1. Introduction

1.1 Object of the Experiment

The object of this experiment is to make you familiar with some of the tools of high energy physics, in particular with scintillation counters and some fast electronic logic. The high energy particles you will detect are cosmic rays (mainly electrons and muons at sea level).

A brief explanation of the principle of operation of the equipment is given in section 4. Read this before starting the experiment. For more information, ask a demonstrator.

1.2 Equipment

Two scintillation counters mounted one above the other, each consisting of 200 x 200 x 10 mm of plastic scintillator, a shaped light guide, an EMI 9813 photomultiplier (PM) and a base.
A Brandenburg photomultiplier power supply model 486
An Oltronix HT distribution unit
A powered NIM crate containing a quad discriminator and a coincidence unit
A 4-channel delay unit
A DVM to monitor the HT on each counter
A Thandar LCD frequency meter
A Tektronix high speed oscilloscope
Various cables to connect equipment
A β source (use source no P/S41 A)

1.3 Safety Points

1.3.1 High Voltage Safety

- NO CHANGES TO HIGH VOLTAGE CONNECTIONS SHOULD BE NECESSARY.
- MAKE CHANGES ONLY UNDER THE SUPERVISION OF A DEMONSTRATOR
- DO NOT OPEN HT UNITS
- TURN OFF HT SUPPLIES WHEN CONNECTING OR DISCONNECTING CABLES

1.3.2. Radiation Safety

- KEEP THE SOURCE IN ITS CONTAINER WHEN NOT IN USE
- DO NOT POINT THE OPEN END AT YOURSELF OR ANYONE ELSE
- DO NOT TAMPER WITH THE SOURCE
- HANDLE USING TONGS
• WASH YOUR HANDS AFTER USING THE SOURCE AND BEFORE TOUCHING FOOD
• DO NOT HANDLE THE SOURCE IF YOU ARE PREGNANT
• RETURN THE SOURCE TO THE STORE WHEN YOU HAVE FINISHED USING IT

2. Procedure

2.1 Initial setting of Counter HVs

Fig. 1 show the interconnection of the apparatus for making the final measurements. At intermediate stages you may have to disconnect some of the signal cables (but not the HV ones). Refer to this diagram to make sure that you have restored the connections correctly.

![Figure 1. Interconnection of apparatus.](image)

Switch on the NIM crate, Scaler, DVM and HV Power Supply. Place the β source in the middle of the upper counter (counter A). Connect the anode of A to channel 1 of the 'scope using a T-piece and 50-ohm terminator (a guide to setting up the 'scope is given in the appendix). Using the HV distribution unit set the voltage on counter B to its minimum value (set the multi-turn resistor to 0) and that of counter A to its maximum (10), set the HV to 1.80 kV on the DVM monitor when you should begin to observe pulses. Increase the HT further until the maximum pulses seen are about 1 V (do not raise the HV above 2.20 kV). Check that there is no DC level from the PM by removing the 50-ohm termination and observing any change in the 'scope trace - if the baseline moves down it indicates a light leak in the counter - turn off the HT and call a demonstrator). Note the HT at which you see 1V pulses. Set the HT on counter A to minimum and repeat the for counter B.

2.2 Use of Discriminators.

Connect the output of the PMs into two of the discriminators - note the input of the discriminator is 50 ohms so no additional 50-ohm terminator is needed. With the source on counter A observe and sketch the pulses from the o/p labelled A on the discriminator unit. If necessary, use a small screwdriver to adjust the "width" control and set it to give a pulse about 30 ns wide.

Repeat for counter B.
For each counter in turn measure the counting rate WITH and WITHOUT the source in place as a function of HV from 1.80 kV to 2.20 kV in 50 volt steps.

### Counter B

<table>
<thead>
<tr>
<th>HV (kV)</th>
<th>No source</th>
<th>With source</th>
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<tr>
<th>HV (kV)</th>
<th>No source</th>
<th>With source</th>
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Plot a graph for each counter showing the count rate against HV for a) no source (the noise rate), b) with source (signal + noise) and c) the difference (the signal). If all is working well, the signal rate graph should show an initial steep rise followed by a plateau as the HV is increased. If the data is approximated by two straight lines, one for the steep rise and the other (horizontal) for the plateau, then the HV should be set to 50V above the value at the intersection of the lines. Show your plots to a demonstrator.

Set the HV for the two counters to the values selected.

You have now finished with the source- return it to its container and then to the store.

### 2.3 Use of the Coincidence Unit

Connect the outputs of the two discriminator channels to the oscilloscope. Set the scope to trigger on input channel 1 and set it to ALT (alternate) mode so that the discriminated pulses from A and B are displayed alternately. Note that A always displays a pulse whereas B shows one only occasionally. When it does it is mainly due to a single particle which has passed through both detectors.

QUESTION: Assuming cosmic rays travel at the speed of light, how long do they take to get from the upper to the lower counter?

Now connect the o/p from the photomultiplier into scope. Note that a 50Ω terminator is required. In your report, sketch the pulse that you can see on the scope, indicating clearly the vertical and horizontal scales and the pulse height and pulse width.

Count and plot the coincidence rate as a function of HT on the counters, varying them together using the controls on the Brandenburg supply only (do not go above 2.2 kV).

Comment on your graph and restore the HT values to those chosen at the end of section 2.2 above.

Now interpose a delay unit between the discriminator output and the coincidence unit for one counter and measure the coincidence rate (for 60s) as a function of delay, adding in the delay due to any additional cable now in this channel. Observe the output from the coincidence unit as a function of delay. Repeat with the other counter delayed and then plot the coincidence
rate as a function of (delay B - delay C). Your measurements should be evenly spaced in terms of the delay, and should range from approx. -20 ns to +20ns.

| Coincidence rate (counts/60s) as a function of (delay B- delay C) (ns) |
|-----------------------------|-----------------------------|
| delay B–delay C | Coinc. rate | delay B–delay C | Coinc. rate |
| 3. Determination of the Cosmic Ray Flux |

Estimate roughly the solid angle subtended by the two counters together and hence determine roughly the vertical cosmic ray flux at sea level in units of $cm^{-2} min^{-1} sr^{-1}$. All necessary calculations should be included in your report.

4. Description of Apparatus

*Scintillation counter and light guide.*

The scintillator is made of plastic loaded with a chemical, which scintillates when a charged particle passes through it. The charged particle loses energy passing through the material (electromagnetic interactions between the field of the moving particle and the atoms of the material). Some of this energy excites the scintillation centre atoms. When they relax, they emit light (normally in the blue or near UV wavelengths - see sample). For the plastic scintillator used here the relaxation time is only a few nanoseconds. The scintillator is connected to a photomultiplier (see below) by a clear plastic lightguide. The purpose of the guide is to funnel light from the scintillator to the front face (photocathode) of the photomultiplier.

*Photomultiplier and base.*

The photomultiplier (PM) used here is an EMI 9813 with 14 stages of amplification. The PM is an evacuated glass tube with a photocathode at one end, a series of amplifying dynodes and the output anode. The photocathode is held at a large negative voltage (~2 kV) and each dynode is held at progressively more positive voltages up to the anode which is at 0 V. Light from the light guide strikes the photocathode and knocks out electrons. The electric field accelerates these towards the first dynode, which they hit with sufficient energy to knock out a few electrons for each initial photoelectron. These are accelerated towards the second dynode where the process is repeated. This continues until the final cloud of electrons hits the anode and produces the output signal (a negative pulse of around 15 ns FWHH). Gains of up to $10^8$ are possible.

The base contains the network (mainly a simple resistor chain) for supplying the voltage to the cathode and dynodes.

*High voltage supply and distribution unit.*

The negative HV to the photomultiplier is supplied by a Brandenburg photomultiplier power supply model 486 and an Oltronix HT distribution unit. The power supply level is set by push
buttons on the front of the unit and a multi-turn potentiometer for fine adjustments. A meter on the front of the unit shows the output voltage. Do not exceed a setting of 2.20 kV.

The output of the power supply is connected to the distribution unit, which can supply up to four photomultipliers via four variable series resistors. Using these resistors each output voltage can be reduced by up to about 200V below the supply voltage. A switch allows the output of each channel to be monitored on a panel meter or output to a DVM for more accurate measurement. The DVM output level is 1 V / 1 kV of HV output.

A DVM is supplied so that you can monitor the HV on each counter

*Logic crate and modules*

A powered NIM crate containing a quad discriminator and a coincidence unit provides the logic modules for the experiment. The crate provides a standard format into which a range of electronic processing modules can be plugged. The crate provides the power supplies used by the processing modules.

A discriminator is a device that gives a well-shaped output pulse for any shaped input pulse above a certain voltage (known as the discriminator level). The discriminators supplied have a preset value of -100 mV. There are 4 independent discriminators in one module. The output from the discriminator is normally close to 0 V and goes to -700 mV for a set period when the input exceeds the threshold (goes more negative then -100 mV). To operate correctly, the outputs of the unit must be properly matched to 50 ohms. Note the effect of removing the 50-ohm terminator from the NOTA output.

A coincidence unit provides a logic level output if signals at its inputs overlap in time. The coincidence unit supplied here has four channels and the number of channels overlapping to create an output signal is set by an individual switch on each channel. If a switch is set to IN then that signal must be present, if set to OUT that signal is ignored. With only two input signals, if both channels are set to IN, coincidences between the two signals produce an output. If only one is set to IN (say on channel A) then any signal on that channel produces an output (there is an output signal for every input signal on that channel). The width of the output signal is equal to the overlap time.

A 4-channel delay unit is used to provide the relative delay between the two channels. A convenient way to make the delay measurements is to connect each output from the discriminator to one channel of the delay unit and thence to the coincidence unit. If similar cable lengths are used for each channel then the difference in delay between the channels is given by the difference in the delay settings for the two channels. Set channel A delay to 0 and delay channel B to get one half of the graph and then set channel B delay to 0 and delay channel A to get the other half.

*Count rate measurement*

In the absence of a counter, a Thandar LCD frequency meter is used to measure the count rate. The input is supplied through a 50-ohm feedthrough to the top (high impedance) input. Low frequency is selected and the 10k/10s timing used. With this selection the unit counts input signals for 10 seconds and then displays the value obtained while it takes another measurement. The suggested way to use this to make measurements is to set up the measuring conditions, ignore the first new value (as conditions may have changed part way through its timing period) and then note the next several values. If you take five values this is equivalent
to counting for 50 seconds and so the statistical significance is better than one 10 second measurement. In addition, you can detect if any one measurement is anomalous. As you are measuring individual counts the expected error level is given by \( \sqrt{N} \) and any measurement more than 3*\( \sqrt{N} \) away from the average is unlikely.

**Signal observation**

A Tektronix high-speed oscilloscope is provided to enable you to observe signals. Because of the relative low rate and short duration of the signals it is not very easy to see them even with a fast scope. The scope should be set to trigger internally on channel 1 for negative signals. Channel 1 sensitivity should be set to 0.2 volts and the timebase to 50 ns /cm. At some point it may be better to change to 200 ns/cm x10 but this is more difficult to set up. Ask a demonstrator for help if you have difficulty getting the scope to display signals.

**Cables, 50-ohm terminators and feedthroughs.**

The HV co-axial cables and connectors are designed to be safe with more than 2.5 kV. However, as stated at the front of the script, never have the high voltage on with an unconnected HV cable lying around. They should always be plugged in.

The signal cables are co-axial 50-ohm cables. This means that they should be matched at the input of units to prevent reflections (and therefore distortions) of the signal. If the input is not matched to 50 ohms, then either use a T-piece and a 50-ohm terminator (this is handy is you want to observe what happens when the match is removed or you want to connect the signal to a second (matched) input) or a 50-ohm feedthrough (these provide a neat way of getting the signal into a high impedance input and matching the cable at one and the same time).