ured on the apparatus. This indicates that no odd powers of $\cos\theta$ appear in the distribution, as demanded by the Bose statistics of the product alphas. A theoretical discussion of the reaction is given by Critchfield and Teller,[5] who also questioned whether further experiment might not show up terms of higher power than $\cos^2\theta$.

Data were not discarded without experimental basis except for one erratic run at 1.4 Mev which could have been due to error in some one point. A run including all nine values of $\cos^2\theta$ at 1.0 Mev placed all nine points consistently but is not presented in Fig. 2 because it was later discovered that the lithium had been evaporating from the aluminum target backing during bombardment. The change, which was indicated to exceed 10 percent during the run, would give a misleading appearance to the data, in particular to the curvature.

The above data suffice to show unmistakably the presence of an even-powered term higher than $\cos^2\theta$ and give its sign and approximate magnitude, but do not resolve the energy dependence if any of that term. The $\cos^2\theta$ term is shown to exhibit a resonance at 1.0 Mev and to drop to a small value at 3.0 Mev.

[5] C. L. Critchfield and E. Teller, Phys. Rev. 65, 10 (1941).

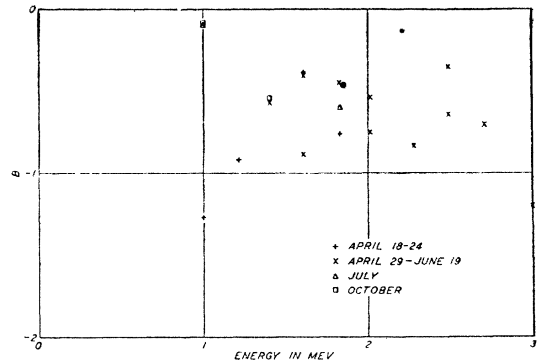

FIG. 5. Observed values of B.

We are grateful to Dr. Hugh Bradner, of the Radiation Laboratory of the University of California at Berkeley, for generously supplying thin Be foils of a type developed for the linear accelerator there.

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The Cosmic-Ray Counting Rate of a Single Geiger Counter from Ground Level to 161 Kilometers Altitude

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The cosmic-ray counting rate of a single Geiger counter has been measured from ground level to an altitude of 161 kilometers. The equipment was carried in a V-2 rocket at geomagnetic latitude $\lambda = 41°$N. Especial care was taken to avoid multiplicative effects from surrounding material. A value of the charged primary cosmic-ray flux of $j = 0.12$/sec./cm^2/steradian, averaged over the upper hemisphere, is implied by the data above 55 km. This interpretation of the counting rate must be qualified by the as yet unknown contribution from secondaries which emerge from the atmosphere and execute orbits in the earth's magnetic field.

1. INTRODUCTION

THIS is one of a series of reports on cosmic ray experiments conducted by this laboratory in flights of V-2 rockets during the past year and a half. The data presented herein were obtained during the flight of July 29, 1947. They are believed to be reliable but are provisional in the sense that they have been obtained in only one flight. A description of this work is thought to be worthwhile at this time for several reasons:

(a) No previous comparable data are known to us.

(b) The technique of using high altitude rockets as vehicles for scientific measurements is not as yet very generally known.

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(c) The next opportunity for repeating these measurements is some time away.

(d) Previous data on the counting rates of single and double counters *vs.* altitude have been obtained by us in V-2 flights on July 30, 1946, December 17, 1946, April 1, 1947, and April 8, 1947. The counters in these flights were parts of another experiment, which will be reported in the near future. In these previous flights no such care was taken to separate the counter from the mass of material in the rocket itself. The counting rates were, therefore, influenced to an important extent by multiplicative processes in the immediate environment. The results are in general support of those reported herein but are not strictly comparable.

The specific objective of this experiment was to learn the counting rate of a single Geiger counter as a function of altitude and especially at altitudes sufficiently great to be considered "above the atmosphere." Particular care was taken to approach the ideal of an unshielded counter, isolated from all other material. Implications as to the absolute flux of charged cosmic ray primaries are discussed. A tentative flux figure is given on the basis of this discussion.

2. APPARATUS

The arrangement of apparatus is shown in Fig. 1. The Geiger counter *P* and the bundle of three Geiger counters *Q*, with a minimum of electronic and other associated equipment, were located in a long cylindrical cloth-filled bakelite tube affixed to the forward end of the missile by dural fittings. The cylinder was surmounted by a wooded cone, and was sealed airtight. The materials used were of minimum thickness, density, and atomic number, consistent with the physical strength required to resist the estimated aerodynamic forces during passage through the atmosphere. The counters *P* and *Q* were rigidly supported by a light fiber framework and were packed in glass wool. The 0.4 mm copper lining of the bakelite cylinder was introduced as an r.f. shield against pulses from the various ground and missile-borne radar equipments involved in tracking the missile.

The Geiger counter *P* was the heart of the apparatus. Its counting pulses were applied to two independent scale-of-eight circuits, whose output pulses were broadened and shaped for characteristic appearance, then applied to the radio telemetering set provided by the Naval Research Laboratory.[1] Pulses were recorded by ground stations during the flight on photographic film moving at the rate of three inches per second and were subsequently analyzed by visual count of the film.

Although it was believed that counter *P* was already well isolated from the rocket by geometrical considerations, the further bundle of three counters *Q* was, at the suggestion of Professor Schein, located so as to intercept all except a small fraction of charged particles coming from the warhead and rocket proper. Double coincidences *PQ* were likewise telemetered.

Significant electronic characteristics of the circuits used are as follows:

(a) By means of an "addition of (radium) sources" test, it was shown that the loss of counts of the over-all system due to resolving time of the scale-of-eight circuit and pulse forming circuit, and the reading of telemetering film was less than 1 percent at a rate of 100 counts/second. This rate was much higher than the highest observed in flight. The measured counter dead time was 400 microseconds.

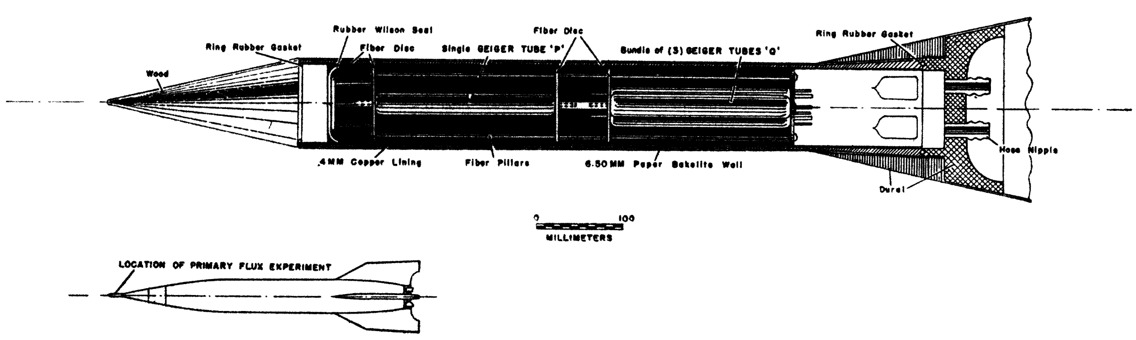

FIG. 1. Diagram of equipment, drawn to scale and showing location in V-2 rocket.

[1] V. L. Heeren, C. H. Hoeppner, J. R. Kauke, S. W. Lichtman, and P. R. Shiffleit, Electronics (March and April, 1947).

(b) The resolving time of the *PQ* circuit was measured as 5 microseconds by means of a "double pulser" giving two simulated Geiger pulses separated by an adjustable time interval. The resolving time was further checked by determining the increase in counting rate of the over-all coincidence system when the individual rates of *P* and *Q* were increased to 40 counts/second and 120 counts/second, respectively, by a suitably located 20 microgram radium source. A figure of 7 microseconds was obtained. During this latter measurement all equipment was operating on internal power with all voltages in final adjustment.

(c) Particular care was taken in assuring the constancy of all measured rates under a considerably wider variation of supply voltages than could reasonably be expected in flight. The Geiger voltage was supplied by a wax-potted stack of Minimax dry batteries. All circuit power was obtained from non-spillable Willard storage batteries and from dynamotors driven from them. The internal power supply operated all equipment satisfactorily for up to a half hour in laboratory tests. In final use it was run for five minutes on the launching platform immediately before take-off and for six minutes of flight.

(d) No amplitude-accuracy requirements were made on the telemetering system nor on any other part of the circuit. The characteristically shaped telemetered pulses were easily recognized in the presence of radio interference. In this flight, however, an exceptional clean telemetering record was obtained during all portions of the flight for which data are reported and the genuineness of all pulses is believed beyond question.

(e) The rate of *P* was obtained through two independent scaling circuits, pulse forming circuits, and telemetering channels. These rates were in complete agreement for all portions of the flight reported.

(f) The four Geiger counters were selected from a batch prepared to our specifications by the Geophysical Instrument Company of Arlington, Virginia. They were of "all metal" type with 0.8 mm thick copper walls, 0.10 mm tungsten wires, filled with a mixture of 10 cm argon and 1 cm absolute ethyl alcohol. The active volume of the counters was taken from geometrical construction as a cylinder 15.0 cm long and 2.38 cm in diameter. The counting rate due to a radium source *versus* voltage for the *P* tube is shown in Fig. 2. It will be noted that there was a slope of 3 percent per 100 volts in the operating region. As used, 15 volt pulses were obtained on the grid of the first tube. In auxiliary experiments the efficiency of these tubes for cosmic-ray particles was tested in coincidence telescopes and found to be greater than 99.3 percent. No appreciable effect on the counting rate of temperatures between 10°–100°C has been found.

3. FLIGHT OF THE MISSILE

The rocket[2] left the White Sands Proving Ground launching platform at 5:55 A.M. on July 29, 1947. (Geomagnetic Latitude 41°N.)[3] The propulsive period terminated at 63 seconds time of flight, altitude 37.5 km., velocity 1510 meters/second. During this period, except for a brief stabilizing period during the first five seconds, the axis of the missile did not deviate from the vertical by more than 6°.

Arrays of high power photo-theodolites and radar sets of the U. S. Signal Corps and the Ballistic Research Laboratories of the Aberdeen Proving Ground provided tracking data on the missile throughout flight.[4] This particular missile flew in a near vertical trajectory. A composite replot of the altitude-time data, kindly provided us by the B.R.L., is shown in Fig. 3. The accuracy of these data considerably surpasses the needs of this experiment. Note that the launching platform is at altitude 1.22 km. Time signals of the B.R.L. master oscillator were transmitted to all tracking stations and to the telemetering stations. It was thus possible to assign accurate altitude values to any time interval on the telemetering record.

At fuel burn-out the aerodynamic trim tabs were thrown "hard over" in order to augment the rate of roll of the missile expected from the slight measured fin asymmetry and to thus provide a measure of stabilization during the vacuum flight. By means of a photoelectric cell system, a roll period of six seconds was observed to have been produced. The zenith angle of the

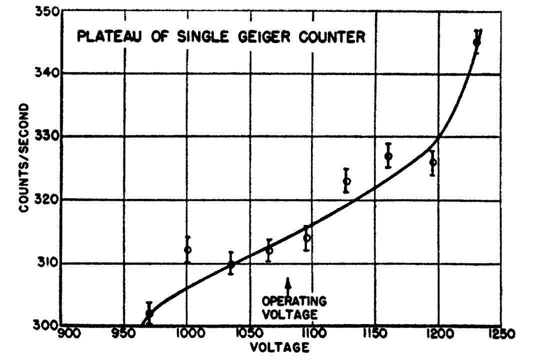

FIG. 2. Plateau of Geiger counter *P*, shown on enlarged vertical scale. The operating voltage in flight was 1080 volts.

[2] For description of the V-2, see H. S. Siefert, M. M. Mills, and M. Summerfield, Am. J. Phys. **15**, 1, 121, 255 (1947) and J. M. J. Kooy and J. W. H. Uytenbogaart, *Ballistics of the Future* (Tech. Pub. Co. H. Stam, Haarlem, Holland, 1946).

[3] A. G. McNish, Terr. Mag. **41**, 37 (1936); T. H. Johnson, Rev. Mod. Physics **10**, 193 (1938).

[4] L. A. Delsasso, L. G. de Bey, and D. Reuyl, "Full-Scale Free-Flight Ballistic Measurements of Guided Missiles," Ballistic Research Laboratories, Aberdeen Proving Ground.

axis of the missile was observed by two B.R.L. photo-telescopes, a 4.5″ and a 10″. The data[5] were unfortunately not complete but sufficed to show that the missile began a slow end-over-end tumble soon after fuel burn out, had its nose toward the ground by about 110 seconds (94 km. altitude), and was continuing to tumble.

The peak altitude, 161 kilometers, occurred at 224 seconds. At 361 seconds, the forward part of the missile was severed from the after part by a distributed charge of two pounds of high explosive, detonated by radio command. This segregation of the missile was accomplished in order to improve the likelihood of recovering photographic film which was part of another experiment. No data were obtained beyond this time.

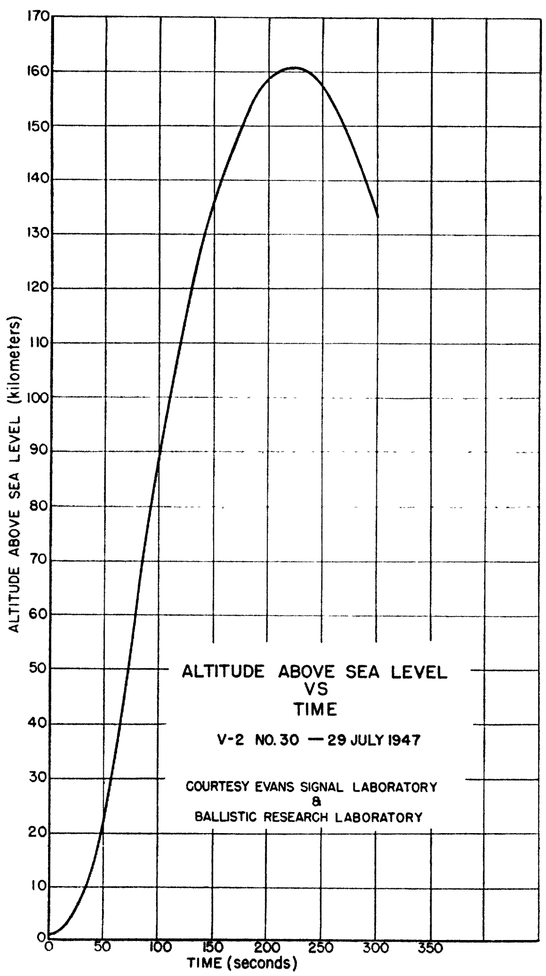

FIG. 3. Observed altitude above sea level *versus* time. Extrapolation of the curve to warhead blow-off (361 seconds) can be done with adequate accuracy by assuming free vacuum fall.

[5] Courtesy of Dr. D. Reuyl, Ballistic Research Laboratories, Aberdeen Proving Ground.

4. DATA

In Silver Spring, Maryland, altitude 0.12 km., with the apparatus vertical in a laboratory covered overhead by about 15 gm/cm^2 of concrete and wood, the rate of P was 1.39 ± 0.01/sec.; the rate of Q, 3.30 ± 0.05/sec.; and the rate of PQ, 0.0075 ± 0.0025/sec.

At White Sands Proving Ground, altitude 1.22 km., with all apparatus fully assembled onto the rocket nose in a thin roofed Quonset hut and in the open on the launching stand, the respective rates of P, Q, and PQ were 1.75 ± 0.01/sec., 3.49 ± 0.12/sec., and 0.010 ± 0.001/sec.

During 110 seconds of recorded data just before take-off the rate of P was checked at 1.75 ± 0.09/sec. Two PQ counts were obtained during this interval.

Data in flight from 0 to 360 seconds were obtained with the exception of a period between 15 and 28 seconds, portion of the period 143 to 214 seconds and portion of the period 320 to 360 seconds. In the earlier omitted period a large number of spurious counts was recorded by one scaling circuit, only a few by the other. It has been tentatively concluded that this was due to excessive vibration of the long cylinder during its passage through the trans-sonic aerodynamic region. Considerable noise on ionization chamber high gain amplifier channels was also noted in this well defined period. In the 143–214 second and the 320–360 second periods, the record was clearly readily in short sections totaling about one-half of the length of the periods.

Reading of the telemetered record is summarized as follows:

−110 to +15 seconds	Continuous
15 to 28 seconds	No data
28 to 143 seconds	Continuous
143 to 214 seconds	Partial
214 to 320 seconds	Continuous
320 to 360 seconds	Partial

In Fig. 4 are plotted the data on the counting rate of P versus altitude. The vertical bars indicate the statistical probable error of each point. A pressure scale in gm/cm^2 was derived

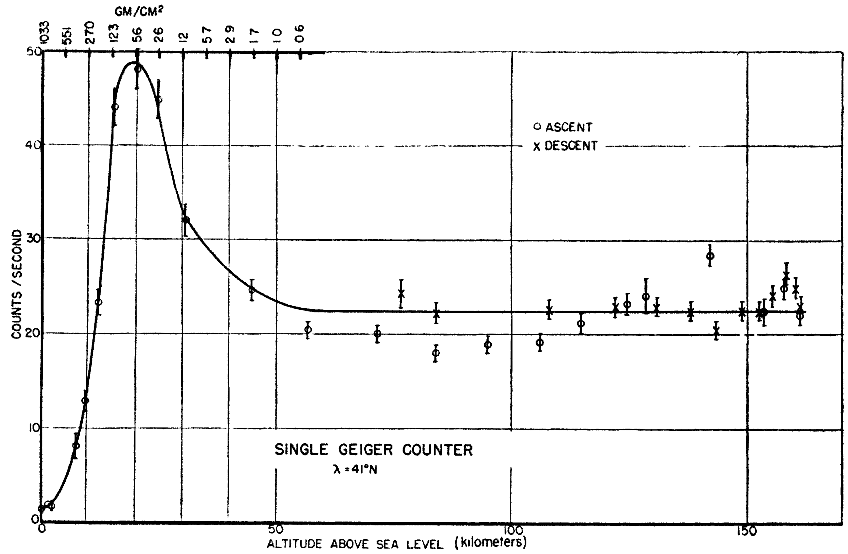

FIG. 4. Plot of the counting rate of Geiger counter *P versus* altitude above sea level. The curve has been drawn flat from 55 km to 161 km at the arithmetic mean counting rate above 55 km.

from standard tables[6] and is indicated at the top of the figure. Although the statistical accuracy of the various points is not sufficient to establish any fine features of this curve, the main features are unmistakable.[7]

A peak counting rate of about 49/second is reached at 19.8 km. (58 gm/cm²). The counting rate then falls off progressively. Between about 55 km. and the highest altitude reached, 161 km., there is a reasonably flat plateau. The average of all data in this range (5048 counts) is 22.4 ± 0.2 counts/second.

In Fig. 5, the smooth curve of Fig. 4 has been transformed to a pressure basis. Aside from the addition of the previously unknown point on the zero pressure axis, the curve resembles those of previous workers.[8] It may be noted that a single counter, being an omnidirectional detector, shares the physical characteristics of an ionization chamber more nearly than that of a counter telescope.[9]

The counting rates of the double coincidence set *PQ* are summarized in Table I. (A slight reduction of the observed counting rates for the two highest altitude points has been made for the finite resolving time of the coincidence set mentioned above.)

Thus, it is clear that the counting rate of the *P* tube is not appreciably influenced by stray effects from the rocket itself. The *PQ* rate is about 1 percent of the *P* rate in the "plateau" region.

Indeed, the rocket subtended a total solid angle of less than 1 percent of 4π at *P*.

With regard to vitiating effects of the immedi-

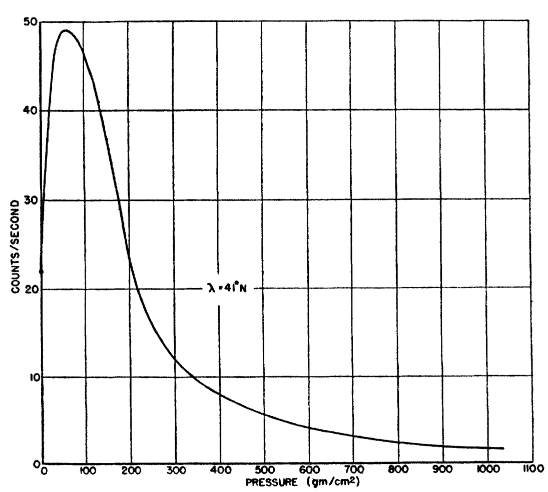

FIG. 5. Counting rate of Geiger counter *P versus* atmospheric pressure in units of gm/cm². This is a smoothed transformation from Fig. 4.

[6] Walter S. Diehl, "Standard Atmosphere—Tables and Data," N.A.C.A. Report No. 218; Calvin N. Warfield, "Tentative Tables for the Properties of the Upper Atmosphere," N.A.C.A. Technical Note No. 1200.

[7] This curve is in striking disagreement with the results of L. F. Curtiss, A. V. Astin, L. L. Stockman, B. W. Brown, and S. A. Korff, Phys. Rev. **53**, 23 (1938).

[8] I. S. Bowen, R. A. Millikan, H. V. Neher, Phys. Rev. **53**, 855 (1938).

[9] H. V. Neher and W. H. Pickering, Phys. Rev. 61, 407 (1942).

ate surroundings of P, nothing is known experimentally. Yet an examination of Fig. 1 makes it appear unlikely that there could have been an appreciable effect.

Considerable care was taken in the arrangement of the counters to assure thermal isolation in flight. It is quite difficult to simulate aerodynamic skin heating in the laboratory. We have made a series of furnace tests which, in conjunction with the appearance of the equipment after recovery from the impact, has convinced us that no appreciable increase in spurious background should have occurred at any time in flight.

The apparent dip in the rate of P at about 80 km. during the ascent was not confirmed on the descent. It may be remarked that a somewhat similar dip has been suspected in the data of previous flights—flights in which the counters enjoyed much more complete thermal isolation.

From an over-all view, a slight reservation in judgment must be held on the subject of thermal effects. But it was especially clear from the furnace tests that no appreciable rise in temperature of the counters could have occurred as soon as 100 seconds. Therefore, a plateau rate of about 19/second is as low a value as would be admitted by present knowledge.

5. DISCUSSION OF DATA AND CONCLUSIONS

The counting rate of a single Geiger counter of unit efficiency for an ionizing ray crossing any portion of its active volume of length l and diameter a is

$$N=\tfrac{1}{2}\pi^2 alj(1+a/2l)$$

in a region in which the flux j is constant over one hemisphere and zero over the other hemisphere, a result which is independent of counter orientation (see Appendices I and II). As indicated by the foregoing discussion of the data from PQ, it seems safe to assume that this result is also independent of missile orientation in the plateau region.

TABLE I. Counting rate of PQ.

Place	Geomagnetic latitude	Altitude	Rate
Silver Spring, Md. (Ground level)	50°N	0.12 km	0.0075±0.0025/sec.
White Sands Proving Ground, New Mexico (Ground level)	41°N	1.22	0.010±0.001
In flight		1.2–13	0.025±0.017
		13–27	0.47±0.12
		27–161	0.17±0.02

If one neglects the counter's spurious background (which could scarcely exceed 0.5/sec.) and naively assumes that the observed plateau counting rate $N=22.4$/second arises from an isotropic charged primary flux over a hemisphere, then the result is

$$j=0.12/\text{sec.}/\text{cm}^2/\text{steradian}.$$

If the lower value of $N=19$/sec. (discussed above) be used, we find

$$j=0.095/\text{sec.}/\text{cm}^2/\text{steradian}.$$

Either of these values is more than twice the flux inferred from the measurements of Millikan and co-workers.[10]

A rough independent check on the operation of the P counter is provided as follows: Mr. J. F. Jenkins of this laboratory has measured with a counter telescope at the same geomagnetic latitude as White Sands the total flux at zenith angle zero from ground level to an altitude of 9.15 km.[11] Combining these flux figures, extrapolated, and Swann's zenith angle dependence of flux data,[12] we find that a P counting rate of 19/second should be expected at an altitude of about 11.3 km. This result is in satisfactory agreement with the results as shown in Fig. 4.

Measurements such as those reported herein should eventually yield an estimate of the loss of energy into secondary forms which are not revealed by ionization in the atmosphere and should provide direct information on the multiplication of the primary radiation. As yet it seems premature to attempt such interpretations until the contribution of re-entrant secondaries can be ascertained.[13]

6. ACKNOWLEDGMENTS

This work has been made possible by the support of the Navy Bureau of Ordnance under

[10] For example, T. H. Johnson, Phys. Rev. 53, 499 (1938); M. Schein and D. J. Montgomery, "Problems in Cosmic Ray Physics," 1946 Princeton Lectures.

[11] Equipment carried in a B-29 airplane (to be published).

[12] W. F. G. Swann, Rev. Mod. Phys. 11, 242 (1939).

[13] H. Kulenkampf, Naturwiss. 21, 25 (1933); T. H. Johnson, Phys. Rev. 56, 226 (1939); W. F. G. Swann, Rev. Mod. Physics 11, 242 (1939); G. J. Perlow and J. D. Shipman, Jr., Phys. Rev. 71, 325 (1947).

Contract NOrd 7386. The opportunity for conducting these experiments in the current series of V-2 firings is due to the Army Ordnance Department and to the White Sands Proving Ground. Time signals and missile tracking were provided by the Ballistic Research Laboratories of the Aberdeen Proving Ground and the Army Signal Corps. The cosmic-ray data were transmitted and received through the excellent telemetering equipment of the Naval Research Laboratory.

We are indebted to Professor M. Schein for several opportunities to discuss cosmic-ray problems during the past year.

Finally, the accomplishment of this experiment was in no small measure due to our associates of the Applied Physics Laboratory, in particular Messrs. L. W. Fraser and J. F. Jenkins.

APPENDIX I

Calculation of the counting rate N of an idealized Geiger counter of diameter a, length l, in a field of charged particles of flux j, isotropic over one hemisphere, zero over the other:

Case 1. *Axis of the tube parallel to the axis of the hemisphere.*

$$N=\int_{\text{Hemisphere}} j\cdot A\cdot d\Omega$$

with A being the projected area of the cylindrical counter on a plane perpendicular to the direction along which the elementary solid angle $d\Omega$ lies. If θ be the angle from the axis of the cylinder to this direction,

$$N=j\int_0^{\pi/2}(\pi a^2/4\cos\theta+al\sin\theta)2\pi\sin\theta d\theta,$$

$$N=\tfrac{1}{2}\pi^2 alj(1+a/2l). \tag{1}$$

Case 2. *Axis of the tube perpendicular to the axis of the hemisphere.*

Similarly to the above

$$N=j\int_0^{\pi/2}(\pi a^2/4\cos\theta+al\sin\theta)\pi\sin\theta d\theta$$

$$+j\int_{\pi/2}^{\pi}(-\pi a^2/4\cos\theta+al\sin\theta)\pi\sin\theta d\theta.$$

The result is identical to that of Case 1.

Case 3. *Axis of the tube at an arbitrary angle to the axis of the hemisphere.*

By simple geometric visualization, it is clear that this general case can be reduced to Case 1. Hence, we conclude that the counting rate of an idealized Geiger tube in a hemispherically isotropic field is independent of orientation and is given by Eq. (1).

APPENDIX II

The conclusions of Appendix I can also be reached by a general argument which applies equally well to a counter volume of any shape, provided the surface is everywhere convex outward. This treatment was suggested to us by Drs. H. E. Newell and N. M. Smith.

Thus the basic integral

$$\int_{\text{Sphere}} j\cdot A\cdot d\Omega$$

yields, in a *spherical* isotropic field,

$$N=\pi jS,$$

in which S is the total surface area of the counter volume.

Inasmuch as the integration involves equal contributions from diametrically opposite directions, the result for a hemisphere is

$$N=1/2\pi jS,$$

independent of orientation of the counter volume. In the case of a cylindrical counter Eq. (1) is obtained as by Appendix I.

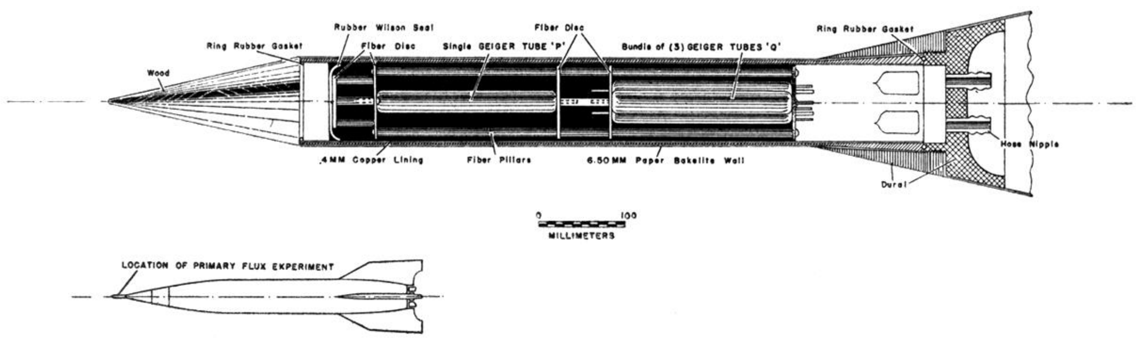

FIG. 1. Diagram of equipment, drawn to scale and showing location in V-2 rocket.