

A New Cosmic-Ray Telescope for High Altitudes

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A cosmic-ray telescope is described having an angular resolution of approximately $\pm 15^\circ$. The distance between the two outermost trays, each containing 8 Geiger counters, is 1 meter. The area of each tray is approximately 24×24 cm². Triple coincidences modulate a transmitter and the signals, including those giving the air pressure and temperature of the instrument, are recorded on the ground. The counting rate is such that at the peak of the curve the relative probable error during a 4 minute interval is about 1.5 percent.

Accidental counts are found to be nearly negligible at all altitudes and latitudes, but some correction needs to be made for loss in efficiency because of the inherent dead time of the counters. An absolute determination of cosmic-ray intensity at the vertical at Pasadena was made in order to express the results as nearly as possible independently of the apparatus used.

I. INTRODUCTION

THE cosmic-ray instrument used by Millikan, Neher, and Pickering¹⁻³ from 1939-1942 in their exploratory work on the variation with latitude of cosmic rays coming in near the vertical, suffered from the major defect of collecting the radiation from too large an angle. With the counters then used, the choice had to be made between a small solid angle giving a low rate of counting or a larger solid angle giving a higher counting rate with its smaller statistical error. The extreme solid angle used was 45° in one direction from the vertical by 25° in the other. The counting rate at the maximum of the curves taken in the United States was such that over a period of four minutes the probable error was about ± 1 percent.

In redesigning the equipment it was thought desirable to keep the counting rate at least as high as in the previous equipment, and to reduce the angle of collection to something like 15° on all sides of the vertical. To accomplish this, required sensitive counter areas of approximately 600 cm², in the shapes of squares, with a separation between outside areas of about 1 meter.

To achieve the above with an instrument of a minimum weight and at the same time to have

¹ H. V. Neher and W. H. Pickering, *Phys. Rev.* **61**, 407 (1942).

² H. V. Neher and W. H. Pickering, *Rev. Sci. Inst.* **13**, 143 (1942).

³ W. H. Pickering, *Rev. Sci. Inst.* **14**, 171 (1943).

the required degree of accuracy and reliability was the problem we set for ourselves.

II. GENERAL DISCUSSION OF REQUIREMENTS

1. Weight

In planning an extended series of flights in regions where winds must be contended with, it is very desirable to keep the number of balloons to a minimum. Two balloons can be handled nearly as easily as one, and their use means that after one bursts, the other will remain to lower the instrument back to earth and serve as a temporary marker, thus facilitating recovery. Two good, 2000-g balloons, which are the largest commercially available at the present time, will lift a load of 8 kg to about 85,000 ft., which for our purpose was sufficiently high. It was therefore desirable to keep the total load, including 1800 cm² of counter area, batteries, amplifiers, transmitter, wrapping, and a suitable framework, down to at least this figure.

2. Accidentals

The counting rate for a single counter could be estimated approximately from previous flights with electroscopes^{4,5} and counters.¹ With the size of counter and counter area used, 2200 counts per second per tray were expected as a

⁴ I. S. Bowen, R. A. Millikan, and H. V. Neher, *Phys. Rev.* **53**, 855 (1938).

⁵ Robert A. Millikan and H. V. Neher, *Proc. Am. Phil. Soc.* **83**, 409 (1940).

maximum. To keep the number of accidentals to less than 1 percent, it was necessary to have a resolving time of about 2×10^{-6} sec., even though triple coincidences were used.

3. Efficiency

Loss in efficiency may be caused by at least two factors. (a) Failure of a counter to respond to the passage of an ionizing particle at low counting rates. (b) A similar failure at high counting rates. The first may occur when a particle passes near the edge of a counter when the product of path length and the pressure of the gas is such that there is some chance of not producing at least one ion pair. The second will occur because of the fact that the counter is dead for a short time after a discharge occurs.⁶ This dead time varies somewhat with the gas pressure, the geometry of the counter, and applied potential but is from 1 to 2×10^{-4} sec. for the average counter.

For a single counter, if τ_0 is the dead time and N ionizing particles per unit time on the average pass through the counter, the relative number missed will be $N\tau_0$ and the efficiency, ϵ , will be $(1 - N\tau_0)$.

Since the over-all efficiency of an n -fold coincidence set is ϵ^n , if the counters are all similar and counting at the same rate, it is desirable to keep n as small as possible consistent with accidentals and other requirements.

4. Power Supply for Counters

In the Geiger counter apparatus used by Millikan, Neher, and Pickering^{1,2} for balloon

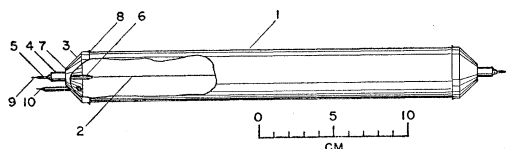


FIG. 1. Light weight Geiger counter: 1. Metal cylinder is formed from copper plated sheet steel, 0.025-cm thick. The joint is a locked seam that is silver soldered together simultaneously with 7 and 8; 2. tungsten wire, 0.0025 cm in diameter; 3. copper plated steel caps; 4. Kovar eyelet containing glass bead; 5. small Kovar tubing; 6. glass covering to Kovar tubing; 7, 8. silver soldered joints; 9. pinched when wire is taut, then silver soldered; 10. tubulation. Copper tubing is pinched to a feather edge to seal. Weight of completed counter, 90 g; sensitive area, 80 cm².

⁶ H. G. Stever, Phys. Rev. 61, 38 (1942).

work a light weight, high voltage supply employing a buzzer, transformer, and rectifier was used. Such a supply was found to be impractical for the present work because of the high current demands of 24 counters each counting at a maximum rate of 250 sec.⁻¹ The current drain at this counting rate was about 25×10^{-6} ampere for this number of counters—a current drain much too large for the high voltage supply used previously.

The development of light weight dry cells has now made it possible to use batteries with a cost in weight of about 1.6 g per volt. The use of such batteries has the very great advantage that the potential on the counters is maintained constant throughout the flight.

5. Mounting

It is highly desirable from every point of view so to mount the components that are to be carried aloft that on landing a minimum of damage will be done. In the series of flights reported in the following article the returned instruments could usually be connected to the proper power supplies, and they would immediately start to count at a rate in close agreement with that before being sent up.

6. Temperature

In the previous flights a double covering of Cellophane and black paper provided a sufficient equilibrium between heat gained from sunlight and heat lost that during a flight the temperature of the instrument varied less than $\pm 5^\circ\text{C}$. On these flights, presumably because of the much larger ratio of surface to mass, the temperature range was usually about $\pm 10^\circ$ from that at take-off. Such small variations in temperature guarantee nearly laboratory conditions during the course of the flight.

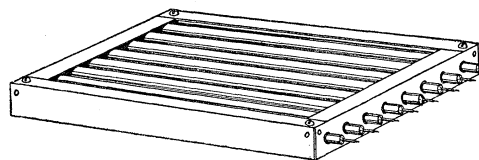


FIG. 2. Eight counters were mounted rigidly in a framework to form a sensitive area of 600 cm². Three of these trays were used to count triple coincidences. The weight of each tray was 850 g.

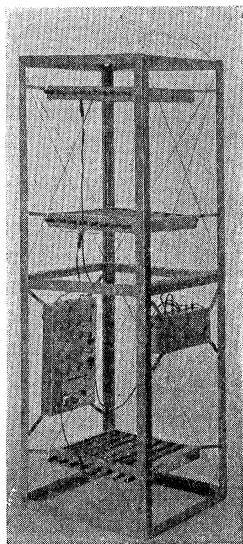


FIG. 3. The components were shock mounted in an aluminum framework. The weight of the whole assembly including 1800 cm² of counter area was 8 kg.

7. Pressure of the Air

An aeroid barometer measured the change in pressure relative to the pressure at ground level at take-off. A more satisfactory instrument for low pressures would be one that measured pressures with respect to a good vacuum. In the flights made with this equipment the errors in the determination of the air pressure were often larger than the uncertainty in the cosmic-ray intensity.

III. DESCRIPTION OF THE APPARATUS

1. Counters

From considerations of weight, ruggedness, and ease of construction it was decided to use metal-walled counters. It was found that sheet steel with a wall thickness of 0.025 cm was sufficient, when bent into the form of a cylinder 3.3 cm in diameter and the seam locked, to withstand atmospheric pressure even when baked at 300° to 400°C. When the steel is copper plated the whole may be silver soldered together in a hydrogen atmosphere.

The small metal tube through the glass beads at the ends permitted a tungsten wire of any desired size to be threaded through after the silver soldering was completed. Actually a tungsten wire 0.0025 cm in diameter was used. While the

wire was taut the ends of the small metal tubes were pinched shut and then dipped into molten silver solder.

The tubulation for evacuating and filling with the desired gases was copper tubing. It was found possible to seal this by pinching it to a feather edge with a properly constructed tool.

The techniques used in the construction of the counters at all times maintained a clean, copper surface inside free from oxides or other contamination. All heating was done in hydrogen or in the presence of other reducing gases so that no liquids at any time were introduced.*

A group of 36 of these counters was silver soldered to a metal manifold and baked at a temperature of about 300°C for half an hour while a good vacuum, using diffusion pumps, was maintained. This was considered sufficient to drive most of the gases, especially oxygen, from the walls.

When cold, the counters were filled, first to a pressure of about 1 cm of Hg with the complex hydrocarbons of the commercial organic liquid called petroleum ether, then 99.8 percent pure argon was introduced to a pressure of 12 cm. A potential of 750 volts was applied to one of the counters of the group, and the total pressure reduced until the threshold occurred at this potential. The resultant pressures were about 0.6 cm of Hg of organic vapor and 6 or 7 cm of argon. This filling procedure has the advantage of exposing the freshly de-gassed copper surface first to the organic vapor. Since the adsorbed gases on the surfaces inside a counter play an important role in their behavior this order of filling seems desirable.

The counters in a given group prepared in the above manner had thresholds within about 10 volts out of 750 volts of each other. The lengths of the plateaus varied but were usually more than 250 volts.

In Fig. 1 is an isometric drawing showing the main features of the counters.

Of about 700 counters made, 600 passed initial tests satisfactorily. Some 25 percent of these were found to develop defects later, mostly because of leaks.

Eight of these counters were held rigidly in an

* A more detailed account of these techniques will be published elsewhere.

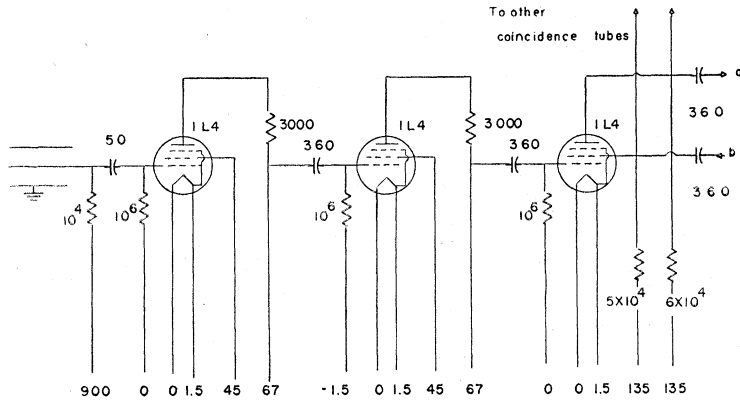


FIG. 4. One of the three amplifier channels operating into a coincidence tube.

aluminum framework as shown in Fig. 2. The counters in each tray were all connected in parallel to form a sensitive area of about 600 cm². The spacing between counter walls was held to a minimum. If the spacings between counters in their trays occurred at random with respect to the spacings in the other trays, then the effect on triple coincidences will be three times as great as the decrease in area of a single tray would indicate.

The total weight of each tray with its 8 counters was 850 grams. It is estimated that this is from 1/2 to 1/3 the minimum weight that could be achieved using glass walled counters of the same sensitive area.

2. Barometer and Thermometer

The barometer and thermometer units were the same as those used in former years.^{7,8} This Olland method of modulating a transmitted radio signal is well adapted to the requirements necessary for transmitting pulses caused by cos-

mic rays. Methods of calibrating and the type of received signal are described in reference 8.

3. Mounting of the Components

An aluminum framework 120-cm high and 38-cm square was made up of 90° angle pieces, as shown in Fig. 3. The strength of the framework and bracing were such that when the instrument was returned to earth by one balloon the components were completely protected against injury. On at least one occasion when both balloons were observed to burst the instrument when returned had a bent frame but the vital parts were undamaged.

The counter trays, the common mounting for the amplifiers and barometer unit and the high voltage batteries were all shock mounted with springs.

4. The Circuits

Electronic circuits generally similar to those previously described were used with the sub-

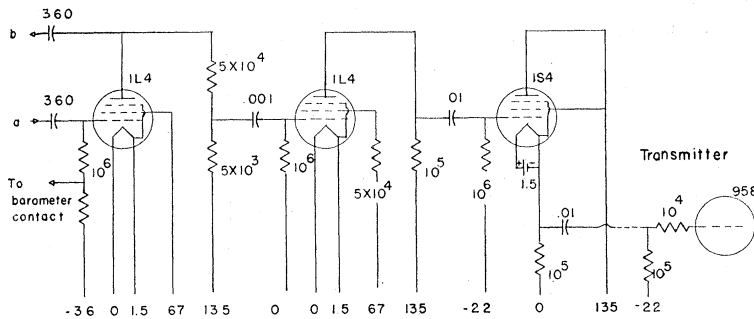
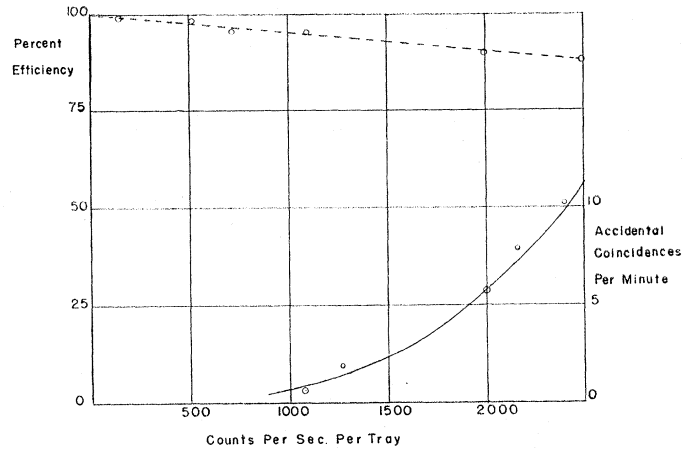


FIG. 5. Multivibrator and modulator unit for feeding transmitter tube.

⁷ H. V. Neher and W. H. Pickering, Rev. Sci. Inst. 12, 140 (1941).

⁸ W. H. Pickering, Proc. I.R.E. 31, 479 (1943).

FIG. 6. Lower curve shows the rate for accidental triple coincidences as a function of the total counting rate of each tray. Upper curve shows the efficiency for real coincidences for the same total counting rates.



stitution of miniature tubes and the change from twofold to threefold coincidences. Figure 4 shows one of the three channels consisting of two resistance coupled amplifier stages followed by a coincidence tube in the normal Rossi arrangement. To obtain a pulse sufficiently large to operate the coincidence tubes and at the same time sufficiently short to reduce accidentals to a negligible value, two stages of amplification were used. This also gives the correct polarity of pulse. The voltage gain of the amplifier was 3 or 4, the output pulse was about 2 microseconds long, and the limiting action resulted in an output pulse nearly uniform in size for a variation of a factor of 2 in size of the input pulse.

Figure 5 shows the remainder of the electronic circuit with the exception of the transmitter which is separately mounted. (Points marked with the letters *a* and *b* in Fig. 4 connect to the corresponding points of Fig. 5.) The output of the multivibrator stage following the coincidence tubes is fed through a phase inverting and isolating amplifier and then a cathode follower to the transmitter. The multivibrator pulse length is approximately 50 microseconds, and the recovery time about 200 microseconds so that no correction to the experimental counting rates of less than 1000 per minute need be made for the resolving time of the multivibrator. The series resistance of 10,000 ohms in the transmitter grid circuit limits the peak plate current to approximately 20 milliamperes, at which current the maximum r-f power is obtained for the "B" voltage (135 volts) used.

The barometer and temperature signals were transmitted in the same manner as in the equipment used in 1941-42. The barometer unit with clock mechanism and bimetallic strip was mounted on rubber grommets at one end of the twelve tube chassis which contains all the electronic circuits exclusive of the transmitter. This unit weighed 650 grams, including the barometer unit. It was suspended on springs slung between two of the legs of the aluminum frame work cage (see Fig. 3).

The performance of the electronic circuits was investigated in detail with particular regard to the over-all efficiency and the accidental rate. To obtain the efficiency loss resulting from the "dead time" of the counters, measurements of coincidence counting rates were made for various total counting rates as controlled by the proximity and shielding of a thorium source. The accidentals were obtained with similar stimulation when the counter trays were arranged so that no one particle could traverse all three trays, a small correction being made for the constant background rate caused by showers. The rate of accidental counts was subtracted from the rate of real coincidences for a given total counting rate of each tray. The ratio of this rate to the rate attributable to real coincidences obtained at low total counting rates of each tray gives the efficiency. Figure 6 shows the curve of percentage efficiency *versus* total counting rate for a tray of eight counters.

The total counting rates to be encountered could be estimated from the data obtained with comparable electroscopes and single counter

TABLE I. Constants of each set of triple coincidence counters.

Set No.	Constant	Probable error	Set No.	Constant	Probable error
1	0.995	±0.008	4*	0.990	±0.010
3	0.963	0.007	8	0.936	0.008
3*	0.981	0.012	12	0.984	0.007
3*	0.970	0.006	15	0.986	0.007
3*	1.009	0.010	15*	1.019	0.007
4	1.011	0.010	16	0.942	0.007
4*	1.022	0.007	17	1.002	0.007
4*	1.005	0.008	19	1.034	0.007

* After being found and returned. Nos. 3 and 4 were each used on four separate flights.

flights of Agra.¹ The assumption is made that the same relation holds between the number of incoming rays and the ionization they produce in an electroscopes at high latitudes as that observed in India. Under this assumption the estimated total counting rates per tray would vary from 1080 sec.⁻¹ at San Antonio to 2200 sec.⁻¹ at Bismarck as a maximum.

The number of accidentals is given, in a triple coincidence arrangement, by $A_{123} = 3\tau^2 N_1 N_2 N_3$, where A_{123} is the number of accidental triple coincidences and N_1, N_2, N_3 are the respective counting rates of the individual trays of counters. The resolving time τ thus computed gave a value of approximately 2 microseconds. This result was checked by measuring accidental double coincidences. In Fig. 6 the theoretical curve of accidentals for a resolving time of 2 microseconds is shown, together with some experimental points. At the maximum counting rates met experimentally, the accidental rate is less than one percent of the real coincidences obtained, and at most counting rates it is negligible.

The stability of the electronic circuits was investigated with reference to changes in the parameters such as B voltage supplies, filament voltages, various bias voltages, and the circuit components. Stable operation was found to occur over large ranges of these variables.

The apparatus was physically designed so that gaseous discharges would not occur at high altitudes. Tests were made at pressures lower than the minimum to be expected and possible points of discharge were shielded or immersed in paraffin. It was also found necessary to cover the Geiger counter beads with pressure tight wax to prevent discharges over the glass.

Commercial dry batteries were used for the

power supplies of the electronic circuits. Filament drains are 50 milliamperes for each 1L4 tube and 100 milliamperes each for the 1S4 and the 958 transmitting tube. The total "B" drain was about 12 milliamperes. The battery pack, excluding the Geiger counter supply, totalled 1400 grams and sufficed to operate the instrument for a minimum of four hours.

V. CALIBRATION

Before the flights started two complete sets consisting of selected counters were set aside to be used only for comparison with the sets that were to be sent up. These two standard sets were intercompared at frequent intervals. The calibrating procedure consisted in operating simultaneously three sets, usually consisting of one of the standards and two of the sets that were to be used. Triple coincidences were recorded. Care was taken to be sure that the roof overhead had low absorption and presented the same appearance to all three sets. Approximately 15,000 counts were used to find the constant by which the readings of the set being calibrated needed to be multiplied to reduce them to that of the standard. As an indication of the similarity of geometry the constants of the individual sets are given in Table I. The probable errors given include the statistical error in the counts recorded by the standard set.

The counting rates on the ground varied from about 22 per minute near sea level to 28 at the higher locations.

In calibrating, i.e., in comparing the sets to be flown with one of the other standard sets, the same high voltage batteries for the counters were used as were used on the flight. This was considered quite desirable, as it eliminated one uncertainty that was present in equipment used in past years. In fact, it was only necessary to substitute a prepared set of batteries to supply the power required by the amplifier tubes for

TABLE II. Determination of the absolute intensity of cosmic rays at the vertical in Pasadena.

	Total No. of counts	Mean barometric pressure	j^*
Ends protected	72,000	29.42 in. of Hg	0.727
Effective length determined	22,500	29.21	0.729

* j is the number of ionizing rays per unit solid angle min.⁻¹ cm.⁻² at the vertical in Pasadena. Elevation = 240 meters above sea level.

the power supply used in the calibration and transfer the connection from the mechanical recorder to the 2.0-meter wave-length transmitter and the set was ready for launching, except for wrapping.

To reduce the rates of the individual sets not only to a common basis but also to a value which had more of an absolute meaning, the counting rate out-of-doors at Pasadena was determined for a counter set of known solid angle and compared with the standard sets. The solid angle was determined by two methods which will be described in more detail elsewhere. Briefly, the first method consisted of covering the spaces between counters with other counters and then making a known length of the counters by placing another at right angles across the ends. This then determined the sensitive area completely except for small unknown regions at the corners. The other method consisted of measuring the effective length of the counters, as was done by Street and Woodward⁹ and by Greisen and Nereson.¹⁰ The results from the two methods are given in Table II.

⁹ J. C. Street and R. H. Woodward, *Phys. Rev.* **46**, 1029 (1934).

¹⁰ K. Greisen and Norris Nereson, *Phys. Rev.* **62**, 316 (1942).

The value of the number of ionizing particles per unit solid angle per minute per square cm, j , determined in this way agrees quite well with that of Greisen.^{10,11} This value has not been corrected for side showers. Preliminary determinations of this effect indicates it introduces not more than a three percent error. The value of j needs no correction for accidentals or loss in efficiency as each correction at sea level was well within the experimental error.

Use of the Equipment

Twenty-five complete sets of the equipment described above were constructed, and twenty flights were made in the summer of 1947 at seven stations in the United States and Canada. The results of these flights are reported in the following article.

The authors wish to take this opportunity of thanking Professor R. A. Millikan for the aid and encouragement he has given this development. Also, we wish to thank Mr. Maurice Rattray for his assistance in making the apparatus. We gratefully acknowledge the financial assistance of the Carnegie Institution of Washington.

¹¹ Kenneth Greisen, *Phys. Rev.* **61**, 212 (1942).

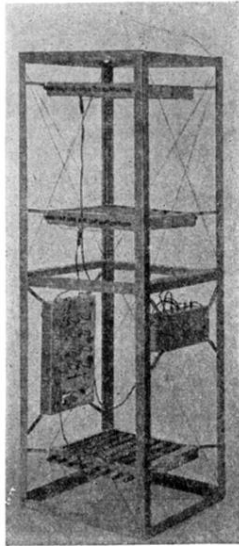


FIG. 3. The components were shock mounted in an aluminum framework. The weight of the whole assembly including 1800 cm² of counter area was 8 kg.