altitudes, all but a few percent of the ionization pulses in an unshielded chamber of our type are caused by nuclear disintegrations. These experiments also confirm the view that most of the coincidences between two neighboring chambers have the same origin, since they show that protons sufficiently energetic to traverse the chamber walls, yet sufficiently slow to ionize heavily, are produced very often in the nuclear disintegrations.

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Sea Level Latitude Effect of Cosmic Radiation*†

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On a recent voyage from Rio de Janeiro to Boston the vertical intensity of the total and hard components of the cosmic radiation were measured with a Geiger counter telescope apparatus. For the hard component the percentage alteration from high latitudes to the magnetic equator was 5.32±0.46 percent. For the soft component it was 4.46±0.61 percent, and for the total radiation it was 5.04±0.55 percent.

I. INTRODUCTION

PREVIOUS measurements of the sea level latitude distribution of cosmic radiation have been made chiefly with ionization chambers, although some measurements have been made with coincidence counter systems. The use of counter systems allows the determination of the effect for the soft component of the radiation either by noting the relationship between the soft component and showers produced in small thickness of lead, or by taking the differences between the intensities of the total and hard components. The extensive measurements by Compton and Turner[1] and by Gill,[2] for example, were obtained by using the ionization chamber method. Coincidence counter measurements have been made by Auger and Leprince-Ringuet,[3] Clay, Bruins and Wiersma,[4] Johnson and Read,[5] Wilson and Turner,[6] and Neher and Pickering.[7] According to Johnson,[8] the agreement between the two methods has been good, taking into account the fact that one might expect a somewhat greater latitude effect for the vertical intensities (measured by coincident counter systems) than for the integrated directional meas-

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* Assisted by the Office of Naval Research with the cooperation of the National Geographic Society.

† A skeleton of the results of this investigation has been published in Phys. Rev. **72**, 1263 (1947).

[1] A. H. Compton and R. N. Turner, Phys. Rev. **51**, 1005 (1937); **52**, 799 (1937).

[2] P. S. Gill, Phys. Rev. **55**, 1151 (1939).

[3] P. Auger and L. Leprince-Ringuet, Comptes Rendus **197**, 1242 (1933); P. Auger, Nature **133**, 138 (1934).

[4] J. Clay, E. M. Bruins, and J. T. Wiersma, Physica **3**, 746 (1936).

[5] T. H. Johnson and D. N. Read, Phys. Rev. **51**, 557 (1937).

[6] V. C. Wilson and R. N. Turner, Phys. Rev. **59**, 931 (1941).

[7] H. V. Neher and W. H. Pickering, Phys. Rev. **53**, 111 (1938).

[8] T. H. Johnson, Rev. Mod. Phys. **10**, 193 (1938).

urements made with ionization chambers, because of the observed increase in latitude effect with altitude.

While agreement of previous measurements of the latitude effect for the total radiation seems good, some ambiguity, at least, is present in the experimental values for the latitude effect of the soft component. This ambiguity, as pointed out by Arley,[9] is exemplified by the conclusions of Heisenberg and Heitler in interpreting the coincident counter data of Auger and Leprince-Ringuet. Heisenberg[10] finds a ten percent latitude effect for the soft component, whereas Heitler[11] finds none.

In the light of the foregoing observations, we should like to present the measurements made by us with a system of coincident Geiger-Mueller counters on a ship voyage between Rio de Janeiro (geomagnetic latitude 12.5 degrees S) and Boston (geomagnetic latitude 53 degrees N) in the summer of 1947. The observations were made as part of the work of the National Geographic Society's expedition to South America to view the solar eclipse of May, 1947.

II. THE APPARATUS

The apparatus consisted of a system of Geiger-Mueller counter telescopes arranged in such a way that three types of events were registered—the passage of an ionizing particle through (1) a triple coincident system in which there was no absorber, (2) 8 cm of lead, and (3) 16 cm of lead. The geometry is shown schematically in Fig. 1. It will be observed that only five trays of counters were used to obtain three triple systems. This entire system of five trays was duplicated in the actual apparatus. In addition to the absorbing lead, a protective shield of one inch of lead was placed around tray number three, which tray was common to the three coincident systems. The purpose of this shield was to reduce the number of accidental counts which might arise from extensive lateral showers.

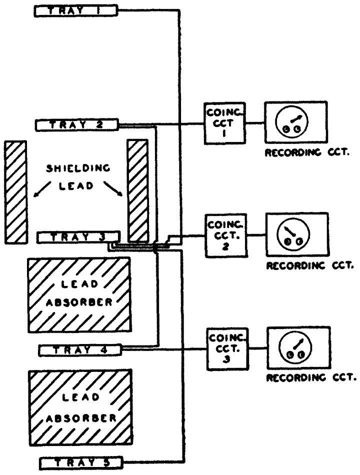

Fig. 1.

The Geiger-Mueller counters used were constructed of 0.007-inch-wall Nonex glass and 0.005-inch-wall seamless copper tubing. The copper cylinder was one cm in diameter and 10.2 cm in length. The axial wire was 0.003-inch tungsten. The counters were a non-self-quenching type filled with a mixture of argon and oxygen to a pressure of 12 cm of Hg. This mixture gave a very good plateau (the order of 200 volts or more and a slope of less than four percent per 100 volts) and a long life.

The high resistance (500 megohms) necessary for successful operation of this type of counter necessitated precautionary measures with regard to possible spurious high resistance leakage to ground in the anode circuit. For this reason the anode lead was led through a mounting tube which was imbedded in a cylinder of sulfur. This served the purpose of giving a rigid support with very good insulating properties which introduced little capacity to the circuit.

There were nine counters in each tray. They were placed side by side in the same plane so that there was considerable area between copper cylinders through which a particle could pass without being detected. For this purely geometrical reason each tray was therefore only about 77 percent efficient in detecting particles which passed through the telescope of which it was a member. From considerations of the counting rate and dead time alone of the counters, each tray would be 99.7 percent efficient. The efficiency of the triple systems was therefore about 45 percent. Since, in this investigation, we were interested only in ratios of counting rates

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[9] N. Arley, Kgl. Danske Vid. Sels. Math.-Fys. Medd. **23**, No. 7.

[10] W. Heisenberg, *Vorträge über Kosmische Strahlung* (Springer-Verlag, Berlin, 1943; Dover Publications, New York, 1946).

[11] W. Heitler, Nature **140**, 235 (1937).

which were nearly the same, the low efficiency served only to lessen the total number of counts received by the apparatus and did not alter the relative counting rates at the extremeties of the latitude curves.

The effective resolving time of the coincident circuits was about 5×10^{-4} second. With this value, the accidental rate of the triple systems was about 5×10^{-5} cts/sec., or less than 0.1 percent of the true coincident rate.

The counters were operated so as to deliver a negative pulse of thirty volts or more to the grid of the associated 6AK5 amplifier tube. The arrival of a large negative pulse on the grid of this tube, which was normally conducting, reduced its plate current to essentially zero. The conventional Rossi circuit was used to establish the coincidences between trays. With the parameters indicated in the circuit diagram, Fig. 2, a triple coincidence caused a positive pulse of 20 volts or more to appear on the grid of the 2D21 thyratron, causing it to strike and therefore operate the counting register (Cyclotron Specialties Company). A double coincidence caused a pulse of only two volts or so and therefore could not overcome the nine-volt negative bias on the thyratron grid. Except for the filament and bias voltages, the other potentials in this circuit may be varied considerably with inappreciable effect on the over-all performance of the telescope. During operation all potentials were maintained within safe limits.

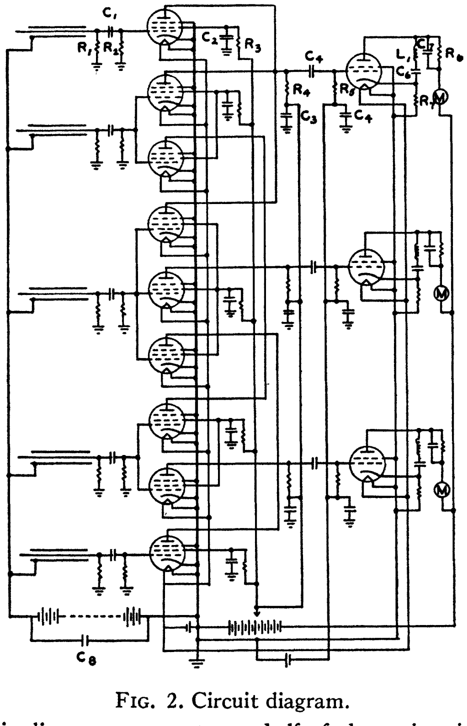

FIG. 2. Circuit diagram.

This diagram represents one-half of the entire circuit. The other half was identical. Values of the parameters were as follows: $R_1=5.10^8$, $R_2=10^6$, $R_3=10^2$, $R_4=R_5=5.10^4$, $R_6=5.10^3$, $R_7=2.10^2$; $C_1=5.10^{-12}$, $C_2=C_3=C_5=10^{-8}$, $C_4=10^{-9}$, $C_6=C_7=5.10^{-7}$, $C_8=2.10^{-6}$; $L_1=30$ mh; 2D21 plate voltage $=+180$ v, 2D21 grid bias $=-9$ v, 6AK5 plate and screen voltages $=45$ v, counter voltage $=-1000$ v.

III. RESULTS

In the discussion of the latitude effect, we shall define the latitude effect, L, in terms of the intensity, I, of the rays as measured at the magnetic equator and in the northern latitudes; i.e., $L=(I_{50}-I_0)/I_{50}$. Superscripts h and s shall refer to the hard and soft components, respectively, and no superscript indicates measurements of the total radiation. Subscripts 50 and 0 shall refer to measurements in the northern latitudes and at the magnetic equator, respectively. In addition, we shall consider that radiation which penetrates 8 or 16 cm of lead as the hard component and that radiation which is absorbed in 8 or 16 cm of lead as the soft component. It is clear that the values for the intensity of the soft component are arrived at from the difference in the values for the total and hard radiations. This method for measuring the soft component has two major drawbacks—the dissimilarity in the geometry or other characteristics of the separate coincident systems, and the increase in the value of the probable error as determined from the difference of the two measured quantities.

The observations are shown plotted in Fig. 3. In this plot the observations for the two coincident systems with the same distribution of lead are combined. In view of the large values of the statistical errors in the individual plotted points, we have combined points between 15 degrees South and 15 degrees North to obtain I_0 and points above 28 degrees North to obtain I_{50}. In this way we obtain the following values:††

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†† We have also combined the data for 8 and 16 cm of lead since the two thicknesses yield practically identical results. The probable errors for the differences have been evaluated according to standard principles. See, for example, H. Margenau and G. M. Murphy, *The Mathe-*

No lead	With lead	Difference
$I_0=3.954\pm0.014$	$I_0^h=2.670\pm0.008$	$I_0^s=1.284\pm0.016$
$I_{60}=4.164\pm0.018$	$I_{60}^h=2.820\pm0.010$	$I_{60}^s=1.344\pm0.021$

Expressing L in percentages, we obtain $L=5.04\pm0.55$, $L^h=5.32\pm0.46$, $L^s=4.46\pm0.61$.

In the computation of the above values, the only errors considered have been those associated with the statistical nature of the observations. In addition to these, there were undoubtedly fluctuations in the counting rates due to magnetic disturbances and temperature and barometric variations. We were unable to obtain sufficient data to apply corrections for these effects. However, in view of the large statistical fluctuations, it is questionable if such corrections would have altered the results significantly.

It is interesting to note that the latitude effects for the total radiation and the hard component are smaller than have been reported previously. Conceivably, this could be accounted for because of different atmospheric conditions existing between Rio de Janeiro and Boston. Of greater interest, however, is the fact that our data strongly indicate the existence of a sea level latitude effect for the soft component whose magnitude is of the same order of magnitude as that for the hard and total radiation, although somewhat smaller in magnitude.

If the soft component is defined as that radiation which is absorbed in 8 cm of lead, the radiation is largely restricted, except for Auger showers, to that which is formed below one kilometer from the earth's surface, by mesotron decay and knock-on processes from the mesotron component existing near sea level, rather than pair formation having to do with primary electrons or with electrons produced near the top of the atmosphere. It is not surprising to us, therefore, to find the latitude effects of the hard and soft components of comparable magnitude.

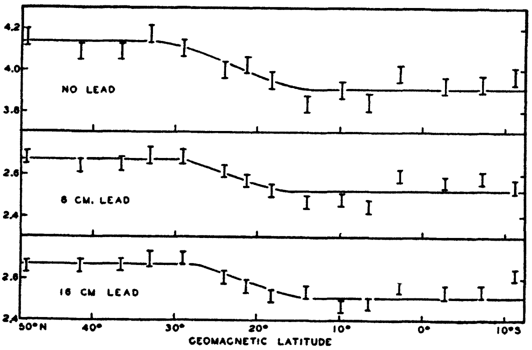

FIG. 3. Vertical coincidence rates at sea level from Rio to Boston.

IV. ACKNOWLEDGMENTS

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matics of Physics and Chemistry (D. Van Nostrand Company, Inc., New York, 1943), p. 498.