Experiment 357: Cosmic Rays

Aim

To familiarize students with the major components of the cosmic radiation at sea level and to introduce students to techniques used in identifying high energy particles.

Reference

Wolfendale, A.W. "Cosmic Rays", Newnes, 539.7223 W85.

Brief Survey of Cosmic Rays

The existence of a penetrating radiation coming from outer space was demonstrated early in the century by measurements on the conductivity of gases. The origin of these "cosmic rays" is still unresolved. They are not of solar origin, and more energetic objects such as supernovae, pulsars and galactic nuclei are considered as potential sources. The primary radiation incident at the top of the atmosphere has been found to consist almost entirely of protons and heavier nuclei with energies ranging from hundreds of MeV up to, in rare cases, about 10^{14} MeV. When they interact with air nuclei, most varieties of elementary particles are produced. Many of the known particles were in fact discovered in cosmic ray studies. The most commonly produced particles are pions and kaons. The charged pions, if they do not interact, decay to muons as do some of the kaons. The majority of the muons traverse the remaining atmosphere without interacting or decaying. These muons form the bulk of the radiation at sea level. Electrons, positrons and photons originating from neutral pions comprise most of the remainder. Hadrons (mostly protons and neutrons) are present at about the 0.1% level only. The two major components may be distinguished by their ranges. The muons (hard component) are relatively penetrating whereas the electrons and photons (soft component) are not.

Experimental Set-up

Fig. 1 shows the general set-up for the experiment. The cabling, except for the dashed portions, should not be altered. Some parts of the experiment do not utilize all six Geiger-Muller (G-M) tubes. **Do not disconnect those not in use.**

The G-M tubes (Centronic G38 - effective area $135\,\text{cm}^2$) are delicate and must be handled with care. They may be handled with the high voltage on. A similar but smaller tube is included for inspection.

The amplifiers were designed and constructed by T.G. Caldwell (M.Sc. thesis available at 4th floor office). Output pulse is $+10\,\text{V}$ and $100\,\mu\text{s}$ wide.

The delay generator introduces a delay of $40\,\mu\text{s}$. Its output pulse is $20\,\mu\text{s}$ wide. The delay generator is used in Part 5 only.

The coincidence unit is ORTEC model 418A. See the instrument manual for details of its operation. Only inputs B, C, D and E should be used. Pull out the locking sleeves before toggling the switches.

1 Introduction

(1) Verify that at a common high voltage of 1230 volts the G-M tubes all operate stably, i.e. on their "plateaux". This may be done by checking that the individual count rates for each tube (unshielded by the steel support or lead blocks) are approximately the same at 1220, 1230 and 1250 volts. One-minute runs suffice here.

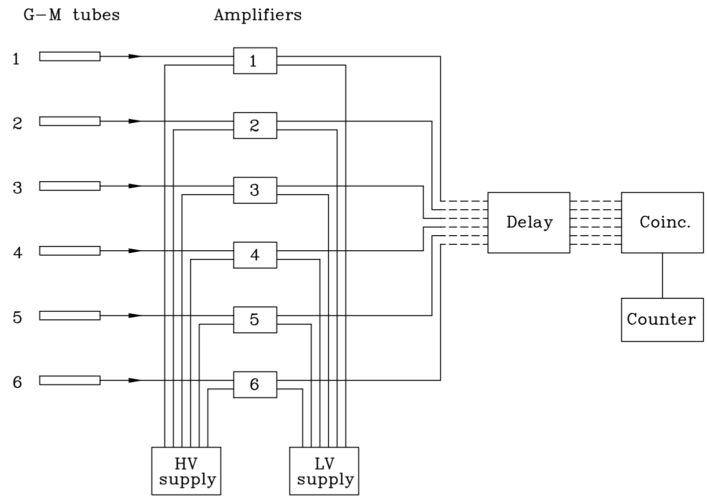

Figure 1: Experimental setup

Question 1: How do the G-M tubes work?

(2) Using the set-up shown in Fig. 2, observe the particle-like nature of the radiation, i.e. check that the triple coincidence rate for three tubes in a line is much greater than the rate when they are not collinear.

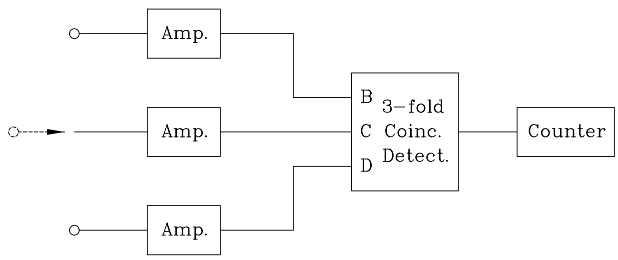

Figure 2: Setup for triple coincidence detection

2 Hard and Soft Components

(3) Using 5 GM tubes in the arrangement shown in Fig. 3, measure the two-fold coincidence rate (1 or 2 or 3) and (4 or 5). The cabling needed to achieve this is shown in Fig. 4. The rate should be

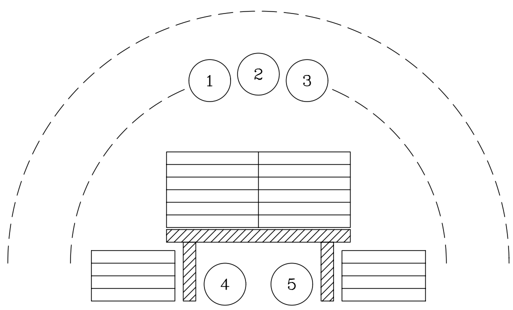

Figure 3: Experimental setup for section 2

measured with 0, 1, 2, ..., 10 layers of lead. Use the gloves provided for handling the lead. By using the "or" technique the count rate is increased and statistical accuracies of $3 - 4\%$ may be achieved in approximately 15-minute runs.

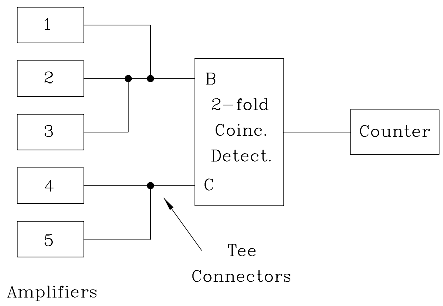

Figure 4: Wiring diagram for section 2

(4) Plot the rate as a function of absorber thickness and identify the hard and soft components.

(5) Using the data given in the Appendix, estimate the effects of the steel layer and the laboratory roof on your results.

(6) Determine the vertical sea-level fluxes and compare your results with those given in the Appendix.

3 Extensive Air Showers (overnight running required)

High energy primaries generate dense showers of electrons and positrons at sea level. These arise from secondary, neutral pions decaying to gammas which pair-produce electrons which in turn multiply in the atmosphere via bremsstrahlung and pair production processes. These showers may be observed by sampling them, e.g. as three-fold coincidences in a horizontal, triangular, unshielded array such as that shown in Fig. 5.

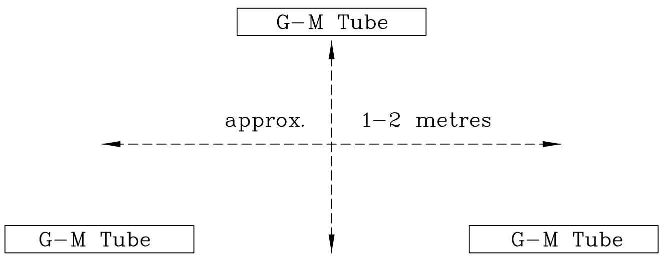

Figure 5: Experimental setup for section 3

(7) Measure the shower rate in an overnight run.

(8) Using the data given in the Appendix, estimate roughly the (minimum) energies of the primaries which produce such showers. Estimate also the primary cosmic ray flux at these energies. Show that the triple coincidences are really caused by showers, i.e. that they are not random coincidences of single counts.

4 Muon Zenith Angle Distribution

(9) Using three GM tubes in the arrangement shown in Fig. 6, measure the two-fold coincidence rate (1 or 2) and 3 as a function of the zenith angle θ.

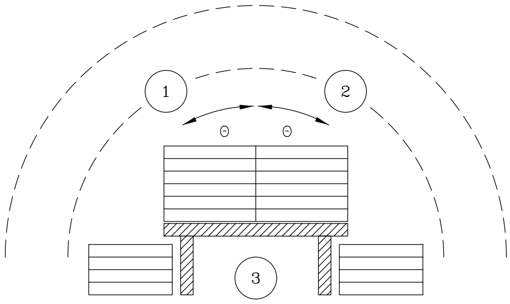

Figure 6: Experimental setup for section 4

(10) Plot the rate as a function of $\cos^2 \theta$. 15-minute runs provide adequate accuracy for these measurements. The lead shielding is of course included to stop the electromagnetic component.

Question 2: Why does the rate fall as increases?

Question 3: Is the rate symmetrical, i.e. equal for θ_L and θ_R? If not, why not?

5 Interactions: Pair Production, Bremsstrahlung and Hadronic

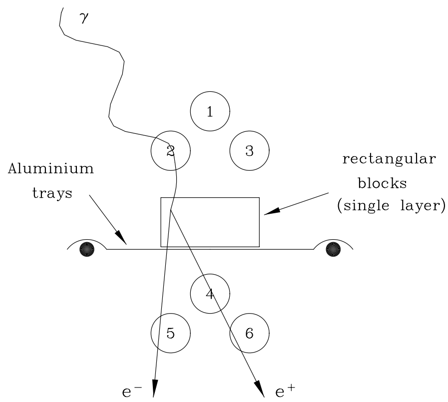

Figure 7: Experimental setup for pair-production

(11) Using the set-up shown in Fig. 7, observe pair production induced in lead by gammas as three-fold coincidences (4 and 5 and 6) in association with a NOT(1 or 2 or 3) veto. To accomplish the veto, any one of the 4, 5 or 6 outputs should be routed through the delay generator prior to the coincidence unit. Why?

The rate measured with the configuration shown in Fig. 8 is quite low and an approximately 45-minute run will be needed. The background rate with the lead target removed needs to be measured also in a similar length run and subtracted.

Question 4: What is the background caused by?

(12) Bremsstrahlung and pair production may be observed with the same set-up but as four-fold 4 and 5 and 6 and (1 or 2 or 3) coincidences (Fig.9). Again the background with the lead removed needs to be subtracted. Similar length runs as those above are needed here.

(13) It is conceivable that the interactions observed in procedure (11) are due to neutrons undergoing nuclear interactions in the lead blocks. Similarly, in procedure (12) protons could be responsible. To rule out these possibilities, measure the interaction rates with the lead target replaced by the aluminium

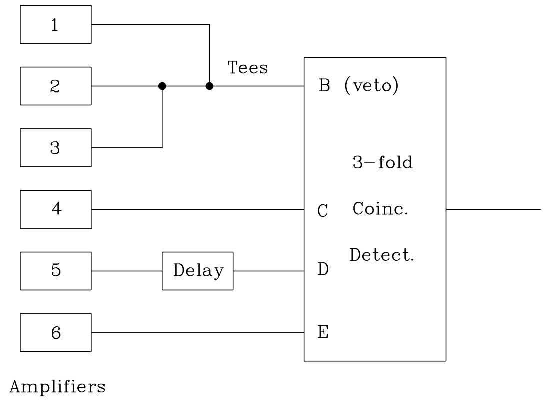

Figure 8: Wiring diagram for detecting pair production

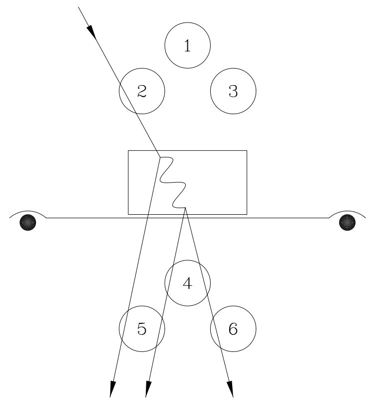

Figure 9: Experimental setup for bremsstrahlung and pair production

target provided. The aluminium target of four layers presents a comparable cross section for nuclear interactions as does the lead target with one layer, but a much smaller cross section for electromagnetic interactions (show this). It will be found that the coincidence rates caused by the aluminium target are relatively low verifying that the interactions observed in procedures (11) and (12) are electromagnetic and not hadronic.

The above use of high and low Z targets to distinguish between electromagnetic and hadronic interactions is used extensively in current high energy particle physics experiments. Similarly, the technique used in Section 2 to identify muons by their penetrabilities is also used extensively.

Appendix

Physical constants (in units adopted in Cosmic ray studies)

Depth of atmosphere (mass of 1 cm^2 column of the atmosphere)		1000 $g\,cm^{-2}$
Electron radiation length x_o (x_o/density is the average distance traversed in matter when energy is reduced to 1/e of its original value)	Air: Al: Fe: Pb Reinforced concrete:	36.20 $g\,cm^{-2}$ 24.01 $g\,cm^{-2}$ 13.84 $g\,cm^{-2}$ 6.37 $g\,cm^{-2}$ 27 $g\,cm^{-2}$
Electron critical energy (energy above which energy loss due to bremsstrahlung is greater than that due to ionization)	Air:	84 MeV
Cosmic ray fluxes in vertical direction at sea level	Hard component: Soft component:	$0.8 \times 10^{-2}\,cm^{-2}\,s^{-1}\,sr^{-1}$ $0.3 \times 10^{-2}\,cm^{-2}\,s^{-1}\,sr^{-1}$

List of Equipment

1. 6 × Centronic G38 GM tube
2. 6 × Amplifiers: Output +10 V, 100 μs wide
3. Delay Generator: Delay 40 μs, output width 20 μs
4. ORTEC model 418A Coincidence Unit
5. Counter
6. HV Power Supply
7. LV Power Supply

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