The assignment of the 51.5-day activity is probably limited to Hg^{203} and Hg^{205}, since it decays by the emission of negative beta-particles to thallium. Tl^{203} and Tl^{205} are the only stable thallium isotopes, and no active thallium has been found to grow from the 51.5-day mercury. Since both slow and fast neutrons produce the activity, the best assignment is Hg^{203} which can be produced by n-γ reaction from Hg^{202}, and by n-$2n$ reaction from Hg^{204}.

THE 5-MINUTE ACTIVITY

In short slow neutron bombardments of mercury, an activity with a half-life of about 5 minutes was produced. No chemical identification of this activity was attempted. Its yield at saturation was about one-tenth of that of the 43-minute activity, which has itself an abnormally low yield in slow neutron bombardments. It cannot, therefore, be decided whether or not this period is due to an impurity. It may, however, be identical with the 5.5-minute mercury, reported by Krishnan and Nahum,[6] and assigned by them to Hg^{205}. We have not studied the radiations emitted by the 5-minute activity.

It is a pleasure to express our gratitude to Professor E. O. Lawrence for his interest and to the staff of the Radiation Laboratory for their cooperation. We are indebted to Professor G. T. Seaborg, Dr. J. W. Kennedy, and Dr. E. G. Segrè for numerous stimulating discussions and suggestions. The financial support of the Research Corporation and the Rockefeller Foundation is gratefully acknowledged.

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Further Tests of the Atom-Annihilation Hypothesis as to the Origin of the Cosmic Rays

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1. Tests in Mexico. The authors had predicted that since the hypothetical silicon-annihilation rays should have enough energy (13.2 Bev) to get vertically through the earth's magnetic field at the equator in Peru, though not in India, there should be found, both at sea level and at all altitudes in the Americas, when vertically incoming rays alone are under test, a very long plateau of uniform cosmic-ray intensities extending north from Mollendo, Peru to about the latitude of Victoria, Mexico (mag. lat. 32.8°). There the strong band due to oxygen annihilation rays (7.5 Bev) should first appear, to be followed in going still further north when the latitude of 40° N magnetic had been reached, by the full entrance of the nitrogen annihilation band (6.5 Bev). The experimental findings were in accord with these predictions. 2. Tests in the United States. In going from Pasadena (mag. lat. 40.7° to St. George, Utah, but 4.1° (280 miles) nearer to the N magnetic pole than Pasadena, the carbon-annihilation band (5.6 Bev) was expected to appear, to be followed by a flat plateau clear up to latitude 54° N magnetic, when helium annihilation rays (1.88 Bev) were expected to appear. A balloon flight at St. George (mag. lat. 44.8°) and another at Pocatello, Idaho (mag. lat. 51°) yielded preliminary results in harmony with these predictions. 3. Evidence that the act of atom-annihilation actually transforms the rest mass energy of an atom into an electron pair. The flat plateau between St. George and Pocatello (mag. lat. 51°) corresponding to the absence of abundant atoms of atomic weight between that of carbon and that of helium, and the definite appearance of a new band between Omaha (mag. lat. 51.3°) and Bismarck (mag. lat. 56°) constitute new and strong evidence for the transformability of the complete rest mass energy of an atom into an electron pair.

I. THE FUNDAMENTALS OF THE HYPOTHESIS

IN a former paper[1] we have presented what may be called the atom-annihilation hypothesis of the origin of cosmic rays and the preliminary evidence found for its utility. This hypothesis assumes that an atom out in interstellar space has the capacity not possessed by an atom in the stars or in any other region in which it is continuously subjected to bombardment from neighboring atoms, of occasionally transforming the whole of its rest mass energy into a charged-particle pair which for the present

[1] Millikan, Neher, and Pickering, Phys. Rev. **61**, 397–413 (1942).

may be called an "electron pair." The kinetic energy of such an electron pair can then easily be computed from the known rest mass of the atom m with the aid of the equation $E=mc^2$, c denoting the velocity of light and E energy in ergs.

Bowen and Wise have recently made the discovery[2] that in ring nebulae (and, therefore, in interstellar space) there are but five abundant atoms (save hydrogen, which could yield for the present purposes no observable effects anyway), namely, He, C, N, O, Si, the last four of which are, according to Bowen, about equally abundant and the first about ten times their abundance, no other atom having as much as a tenth of the abundance of any of these five.

In view of this discovery the foregoing hypothesis requires that the only "*field-sensitive*" cosmic rays that can get into the earth's atmosphere so as to be observable in balloon flights would have to be the annihilation rays of one or another of these five atoms.

To understand fully the reasons for this conclusion it is also necessary to be familiar with the Lemaitre-Vallarta analysis of the effects of the earth's magnetic field on incoming electrons, an analysis which, when combined with Millikan and Neher's observations on the longitude effect in cosmic rays, shows that it requires vertically incoming electrons of an energy of 17 Bev to get through the earth's magnetic field at the magnetic equator in southern India, while it requires not more than 13 Bev to get through at the magnetic equator in the neighborhood of Peru. This difference is due to the fact that the earth's magnetic field is weaker on the Peru side of the earth than on the India side.

II. WHY EVIDENCE FOR THE LATITUDE OF ENTRANCE OF SILICON-ANNIHILATION RAYS HAD TO BE SOUGHT IN INDIA

From the mass of the atom of silicon, the silicon-annihilation rays are easily computed to have an energy of 13.2 Bev. Also from the Lemaitre-Vallarta curves one can compute that the magnetic latitude in India at which vertically incoming silicon-annihilation rays could first break through the earth's magnetic field as one moves northward from say Madura, which is on the magnetic equator, is about 20° N magnetic. This is less than 200 miles north of Agra, where is located the most important meteorological observing station of the British Indian Meteorological Service. Agra therefore possessed special advantages as a flight point.

However, vertically incoming silicon-annihilation rays, though they could not get in at Agra should be found in full strength, for example, at Peshawar (mag. lat. 25°), the northernmost meteorological observing station available in India, for we had computed that the energy necessary to get through there should be but 12.4 Bev.

But since there are no abundant atoms of rest mass energy between 17 Bev and 13.2 Bev, according to the present hypothesis there could be no new cosmic rays entering the earth vertically between Madura and Agra, where we computed that the energy necessary to get through was 15.4 Bev.

Further, since there are no abundant elements of rest mass energy between 13.2 Bev and 7.5 Bev —the latter being the rest mass energy of the oxygen atom—there should be found no new vertically incoming cosmic rays other than those of silicon anywhere in any latitude south of about 32° or 33° N magnetic, where the oxygen annihilation rays ought first to begin to break through the blocking effect of the earth's magnetic field.

To test experimentally the requirements of this hypothesis as to the silicon annihilation rays it was clearly necessary, then, to go to India and measure *the total vertical incoming cosmic-ray energy at or near the magnetic equator* and then to make similar measurements both at a latitude just a little south of the computed latitude of first entrance of the silicon annihilation rays and, second, at a latitude definitely north of that of first entrance of silicon rays. These considerations, supplemented by the local conveniences for observing, dictated the choice of Bangalore (mag. lat. 3° N), Agra (mag. lat. 17.3° N), and Peshawar (mag. lat. 25° N) as the three best locations in India for measuring by high balloon flights the total incoming cosmic-ray energy.

The predicted flat plateau of vertically incoming cosmic-ray energies between the magnetic

[2] I. S. Bowen and A. B. Wise, Bull. Lick Observatory **19**, 1 (1939).

equator and Agra and the definitely predicted entrance between Agra and Peshawar of a new band corresponding to silicon annihilation rays could, of course, be tested only when vertically arranged coincidence counters were used as the measuring instrument in high flights, since it was the energies of vertically incoming rays that were the subjects of the foregoing computations.

When the measuring instruments used are either single counters or electroscopes—instruments which respond to rays coming in from all directions, the Lemaitre-Vallarta curves[3] show clearly that the flat plateau for vertically incoming rays between the equator and Agra should be replaced by an incoming cosmic-ray energy which should increase continuously with increasing latitude. The measurements made in India by all three of these methods, double coincidence counters, electroscopes and single counters, showed in every case the behavior predicted by the hypothesis. So far, then, as the observations in India went (there were made between November 30, 1939 and February 10, 1940 over forty successful flights) the predictions of the hypothesis were fully satisfied.

III. PREDICTION OF A VERY LONG PLATEAU OF CONSTANT VERTICALLY INCOMING COSMIC-RAY INTENSITY FROM SOUTHERN PERU UP TO MIDDLE MEXICO

There was also presented in the former reports upon this work such evidence as a careful study of earlier observations made by some of the authors offered in support of the atom-annihilation hypothesis. All of these data, however, had been taken with electroscopes rather than with vertical coincidence counters, and this made the interpretation somewhat uncertain.

For example, since, on the Peru side of the earth vertically incoming silicon rays can get through the earth's magnetic field at the equator, and since there should be no other rays of lower energy than those of silicon (13.2 Bev) to get to earth until one reaches the latitude of about 33° N, where the vertically incoming oxygen annihilation rays (7.5 Bev) should be able to get to earth, *the hypothesis clearly predicted a long flat plateau of unchanging vertically incoming cosmic-ray energy extending from the magnetic equator near Mollendo, Peru, clear up to about the latitude of Victoria, Mexico* (mag. lat. 32.8° N).

There had been found some evidences for the existence of this plateau in flights made in 1932 in both Panama and Peru in which *electroscopes* had been taken up to altitudes of 22,000 feet without showing any differences in their readings whether the flights were made in Peru on the magnetic equator or in Panama (mag. lat. 20° N). This was entirely different from the results obtained with electroscopes in India between the same latitudes. Also, in sea-level readings made in '32, '33, and '34 in voyages from Mollendo to Los Angeles there had been found in electroscope readings no change until a magnetic latitude of about 21° N was reached, at which point the readings began to rise and continued to do so until Los Angeles was reached. It was accordingly predicted that if one had taken, or could take, these readings with vertical coincidence counters instead of with electroscopes, there would be no increase at all in going from the magnetic equator in Peru clear up to the magnetic latitude of about 33° N (Victoria in Mexico).

The foregoing prediction made it possible to obtain a very crucial test for the hypothesis, especially since its critics were willing to concede that if a flat plateau was found on the Peru-Mexico side of the earth between magnetic 0° and 33° N, it would be convincing evidence in its favor. They were not so sure that the flat plateau which had already been found in India between magnetic latitudes 3° and 17.3° was entirely convincing evidence, since in any case the *rate* of change in incoming energy would be expected to be small near the equator, even for such *continuous* laws of distribution of incoming energy with latitude as had been suggested by others.

IV. NEW EQUIPMENT FOR MAKING CRUCIAL TESTS IN MEXICO

In view, then, of the crucial character of observational work in Mexico, in spite of the absorption of all the authors in war duties it was decided to be essential to take a month off in December, 1941, and to try to make in Mexico observations similar to those made in India

[3] See curve 1, Fig. 2 in Phys. Rev. **61**, 401 (1942); or Fig. 10, Phys. Rev. **50**, 503 (1936).

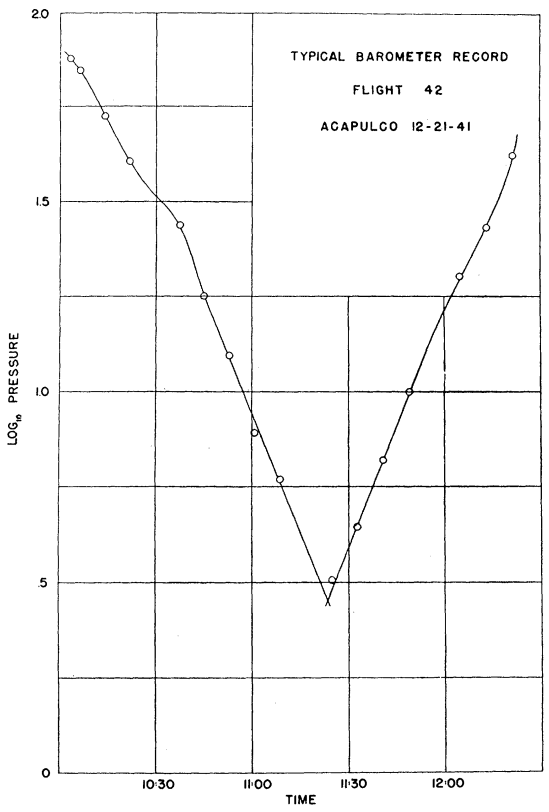

FIG. 1. Shows method of determining the pressure in mm of mercury at any instant during the flight, also the time and altitude at which one of the two supporting balloons burst.

between November, 1939 and February, 1940, save that the Mexico experiments were to be made only on vertically incoming cosmic-ray energies and hence not with electroscopes or single counters.

In order, however, to render the Mexico tests independent of such flight facilities as are usually available only in well-equipped meteorological stations, and in order to be in position to change the desired latitudes for the flights independently of the locations of such stations, in November, 1941 there was fitted out a covered truck as a travelling cosmic-ray laboratory. This left Pasadena on December 2nd and was driven via Laredo, Texas, from Pasadena to the most southerly accessible point in Mexico, *viz.*, Acapulco, and then back to Pasadena. Enroute careful measurements were made on vertically incoming cosmic-ray energies by balloon flights at or near Acapulco, Mexico (mag. lat. 25.8° N), Valles, Mexico (mag. lat. 31.15° N), Victoria, Mexico (mag. lat. 32.8° N), and Pasadena, U. S. A. (mag. lat. 40.7° N).

Also, careful measurements were made with vertical coincidence counters in from four- to ten-hour runs on the "ground rate of cosmic-ray counts" at all these places, and also at San Antonio, Laredo, and Monterrey (Mexico). This series of ground measurements was taken first because they were needed as reference rates at all the places at which balloon flights were to be made, but also because the ground rates, though representing but a trifling part of the vertically incoming energy ought clearly to present a correct reflection of *the variation with latitude* of the whole vertically incoming cosmic-ray energy such as was to be measured in the balloon flights.

The technique of measuring the vertically incoming energy was the same as that used in India, save that one of the authors, Pickering, introduced the improvement of inserting the "scaling mechanism" at the receiving end instead of at the transmitting end, which had of course to be taken up with the balloon.

This scaling mechanism provides that only every second, or every fourth, or eighth, or sixteenth, or thirty-second cosmic-ray shot is registered on the recording tape. It will be described in *The Review of Scientific Instruments.*

This arrangement, though operating on 1.7 meter waves is sensitive to the waves emitted by automobile spark plugs—a condition which made it necessary to choose observing locations some miles distant from paved highways or other lines of automobile travel. This is not as difficult a condition to fulfill in Mexico as in the United States.

V. THE OBSERVING TECHNIQUES

The standard procedure followed in all flights at a particular location is as follows: On the day or night preceding the flight the coincidence counter-pair to be used in the flight is carefully compared with a standard counter-pair by setting the two up side by side in the truck laboratory, each being provided with a mechanical counter which registers the number of shots traversing each counter-set throughout say a six-hour run. This establishes the standardized

TABLE I. Summary of ground level counts with standard set.

	Counts	Time in minutes	Rate per minute	Paulin bar. reading	Corrected rate	Mean rate	
Acapulco (mag. lat. 25.8°)	5004	208	24.0	29.91	24.9	90	90.5
Valles (mag. lat. 31.15°)	6005	246	24.4	29.92	25.3	91	
Victoria (mag. lat. 32.8°) Dec. 10	13585	504	27.0	29.03	25.9	94	94
Victoria (mag. lat. 32.8°) Dec. 28	8086	304	26.6	29.30	26.1	94	
Monterrey (mag. lat. 34.6°)	5797	197	29.5	28.42	26.5	96	95.3
Laredo (mag. lat. 36.65°)	16408	633	25.9	29.70	26.4	95	
San Antonio (mag. lat. 38.5°)	6747	239	28.2	29.25	27.6	100	98
Junction, Texas (mag. lat. 38.5°)	11171	370	30.2	28.17	26.6	96	
Pasadena (mag. lat. 40.7°)	29736	1073	27.7	29.50	27.7	100	100

Corrected rates to Paulin reading of 29.50.
Correction 0.9% per 0.1".

ground-level-rate of cosmic-ray bombardment at the given locality.

During the same period another observer has calibrated the aneroid to be carried up in the flight. This is done by having in the truck-laboratory an air pump and a closed chamber with glass top and sides in which the aneroid can be placed and the pressure reduced by any desired number of steps as read off on a mercury barometer column, also connected into the variable pressure chamber. In this way the movements of the aneroid arm as recorded in the immediately succeeding flight on the tape of the so-called "Galcit" meteorograph (of the Olland type) give at once the pressure in millimeters of mercury at any instant of the flight. Indeed, the barometer readings recorded on the moving tape of the meteorograph in this artificial flight made in the truck-laboratory, just before the actual flight, with the aid of the mercury-column-barometer and the variable pressure chamber constitute exactly the same series of readings that the aneroid will record immediately thereafter when it is sent aloft. For, although the barometers used have, in fact, a very nearly negligible temperature coefficient, it has been found that in practice, by suitably covering with black paper the basket in which the instruments are sent up, the temperature inside the baskets, as read also on the tape of the Galcit meteorograph, is actually held very nearly constant throughout a flight, so that barometer errors due to stratosphere temperatures are quite fully eliminated. As in all high altitude flights, however, in spite of great care used in the calibration of the barometers, when the pressures fall to the values between ten and forty millimeters of mercury, the barometer readings introduce one of the chief sources of inaccuracy in the duplication of flight-curves.

VI. METHOD OF COMPUTING AND PLOTTING THE CURVES

In all high altitude flights the most satisfactory method of handling the barometer record as recorded on the tape is much the same as that used by Millikan and Bowen in 1922 in the first cosmic-ray flights made to altitudes requiring the use of automatic recording electroscopes in place of human observers. The procedure is as follows. After the pressures have been read off in mm of Hg from the tape-record and the barometer calibration curve obtained as above, the logs of the pressures in mm of Hg are plotted as ordinates against the times measured from the instant of release of the balloons as abscissae.

Since in a quiet atmosphere of uniform temperature the rate of ascent is practically constant, in such an ideal atmosphere the logs of the pressure plotted against time of ascent should be a straight line. In practice the curve shows some departures from linearity, especially below the stratosphere, less so in it. A very typical curve is shown in Fig. 1. In general it is found that the most consistent curves are obtained by very carefully joining the series of observed log-pressure points by straight lines, as shown in the figure. The point of intersection of the lines corresponding to ascent and descent then gives with much reliability the time of bursting of one of the balloons and the altitude at which this event occurred. Errors in drawing this time log-pressure curve are, however, responsible for no small part of the observed straggling of the

points, and such lack of duplicability, amounting to possibly five or six percent, as sometimes appears between different flights taken but a few hours apart and apparently under the same conditions.

VII. TESTING IN MEXICO OF THE PREDICTIONS OF THE HYPOTHESIS

1. The first and simplest prediction, actually made and published in April, 1941, was that if sea-level or ground observations reduced to the same level were taken with vertical coincidence counters instead of with electroscopes, the heretofore observed increase in cosmic-ray rate which sets in with electroscopes at mag. lat. 21° or 22° [see Fig. 3, Phys. Rev. **61**, 402 (1942)] would not appear until about the latitude at which oxygen annihilation rays would be expected to get vertically through the earth's magnetic field, say at mag. 33° N. Here a rapid rise should set in and be completed when the observers had moved northward, say 6° or 7°, or enough to enable both oxygen annihilation rays (7.5 Bev) and nitrogen annihilation rays (6.6 Bev) to break vertically through the earth's magnetic field. This latitude of full appearance at sea level of nitrogen rays was expected, from previous experiments in taking electroscopes south on shipboard from Los Angeles harbor, to be within a degree or so of that harbor, which is itself half a degree south of Pasadena.

No further sea-level rise was expected in going north of the latitude of entrance of the nitrogen-annihilation rays since carbon annihilation rays (of energy 5.6 Bev) were not thought able to extend their influence down as far as to sea level. Indeed, electroscopes taken on sea-level, summer, voyages had never shown any rise in going north of Pasadena.

The observed ground-level counts on this trip taken with the same standard set and corrected as indicated to reduce them to a common elevation were as shown in Table I, the accurate value at Pasadena, representing 29,736 counts (18 hours), being taken as 100. Since the readings at Acapulco, Valles, Monterrey, San Antonio, and Junction contain but from 5000 to 10,000 counts each, it is estimated that they should be assigned an uncertainty of about two percent, or twice the statistical "probable

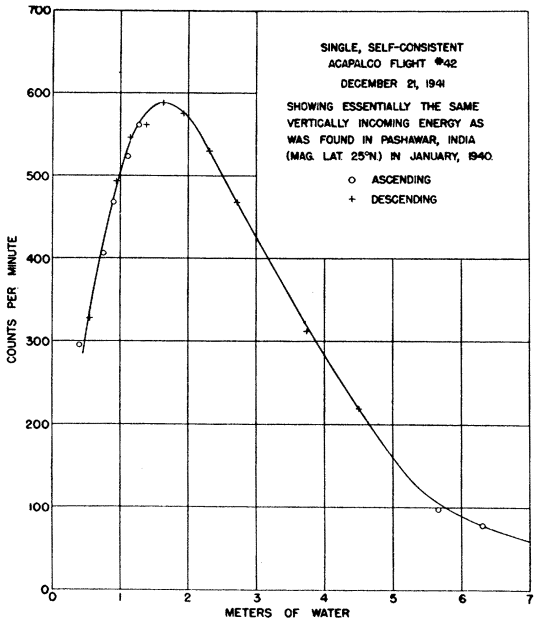

FIG. 2. Best single flight curve taken at Acapulco. Area about 5.8 percent less than the corresponding curve taken at Peshawar (see page 411 of reference 1).

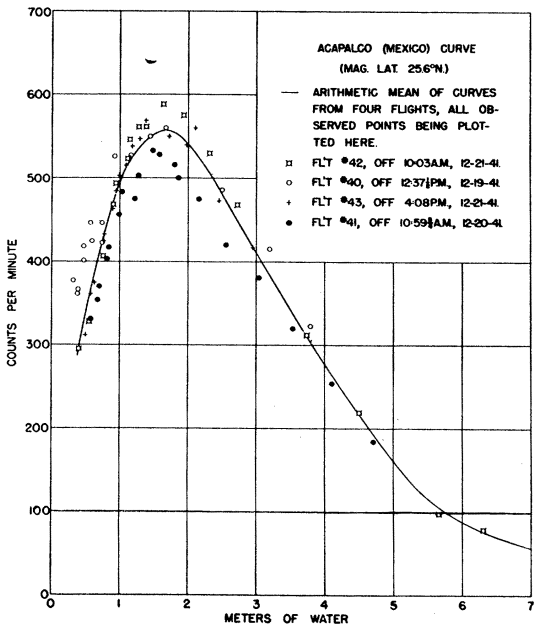

FIG. 3. Every individual observation taken in all four of the Acapulco flights is recorded in Fig. 3. The best obtainable smooth curve is drawn for each of the four flights. The final full curve shown is the arithmetic mean of these four curves.

In general, in all these curves each recorded point is the actual counting rate in a four-minute interval in that flight at the recorded mean pressure in that interval.

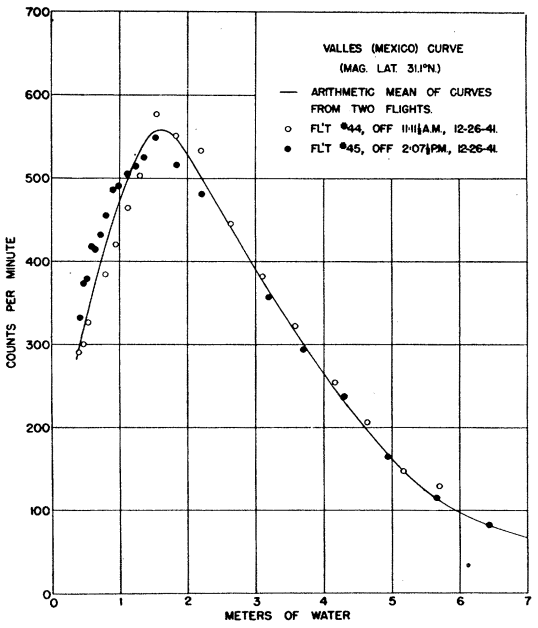

FIG. 4. The full curve is the arithmetic mean of the curves from the flights, two only, made at Valles, all observed points being recorded as in Fig. 3.

error" which for 6000 counts is about one percent. Within these limits the readings all show a satisfactory consistency though those at San Antonio and Junction show the maximum permissible divergence. Their mean is doubtless a better reflection of the condition at that latitude than is either one of the two readings. The significance of the last mean column of Table I in terms of the hypothesis is: (a) that the oxygen annihilation rays are fully in at Monterrey, about three degrees above the latitude at which their effect first began to appear, *viz.*, just a little south of Victoria (the effective angles covered by the counter-pair were 25° crosswise, 45° lengthwise); (b) that at Laredo, two degrees above Monterrey, the effects of vertically entering nitrogen rays have not begun to appear; *in other words, that there is here some evidence for the existence of a very short but possibly observable plateau between the latitudes of first entrance of vertically incoming oxygen and nitrogen annihilation rays;* (c) that nitrogen annihilation rays have *begun* to appear in the two degree interval between Laredo and San Antonio, i.e., at about mag. lat. 37°; (d) that, as in the case of oxygen, three degrees farther north, i.e., by lat. 40°, they are fully in, as the Pasadena reading at lat. 40.7° shows; (e) that, as Bowen's spectroscopic observations indicated, the incoming oxygen and nitrogen rays are very closely equal in energy, the additional percentage of counts brought in by oxygen being $95.3-90.5=4.8$ and that by nitrogen $100-95.3=4.7$.

So far, then, as vertically incoming ground-level readings are concerned, the predictions of the hypothesis are verified with unexpected completeness.

2. The second test of a prediction from the hypothesis is found in a comparison of the *total* energy coming in vertically at Peshawar, India (mag. lat. 25°) and Acapulco (mag. lat. 25.8°).

The hypothesis requires that the vertically incoming rays measurable at both places be simply silicon-annihilation rays. They should, therefore, be of the same total energy unless the intensity of these rays had changed in the two-year interval between the times of measurement at these two widely different localities.

On the other hand, any kind of a continuous distribution in the energy of the vertically

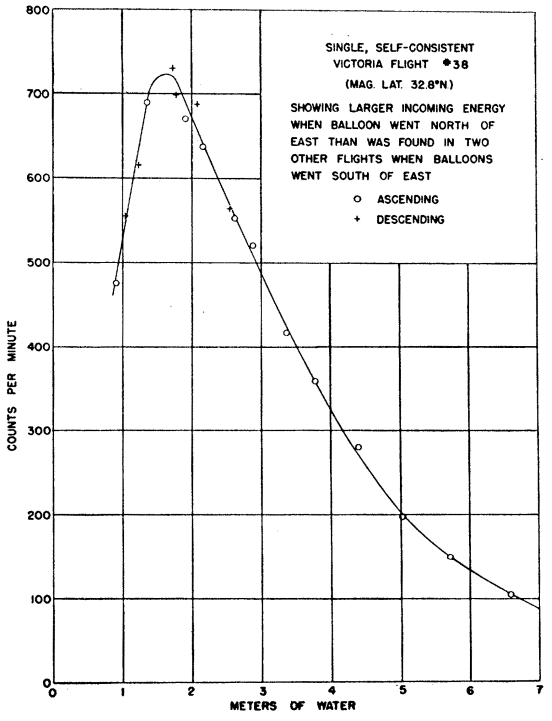

FIG. 5. Flight showing largest energy-area of any of the three flights made at Victoria. In this flight the balloon went north of east.

incoming rays requires that the energy coming in at Acapulco be larger than that at Peshawar, and that for two reasons: First, Acapulco is 0.8° farther north than is Peshawar, and hence should let through more rays for this reason alone. But, second, the earth's retarding magnetic field is in fact notably weaker at Acapulco than at Peshawar, so that, with any *continuous* distribution of incoming energies, more rays should have the energy to get through at the same latitude in the Americas than in Asia. The hypothesis in question denies the possibility of either of these effects.

Five different flights were made in Acapulco to test this point, four of them being reasonably successful. The fifth was not usable. The best of these flights (Fig. 2) gave within 6 percent the same vertical cosmic-ray energy as that found in the observations taken in Peshawar two years earlier. The mean in Acapulco, however (see Fig. 3), was 8.3 percent lower, not higher, than that in Peshawar. This result, then, is definitely

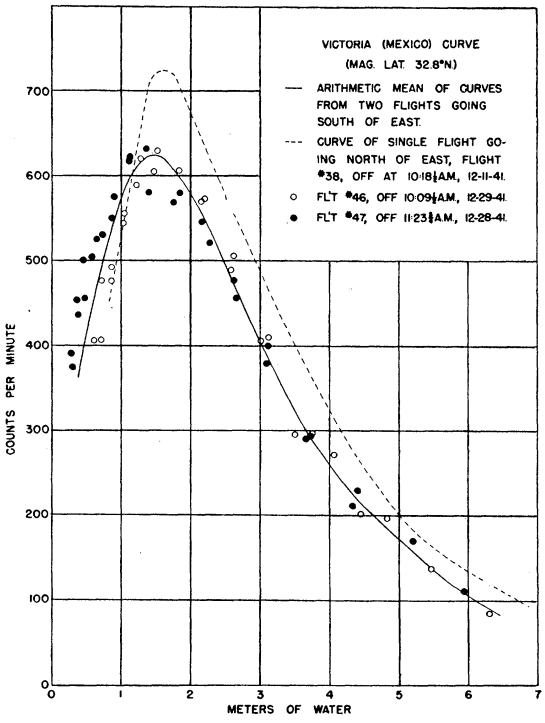

FIG. 6. The full curve is the mean of two flights at Victoria when the balloons went south of East, the broken curve the single flight in which the balloons went north of east. Therefore lat. of Victoria, mag. 32.8° N is thought to be very close to the latitude of first entrance of oxygen annihilation rays.

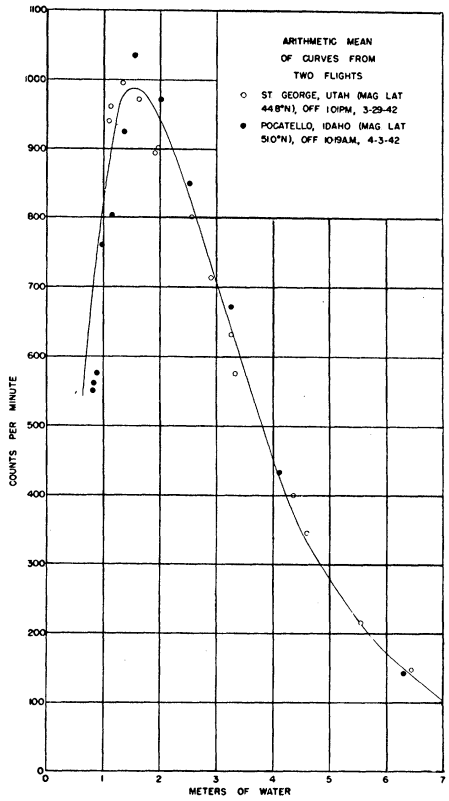

FIG. 7. Shows that there is practically no new energy entering vertically in the long latitude stretch between St. George and Pocatello, although there is clear evidence of the entrance of carbon annihilation rays between Pasadena and St. George (Utah).

inconsistent with the continuous energy distribution hypothesis unless a very considerable reduction in incoming cosmic-ray energy be assumed to have taken place since January, 1940, when the measurements at Peshawar were made. On the other hand, a much smaller change, or possibly no change at all, would be necessary to bring the readings into harmony with the atom-annihilation hypothesis since the observed differences could be more than covered by a 5 percent uncertainty such as we had estimated might exist both at Peshawar and at Acapulco. However, two sets of observations taken five years apart (1935–1940) in both Madras, India, and San Antonio, Texas, have shown no evidence of a time-change in this particular five-year interval, so that it is perhaps better to explain the 4.2 percent divergence of both the Peshawar and the Acapulco curves from their mean as falling within the limits of observational uncertainties,

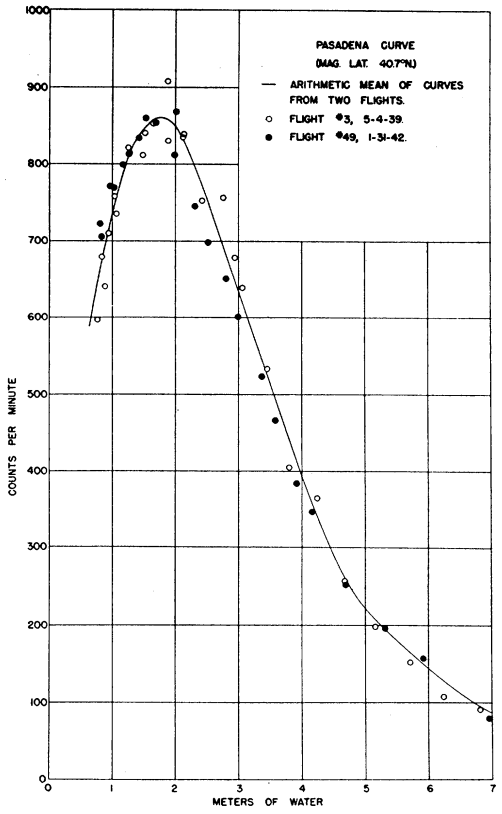

FIG. 8. At the latitude of Pasadena the annihilation rays of both oxygen and nitrogen appear to be able to get fully in vertically.

especially since different modes of recording were used in taking them.

3. A third and a most striking and unambiguous verification of prediction is seen by comparing the mean curve at Acapulco (Fig. 3) with the mean curve at Valles 5.3° farther north. (See Fig. 4.) These curves show no differences at all. This result, taken in conjunction with the result of the airplane flights at Panama and Arequipa in 1932[4] furnish excellent proof of the existence of the long plateau of constant cosmic-ray intensity extending from the equatorial latitude in Peru clear up to about mag. lat. 33° in Mexico. Furthermore, these results are in full agreement with the "ground-level" findings stated in VII (1) above.

4. Although there were found, in going north from Acapulco to Valles (370 miles) no additions at all to the vertical rays coming in at Acapulco, yet in going only 112 miles still farther north, *viz.*, from Valles to Victoria, both the ground level counts and the total vertically incoming energy obtained from the Victoria flight curves show an unambiguous increase. (See Figs. 5 and 6.)

5. There is evidence in the flight curves taken at Victoria that it is within a very few miles of Victoria that the oxygen annihilation rays begin to get in vertically. The ground-level reading was taken in the hotel grounds in the middle of the city. To avoid interference during the flight the truck was driven out into the "bush" not over four miles southeast of the town and the flight there in which the wind carried the balloons a little north of east revealed notably more incoming energy (see dotted curve Fig. 6) than did either of the two flights in which the wind carried the balloons a little south of east, so that *it seems to be right at the latitude of Victoria that the oxygen annihilation rays first get in vertically.*

VIII. A FIRST ATTEMPT TO TEST IN THE UNITED STATES THE PREDICTIONS OF THE HYPOTHESIS OF THE EXISTENCE OF THE CARBON AND HELIUM ANNIHILATION RAYS

The authors took off one week at the end of March, 1942 to try to test the prediction of the hypothesis, first, as to entrance not far north of Pasadena of a band of carbon annihilation rays (5.6 Bev); second, of the existence north of this latitude of a flat plateau of constant cosmic-ray intensity extending up to the latitude of entrance of the predicted band of helium annihilation rays (1.88 Bev). Because of unfavorable weather and several mishaps they got but two good flights, one at St. George, Utah (mag. lat. 44.8° N), which is but 4 degrees, or 266 miles nearer the north magnetic pole than Pasadena (mag. lat. 40.7° N), and one at Pocatello (mag. lat. 51° N), which is 6.2 degrees or 428 miles nearer the north magnetic pole than St. George. These two flights are plotted in Fig. 7 and the mean of two good flights at Pasadena in Fig. 8. It is to be regretted that the limited time and other conditions did not permit more flights at each of the two foregoing most northerly latitudes so as to add the weight of multiple observations to the evidence, and it is proposed to repeat and extend these observations as soon as

[4] See Fig. 4, Phys. Rev. **61**, 403 (1942).

peacetime conditions prevail. However, these two flights as recorded on the moving tape showed excellent consistency, so that the results obtained in them should have a very considerable degree of reliability. They seem to show with great certainty, first, the entrance of the carbon-annihilation rays between Pasadena and St. George, and, second, the altogether flat plateau extending from St. George to Pocatello. The latitude of entrance of the helium rays, as computed from the Lemaitre-Vallarta curves, is at mag. 54° N, only three degrees above Pocatello. Further, it is certain from preceding flights with electroscopes that between Omaha (mag. lat. 51.3°) and Bismarck (mag. lat. 56°) a group of new rays of energy about two billion electron volts does appear. *So far, then, as experiments have now gone no results have been obtained from the studies in India, in South America, in Mexico, or in the United States which are out of harmony with the predicions of the atom-annihilation hypothesis of the origin of cosmic rays.*

IX. COMPARISON OF OBSERVATION WITH THE COMPUTATIONS OF LEMAITRE AND VALLARTA ON THE ENERGIES OF VERTICALLY INCOMING ELECTRONS AT DIFFERENT LATITUDES

The curve labeled 1 on the original Lemaitre-Vallarta diagram[5] gives the computation of these authors of the energy required for an electron to reach the earth vertically as a function of latitude. This curve, however, is computed on the assumption of a magnetic field symmetrical about a north pole situated at lat. 78° 30″, long. 69° 0″ W, and having a field strength at the magnetic equator which requires an electron to have an energy of 15 Bev to reach the earth vertically there. From Millikan and Neher's measurements on the longitude effect at sea level at the equator these authors have estimated the energy necessary to get in at the equator in India as 17 Bev and in Peru as 13 Bev. In order, then, to find the energy necessary for an electron to reach the earth vertically at Victoria, mag. lat. 32.8°, the value found at that latitude from the Lemaitre-Vallarta curve has been multiplied by 13/15. This procedure yields 7.5 Bev, so that the Lamaitre-Vallarta curve modified in this way predicts exactly the latitude at which oxygen annihilation rays of energy 7.5 Bev do actually appear first to reach the earth vertically.

In order to make a similar computation for the electronic energy required to reach the earth vertically at Pasadena, it was for this case thought more legitimate to use as the base in the computations the equatorial value 15 Bev instead of 13 Bev, the reasons being, first, that the nearer one approaches to the pole the less should be the influence of the dissymmetry that produces the equatorial longitude effect; and, second, the farther west one moves in America the more should the stronger equatorial field in the Orient influence this base. Using, then, for Pasadena the Lemaitre-Vallarta base of 15 Bev

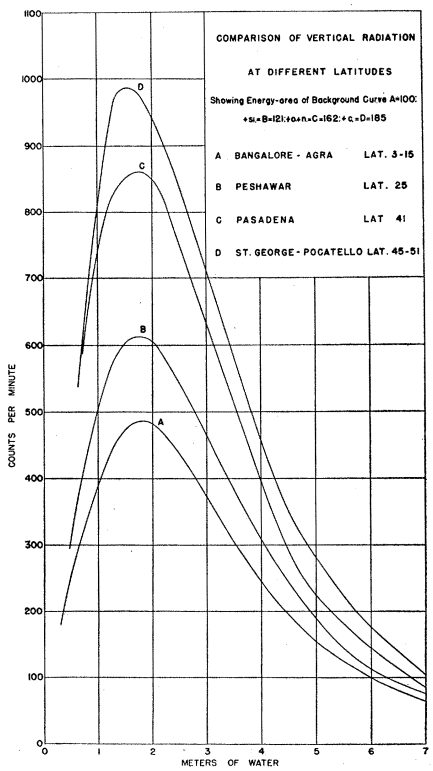

FIG. 9. Shows that the cosmic-ray energy brought to earth vertically by silicon annihilation rays (curves B–A) is 21 percent of the energy of the earth's cosmic-ray non-field sensitive or background energy (curve A); that oxygen and nitrogen annihilation rays bring in a joint energy (curves C–B) of $162-121=41$ percent of curve A, the equivalent of $20\frac{1}{2}$ percent each: that carbon annihilation rays (curves D–C) bring in an energy $185-162$, or 23 percent of curve A; so that Si, O, N, C atoms are all thought to contribute nearly equal amounts of atom-annihilation cosmic-ray energy.

[5] See Fig. 10, Phys. Rev. **50**, 503 (1936); also reproduced in Fig. 2, Phys. Rev. **61**, 401 (1942).

instead of 13 Bev one finds the energy necessary for an electron to get in vertically to be 5.84×10^9, somewhat too large to enable the carbon annihilation rays of energy 5.6 Bev to reach the earth vertically at Pasadena, as in fact the experiments of the last section show that they actually fail to do.

In the same way and again using the base 15×10^9 the vertical energy necessary to get in at St. George comes out 4.41 Bev, so that the carbon rays of energy 5.6 Bev should be fully in at St. George as they were in fact seen to be from Fig. 8.

By the same procedure the latitude at which helium annihilation rays of energy 1.88×10^9 should first enter vertically comes out mag. 54° N. This is only 3 degrees above that of Pocatello where the total area beneath the curve comes out quite the same as that corresponding to St. George. So that the evidence for the existence of the flat plateau in the stretch of latitudes requiring an energy of vertical entry between 5.6×10^9 and 1.88×10^9 appears to be quite good.

X. COMPARISON OF THE VERTICALLY INCOMING, FIELD SENSITIVE, COSMIC-RAY ENERGIES BROUGHT TO EARTH BY THE ANNIHILATION RAYS OF SI, O, N, AND C.

It has been shown in preceding articles[1] that the background of non-field-sensitive cosmic-ray energy is not more than forty percent of the total cosmic-ray energy with which the earth is being continuously bombarded.

In terms of the total of this non-field sensitive cosmic-ray energy taken as a base one can estimate with considerable certainty the relative field-sensitive cosmic-ray energies brought to earth by the annihilation rays of the four atoms Si, O, N, and C, as follows: To get a numerical value for the base one measures with a planimeter the total area underneath the mean Bangalore curve *A*, Fig. 9. The best measure now obtainable for the energy brought in by vertical silicon rays will then be the difference between the area of the mean Peshawar curve *B* and the mean Bangalore curves, *A* (Fig. 9). Similarly, the difference between the area underneath the mean Pasadena curve *C* and the Peshawar curve *B* is a measure of the joint energy brought in vertically by the field sensitive annihilation rays of the oxygen and nitrogen atoms. Some evidence has already been brought forward in §7 for the conclusion that these two annihilation rays have an approximately equal energy content. Similarly, the difference between the mean St. George-Pocatello curve *D* and the mean Pasadena curve *C* gives the energy brought in vertically by carbon annihilation rays. The actually measured areas underneath these four curves are given in the second column of Table II, while the third column gives the relative values in terms of Bangalore-Madras as a base.

TABLE II. Areas under curves, numerical and relative values.

Bangalore-Madras	65.7	100
Peshawar	79.0	121
Pasadena	106.2	162
St. George-Pocatello	122.1	185

The energy content of these four annihilation rays is thus seen to be very nearly the same. This is not quite the conclusion drawn from Bowen's spectroscopic measurements on ring nebulae, for according to them the relative *abundance*, rather than the relative energy, of these four atoms in interstellar space is the same for the four. If all these four atoms have the same chance of undergoing the transformation of their rest mass energy into an electron pair, then these cosmic-ray measurements are in agreement with Bowen's spectroscopic measurements to the extent that the same relative abundance is assigned by both methods to carbon, nitrogen, and oxygen atoms. Since, however, the rest mass energy of silicon is about double that of each of the other three atoms, the foregoing evidence from cosmic-ray data would indicate an *abundance* of silicon atoms in interstellar space of about half that of each of the carbon, nitrogen, and oxygen atoms. This much of a discrepancy would probably not be outside the limits of Bowen's own estimate of his uncertainty.

To account for the fact that about 60 percent of the total incoming cosmic-ray energy is field sensitive and only 40 percent non-field sensitive (this non-field sensitive part corresponding to the area underneath the Bangalore curve) it would be necessary to assign to helium annihila-

tion rays an incoming cosmic-ray energy in terms of Bangalore as a base of $(100/.40)-185.=65$, or about three times the energy brought in by say carbon annihilation rays. But since helium's rest-mass is but one-third that of carbon its *abundance* would from these figures have to be about nine times that of carbon. It will be recalled that Bowen's spectroscopic measurements assigned helium about ten times the abundance of the atoms of carbon. *So far, then, as the abundance of the elements in interstellar space is concerned the present atom-annihilation hypothesis as to the origin of cosmic rays assigns to the different atoms involved an abundance in interstellar space that is in quite reasonable agreement with Bowen's spectroscopic findings.*

XI. THE NATURE OF THE INCOMING PARTICLES

If the foregoing evidence as to the latitudes of first entrance of the annihilation rays of Si, O, N, C, and He is considered convincing, then the incoming particles must be *electrons* and not essentially heavier particles like protons or even mesotrons, though in view of the short lifetime of the mesotron that particle seems to be barred out for other reasons than its available mass. If, then, the transformation of rest mass energy in the case of the helium atom gave rise to a pair of protons rather than a pair of electrons, then the total available energy for getting these protons through the earth's magnetic field would be not 1.88 Bev, but 0.94 Bev, in which case the latitude of first entrance of these helium annihilation rays would be considerably north of Saskatoon (mag. lat. 60°). But in fact as one goes north, the latitude of entrance of the last significant group of new rays, designated herein as helium-annihilation rays, does appear between the latitude of Omaha (mag. 51.3° N) and that of Bismarck (mag. 56° N). This is certainly very close to the lat. mag. 54° N computed from the Lemaitre-Vallarta curves as the first latitude of entrance of helium annihilation rays on the assumption that the whole rest mass of the helium is transformed into an electron pair.

Thus far no new rays coming in north of Bismarck have been found by anyone. It is true that as yet the energies of *vertically* incoming rays have not been determined north of Pocatello (mag. 51° N) as the authors plan to do as soon as world conditions permit. Since, however, the Lemaitre-Vallarta curves show that in these northern latitudes the differences between the curves of incoming energies obtained from electroscope readings should show but small differences from those obtained from vertical counter readings the following conclusion from already existing measurements seems to be fully justified, *namely, that from the standpoint of the atom annihilation hypothesis as to the origin of cosmic rays the incoming cosmic-ray charged particles must be electrons rather than protons or any other particles essentially more massive than electrons.*

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