. The dimensions of SH along with the Am-241 source and SB detector positions are also illustrated.

Electron Generation

Figure 4 is a schematic diagram of the experimental setup used to measure the number of electrons generated within the SH by the Am-241 source. The Am-241 source is inserted in the SH as shown in Figure 3 and the components of the EAS are inserted in a steel tube which is then sealed on both ends. This minimizes any external noise. A side port is used to insert the SB detector and align it directly across from the Am-241 source. Once the EAS and SB detector are positioned within the steel tubing the required electronics as shown in Figure 3 were connected.

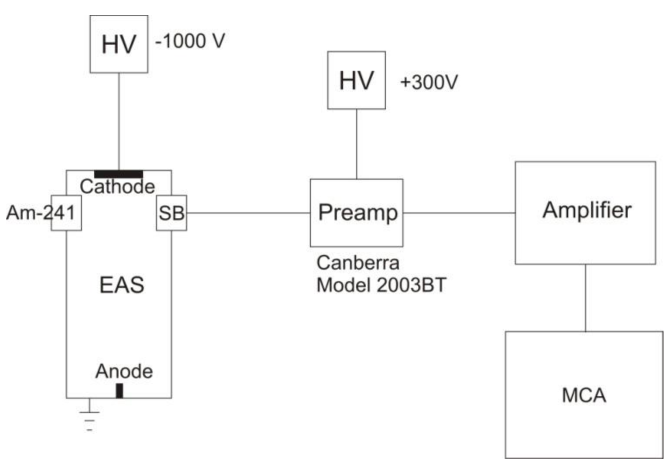

Figure 4: Experimental setup used to test measure the electron-ion pairs generated within the SH. A multi-channel analyzer (MCA) was used to collect the alpha particles detected by the surface barrier (SB) detected emitted from the Am-241 source.

Electric Field Generation

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 using resistors between the brass electrodes to divide the applied voltage within the drift region of the EAS. Table 1 lists the resistor values and corresponding voltages applied to the brass electrodes along the EAS given a HV of -1000V is applied to the source holder.

Table 1: A list of the applied voltage (V) to the nine electrodes (E) corresponding to Figure 1, along with the resistor values used between the adjacent electrodes (E) to divide the applied high voltage along the nine electrodes of the EAS (i.e. a value of 270 kΩ was used between E2 and E3). *The Outer Cylinder (E9) is connected to ground.

EAS Brass Electrode	Resistor (kΩ)	Voltage (V)
Source Holder (E1)	n/a	-1000
Brass Ring (E2)	0	-1000
Brass Ring 1 (E3)	270	-843
Brass Ring 2 (E4)	270	-686
Brass Ring 3 (E5)	270	-529
Brass Ring 4 (E6)	270	-372
Brass Ring 5 (E7)	270	-215
Aperture Grid (E8)	270	-58
Outer Cylinder (E9)*	100	0

ION Generation and EAS Simulation Study

Ion Pairs

The Am-241 alpha particles generate ion pairs as they travel through the air. Using the SB detector we were able to measure the energy of the alpha particles at the SB detector and then calculate the average energy loss of the alpha particles and the average number of electron-ion pairs generated within the source holder. Using the two known alpha particles emitted by a Uranium-238 source (4.196 MeV and 4.7758 MeV) the SB detector was calibrated with energy. The energy of the alpha particles emitted by the Am-241 source is 5.465 MeV. By measuring the energy of the emitted particles at the SB detector as a function of distance from the source, the energy loss in air within the source holder was obtained. Figure 5 displays the alpha energy loss measured with the SB detector as a function of distance from the source.

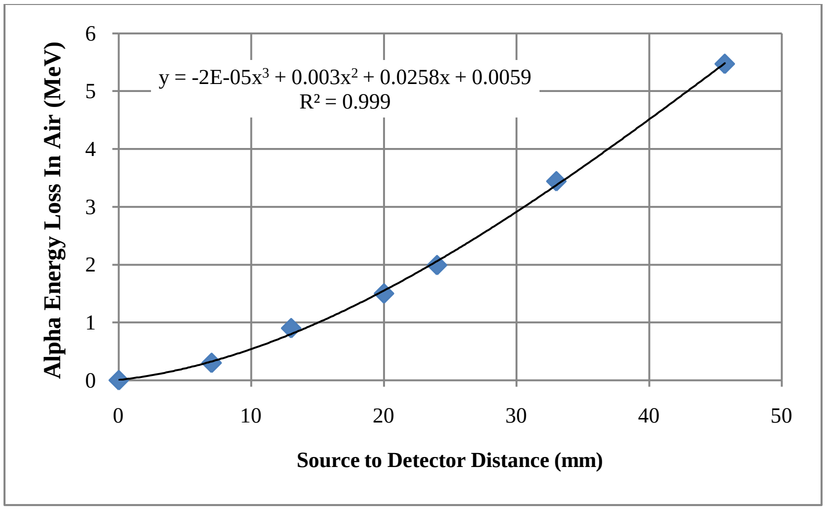

Figure 5: Am-241 alpha energy loss in air as a function of distance from the source. The surface barrier (SB) detector was place directly across from the source at various distances from the source to measure the energy.

Using the measured energy loss of the Am-241 alpha particles and the NIST data for the range of alpha particles in air, the average number of electron-ion pairs generated within the ionization region of the source holder per alpha particle emitted is 31 000 which corresponds to an energy loss of 1.088 MeV. Figure 6 is a graph of the Am-241 alpha peak as detected by the SB when aligned within the source holder as shown in the experimental setup in Figure 4. Given approximately 31 000 electron-ion pairs are generated within the ionization region of the source holder per alpha particle and if there is no electron attachment than we expect all 31 000 electrons to be guided through the drift tube of the EAS and collected by the anode wire.

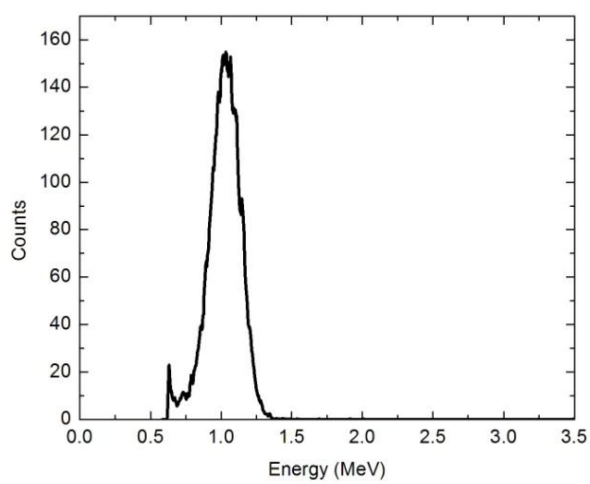

Figure 6: Spectrum obtained using the MCA and the configuration of the Am-241 source and SB detector as shown in Figure 3.

SIMION® Simulation

In order to verify the electric field within the EAS and to ensure the electrons (and/or negative ions) are directed toward the anode wire a simulation using SIMION® was conducted. The SIMION® software allows for the input of the detector geometry and to apply the desired voltages to the electrodes. In addition to the voltages of the nine electrodes listed in Table 1, a voltage of +1000 V was also applied to the anode wire for the simulation. Figure 7 is a snapshot of the simulation after flying 100 electrons through the EAS. From the simulation an electric field of ~ 200 V/cm is calculated along the axis of the cylinder. This electric field value is ideal for electron drift within the drift tube of the EAS (1) and minimal electron attachment in O_2 (2).

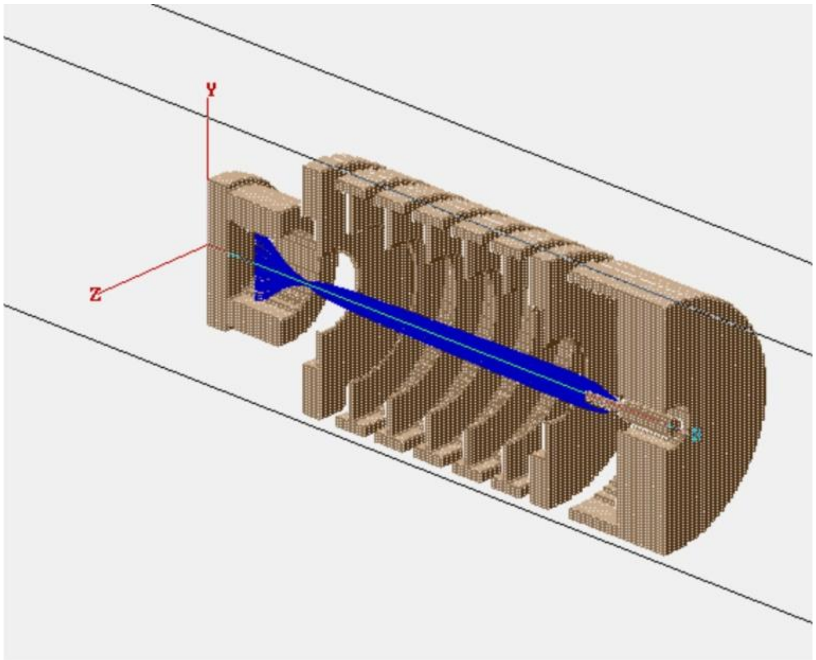

Figure 7: SIMION® simulation of the EAS detector in vacuum. The blue represents 100 electron trajectories originating at the source holder (left in figure) and ending at the anode wire. The voltages listed in Table 1 were applied to the electrodes and +1000 V was applied to the anode wire.

Future Work

Given the initial simulation has provided positive results on the trajectories of the electrons towards the anode wire, the next steps include additional simulations using SIMION® and experiments using the EAS. Using the SIMION® software a simulation of the EAS in an air environment instead of vacuum will provide information on how the electron trajectories may be affected due to the presence of air within the EAS cavity. In terms of experimental studies, the first step is to connect the anode wire to a HV source and preamplifier and observe if a signal coming from the generated electrons by the Am-241 source can be detected. Once these studies are completed additional experiments using the EAS can be conducted to assess the sensitivity of the system on electron attachment.

Acknowledgements

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