An Automatic Ionization Chamber*

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The ionization chamber described herein has the following characteristics: 1. It recharges itself after having collected a definite charge. 2. It generates a pulse at the instant of recharging that is easily amplified electronically. 3. The constant of the ionization chamber is independent of the constants of vacuum tubes but does depend on the constancy of a quartz fiber, the pressure of the gas, and the potential of the charging battery. It has been successfully used to measure cosmic-ray ionization at balloon altitudes both in the United States and in northern Greenland.

I. INTRODUCTION

IN determining the latitude effect of cosmic rays at very high altitudes, both ionization chambers[1] and Geiger counter telescopes[2] have been used. Each has its advantages and disadvantages. In particular the counter telescope responds to radiation from within a certain solid angle determined by the geometry of the system while the ionization chamber responds to radiation from all directions. The ionization chamber gives a measure of the total cosmic-ray energy per unit time per unit area falling on top of the atmosphere, for it is well known that this is given by the area under the ionization *vs* atmospheric-depth curve. The counter telescope does not give directly this measure. Experience has also shown that ionization chambers can be made reliable over a period of years, while counters, both by their very nature and the complication of the electronics involved, tend to be less so.

It was the need of a reliable, light weight device that would transmit its information to a receiving station on the ground that prompted the development of the instrument described herein.

II. THE QUARTZ SYSTEM

In Fig. 1a the relative locations of the ion collector *C* and the quartz fiber *F* are indicated. The collector is a tapered, fused quartz rod, the upper portion of which is coated with a thin layer of colloidal graphite (commercially called "Aquadag") to make the surface a conductor. A section near its lower end, *E*, is left uncoated to act as an insulator. The base of the quartz rod is cemented into the support *K*. The gold-coated fiber *F* is approximately 5 microns in diameter and 7 mm long. It is fastened at right angles to the flattened metal "Kovar" support *A* by means of "Aquadag." The rod *A* is insulated electrically from the base supports by means of the glass bead shown. An electrical connection to *A* leads out of the base of the ionization chamber. The quartz fiber and its mounting are surrounded by a metal shell *S* except for a hole in the top through which passes the collector into the ion chamber.

When uncharged, the gold-coated fiber *F* rests against the graphite-coated collector *C*. When a potential is applied to *A*, the collector *C* becomes charged also. The electrostatic repulsion between the two causes the fiber to be repelled, and it takes up a position represented by Fig. 1b. As the collector collects ions, its potential and charge decrease and the fiber *F*, which is maintained at battery potential, gradually approaches *C*. When *F* has thus approached to within a short distance from *C*, the image force overcomes the repulsion due to the like charges and *F* becomes unstable; it rapidly touches *C*, then flies away leaving *C* charged. In the cases measured, the change in potential of *C* necessary to have the recharging process occur is about $Vo/3$ where Vo is the potential of the charging battery.

For a constant rate of ionization, the collector will thus be charged up at regular intervals of time. Because of the flow of current occurring at the instant of contact a voltage pulse may be produced in the lead to the charging battery through a resistor and this pulse may be duly amplified.

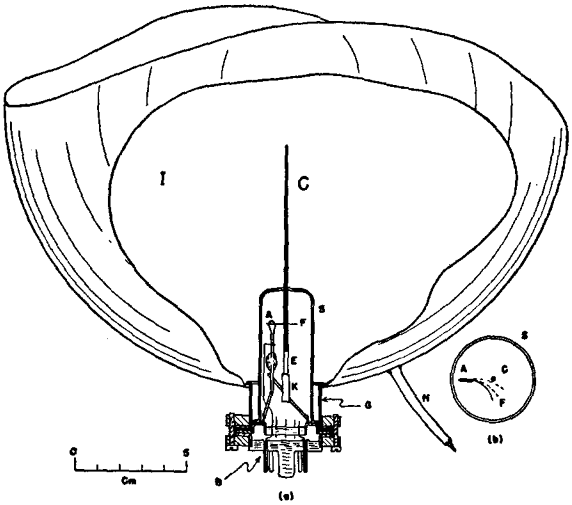

FIG. 1. Automatic ionization chamber. The extension G, inner shield *S*, and base *B*, are standard radio tube parts. Quartz film *F* touches and flies away from collector *C*, when *C*'s potential drops to a definite value.

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* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Bowen, Millikan, and Neher, Phys. Rev. 52, 80 (1937).

[2] Biehl, Montgomery, Neher, Pickering, and Roesch, Revs. Modern Phys. 20, 360 (1948).

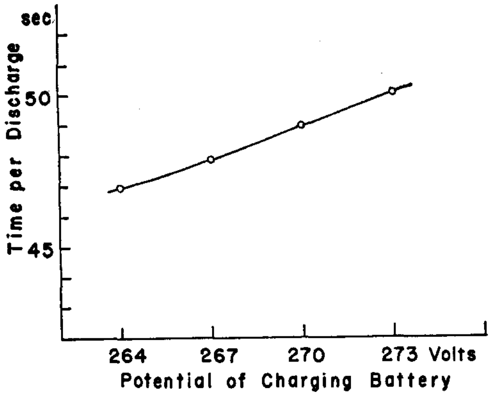

FIG. 2. The time between chargings is dependent upon the potential of the charging battery, as shown. This dependence is approximately 0.7 percent per volt.

The oscilloscope shows that the pulse developed across 20 megohms resistance is approximately five volts, lasts for 10^{-4} sec, and successive ones are all the same height and shape as nearly as can be measured on the screen. The charge that flows during the pulse is approximately 3×10^{-10} coulomb.

It might normally be expected that there would be considerable variation in the mechanical contact between the fiber and the collector resulting in erratic charging. The experimental fact is that with clean surfaces any erratic behavior is certainly less than the random fluctuations due to the finite numbers of particles passing through the sphere.

III. THE IONIZATION CHAMBER

For the use planned, namely, a light weight equipment for use with balloons, a spherical ionization chamber of 0.05-cm thick steel and 25 cm in diameter was used. The hemispheres were copper-plated, spot-welded together at an overlapping joint at the equator, and then silver-soldered with an atmosphere of hydrogen inside. During this same silver-soldering operation the extension *G* [Fig. 1a] and the copper tubulation *H* were also silver-soldered in place.

A vacuum-pressure seal is made by inserting a polyethylene gasket between the base and the extension *G*, and using two steel rings drawn together by screws. No trouble was experienced with these seals, and they remain tight under pressure with no apparent deterioration with time.

After inserting the mounting holding the quartz system, the sphere was evacuated and baked at 100°C for 24 hours. At the end of this time, carefully dried, pure argon was admitted to a pressure of 8 atmospheres.

TABLE I. Effect of tilt on the times of charging.

Angle of tilt	Time per discharge
Vertical	88.52 sec
13°N	88.63 sec
13°W	88.38 sec
13°S	88.54 sec
13°E	88.32 sec

A particular feature of the design of this instrument is the use of standard radio tube parts. Thus the octal base, stem (containing the connections through the envelope), and the section *G* are all type 6L6 tube parts. The shell *D* is that of a type 6F6 tube. Considerable simplification thus results.

IV. RESULTS OF TESTS

After making and testing a group of 40 of these ionization chambers, several points have come to light that will be of interest to anyone making similar instruments.

A. The region of contact between the gold-coated quartz fiber and the Aquadag-coated collector must be clean and particularly free from organic contamination. If this is not so, the collector will not charge up to the same potential each time. This will result in larger fluctuations in the interval between chargings than is to be expected from the finite number of ionizing particles passing through the ion chamber. The criterion set for those instruments that were accepted was that this fluctuation must be less than twice that expected from purely statistical fluctuations. For singly-charged, minimum ionization particles, the random fluctuations give rise to a standard deviation of about 0.4 percent per discharge.

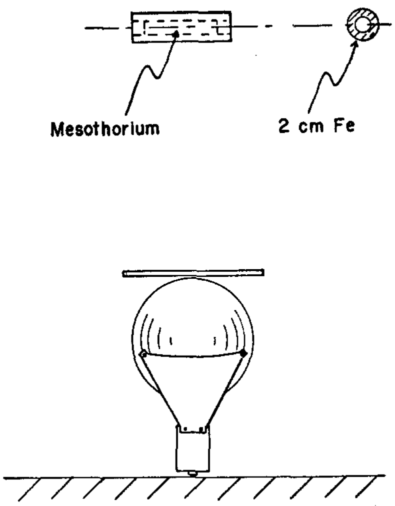

FIG. 3. In comparing one instrument with another a source of mesothorium was used which was in equilibrium with the C''.

It is of interest that if both the collector and the fiber are coated with gold, the cohesive forces are sufficiently great so that the fiber will not always fly away. No trouble of this sort was experienced with gold against graphite.

B. At high rates of ionization the argon must be quite pure if volume recombination is to be kept down. It was found that a partial pressure of oxygen of 0.15 mm of mercury in 10 atmospheres of argon was sufficient to cause a 17 percent decrease in the collected current at 10 times the maximum rate of ionization to be expected during a flight to high altitudes. With care in baking the spheres and drying the argon it was possible to keep the linearity of rate of charging *vs* ionization to within 1 percent, up to rates several times those to be expected.

C. It was found with some of the instruments that for a constant rate of ionization the rate of charging changed with time, usually becoming constant after an hour. This was traced to a slight leakage or possibly a "soak-in" of charge on the insulation part of the quartz collector. This was remedied by heating this portion of the quartz rod to just under its softening point just before assembly.

D. There is a dependence of the rate of charging on the potential of the charging battery as shown in Fig. 2. The spheres were quite uniform in this dependence. In use this dependence was not of importance since the ion chambers were calibrated just prior to being used, as will be described later.

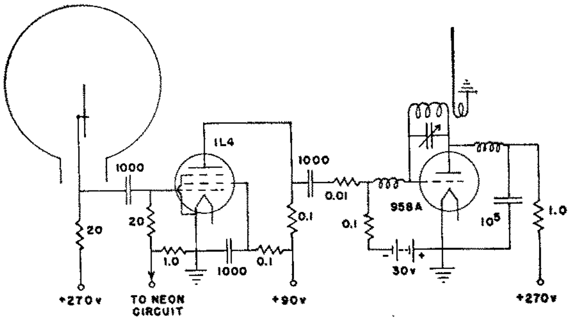

FIG. 4. Amplifier and oscillator circuit. The transmitter is pulse modulated and radiates approximately 0.5 watt in 10^{-4} sec. The neon circuit is associated with the barometer unit (see reference 3). Resistance values are in megohms while capacitances are given in micro-microfarads.

E. The dependence of the rate of charging on tilt was negligible as will be seen from the data given in Table I. This is good evidence that the electrostatic forces are much larger than the gravitational forces.

F. Calibration was made in terms of secondary standards that were carefully compared with each other. These in turn were compared with our older ionization chambers that recorded photographically and which have been used on numerous occasions in past years in this country, Canada, and India. This then gives a means of comparing our present results with those obtained previously.

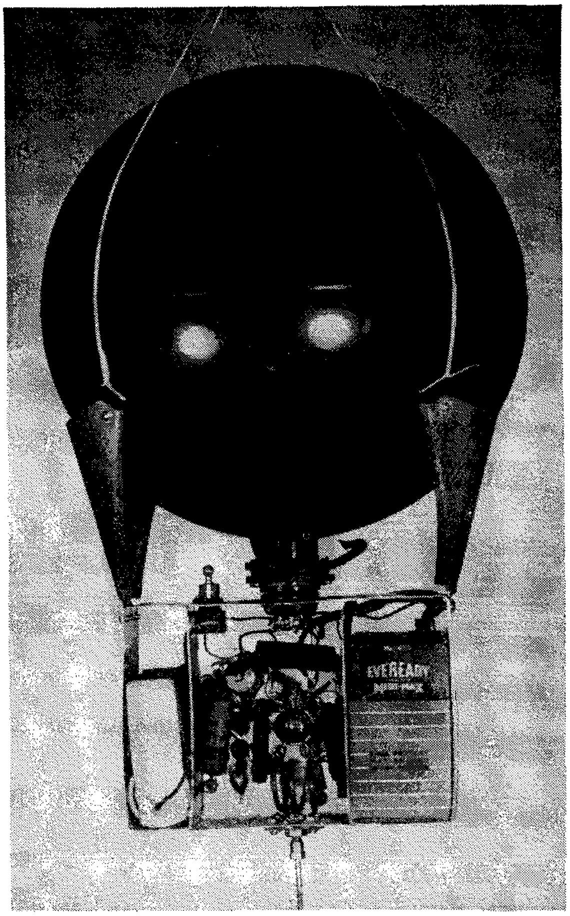

FIG. 5. The assembled instrument with batteries weighed 2.2 kg. Added heat insulation, black cellophane covering, and lines brought the total weight to 2.8 kg.

The method of comparing one ionization chamber with another was to use a source of mesothorium in equilibrium with thorium C''. This was inclosed in an iron shield with a 2-cm thick wall and was then located above the ion chamber as shown in Fig. 3. A one-quarter inch steel plate directly above the sphere tended to further minimize the effect of varying wall thickness of the different spheres. Some scattering occurred from the floor and surroundings but this was small. No differences in the response of the instruments to this scattered radiation was found. The wall thickness of the different spheres was closely the same, having been spun out of material of the same thickness.

This comparison with the instruments kept as standards was made with the batteries used during the particular flight.

The batteries used with the standard instruments were continuously checked during the periods of calibration, and these potentials were known to ±0.2 volts out of 270 volts.

In calibrating, the pulse, as amplified by the 1L4, Fig. 4, was fed into a registering circuit and the time

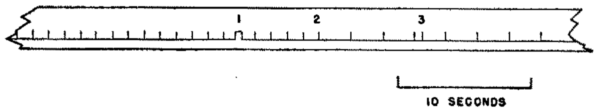

FIG. 6. Section of typical record. Timing marks, 1, are spaced at minute intervals (32 cm) along the tape. At 2 the barometer contact changed resulting in a new rate of neon flashing. At 3 an ionization signal was received.

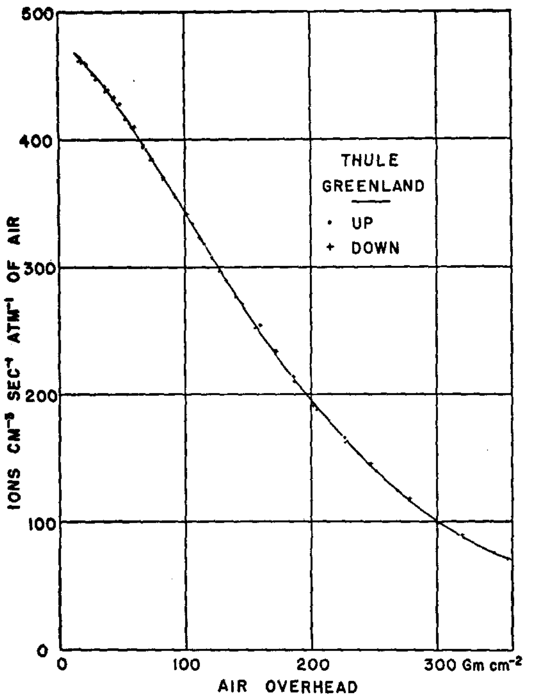

FIG. 7. Sample record taken at Thule, Greenland (geomagnetic latitude 88°N), on August 5, 1951.

was recorded for a given number of pulses. The criterion set was that the time per pulse from day to day should not depart from the average by more than ±1 percent and most were within ±0.5 percent. The time between pulses, which was adjusted to be somewhat shorter than that to be expected during a flight, was approximately 20 seconds.

The instrument as assembled, without the covers to the battery and circuit box, is shown in Fig. 5. The barometer element[3] was mounted on one of the covers. The weight of the whole assembly including wrapping was 2.8 kg.

The consistency of behavior of the instruments when checked at different times indicates that the limit of error in comparing one flight with another was ±1 percent. From the actual flight records that were made simultaneously at Bismarck and Thule, Greenland, the consistency from flight to flight was considerably better than this. At the higher altitudes, where atmospheric temperature differences are less important, the probable errors in the curve, as plotted for a single flight, appear to be approximately 0.5 percent.

A section of a typical record is shown in Fig. 6. This was taken on August 5, 1951, at Thule, Greenland, geomagnetic latitude 88°N. It was made originally on a 16-mm paper tape driven by a synchronous motor and running at the rate of 32 cm per minute. The line on the tape was drawn by a pen actuated by an electromagnet whose resolving time was approximately 0.05 sec. There is a chance that the ionization pulse will occur so close to a barometer-neon pulse that it will not be resolved. It turns out that this is not serious, first because the spacing between ionization pulses follows a very definite pattern due to the constancy with which the pulses occur for a given rate of ionization, and second, because one usually averages several of these pulses since they are transmitted at rather frequent intervals. Thus at high altitudes the spacing between every 8 or 10 is usually taken.

Timing marks, at 1 minute intervals, are put on the tape by a clock mounted on the recorder.

The error introduced by taking the record off the paper tape is negligible. In most cases the distances measured were of the order of 50 to 100 cm and these distances could be measured to less than 1 mm.

On several flights a thermometer unit, working on the Oland principle,[4] was fastened to the other side of the battery-circuit box. These signals were recorded on the same tape. Our experience of the past was confirmed by these measurements, namely, that with proper wrapping the temperature of the instrument during daylight flights changed less than ±10°C during the flight. At night the temperature on some occasions dropped below 0°C, but in all cases the points coming down agreed very well with those going up, which indicates the insensitivity of the instrument to changes of temperature.

Shown in Fig. 7 is a typical curve obtained on August 5, 1951, at Thule, Greenland. Plotted are the points taken both going up and coming down. At pressures above 500 g cm^{-2} the time between pulses becomes quite long, and the records are usually stopped at about this pressure.

The ionization values are expressed in ions cm^{-3} sec^{-1} per atmosphere of air and are directly comparable with those we have published in past years.[5]

Results from a series of flights made at Bismarck, North Dakota, simultaneously with those made at Thule, Greenland, and certain intermediate latitudes, are being published elsewhere.

It is a pleasure to acknowledge the assistance of Dr. Bernard Steenson, Mr. Edward Stern, and Mr. Alan Johnston, who assisted in the construction and testing of some 40 of these instruments.

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[3] H. V. Neher, Rev. Sci. Instr. 24, 97 (1953).

[4] H. V. Neher and W. H. Pickering, Rev. Sci. Instr. 13, 143 (1942).

[5] Bowen, Millikan, and Neher, Phys. Rev. 53, 855 (1938).