An Affordable Particle Detector For Education

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Abstract

This project continues ongoing work done at Bristol University researching an affordable, safe particle detector to be used as experimental apparatus in 'A Level' education. In particular we built and tested Resistive Plate Chambers (RPCs). Typical configurations used in high energy physics use a gas mixture that includes freon and isobutane. We obtained results avoiding the use of freon which is a greenhouse gas and also looked at possible replacements for isobutane which is highly flammable.

Introduction

All main UK A-Level syllabus[5] feature particle physics at some point. Some feature cosmic rays in particular (Ref). Commercially available particle detectors seem to be restricted to cloud chambers and although there are relatively cheap [1] ones available, they need a source of dry ice, a resource that we estimate less than half of UK schools have access too [2]. A further problem with cloud chambers is that data is difficult to log. Although a video camera arrangement can be used, this is relatively costly in terms of equipment and requires time-consuming human analysis to get results. This also closes off the possibility of collaborative experiments such as the Swedish SEASA project where particle detectors from different schools are linked into a huge detector array[1] which is potentially valuable in terms of research.

We considered many other types of detectors to investigate. Work has already been done on scintillation based detectors and is being continued in a parallel project by a colleague at Bristol[2] however the latest estimates for costs are still quite high, £200 for a cloud chamber and at least £180 for scintillation based detectors[3]. We decided to investigate an entirely new avenue for the Bristol project and look into Resistive Plate Chambers (RPCs) chiefly because of the apparent low cost of materials for the chamber and the relatively simple design principle.

Most research into RPCs is for use in high energy physics laboratories and other industrial environments, not the classroom where the equipment will be in close proximity to schoolchildren. There are many inherant safety risks involved in RPCs which we aim to minimise in this project. In addition we have to take into account that, should the project be successful, our design will be produced in large numbers, we should try and avoid the use of harmful greenhouse gases which are prevailent in most current industrial RPCs.

RPCs were first devised in the early eighties[7] as an economic replacement for large-area scintillator detectors. However since then they have evolved considerably both in improvements on the basic design as well as adaptations to more specialist applications.

A Basic RPC Design

An RPC is closely related to the spark chamber in that it registers charge freed from ionising particles.

Figure (Ref) illustrates the basic RPC design which is made up of several layers. Moving from the centre we have a gas gap, followed by resistive plates, then the high voltage electrodes, followed by another layer of insulation and finally topped off with an arrangement of conducting readout strips.

The principle is much the same as other ionisation chambers in that a passing charged particle ionises the gas locally along its path in the gas gap. The resulting electrons and ions move towards opposite electrodes and it is this movement of charge that we measure. What makes RPCs different is the inclusion of resistive plates between the electrodes.

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[1] Fisher Scientific supply a Cloud Chamber kit in the US for *$60.45* [Cat. No: S52008]

[2] See research undertaken in section **??**

Figure 1: Schematics of a basic RPC

Resistive Plates

By resistive plates we mean a layer of material which is highly resistive. In early designs this was usually bakelite however the general trend now is towards float glass.

RPCs are closely related to spark chambers, however when a spark forms in a spark chamber a plasma channel forms which is highly conductive. This is sustained by the huge amounts of heat caused by a high current flowing along the channel in turn due to the high voltage between the electrodes. In order to overcome this the high voltage is not on continuously but rather ‘triggered’ by two seperate external detectors so that we see a momentary spark which is along the path of ionisation rather than a continous, unpredictable arcing. These external detectors tend to be the main reason why spark chambers cost so much[3].

The inclusion of two resistive plates make a big difference. Figure **??** shows a circuit diagram for an RPC and a spark chamber. R_{plasma} is low, whereas R_{plate} is very high (around $10^{1}1 - -10^{1}6\Omega$/Square for float glass). When we have a high voltage applied across just R_{plasma} as is the case with the spark chamber, the current is very high according to Ohm’s Law. However if R_{plasma} is nestled, in series, between two R_{plate} then the voltage across R_{plasma} is given by,

$$V_{plasma} = \frac{V}{2R_{plate} + R_{plasma}}$$

which is much lower than V, hence the current will be less and the plasma will dissapate once formed.

Originally the resistive layers were bakelite which had the right resistivity properties but had to be treated with linseed oil to obtain a smooth plane surface(Ref). Smoother surfaces help reduce electric noise [6] More recently

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[3] Bristol University Physics Department’s spark chamber cost in the region of £10,000!

float glass has been used since this has similar resistivity properties and does not need treating. It is also inexpensive and readily available in large sheets. The electrodes are typically graphite and applied to the outer surfaces of the resistive layers as paint. Graphite electrodes which have a fairly high resistance in comparison to, say, silver prevent the dispersion of the charge from happening too rapidly to reigister and are also electrically 'transparent' so that charge can be induced on the readout strips[**?**].

The gas mixture varies greatly between RPC designs, however they all have the following key properties,

1. Must be ionised only by particles of high enough energy as to be cosmic rays. Since cosmic ray energies are usually very high indeed (up to $20GeV$)this role is typically fulfilled by a noble gas such as Argon.
2. Must absorb residual ultraviolet light from the ionisation process to prevent further ionisation elswhere in the chamber. This gas is known as the 'quencher'.
3. Must have a high electron affinity to prevent too much lateral spread of electrons in the chamber.

Much research has gone into the gas mixture. Typical quenchers are Butane, Isobutane and Oxygen. Typical gases with high electron affinity include Carbon Dioxide, Freon and Sulpher Hexaflouride. Some real progress has been made by a Japanese group in finding a mix that is not highly flammable and does not include greenhouse gases[**?**].

Another important consideration is the

Further Study

RPC

Cerenkov detector in a Thermos flask

Appendix

Model

Reusing the code

Survey Results

Bibliography

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