Educational studies of cosmic rays with a telescope of Geiger–Müller counters

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Abstract

A group of high school students (XII Liceum) in the framework of the Roland Maze Project has built a compact telescope of three Geiger–Müller counters. The connection between the telescope and a PC computer was also created and programmed by students involved in the Project. This has allowed students to use their equipment to perform serious scientific measurements concerning the single cosmic ray muon flux at ground level and below. These measurements were then analysed with the programs on the basis of current knowledge on statistics. An overview of the apparatus, methods and results have been presented at several student conferences and recently won the first prize in a national competition for high school students' scientific work. The telescope itself, in spite of its 'scientific' purposes, is built in such a way that it can be hung on a wall in a school physics lab and count muons continuously. This can help to raise in interest in studying physics among others. At present a few (three) groups of young participants of the Roland Maze Project have already built their own telescopes for their schools and some others are working on it. This work is a perfect example of what can be done by young people when respective opportunities are created by more experienced researchers and a little help and advice is given.

Introduction

Cosmic rays (CR) were discovered in 1912 by Victor Hess. In his balloon flights he found an increase in the discharge rate of an electroscope with the height of the balloon. The electroscopes used in the pioneering years of cosmic ray physics were soon replaced by more sophisticated equipment: cloud chambers and Geiger–Müller counters. The former allow one to photograph tracks left by electrically charged particles in overcooled clouds. The latter give an electrical signal to any kind of electronic register. The simplicity of the Geiger–Müller (GM) counter makes it very useful.

The GM counters used by Rossi around 1930 worked in a coincidence mode, made from three electronic valves [1]. This significant electronic achievement of its time is shown in figure 1.

The coincidence method was used also by Roland Maze in an apparatus built by him on the roof of the École Normale Supérieure in Paris. It consisted of three sets of GM counters working in different coincidence modes. In 1938, Maze and Auger announced the discovery of huge

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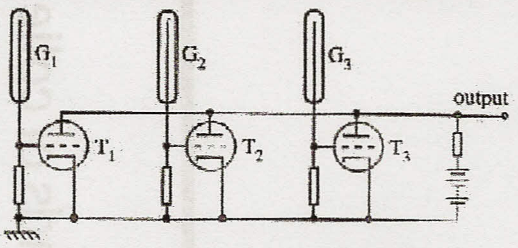

Figure 1. Three-fold coincidence circuit by B Rossi.

cascades of charged particles [2]. The CR particles initiating such phenomena have to have enormous energies, millions and even billions times greater than 'usual' resulting from radioactive decays and other nuclear reactions known in those days.

Cosmic ray studies have been recently intensively developed, especially in the region of the upper limit of the energy spectrum, where several events involving cosmic ray particles with energy exceeding 10^{20} eV (≈50 J) have been observed. Their existence is a very serious physical problem.

The experimental set-up for recording such events usually consists of a number of relatively simple particle detectors spread over a large area.

This is the point where high school education can meet high science. It is hard to imagine another subject of such great importance which can be studied jointly by scientists and students. It is not surprising that at present there are related projects under construction in the USA and in Europe [3].

One of them is the Roland Maze Project [4]. The proposed detection stations would be placed in the buildings of high schools. The detection system of one station (school) consisting of four plastic scintillators in different coincidence modes allows one to conduct (in parallel with the main scientific object of the project: studies of extremely high energy cosmic rays) independent observations and studies for each group participating in the project. It covers the whole, wide region of cosmic ray particle energies, giving the ability to study geophysics and atmospheric phenomena as well as monitoring the Sun's activity and space weather.

We have gathered many students interested in making 'big physics'. The construction of the project detectors and all the systems is going on, but in spite of that we have proposed many other activities to the students in order not to lose the initial impact.

Telescope of Geiger–Müller counters

One of the many by-products of the Roland Maze Project is the idea of making small cosmic ray detectors/counters which can be hung on the school wall showing to everybody that cosmic rays are everywhere and raising the interest in science in general.

The counters are arranged in telescopes of three Geiger–Müller counters working in coincidence. Such a set-up reminds us of the very first array of Maze and the school station of the Roland Maze Project.

The telescopes are to be built entirely by groups of students from each school. The only parts which cannot be made by them are GM counters, which are made in the A Sołtan Institute for Nuclear Studies in Łódź (the estimated cost of one tube is about 20 €). The counters are of glass with external cathodes. Such GM counters are called Maze type.

The electronic schemes of the particular circuits are also to some extent created by the students, especially if there is one in the group with some electronic experience. If there is no one, a general scheme is given and the particular solutions are then found empirically. This leads to breaking some electronic components, but eventually it leads to great satisfaction which is one of the more important factors when doing science and is hard to explain to the students in any other way.

The telescope whose results we want to present in this paper was made by students of the XII Liceum in Łódź (KK, RP and RS). A schematic view of the telescope is shown in figure 2.

The high voltage of about 1500 V needed to supply the GM tubes is created by a modified TV

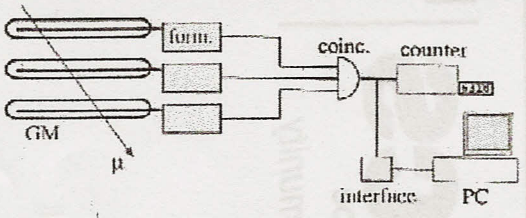

Figure 2. The schema of the telescope of GM counters.

HV transformer with a primary winding connected to a simple pulse generator of 5–12 V and secondary to the Villard cascade. The coincidence was realized with standard TTL monostables 74121 with a duration time of about 2 μs. A four-digit, seven-segment display of height about one inch was used to show the number of counts.

The telescope was equipped with a simple interface built on the basis of the 555 circuit used to connect it to the PC class computer. The interface was originally programmed under DOS in BASIC. The computer is able to continuously register telescope counts and to write them successively onto the computer disk.

All the documentation is available and can be obtained from the Roland Maze Project team.

Results

In figure 3 we show the number of counts registered every hour since the beginning of 2006 to the end of January. As is seen there are no abrupt (unexpected, as will be discussed later) changes, and this allows us to state that the telescope is working properly and rather stable.

The single muon flux changes with time, as has been known for a long time. The most pronounced modulation relates to the atmospheric pressure. Low energy (~GeV) muons originate

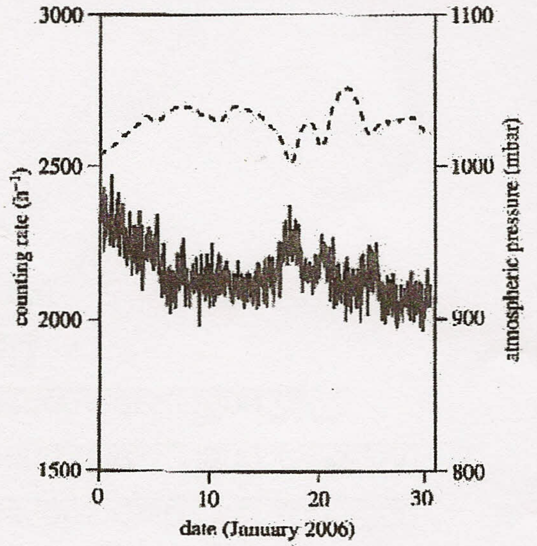

Figure 3. The telescope counting ratio (solid line and left scale) and atmospheric pressure (dashed line and right scale) registered in January 2006.

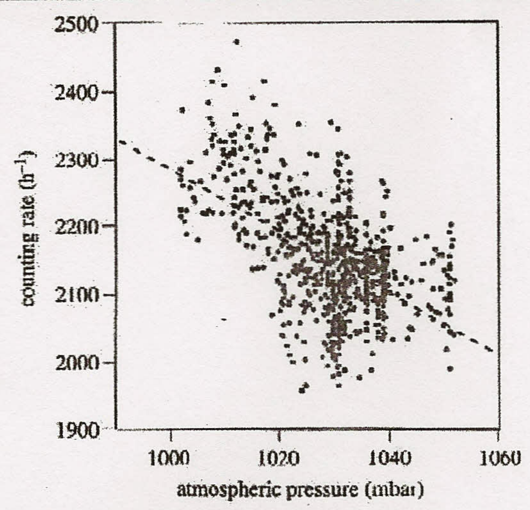

Figure 4. Scatter plot of telescope counting rate versus atmospheric pressure registered in January 2005. Each point represents the counting results from one hour.

in the upper levels of the atmosphere and have to traverse almost the whole atmosphere (hundreds of grams per cm^2 of air). The amount of air above us changes continuously. These changes are a subject of interest to billions of people around the world. They are presented several times every day in TV weather reports on most of the TV channels as values of the atmospheric pressure. The pressure of 1000 mbar informs us that above every square centimetre there is about 1 kg of air.

If the atmospheric layer to traverse is thicker then the flux of muons is diminished, mainly due to energy losses. Thus an anticorrelation of the telescope counting rate and atmospheric pressure is expected. The values of the pressure from the local meteorological station Lublinek were taken from the respective Web page and they are plotted in figure 3. Fortunately, because of the very rapid and substantial changes of the pressure in January, the anticorrelation is clearly seen by the naked eye.

To study it in detail, in figure 4 we show the scatter plot of the telescope counting rate versus atmospheric pressure. The dashed line plotted there is the best linear fit. To relate our result to the one known from the literature we can express it as a relative change of the counting rate with respect to an increase in pressure of 1 mbar. Such a value is called a *barometric coefficient*. Our result is $-0.21 \pm 0.04\%$ mbar^{-1}.

It is interesting to mention the work of an Italian group [5]. Their general idea was similar—

to study the barometric effect with the help of simple computerized apparatus based on one small GM counter. Comparison shows that the results obtained by them, -0.051 ± 0.015 (or even -0.023 ± 0.009, based on 3.5 months of running the experiment), are significantly different from ours. The simple explanation for this difference is that the coincidence of three GM counters used by us guarantees that the counts we registered are definitively particles crossing areas of our GMs, and taking into account the thickness of the GM counter walls they have to be mostly cosmic ray generated muons. Without such a coincidence the single GM counter measures any kind of radiation which can penetrate the active GM counter volume. Only a fraction of it depends on atmospheric pressure.

The known flux of vertical muons given by the Particle Data Group gives the expected counting rate, and after simple geometrical integration we checked that it is consistent with our measured value (shown in figure 3).

Further planned measurements

The telescope can be used also to make other measurements, among which the most obvious is determining the zenith angle dependence of the single cosmic ray muon flux. It is known that this dependence is a power law in the cosine of the angle. If this is so then it can be shown that, when the plane of the GM telescope is inclined, the counting rate decreases by the factor determined exactly by the same power law. The value of the index could in this way be the subject of direct measurement.

Studies of the temperature effect as well as searching for periodic muon flux variations (27 days, one day, semidiurnal to name only the shortest) are possible subjects of further interesting studies. They need not only a much longer period of observation, but also special tools for seeing something (a signal) where it is not seen 'by the naked eye' obscured by 'a noise'.

An attractive project is looking for correlations of CR flux with other phenomena, e.g., studies on the influence of the cosmic ray intensity on the Earth's climate, weather, or on the wheat price in medieval England. The question of whether CR muons are correlated with average marks in school tests can attract large numbers of students.

Conclusions

We have shown that cosmic rays are among the subjects of contemporary physics which are particularly useful for raising interest in science amongst students at high schools. The present work proves that students are able to construct apparatus which may be used to give quite accurate data on cosmic rays at ground level. The value of the barometric coefficient can be obtained and other interesting studies can be performed. The analysis of the data gives a perfect possibility for students to be introduced to statistical methods at a level not available in standard courses.

The Geiger–Müller telescope hanging on a classroom wall and showing continuously the number of muons crossing it works well at increasing the mental horizons not only of young people but also of all who see it.

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K Kolodziejczak, R Pierzynski and R Sobczak (left to right above) are students of the XII Liceum in Lodz. They have been involved in activities of the Roland Maze Project for about two years. This year they finish high school and will go on to university to study subjects including informatics and high technology.