Construction of a Spark Chamber for Public Demonstration

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Abstract

Spark chambers are particle detectors whose low cost and bright visuals make them excellent for institutions to use in public demonstrations. Our spark chamber consists of an air-tight acrylic box, grooved to allow seven aluminium plates to fit inside. Once sealed, the container is flooded with a mix of helium and neon gas. A high voltage is applied to the aluminium via a high-voltage pulser which receives signals from a cosmic ray telescope. The high voltage will cause sparks that arc between the aluminium, along the trail of ions left by the particle which the telescope detected.

Introduction

Presenting information in a form the casual viewer will understand can be challenging. In physics, simple and clever demonstrations have been devised across a wide range of topics. Relating concepts becomes easier when there is something tangible for the viewer to interact with. Spark chambers are a good candidate for demonstrations of particle physics because of their bright visuals and low cost. Spark chambers were originally built as particle detectors in the 1930s and used through the 1960s but have since been replaced by newer detectors. The most basic structure of a spark chamber is a container with parallel metal plates and filled with a gas. When a cosmic ray travels through the chamber it leaves a trail of ions in the gas. A high voltage is applied to alternate plates, with grounded plates in between, which induces sparking along the trail of ions. To know if a particle has passed through the chamber, it is placed inside a cosmic ray telescope. The cosmic ray telescope detects a particle passing through it and activates the high-voltage pulser, which charges the plates and causes them to spark.

Methods

In order to better understand the spark chamber an ancillary study was made on the cosmic rays that will trigger the system, particularly the muon. The muon, also known as a μ meson, is an elementary particle with a charge of ±1, a mass of 105.7 MeV/c^2 and a lifetime of 2.2 μs (Nave). Muons are a common particle, with roughly 10,000 striking every square meter of the Earth's surface every minute. They are produced when a proton strikes an oxygen or nitrogen atom in the upper atmosphere producing a Pion which then decays into a muon. Time dilation occurs because the muon is travelling at relativistic speeds when it is produced. In addition, the muon is a lepton and is able to pass by other atoms without strongly interacting. This means the muon will survive long enough to reach the surface of the earth, leaving a trail of ionization in its wake. It is this trail of ions that the spark chamber visualizes.

The first goal of this project was to design the coincidence circuit for the cosmic ray telescope, which detects the muons. Upon studying the telescope we realised the design was surprisingly simple. When a cosmic ray strikes the fluorescent dye in a block of plastic known as a scintillator, the dye will emit light. This light is guided into a photomultiplier tube, or PMT, which outputs an analog signal when it detects a photon. When the photon strikes a photocathode it produces an electron. This electron, traveling through the tube, collides with several dynodes in series which, because of the effects of secondary electron transmission, release more electrons at each stage. After the last dynode the entire shower of electrons is collected to form the PMT's analog output. Because this signal is noisy and varies from pulse to pulse it is fed into a discriminator, which performs two actions. First it stabilizes the timing of the pulse. Then it checks to see if the amplitude of the stable pulse crosses a set threshold. Once a PMT signal above the threshold is received the discriminator outputs a logic signal. A logic module uses an AND gate to determine whether two signals occur in coincidence with each other. By having scintillators on the top and bottom of the telescope connect to the same logic module, one can identify when a cosmic ray has passed through the centre of the telescope. Note that because the cosmic ray will strike the top scintillator first, its signal may need to be delayed before it reaches the logic module in order to achieve coincidence. Having completed the design of the cosmic ray telescope, a faculty member chose to build it outside of this project. For their component list, see Appendix A. For a diagram of the spark chamber within the cosmic ray telescope, see Appendix B.

The next goal of the project was to design the chamber itself. This proved to be more involved, as there were some important considerations to take into account. First was the emphasis on keeping the plates parallel within the chamber to prevent preferential sparking. Another was to prevent sparking off the cut edges of the plates. One paper addressed theses issues by offering two types of construction, the “sandwich type” and the “box type” (Collins). The box type is a clear container in which are placed metal plates separated by plastic spacers. While this solves the parallel plate issue, it does nothing to prevent the edge sparking. The sandwich type uses slices of clear acrylic, glued between the plates to form a box. This does prevent sparking from the edges, but makes it difficult to disassemble. We believe the chosen solution mitigates sparking and keeps the plates parallel while also preserving the ease of disassembly. In our chamber, the acrylic plates are milled with grooves to slot the aluminium into. This buries the plate edges in acrylic and prevents them from sparking. The grooves, cut by computer control, are parallel to 1/100th of an inch.

The next step was to determine the measurements of the chamber. Due to the nature of the chamber, clarity of the spark was a major factor. To provide a clear chain of sparks, we chose to insert seven plates into the aluminium. Plate gaps used in other chambers ranged from 0.8 cm to 1 cm, attempting to balance visibility with required voltage (Collins; Joo). Larger gaps require more voltage before the spark is produced. For this project imperial units are used to easily communicate with the metal and acrylic suppliers, hence the plate gap for this chamber is 0.3 inches, or about 0.8 cm. The container is a box constructed of

0.7 inch thick acrylic. Its panels are assembled as depicted in Appendix C. To provide a large clear viewing area it was decided that the side panels should be 12 x 6 inches and that their outer faces would be 12 inches apart. Thus the top and bottom panels are 12 x 12 inches and the face panels are 12 x 7.4 inches. This allots roughly 1 inch of free space above and below the stack of aluminium plates. All together, the container will have an internal volume of 6 x 10.5 x 12 inches. A computer controlled milling machine was used to cut grooves in the side and face panels that are 0.26 inches wide and 0.25 inches deep. The plate gap, 0.3 inches, occurs between the milled grooves. The aluminium plates are 0.25 inch thick, initially with side lengths of 11 and 12.5 inches. These were sheered to fit within the chamber. They are connected to the high-voltage trigger via screws, inserted through the walls of the container, and tapped into the narrow edge of the plate. To allow for gas flow through the system, holes were drilled into the walls between the plates. Hoses can be inserted into these holes such that the output of one hole becomes the input of the hole beneath it. Finally, the plates themselves are bound together by tapping screws between them. Every part of this chamber can be removed from the rest to be cleaned or replaced. This is an important feature for a device slated to be used in a classroom environment.

Current and Future Work

The cosmic ray telescope caused some delay in the construction of the spark chamber. Originally under the purview of this project, a professor realized that other student's projects would benefit from the telescope also and began to pursue it independently. It was finished several months after the original expected date, which limited the completion of the construction of the spark chamber.

Focusing on the chamber itself, the measurements were taken and the parts ordered. There was a slight delay in finding a machine shop to mill the plates, but it was resolved quickly. We got quite far on the construction of the chamber. All the acrylic has been milled, and screws tapped into the aluminium plates. Four screws have also been sunk into the acrylic. Two are on the face with the electrical connections, and two on the opposite plate. They hold a single side plate in place, adding rigidity to the chamber. There is a decision to be made before more work is done: whether screws should be tapped into all the acrylic to bind the faces together, or whether some plates should be bound by adhesive? If screws are used, a silicone caulk would need to be applied to the seams to keep the chamber airtight. If the adhesive is used, the electrical and side plate could still be removed, but the others would be permanently bound and would no longer require caulk on their seams.

Testing

The spark chamber's design is similar in many respects to the basic parallel plate capacitor. Because of this, we decided to calculate the capacitance of our chamber. First, we model the individual plate pairings. As a complication to the classic formula, our plates are partially embedded in acrylic which has a higher permittivity than that of air. This acts like two capacitors in series, so we add them together.

$$C = \frac{e_0 k A}{D} \quad (1)$$

$$C = \left(\frac{e_0}{D}\right)(k_1 A_1 + k_2 A_2) \quad (2)$$

Where e_0 is the permeability of free space, D is the distance between the individual plates, k_1 is the relative permittivity of the air, A_1 is the exposed area of the plates, k_2 is the relative permittivity of acrylic, and A_2 is the area of the plate enclosed by acrylic. By substituting the values for our chamber into tis equation we find our expected capacitance.

$$C = \left(\frac{8.854\text{x}10^{12} C^2 N^{-1} m^{-2}}{0.008 m}\right)(1*0.081 m^2 + 3.5*0.00742 m^2) \quad (3)$$

$$C = 1.18\text{x}10^{-10} F \quad (4)$$

This value is only for one plate pair, of which there are six, so we multiply the result to get $7.10\text{x}10^{-10}$ F, or 0.71 nF. To verify our expected result we used a digital multimeter to test the actual capacitance of our chamber. We found that the chamber has a capacitance of 0.8 nF, which is reasonably close to our expected value.

The chamber was then brought up to 8,000 volts in ambient air to check for accidental discharge. We were looking for shorts in the cable connecting to the plates and near the contacts. The chamber held the charge well and we detected no arcing. It should be noted that 8 kV is not enough to cause the plates to spark in air. To see what voltage would be needed we employed Paschen's

Law. Derived from Friedrich Paschen's curve, Paschen's Law relates the voltage to the pressure-gap length.

$$V = \frac{a\,pd}{\ln(pd)+b} \tag{5}$$

In air, the constant $a = 4.36\text{x}10^7$ V/(atm m), and b = 12.8. By setting p = 1 atm and d = 0.008 m, we find that the expected breakdown voltage would be about 43,825 V.

Continuing

Before we achieve sparking there are a number of items to complete. The aluminium plates, after several washings, seem to still have grease on them. A more thorough cleaning would be recommended. A design for the high-voltage pulser has been drafted for construction. Collins cites the delay time of his high-voltage/spark gap circuit to be between 480 and 550 ns (Collins). As soon as they form, the ion trails will begin to dissipate, making it imperative that the pulser raise the voltage of the plates before the trail is lost. A decision is still being made between the use of thyratrons and thyristors as the triggering mechanism. Lastly, a gas flow system needs to be added to the chamber. Because the dielectric constant of air is too high, a different gas with a lower breakdown voltage must be used. This gas is often a mix of Helium and Neon (Collins, Joo). The gas flow system has been designed in part, and the holes in the sides of the chamber that allow it to connect to the system have already been drilled.

Conclusion

Though the spark chamber has yet to be completed, this project should be considered a success. The project laid the framework for further studies of the construction of particle detectors and has aided in the understanding of the fundamental principals that drive their operation. Once the remaining parts are completed and assembled, this spark chamber will be an excellent tool for public demonstrations.

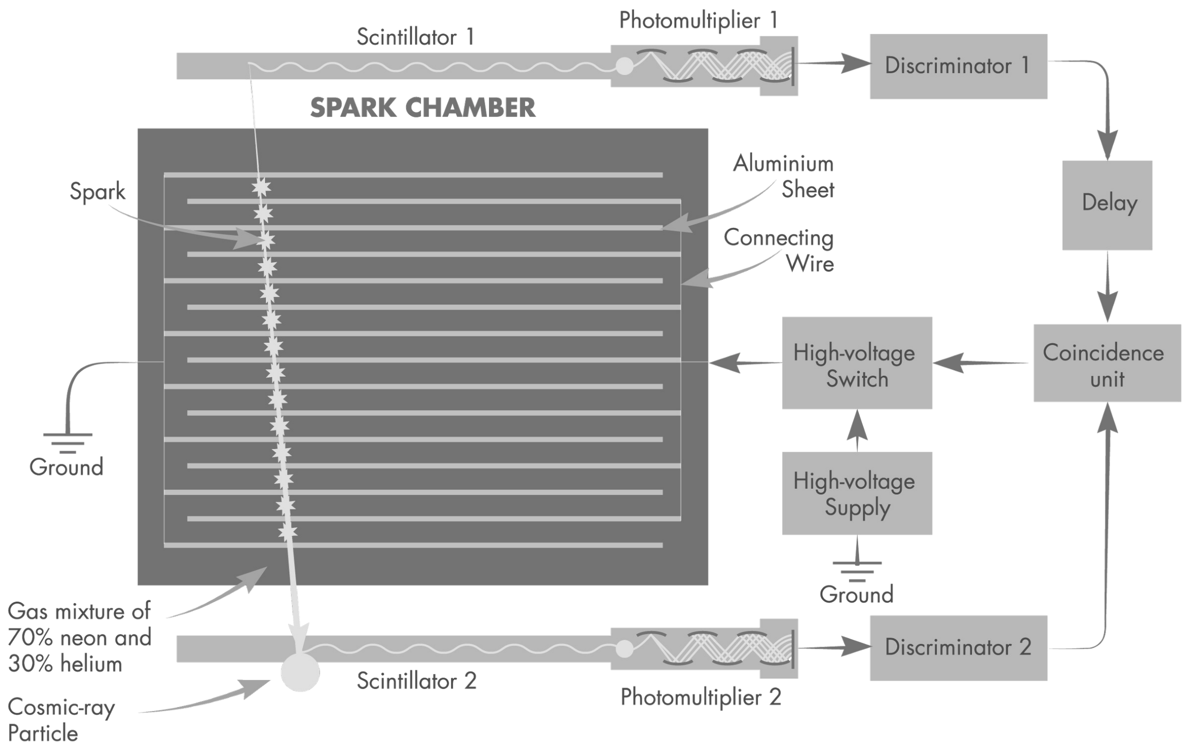
Appendix A

Component list for the cosmic ray telescope with vendors and estimate prices.

Component	Vendors	Price
High Voltage Crate (MPOD Mini)	Wiener (Plein & Baus Electronik)	$4,000.00
High Voltage Module (MPOD 8-channel SHV)	Wiener (Plein & Baus Electronik)	$3,400.00
NIM Crate (NIM Compact 150W)	Wiener (Plein & Baus Electronik)	$2,763.00
NIM Discriminator (NDL8)	Wiener (Plein & Baus Electronik)	$3,000.00
VME Crate (6U VME 195 Mini)	Wiener (Plein & Baus Electronik)	$4,660.00
VME Controller (XVB602)	GE Intelligent Systems	$3,400.00
VME ADC (V792NC)	Caen Systems	$4,229.00
VME TDC (V775NC)	Caen Systems	$4,413.00
Trigger Supervisor	Donation	$5,000.00
Phototubes	Donation	$3,200.00
Phototube Bases	Vorg Electronics	$1,600.00
High voltage and signal cables	Caen Systems	$1,000.00
DAQ Computer	Donation	$2,000.00
Oscilloscope (4-channel 300 MHz)	Tektronix	$9,480.00
Scintillator paddles and light gides	TRIUMF	$3,600.00

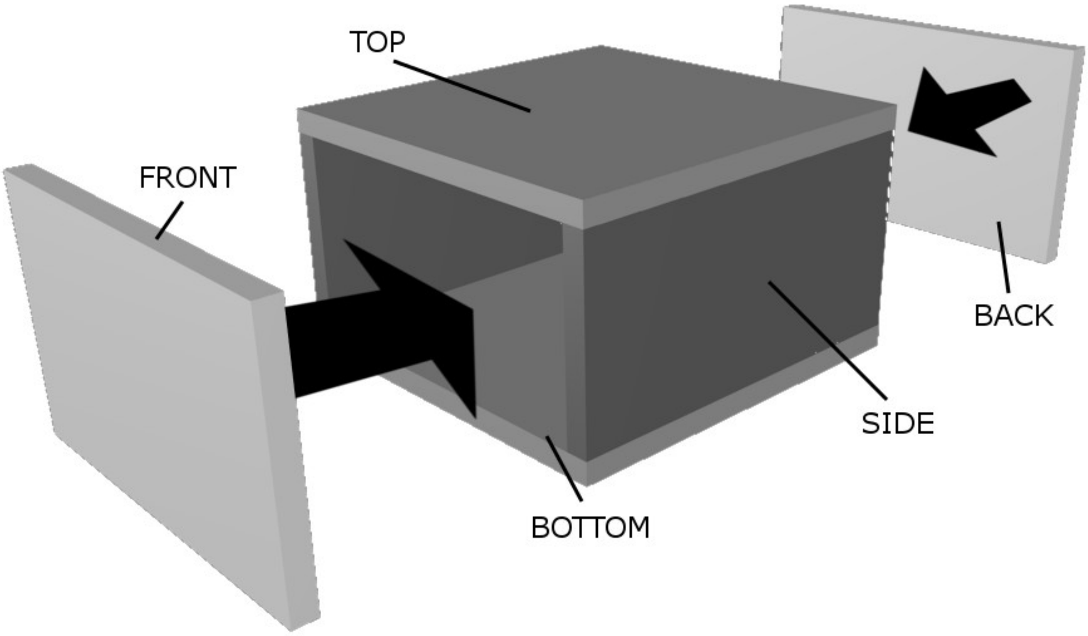
Appendix B

Diagram of the spark chamber inside a cosmic ray telescope (spark).



Appendix C

A diagram of the construction of the container.



Note: The electrical connections to the aluminium plates were made in the face labeled as front. The side in the foreground is currently held in place by four screws: two from the front face and two from the back.

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