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Cosmic-Ray Observations in the Stratosphere*

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With radio methods devised as a part of a program for development of radiometeorographs, it has been found possible to record the response of a Geiger-Müller tube counter to cosmic rays at altitudes up to 116,000 feet. Records were made automatically by means of a recording receiver at a ground station. The results show a gradual rise in cosmic-ray intensity which is clearly evident at a pressure of about 500 millibars and then decreases slightly at a pressure of about 300 millibars after which the rise to maximum intensity at a pressure of about 100 millibars is very rapid. This maximum is about 150 times the count recorded near the ground level and is followed by a rapid decrease in counting rate at pressures below 100 millibars. At the highest altitude reached, approximately 116,000 feet, where the pressure is only 5 millibars, the counting rate falls to a value which is about the same as that observed at a pressure of 600 millibars. The general trend of these observations indicates that as the limit of the atmosphere is approached the counts continue to decrease, confirming the view which has been put forward by other observers that the greater part of cosmic-ray phenomena are due to secondary effects generated within our atmosphere.

I. Introduction

SINCE an important part of our knowledge of cosmic rays is to be obtained from information at high altitudes in the stratosphere at various latitudes, a ready means of obtaining such information should prove valuable. In the opinion of the authors the most promising method which has so far been conceived is that of automatic radio equipment attached to small balloons arranged to transmit the data to a ground station. Recovery of equipment is not necessary to secure the record so that observations may be made at any point where a satisfactory receiving station can be erected. Our experience with radiometeorographs[1] has revealed that the radio problems involved are very simple and that transmitting and receiving equipment can be made to function with a considerable degree of reliability. We have been able to demonstrate that it is readily possible to set up a receiving station of ample sensitivity which will respond only to signals from a transmitter operating at the desired wave-length. All problems of electrical interference, atmospheric and similar disturbances have been overcome under the conditions of our experiments so that the records obtained are absolutely clear and unambiguous.

The following paper gives the result of 18 successful ascensions from the National Bureau of Standards during the last six months. These ascensions were undertaken to test the equipment under all usual operating conditions and to secure data at this latitude to compare with similar data obtained near the magnetic equator and reported in the adjoining paper. In addition we were also fortunate in obtaining data on cosmic-ray counts at a new high altitude, approximately 116,000 feet, corresponding to a pressure of about 5 millibars or to within $\frac{1}{2}$ of 1 percent of the top of the atmosphere.

II. Description of Equipment

The first requirement in designing equipment for this work is that it shall not have excessive weight. To attain really high altitudes in the stratosphere the difficulties are much lessened if the load does not exceed about 5 pounds. Larger loads require the use of extra size balloons or of a large number of small balloons. In either case the launching except under most favorable conditions is a problem, and the expense of an ascension is considerable.

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* Publication approved by the director of the National Bureau of Standards of the U. S. Department of Commerce.

[1] L. F. Curtiss and A. V. Astin, J. Aero. Sci. 3, 35 (1935).

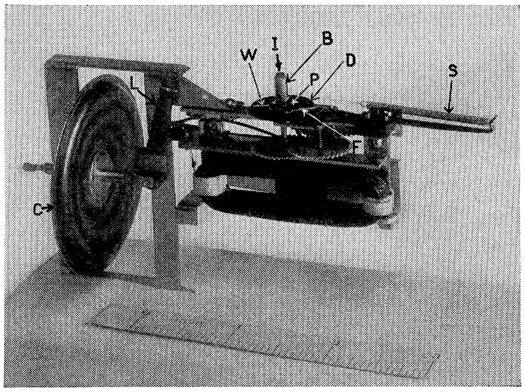

FIG. 1. Olland type radiobarograph for cosmic-ray balloon observations.

It is also desirable to utilize the "hot-house" arrangement devised by Regener and Pfotzer[2] to keep batteries and instruments at a fairly constant temperature. This led us to adopt a double-walled Cellophane inclosure similar to that used in early trials with radiometeorographs for which we have records of inside temperatures showing that they rarely fall below 20°C.

Within the inclosure were mounted the following items of equipment: transmitter, counter with its associated vacuum tube circuit and relay, barograph, and necessary batteries.

The transmitter used is essentially the same as the push-pull 5-meter transmitter described in an earlier paper,[1] with the substitution of a voltage fed for a current fed antenna. This change eliminated the trailing half of the doublet-antenna and made launching much simpler. No difference in transmitting efficiency was observed in making this change.

The Geiger-Müller tube counter and circuit is described in detail in the adjoining paper.[3] The counters were filled with argon to a pressure of about 4 cm and operated at 400 to 500 volts. This voltage was supplied by 10 units of the new 45-volt radio batteries, weighing about 2 oz. each, recently developed for radiometeorographs.

An important part of the equipment is the barograph which is a modified radiometeorograph which has been designed at the National Bureau of Standards. Since for cosmic-ray observations the pressure alone is of interest this instrument is arranged to give pressure readings by radio employing the well-known Olland principle. A photograph is shown in Fig. 1. A tiny radiometeorograph electric motor carries a Bakelite disk *D* on its output shaft, which turns at a speed of 4 r.p.m. Collar *B* turns freely on the same shaft and is provided with an external thread and an internal insulating sleeve, *I*.

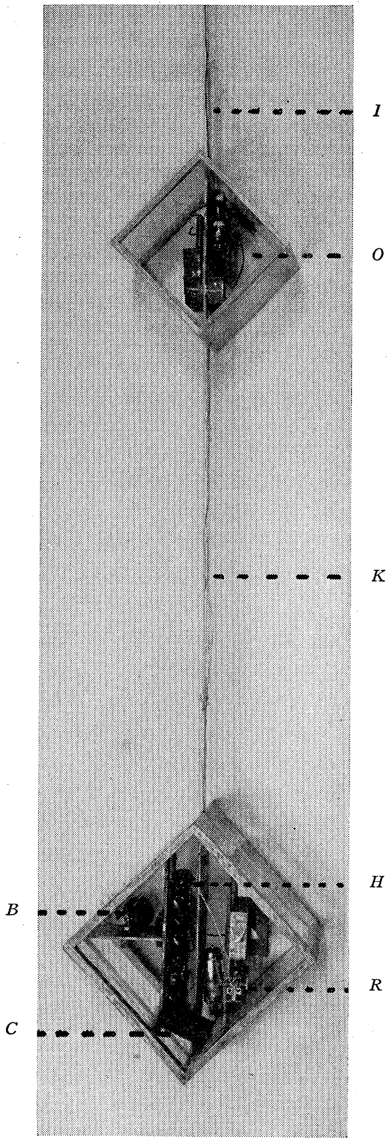

FIG. 2. Complete balloon equipment mounted in Cellophane inclosure. *I*, Antenna. *O*, 5-meter oscillator with batteries. *K*, Keying wires. *H*, 400 volt battery for counter. *B*, Barograph. *R*, Relay. *C*, Geiger-Müller tube counter in light-tight shield.

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[2] E. Regener and Pfotzer, Physik. Zeits. **35**, 779 (1934).
[3] Korff, Curtiss and Astin, Phys. Rev. **53**, 14 (1938).

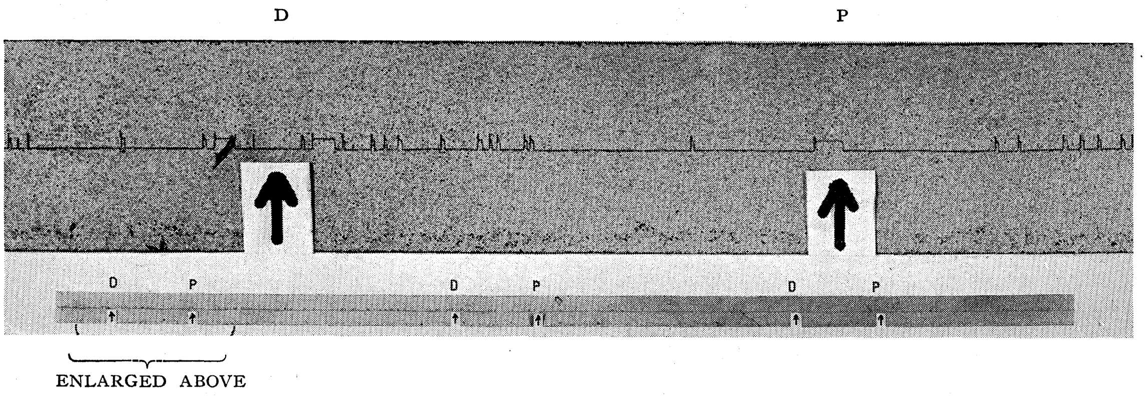

FIG. 3. Sample of tape from actual record showing barograph signals and cosmic-ray counts.

A fine Nichrome wire, approximately 3 mil in diameter extends from the spring, *S*, around the threads of the collar, *B*, and is attached to an insulating lever, *L*, which magnifies the motion of the aneroid capsule *C*. This motion causes the collar *B* to rotate and as it does so the platinum-iridium arm, *P*, rotates with it about the motor shaft as an axis. As this platinum arm turns it contacts a similar wire *W*, imbedded in the Bakelite disk, *D*, once for each revolution of the motor shaft. There are also two fixed contacts, *F*, which give a reference point for measuring pressures on the tape of the ground recorder. As the platinum wires, *W*, *P* and *F*, come in contact they key the transmitter by means of a pair of wires running up to it. These wires are attached, one to the frame of the barograph and the other to the insulated metal support for the spring, *S*. This contact causes the transmitter to emit a short signal which is picked up by the ground station. This arrangement requires the transmitter to be energized for a very small fraction of the total time so that a relatively strong signal can be used without increasing the weight of the *B* batteries. These strong signals are easy to locate and the problem of keeping the receiver tuned is much simplified.

The complete equipment is shown in Fig. 2 in which the transmitter and its batteries are in the upper compartment, and the counter and its batteries in the lower. This separation of $\frac{1}{4}$ wavelength was found necessary to prevent a feedback of the 5-meter signal into the vacuum tube circuit of the counter rendering the counting circuit inoperative. With all parts in place ready to be released this outfit weighed about 2100 grams or a little less than 5 pounds.

The receiver used in the observations reported here was a commercial superregenerative 5-meter receiver altered for satisfactory operation of a relay and tape recorder. This was accomplished by adding a rectifier tube much as described by Bent.[4] Our modifications resulted in a receiver which would actuate a relay only in response to a signal in the 5-meter band. Electrical interference, atmospherics and similar disturbances had no effect, since, to operate the relay, a train of 5-meter waves of sufficient duration to silence the regenerative oscillator is required.

The relay connected to the output of the receiver was used to actuate a tape recorder using waxed paper tape. A sample of actual record taken at an altitude of about 64,000 feet is shown in Fig. 3. *D* represents the fixed double signal of the barograph and *P* the contact of the pressure arm. All other shorter signals are pulses from the Geiger counter. The enlarged section is the left-hand end of the lower strip which shows how the pressure signals repeat every 15 seconds, with the shorter cosmic-ray signals distributed in a random manner between them.

III. RESULTS OBTAINED FROM BALLOON ASCENSIONS

There are many factors which affect the altitude to which a rubber balloon, of the type used in this work, will rise before bursting.

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[4] A. E. Bent, Bull. Am. Meteor. Soc. **18**, 99 (1937).

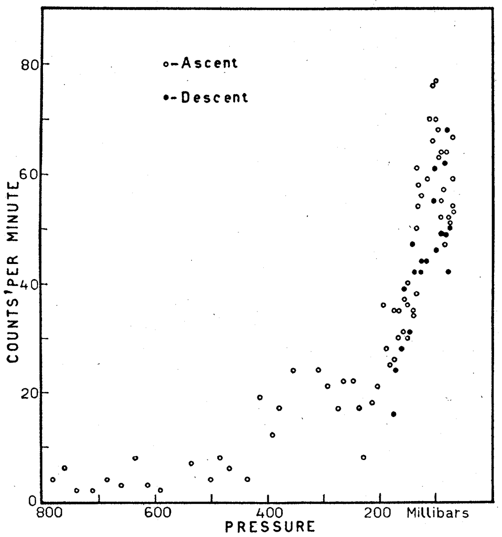

FIG. 4. Graphical representation of data from a single flight to 56,000 feet.

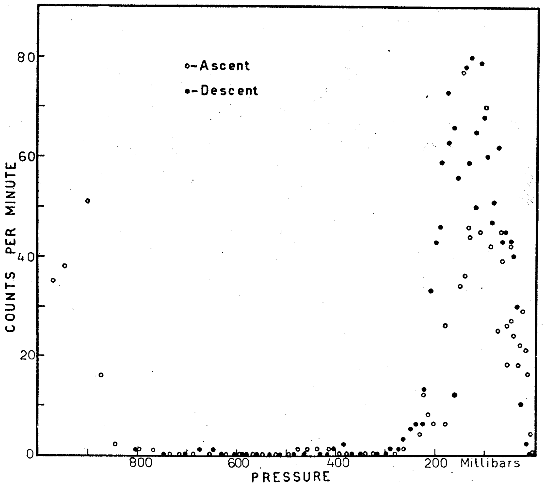

FIG. 5. Complete data from single flight to 116,000 feet showing low counting rate near the top of the atmosphere.

These factors do not seem to be very well known or understood at present. We have been able to show to our own satisfaction that some of the ideas on the subject which are prevalent do not hold. For example, it is assumed that the lower the inflation the higher the altitude to which a rubber balloon can go. As the result of repeated trials we have found this not to be true. This unexpected result can be explained we believe by the effect of the sun on the rubber. A fairly rapid ascensional rate seems to be required to prevent local over-heating and premature bursting. We also have found a wide difference in behavior of individual balloons so that at best the attainment of the maximum altitude of which these balloons should be capable is a matter of chance. For the most part we have used rubber balloons weighing about 650 grams with a nominal bursting diameter of 20 feet. Three to five such balloons inflated to a diameter of about 1.8 meters and having a free lift of about 1380 grams were used on each flight. The total free lift was thus nearly 4000 grams or about 1800 grams more than the load attached.

A total of 24 ascensions have been made between June and November, 1937. The balloons were released from the roof of one of the buildings of the National Bureau of Standards.

The penthouse containing the receiver was on the same roof facilitating last minute adjustments of the receiver. There was usually a slight shift in tuning directly after the take-off. For the remainder of the ascension retuning was rarely required. In the course of this work several difficulties were encountered and eliminated so that of the total number only 18 ascensions gave results on which we could rely. The first difficulty was traced to electrical leakage over the outside of the glass envelope of the Geiger-Müller counter. This was remedied by careful washing in alcohol and ether and dipping in molten Superla wax. It was soon found that some of the counters were sensitive to ultraviolet light. It was finally found necessary to inclose them in light-tight thin walled hard rubber cylinders. Thorough electrical insulation of all parts of the equipment was attained by dipping all supports in molten Superla wax.

In order to determine the behavior of our counting circuit at the very low pressures encountered in the upper stratosphere, we mounted an exact duplicate of our equipment under a large glass bell jar and pumped it down to 5 millibars residual pressure. We then compared its counting rate with a radium preparation at a fixed distance with that obtained at atmospheric pressure and also tested its recovery from a very rapid counting rate by bringing the radium close and quickly removing it to a distance. As a result we found the behavior of the equipment to be the same at reduced pressure as at atmospheric pressure.

Our Washington results are illustrated by the two curves in Figs. 4 and 5. In each case the values for the number of counts per minute is taken directly from the wax-tape record. In arriving at a value of the count per minute for a given pressure we took the count for each successive minute and the average of the 4 pressure readings obtained in the same interval. The results shown in Fig. 4 are those of an average ascension. The minimum pressure is 65 millibars corresponding to an altitude of about 56,000 feet. A secondary maximum obtained in nearly all ascensions at about 350 millibars is shown as well as the principal maximum at about 100 millibars. The values obtained for a part of the descent are also shown. In most cases we were able to follow the signals until the balloon was only a mile or so high when the horizon cut the signals since by this time the balloon would be from 100 to 200 miles distant. We know the point of landing for about 3 of every 4 ascensions since the equipment was found and returned to us. Unless two or more balloons broke simultaneously, which happened occasionally, the descending record agreed well with the ascending record. This fact shows particularly well in Fig. 5 where we show the result of the highest ascension to a pressure of 5 millibars or about 116,000 feet. We succeeded in making 3 ascensions to near this pressure, which is lower than that attained in a previous ascension[5] to a pressure of 8 millibars which at that time was considered an altitude record for this country. The difference in altitudes associated with the pressures is accounted for by the fact that at that time an incorrect altitude table was used. The altitudes quoted in this paper are based on the "standard atmosphere."[6]

As is evident from the arrangement of the circles which show the counting rate at various pressures, the counter used to obtain the data represented in Fig. 5 had an exceptionally low blank. For several minutes its counting rate after passing an altitude of about 3000 feet was considerably less than 1 per minute. However, it is interesting to note that at the beginning of this ascension from the ground up to 3000 feet a counting rate of 30 or 40 per minute was observed falling abruptly at about the 3000 foot level. This ascension was made early on a morning when the air was unusually free from any evidence of motion. A misty haze blanketed the region and the atmosphere had been stagnant throughout the preceding night. We attribute this high activity to a layer of radium emanation which had slowly diffused to the height of 3000 feet during the stagnant period. This effect was never observed on clear, windy days.

The interesting result of the cosmic-ray observations on this ascension is the low value which the cosmic-ray count also rapidly reaches at the maximum altitude. During the 14 minutes the equipment was below the 15 millibar pressure the average cosmic-ray count was 0.5 per minute indicating a cosmic-ray intensity as low as that at 600 millibars, and about 1 percent of that at the maximum of the curve. We regard this as a striking confirmation of the view that most of the observed cosmic-ray phenomena are secondary effects produced within our atmosphere. The primary rays are either of such a nature that the type of equipment which is generally used does not detect them or are relatively few in number when compared with the secondaries.

The net results of observations covered by this

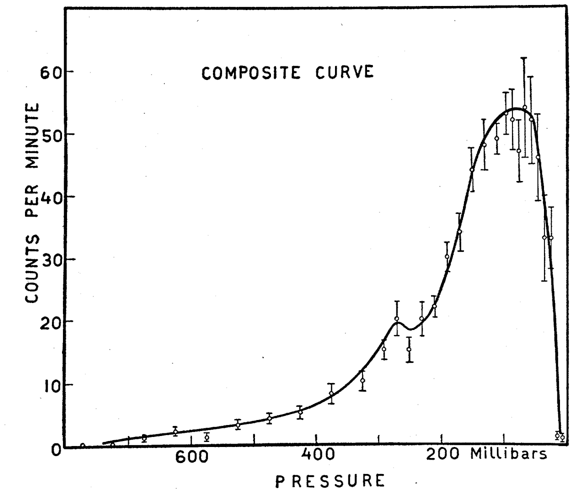

FIG. 6. A composite curve showing average value of cosmic-ray counts obtained from the 10 highest flights. Vertical lines represent the probable error of the arithmetic mean.

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[5] L. F. Curtiss and A. V. Astin, Science **83**, 411 (1936).

[6] N. A. C. A. Technical Report No. 538. Annual Report 1935.

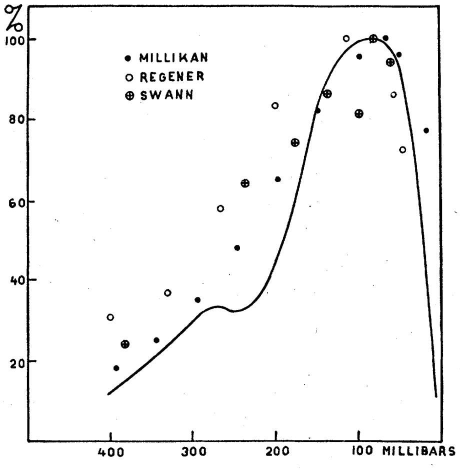

FIG. 7. Our composite curve shown in comparison with measurements reported by other observers.

paper are conveniently shown by a curve representing the average values of counting rates plotted against pressure as a composite curve for our ten highest flights. This is shown in Fig. 6. The counters by which these data were obtained were made as nearly alike as possible and the counting rates and counting voltages were consequently very similar. The blank or accidental discharge rate for each counter was determined from the counting rate at 800 millibars and subtracted from the counting rates at all lower pressures. The counts were then averaged directly without any multiplicative factor. This was not the case in the adjoining paper in which counting rates varied by as much as six to one due to intentional differences in the counters. The vertical lines show the value of the probable error of the arithmetic mean for each point. Below 50 millibars 4 records were available for averaging and the last two points were averaged from 18 minutes of a record of a single flight during which the apparatus was in the pressure range indicated.

IV. DISCUSSION

The precision of the measurements reported is from their very nature not great. By counting methods observations over many minutes at each altitude would be required to give an accuracy of even a few percent. For this reason too great weight cannot be given to these preliminary observations in discussing their bearing on cosmic-ray problems. However, one or two points do stand out perhaps with sufficient clarity to warrant a comparison with results obtained in other ways.

One interesting feature is that the general trend of our single counter measurements agrees well with coincidence measurements obtained by Regener and Pfotzer[7] using a triple counter arrangement and, therefore, taking in a limited solid angle of rays in the vertical direction. Earlier measurements with ionization chambers by Regener[8] and others indicated a leveling of the cosmic-ray intensity at the maximum. Since coincidence counters revealed a marked decrease beyond the maximum it was assumed that this difference was due to the fact that coincidence counters took in a definite solid angle whereas ionization chambers were nonselective as regards direction. That this conception is in error is also shown by the results published by Millikan, Neher and Haynes[9] where measurements to a pressure of 17 millibars are reported. The same rapid descent in intensity beyond the maximum is shown to be obtained with an ionization chamber. Our results merely trace this curve to about one-third the lowest pressure which they attained and indicate that this downward descent continues as the limit of the atmosphere is approached.

Attention should also be called to a difference which seems to exist between our single counter measurements and those by ionization chambers, namely, that the rise of the intensity of curve with decreasing pressure is more rapid in our measurements and also falls more sharply after passing the maximum. This is shown in Fig. 7, where our composite curve is drawn for comparison with measurements by other investigators. The solid circles represent the measurements with an electroscope by Millikan in July, 1936 at San Antonio, Texas and reveal the difference in steepness of the rise and fall of cosmic-ray intensity, when compared with our curve.

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[7] E. Regener and G. Pfotzer, Nature **136**, 718 (1935).

[8] E. Regener, Naturwiss. **25**, 1 (1937).

[9] R. A. Millikan, H. V. Neher and S. K. Haynes, Phys. Rev. **50**, 992 (1936).

The rapid decrease in intensity below a pressure of about 100 millibars presents something of a paradox since it must mean that the primary radiation is of such high energy that it affects counters and ionization chambers to a moderate degree compared with the secondary radiation. On the other hand this radiation is so absorbable in the atmosphere that it is nearly all converted into secondaries within a layer equivalent to 2 meters of water and results in an intense emission of secondary particles at a very high altitude after traversing a comparatively thin layer of the atmosphere. There are several ways to explain this paradox qualitatively on the basis of knowledge we already have regarding the possible nature of the primary radiation. The simplest is to assume that much of the primary radiation is of the nature of heavy charged particles. Such particles will have the requisite energy associated with them at much lower velocities than would electrons or positrons. As a result of their electrical charge they would experience a magnetic deflection in the earth's field which could be made to agree with that experienced by electrons by assuming that they carry multiple charges. Since these particles would be like alpha-particles of very high velocity they would be converted quite rapidly into secondary radiation in the upper atmosphere. At the same time, since their number in comparison with that of the secondary particles would be small, the low value of cosmic-ray intensity in the upper stratosphere would be explained. This hypothesis might also help to explain the principal difference which appears between our single counter measurements and those by ionization chambers, namely, that the rise of the intensity curve with decreasing pressure is more rapid in the former case and also falls more sharply after passing the maximum. If heavy particles are involved in the primary beam or in the secondaries originating from it, one might expect the ionization chambers to show higher values than counters. As already mentioned, such an effect is visible in our composite curve since our results lie below those obtained by Millikan with an electroscope on both sides of the maximum.

We should also like to point out a second point of difference between our results and those of Millikan which is a definite indication of a secondary maximum of intensity at a pressure of about 300 millibars. This is revealed in our composite curve, Fig. 7, and is even more clearly evident on many of the individual records. Since this peak in the curve does not occur in results reported from Peru in the adjoining paper, the radiation contributing to this secondary maximum must be considerably affected by the earth's field. If this explanation for its appearance in our results is correct, observations at higher latitudes should reveal this secondary maximum more clearly.

The chief value of this report, however, is believed to be that it shows that automatic observations in the stratosphere to altitudes of at least 120,000 feet can be made with ease and reliability as far as transmission of data is concerned. Thus at a comparatively low cost frequent observations are possible which will greatly improve the accuracy of the combined results. This seems to offer a way to obtain the much-needed information regarding the nature of the main group of primary particles entering our atmosphere and the processes which lead to their conversion into secondary radiation.

V. Acknowledgments

We take great pleasure in expressing our appreciation to Dr. Lyman J. Briggs, Director of the National Bureau of Standards, and to Dr. J. A. Fleming, Director of the Department of Terrestial Magnetism, Carnegie Institution, Washington, D. C., for their encouragement and support in this work which otherwise would have been impossible.

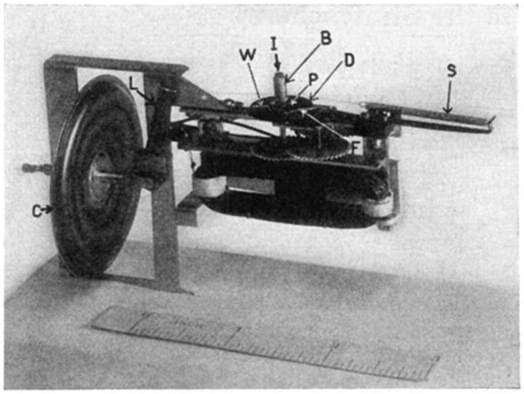

FIG. 1. Olland type radiobarograph for cosmic-ray balloon observations.

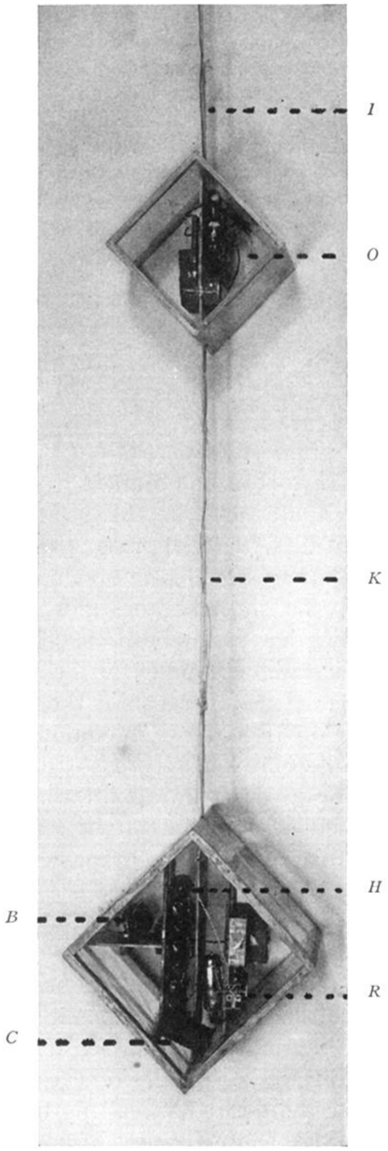

FIG. 2. Complete balloon equipment mounted in Cellophane inclosure. *I*, Antenna. *O*, 5-meter oscillator with batteries. *K*, Keying wires. *H*, 400 volt battery for counter. *B*, Barograph. *R*, Relay. *C*, Geiger-Müller tube counter in light-tight shield.

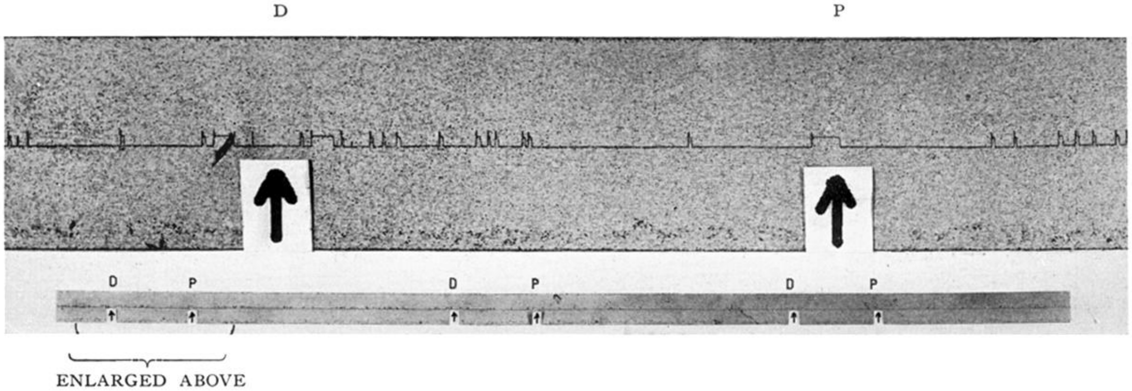

FIG. 3. Sample of tape from actual record showing barograph signals and cosmic-ray counts.