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Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki
(Journal of Experimental and Theoretical Physics)
Vol 21, No 9, pp 1009-1022, Russian Mo per, Sep 51

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STUDY OF THE MASS SPECTRUM OF COSMIC RADIATION PARTICLES AT SEA LEVEL

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(Zh ETF, 21, No 9 (Sep'51), pp 1009-1022)

A new, substantially improved mass spectrometer is described which lends itself to greatly enhancing the reliability of trajectory determinations and accuracy of measurements of mass. By means of this apparatus the mass spectrum of particles of cosmic radiation has been determined at sea level.

Study of the mass spectrum of particles which are among the constituents of cosmic radiation at sea level has been made repeatedly. In publications [1-3] measurements were made by a method very close in principle to that which we have used. Determination of the mass in all these publications was effected by simultaneous measurement of impulse in Wilson's chamber and of the particle range within dense absorbers. The results of these publications will be discussed following a presentation of the results of the present work.

Measurement of mass has been effected by us from impulse and range in a dense absorber. The impulse was measured by means of a method which was first utilized by Alikhanyan, Alikhanov and Vaisenberg for the same purpose at an altitude of 3200 meters and based on the determination of the particle trajectory within a magnetic field, from several points obtained by means of counters.

Description of the Apparatus

The magnetic field was provided by a permanent magnet (4960

Oe) within a gap 8 centimeters wide. The poles were 70 centimeters long and 30 centimeters wide. By means of counters we could obtain 5 coordinates of the trajectory within the plane of the poles and 5 coordinates within the plane perpendicular thereto.

Each pole was provided with 3 grooves as shown in Figure 1, and at these points 3 flat boxes were introduced into the magnetic field, the boxes containing rows of counters for determining the points of the circular trajectory as well as the points of the trajectory within the plane perpendicular thereto. Two identical boxes with rows of counters were placed above and below the gap of the magnet.

Counters located lengthwise of the magnetic field had a diameter of 4.6 millimeters and within the 5 coordinate rows there were 52 of them in each. The wall thickness of the counters was equal to 0.1 millimeter Cu, and in experiment IV, to 0.1 millimeter of Al. Counters placed perpendicularly to the magnetic field had a diameter of 9.6 millimeters, and in all of the five rows there were 8 of them in each row. The wall thickness of these counters was 0.1 millimeter Cu, and in experiments III and IV, 0.1 millimeter Al.

For operation of the unit a triple discharge coincidence in three small counters, one in each of rows I, III, and V was required.

Each counter was connected to an individual neon tube which ignited on discharge within the counters; the ignited tubes were photographed by means of a motion-picture camera. All the rows of counters separating one filter from another, that is rows VI, VII, and VIII, were overlapping double layer rows. In addition, rows

VI, VII and VIII were connected in a delayed coincidence system, so that it was possible to determine that a particle passing through rows I, III, and V, on being stopped within a filter above rows VI, VII and VIII, produced a secondary particle which with time lag in excess of 0.4 - 0.7 μ seconds induced operation of counters in row VI, VII or VIII. Delayed coincidence from 0.4 to 7 μ seconds were registered by the system within five intervals.

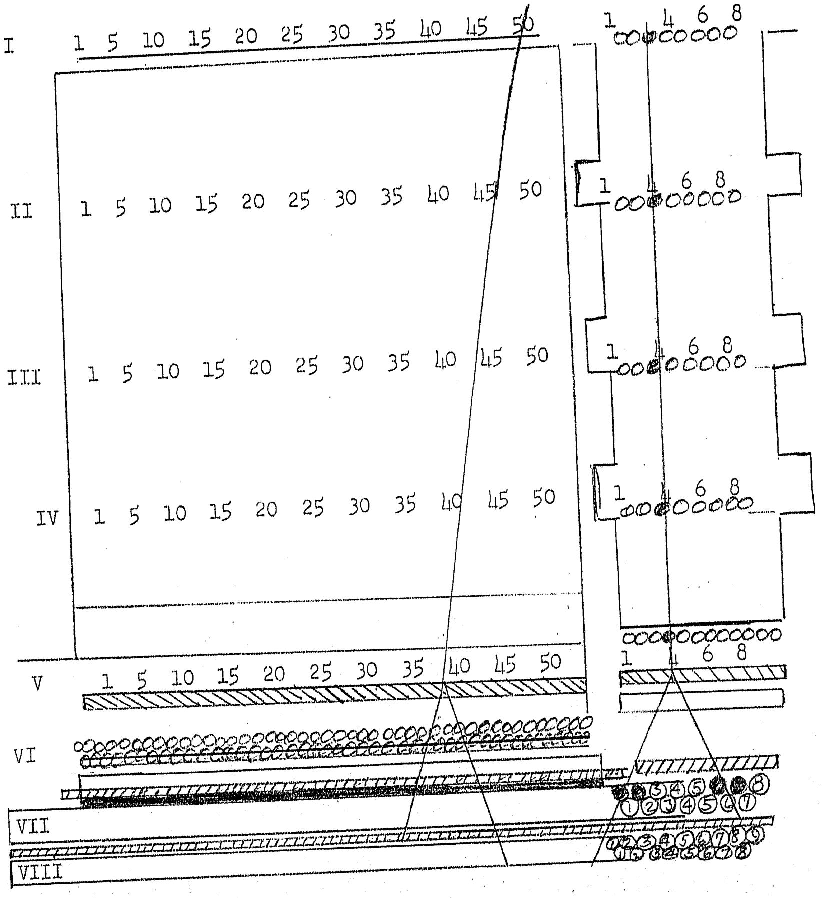

Figure 1. Diagram of mass spectrometer. A rapid positive particle (p $1.5 \cdot 10^9$) has produced a star in the graphite filter

In some of the experiments the ionization capacity of the particles was measured by means of a ten-layer low efficacy counter. Each layer consisted of a flat aluminum box 40 centimeters long, 12 centimeters wide, and 0.8 centimeters high. Inside the box a system of threads was stretched. The counter was filled with a mixture of helium and alcohol, and its efficacy for relativistic particles was about 0.30. The threads of each box were connected to a single neon cell and the number of operating layers was determined by the number of ignited neon tubes. This ionization capacity measurement method is of statistical nature; hence, ionization capacity can be determined for those particles which were registered in an appreciable number.

Graduation of the counter was effected either by ionization capacity of mesons of a mass up to 230 m_e which were retained in the last filter or by ionization capacity of hard particles.

Processing of Trajectories

The film with photographs of the ignited neon tubes was projected by means of a diaprojector onto a panel with push buttons disposed exactly like the neon tubes are disposed on the stand supporting all the panels. Those push buttons which coincided with the black spots of the ignited neon tubes, were pushed, thereby switching on the corresponding electrical bulbs affixed to a table in positions exactly reproducing the disposition of counters within the magnet. Thus it was possible to produce upon the table a light copy of all counters within the section of both planes, to examine the trajectory, to measure by means of templets the radius of trajectory curvature, to verify upon a "straight line" the trajectory within the second plane, etc.

Measurement of the radius of curvature was carried out so that minimum as well as maximum radii were measured, which passed through the five given points, having as terminal dimensions -- the diameter of the counters. By obtaining for each trajectory 8 - 11 coordinates and being able to examine each trajectory spatially, we attained for each individual trajectory a degree of reliability which may be obtained in the Wilson chamber. It is inconceivable that there should remain any appreciable probability of false trajectories formed by the passage of two or more particles through individual rows, so that 4 - 6 points would be disposed circumferentially within one plane and concurrently 4 - 5 points would be collinear in the other plane. The mass values were calculated on the basis of Rossi's data [4].

Description of the Experiments

Experiments were conducted under the following conditions:

Experiment I. Above row V there was placed a filter of 2.7 centimeters of Al, and one centimeter Pb; above rows VI, VII and VIII, one centimeter Pb for each one. Over the entire unit was placed a filter of 10 centimeters Pb. A small part of the experiments was conducted without a filter over the entire unit, in which case there remained over the entire apparatus only the 10-15 grams/square centimeter of matter of the ceiling and roof.

Experiment II. Above row V was placed a filter of 6 centimeters C, above each of rows VI and VII, 2.5 centimeters C, and above row VIII, 4 centimeters C.

Experiment III. Above row V was placed a filter of 6 centimeters C, above each of rows VI and VII, 2.5 centimeters C, and above row VIII either 0.6 centimeters Pb or 2.5 centimeters C. Over the entire unit was placed a filter of 50 centimeters Pb.

Experiment IV. Above row V was placed a filter of 6 centimeters C, above each of rows VI, VII and VIII, 1.5 centimeters graphite. Over the entire unit was placed a filter of 7-10 centimeters Pb. All counters in rows II, III and IV were aluminum.

Errors in Calculation of Particle Mass ($m = 200\text{-}300\ m_e$)

In the determination of mass of the particle retained within the filters, the following errors occur: (1) error in determination of impulse of the particle due to terminal dimensions of counters and irregularities of the magnetic field; (2) error in determination of impulse of the particle due to scattering within walls of counters in rows II, III, and IV; (3) error in determination of particle range due to terminal thickness of intercepting filters and range fluctuations (According to Pomeranchuk data [5] the range fluctuations due to the circuitous effect resulting from scattering in lead is 7.5 percent, in graphite they are practically equal to zero; range fluctuations due to the fluctuation of ionization losses in lead and in graphite are about 4-5 percent. In calculating the error $\overline{\Delta m}/m$ these fluctuations were taken into account).

The probable error in determination of the radius of curvature of the trajectory, due to terminal dimensions of counters is equal to 1-1.5 percent. The error in measurement of impulse, due to irregularities of the magnetic field constitutes 0.4 percent and is of no practical importance.

Projection of the mean angle of scattering, computed by means of the corrected formula of Williams [6], taking into account the cylindricity of the counters, is equal to 0.5 degrees for one row of copper counters. This results in a 4.8 percent error in the value of the radius for a particle having a mass of 200-300 m_e. In the case of aluminum counters this error is equal to 1.9 percent.

The mean quadratic error in calculation of particle mass in the first experiment ($\overline{\Delta} m/m$) is equal to 12.5 percent, in the second it is 10 percent, in the third -- 8.5 percent and in the fourth -- 6 percent. The last error is only twice the theoretically attainable minimum of 3 percent (due to range fluctuations).

Results of Experiment I

In experiment I, with no filter above the entire unit numerous instances of particle propagation within the lead filters over rows V and VI were observed. These instances were evidently caused by electrons. Data obtained under these conditions made it possible to determine experimentally the efficacy of elimination of electrons.

(a) Electrons in the soft component. For an analysis of the efficacy of electron elimination from the soft component, that is from the group of particles retained within the filters, there were selected from 12 films those trajectories which produced "additional" discharges in row V or VI or concurrently in both of these rows. The electron trajectories were subdivided into three types.

In those of the first type propagation is fully certain: many additional discharges are present and the trajectory can be attributed to an electron with complete certainty. The second type composes those trajectories in which a few additional discharges were observed. The third type is characterized by the fact that omission of discharge of a counter in one of the rows VI or VIII occurs. For example, the electron has undergone propagation in the first filter, but has produced only a single additional discharge in row V; in row VI not a single counter has been discharged, whereas row VII has shown a discharge. This signifies that a photon (or photons) passed through row VI, and within the lead filter over row VIII it has been converted to an electron, and this electron has affected row VII. Table 1 shows a detailed analysis of trajectories of the electrons.

Table 1

Number of films	125-136
Number of registered particles	19,471
Number of trajectories of electrons of type one and two in the interval of impulses $1.8\text{-}4.0 \cdot 10^8$ eV/c	106
Number of trajectories of electrons of type one, two and three in the interval of impulses $1.8\text{-}4.0 \cdot 10^8$ eV/c	116
Same as above, in the interval $2.4\text{-}4.0 \cdot 10^8$ eV/c	81
Number of trajectories with one additional discharge in the interval $1.8\text{-}4.0 \cdot 10^8$ eV/c	22
Same as above, in the interval $2.4\text{-}4.0 \cdot 10^8$ eV/c	10
Number of trajectories without additional discharges in the interval $1.8\text{-}4.0 \cdot 10^8$ eV/c*	19
Same as above, in the interval $2.4\text{-}4.0 \cdot 10^8$ eV/c*	10

(*) This number does not include trajectories of particles the impulse and range of which corresponded to a mass 200-300 m_e.

(b) Electrons in the hard component. The number of electrons in the hard component was determined from two films No 124 and No 125, for the impulse intervals under consideration, $1.8\text{-}4.0 \cdot 10^8$ and $2.4\text{-}4.0 \cdot 10^8$ eV/c.

Trajectories of electrons were considered as those trajectories having at least two additional discharges in rows V or VI. The total number of such trajectories for 3350 hard particles amounted to 15, within the interval $1.8\text{-}4.0 \cdot 10^8$ eV/c and 13 in the interval $2.4\text{-}4.0 \times 10^8$ eV/c. Correspondingly, this gives in 12 films for 19,470 hard particles, 88 electrons in the impulse interval $1.8\text{-}4.0 \cdot 10^8$ eV/c and 76 electrons in the interval $2.4\text{-}4.0 \cdot 10^8$ eV/c.

Determination of the effectiveness of electron selection. Thus, the total number of electrons having produced propagation of one form or another, within the impulse interval $1.8\text{-}4.0 \cdot 10^8$ eV/c, is equal to $116 + 22 + 88 = 226$. For these 226 electrons there are within the same impulse interval 19 soft particles which have not produced propagation. Assuming that all the trajectories not accompanied by additional discharges are also trajectories of electrons which fortuitously have not produced a noticeable propagation, then the effectiveness of exclusion of electrons in the impulse interval $2.4\text{-}4.0 \cdot 10^8$ eV/c will be correspondingly $167/(167 + 10) = 95$ percent. If, however, one eliminates as electrons only those trajectories which are accompanied by obvious propagation, that is, those having numerous additional discharges, and considers as electrons all those instances producing but a single additional discharge, the effectiveness of elimination of electrons is still $204/245 = 84$ percent in the first interval of impulses, and $157/177 = 89$ percent in the second. Thus the method of electron elimination by propagation within lead filters, as determined by means of rows of coordinate counters, has been found to be very effective.

In paper [7] efficacy of electron segregation by propagation for impulses below $1.8 \cdot 10^8$ eV/c is estimated at 70 percent on the basis of experimental data. For impulses in excess of $1.8 \cdot 10^8$ eV/c, the authors were unable to obtain experimental data, and, resorting only to theoretical considerations, have deemed that in this instance the effectiveness is considerably greater. As can be seen from the above cited data, the effectiveness of electron exclusion in the region of high impulses is actually close to unity.

(c) Spectrum of mesons (in the absence of a filter over the entire unit). Having ascertained that effectiveness of electron exclusion is very high within the impulse interval $2.0\text{-}4.0 \cdot 10^8$ eV/c, we can, by using the same method of propagation, separate the electrons from the mesons which are retained within the filters and have under these experimental conditions impulses within the interval $1.3\text{-}2.0 \cdot 10^8$ eV/c. Per 19,470 hard particles there were obtained 130 trajectories, that is 0.66 percent, which we attributed to mesons having a mass up to 400 m_e; 84 trajectories, that is 0.43 percent, positive heavy particles having the mass of a proton or greater; 2 trajectories of similar heavy negative particles and 194 trajectories, that is 1 percent, having produced appreciable propagation and hence attributed to electrons.

From the cited figures it can be seen that the number of electrons retained within the filters is not very great in comparison with the number of mesons, and that even in the case of a not so nearly perfect method of electron elimination, the spectrum of mesons having a mass up to 400 m_e will not be strongly distorted by the "passing" electrons.

On comparing the cited data with results obtained at Alagez, we see that at an altitude of 3200 meters the number of protons relative to that of hard particles is 5-6 times greater than at sea level. The hard component increases from sea level to an altitude of 3200 meters by 1.8-2 times, so that the absolute increase of the effect is of about 10 times. Such an increase corresponds to an absorption coefficient of 130 grams/square centimeter. It is known that such an absorption coefficient is attributed to the so-called third component, or component N, responsible for nuclear processes.

(d) Spectrum of mesons under 10 centimeters Pb. Over a period of 350 hours the unit operated under a lead filter 10 centimeters thick. During this time there were registered approximately 232 particles having a mass up to 400 m_e, 60 positive particles having the mass of a proton or larger and 50,000 particles which had passed through the filters. Thus, at sea level under a lead filter 10 centimeters thick, there are observed 0.46 percent mesons and 0.12 protons and heavier particles, having ranges within the interval from 2 to 5 centimeters Pb.

For the total of 50,000 particles there were observed 3 trajectories of negative particles having very large impulses (mass in excess of 2000 m_e) which were retained within the filters: two in the first filter and one in the last. If one assumes that this one trajectory is that of a hard particle, having passed through the last row, and taking into account the fact that the region of great impulses, i.e., in excess of $3\text{-}4 \cdot 10^8$ eV/c, comprises 90 percent of all hard particles, then the probability of passing through a two layer row of counters is less than $5 \cdot 10^{-5}$. Insofar as particles with a mass between 400 and 1100 m_e are concerned, their number in this experiment amounts to 9. This region of mass is being considered in detail in a subsequent experiment wherein the experimental conditions make it possible to select in a more dependable manner each trajectory without incurring the risk of mistaking, as due to absorption, its removal from the filter as a result of repeated scattering under a large angle within the lead filters.

A comparison of the intensity of individual components of the spectrum in the presence and in the absence of a lead filter over the entire unit shows that the number of protons and other heavy positive particles decreases by 3.5 times under 10 centimeters of Pb; the number of mesons, however, is altered but little by introduction of the lead filter.

(e) Exclusion of electrons by means of lead filters over the apparatus. The most efficient method of excluding electrons is, of course, their absorption within a filter of Pb 5-10 centimeters thick; 10 centimeters Pb corresponds to 21 cascade units of length, and therefore, on passing through this filter, electrons of greatest possible energy are fully degraded and within the impulse region of $1.8 \cdot 10^{8}$ eV/c there will remain essentially only equilibrium electrons formed within the lead as δ-electrons. The number of these electrons must be negligible. When a 10 centimeter Pb filter was placed over the unit, in the soft component within the impulse interval $1.8\text{-}2.4 \cdot 10^{8}$ eV/c, two instances of propagation were observed for the 50,000 hard particles.

From Table 1, it is apparent that in the absence of lead over the unit, in the soft component 157 electrons within the impulse interval $1.8\text{-}4.0 \cdot 10^8$ eV/c were observed for the 19,470 particles. This amounts to about 400 electrons for 50,000 hard particles. Thus, a filter consisting of 10 centimeters Pb decreases the number of electrons at sea level by at least 50 times.

RESULTS OF EXPERIMENT II

In experiment II, as previously stated, the intercepting lead filters were replaced by graphite filters. This was done on the basis of the following considerations. First, in the second experiment a system of delayed coincidence registration was in operation. In a graphite filter, the mesons, positive as well as negative, not interacting with nuclei, yield disintegration electrons, as a result of which these negative mesons can be differentiated from the negative mesons strongly interacting with the nuclei. Second, on examination of the rare trajectories of particles having a mass greater than 400 m_e many trajectories must be excluded due to the possibility of trajectory egress from the filters in a lateral direction because of scattering in the lead filters, i.e., the possibility of false absorption.

In experiment I we have ascertained that a lead filter 10 centimeters thick placed above the unit, almost completely excludes electrons, and, consequently, in the presence of such a filter there is no need to have in the unit intercepting lead filters for the specific purpose of electron determination by propagation within such filters. Moreover, the probability of electron absorption

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In this experiment there were registered in all three filters, 450 particles with a mass up to 400 m_e, 15 particles with a mass in excess of 400 m_e but less than 1200 m_e, and 283 particles having the mass of a proton or greater. 68 trajectories of 450 gave delayed coincidence in rows VI or VII, with a delay of more than 0.6 μ seconds. These 68 trajectories must pertain to only that part of the 450 particles which were retained within the first two filters, and their number is equal to 234.

The spectrum of particles retained within the first two filters is shown in Figure 2. The curve in Figure 3 refers to trajectories having produced delayed coincidence. A spectrum of mass greater than 1000 m_e is shown in Figure 4. Attention must be called to the fact that in the spectrum of Figure 3 the number of negative particles in the region of mass 160-250 m_e constitutes 16 of 37, while in the region of mass 250-370 m_e it is 7 of 31. The mean value in the case of negative particles, namely, $m_+ = 238 \pm 4\ m_e$; $m_- = 224 \pm 5\ m_e$.

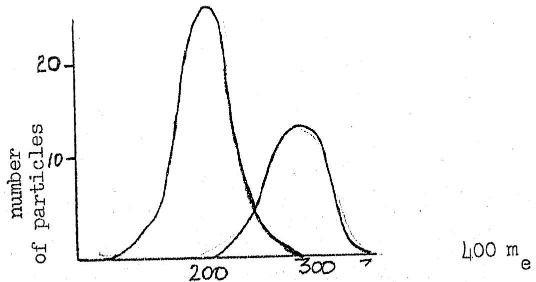


Figure 2. Experiment II. Spectrum of particles having a mass up to 400 m_e retained in filters 1 and 2.

Exclusion of trajectories of particles with mass greater than 300 m_e, as being incorrect or possibly incorrect, was made in those instances when: (1) it was possible to plot through given points a trajectory grazing the pole, and (2) scattering within the filters over angles of yet appreciable probability would remove the particles from the filter by-passing the counters and give rise to false absorption. In such a selection from 48 trajectories giving a mass with the interval 300-400 m_e, 14 were excluded; from 26 trajectories indicating a mass within the interval 400-1200 m_e, 11 were excluded. The remaining 15 trajectories gave the values of mass shown in Table 2 (page 1017).

The number of particles with a mass greater than 400 m_e, thus constitutes 3.4 percent of the particles with a mass up to 400 m_e. Four negative particles having very large impulses were retained within the filters.

Let us review the causes that can lead to the formation of trajectories which stimulate particles having a mass in excess of 400 m_e. Since we select and examine only the correct trajectories, which do not arouse any doubt as to representing in each instance the actual undistorted trajectory of a single particle, the entire problem is reduced to ascertaining what takes place within the filters on absorption of the particle. The possibility of false absorptions due to leaks in the rows of counters is completely excluded. A possibility of egress of a particle from the filters with by-passing of the counters, as a result of scattering (false absorption), is very remote. Bearing in mind such a possibility, the examination of individual trajectories obtained in experiment II, one must assume in one instance the "exit" of a particle from the filters caused by scattering, in a 2.5 centimeters thick graphite filter, over an angle the projection of which is more than 18.5 degrees (mass 505 m_e), and in two instances over an angle the projection of which exceeds 24 degrees (mass 407 and 475 m_e), and in still one other instance over an angle the projection of which is 37 degrees (mass 415 m_e). At the same time the maximum angle of scattering in carbon for particles having a mass of 200 m_e and an impulse of about 2.5-3.0 x x 10^8 eV/c is approximately 12.5 degrees. The probability of scattering over angles exceeding the maximum, is known to be practically equal to zero. Therefore, in experiment II the coulomb scattering within the filters cannot give rise to false absorptions.

A supposition to the effect that the deceleration of all 15 particles has occurred as a result of non-coulomb interaction of passing mesons with impulses in the interval $2\text{-}3.7\cdot 10^8$ eV/c, would lead, in the case of carbon, to a section of such interaction $\sigma \approx$ $\approx$ $0.5\cdot 10^{-26}$ square centimeters. In the region of impulses in excess of $6\cdot 10^8$ eV/c 4 negative particles were registered. An analogous assumption would lead in this region to a section $\sigma = 10^{-28}$ square centimeters, that is 50 times smaller than would be obtained in the region of impulses $2\text{-}3.7\cdot 10^8$ eV/c. One could assume, of course, that there exists a very strong dependence of section upon impulse, so that with a 2-3 fold change of energy the section decreased by several times the factor of ten. But in such a case one might expect that such a strong dependence would also manifest itself within the interval $2\text{-}3.7\cdot 10^8$ eV/c. Meanwhile distribution inside the impulse interval presents a grouping in the region of impulses $2\text{-}2.6\cdot 10^8$ eV/c (8 particles), then a gap from 2.6 to $3.2\cdot 10^8$ eV/c (6 particles) and thereafter in the interval from 4.85 to

$6.25 \cdot 10^8$ eV/c there is another gap.

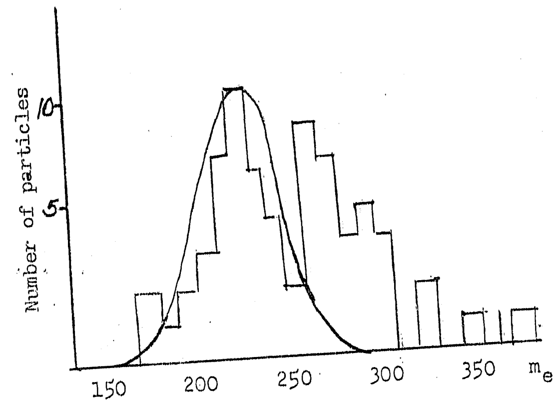


Figure 3. Experiment II. Spectrum of particles for which disintegration was registered after stopping in the filter

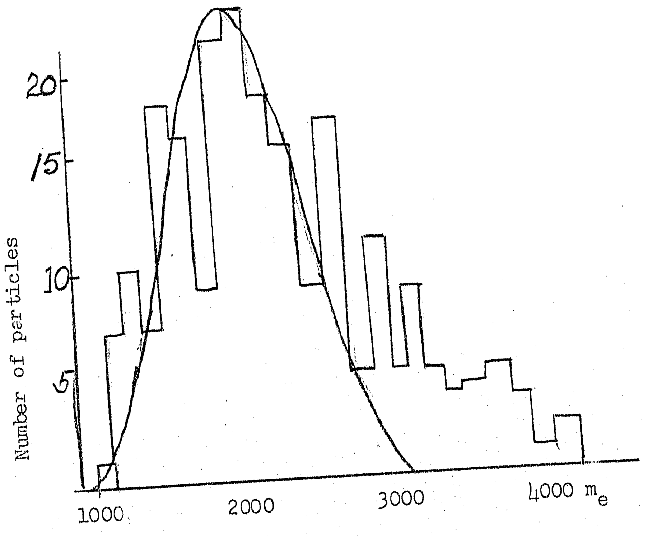


Figure 4. Experiment II. Spectrum of particles having a mass greater than 1000 m_e.

We can also estimate the value of the section for nuclearly active mesons having a mass of 280 m_e which would cause 15 of such mesons to be stopped in the filters due to ionization losses. In the impulse interval of width $3.5 \cdot 10^7$ eV/c, in our three filters there were stopped 450 mesons of which not more than 1/3 had a mass of 280 m_e. Let us assume that the distribution of these mesons by impulses is independent of the impulses. Then in the region from 2 to $3.7 \cdot 10^8$ eV/c, that is in the interval of width $1.70 \cdot 10^8$ eV/c, there will be about 650 of such mesons. Therefrom, we have that of the 45 passing mesons, one undergoes sharp decelerating action, and therefore $\sigma = 3.5 \cdot 10^{-26}$ square centimeter in the case of graphite. Although the possibility of such an explanation is not unexcluded, its probability is remote, since there still remains unexplained the appreciably apparent grouping of trajectories, which indicates that these trajectories are determined by a process not connected with the specific nature of losses, but are most likely representing trajectories of two particles which differ in mass, one with a mass of about 550 m_e and the other with a mass of about 1000 m_e.

Table 2

Masses of 15 Particles

Mean mass in m_e		Mean mass in m_e	
-407	Stopped in filter 3	-735	Stopped in filter 3
-415	Stopped in filter 1	+950	Stopped in filter 2
-455	Stopped in filter 1	-1000	Stopped in filter 1
+475	Stopped in filter 3	+1100	Stopped in filter 2
+500	Stopped in filter 2	+1100	Delay in row VII by 2-2.5 seconds
+500	Stopped in filter 2		
-500	Stopped in filter 2	-1175	Stopped in filter 3
+620	Stopped in filter 2	-1400	Stopped in filter 1

RESULTS OF EXPERIMENT III

In experiment III 207 particles were obtained with a mass smaller than 300 m_e, 3 particles with a mass between 300 and 340 m_e, 2 particles with a mass greater than 450 m_e, 13 heavy positive particles and not a single heavy negative particle. Figure 5 shows the distribution curve of the particles by masses in the first two filters. The maximum number of particles is observed for a mass of value 215 m_e. The Gaussian curve of errors with a peak at this mass value and a mean quadratic deviation $\overline{\Delta m}/m = 9$ percent practically includes all the particles, leaving outside of its confine in the region of mass > 250 m_e, 15-25 particles.

The results of the experiment with a 50 centimeter Pb filter over the unit differ sharply from the results of the second experiment. In experiment II for the 220 particles with a mass smaller than 300 m_e there were 16 particles with a mass from 300 to 370 m_e, that is 8 percent; in experiment IV there are 2 percent of them. In experiment II for 450 particles with a mass up to 400 m_e there are 13 particles, that is 3.0 percent of those having a mass greater than 450 m_e and smaller than that of a proton. In experiment IV for 210 particles with a mass up to 400 m_e there are 2 particles with a mass greater than 450 m_e, that is 1 percent. This last named fact is still another indication that the 13 particles with a mass $>$ 450 m_e could not have been obtained as a result of any effects connected with the behavior of hard mesons within the filters, since under 50 centimeters Pb the mesons are present in the impulse interval $2.5\text{-}3.7 \cdot 10^8$ eV/c, in an amount essentially not less than that which is present under a filter of 10 centimeters Pb.

For particles having produced delayed coincidences, mean values of mass for negative and positive particles were calculated. They were found to be practically the same and equal to $m_+ = 228 \pm 4.5\ m_e$ and $m_- = 233 \pm 5\ m_e$, respectively. Finally, in experiment II the mean mass value (according to Figure 2) is equal to $m = 232 \pm 1.5\ m_e$, while in experiment III with the same filters (according to Figure 5) $m = 218 \pm 2\ m_e$.

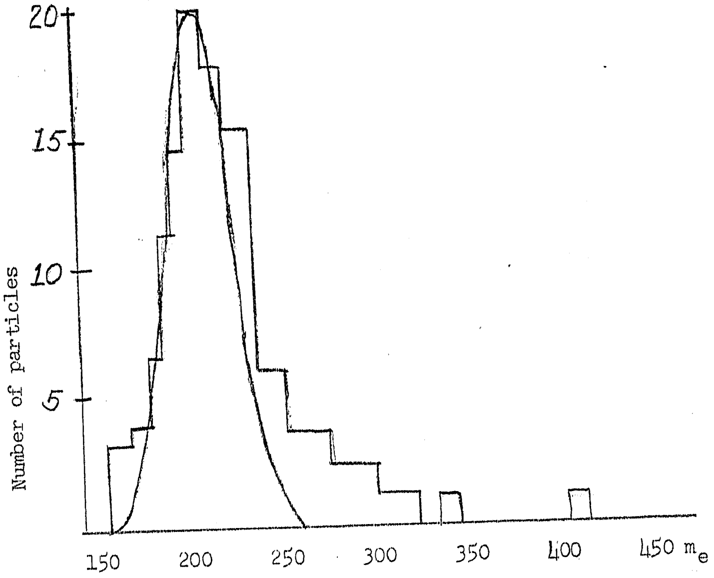


Figure 5. Experiment III. Spectrum of particles having a mass up to 450 m_e which were stopped in filters 1 and 2

RESULTS OF EXPERIMENT IV

In experiment IV over a period of 726 hours 249 particles with a mass smaller than 400 m_e were obtained, 118 positive particles having the mass of a proton or greater, 8 particles with a mass between 400 m_e and the mass of a proton, 5 negative particles having large impulses. The spectrum of mass up to 400 m_e is shown in Figure 6. There were registered 74 particles which gave delayed coincidence, and their spectrum is shown in Figure 7. In this figure the existence of two kinds of mesons is clearly apparent, not only from the fact that there has occurred separation, even though incomplete, of two mass lines, but also because of the large positive excess in the region of masses greater than 250 m_e. For 15 positive particles with a mass greater than 250 m_e, there are 2 negative, while in the region up to 250 m_e there are, for 34 positive particles, 23 negative particles.

The spectrum of all the observed particles shown in Figure 6, although it does not reveal the same well defined separation of two mass lines, still shows the existence of a second group of particles in a manner no less distinct than is the case of the mass spectrum obtained in experiment II. The width of the mass line in experiment IV is considerably smaller (by 1.5 times) than in experiment II, the width of the mass spectrum, however, has remained practically unchanged, and the second group of particles has become apparent as a sharp step in the region of masses 250-280 m_e. The number of particles in the second group constitutes approximately 1/5-1/3 of the number of particles in the first group. The same as in the second experiment, the mean value of mass of positive particles having produced delayed coincidences is larger than the mean value of mass of the negative particles, namely: $m_+ = 234 \pm 4\ m_e$, $m_- = 224 \pm 4\ m_e$.

The spectra of particles obtained in experiment IV, the same as the spectra of experiment II, differ sharply from the spectra obtained in experiment III, wherein all the observed particles form a single group with a mass of about 220 m_e.

The mean value of mass for trajectories of particles having produced delayed coincidence is as a rule somewhat higher (by 2-2.5 percent) than the mean value for the remaining particles. This is related to the fact that the range of particles which produce delayed coincidences is somewhat decreased assuming that on the average the particles stop in the middle of the filter. Actually, the penetration of a disintegration particle into the next layer of counters is facilitated in those instances when the particle stops in that side of the filter which is nearer to this layer of counters. Apparently, this is also a cause of the somewhat odd shape of the mass line.

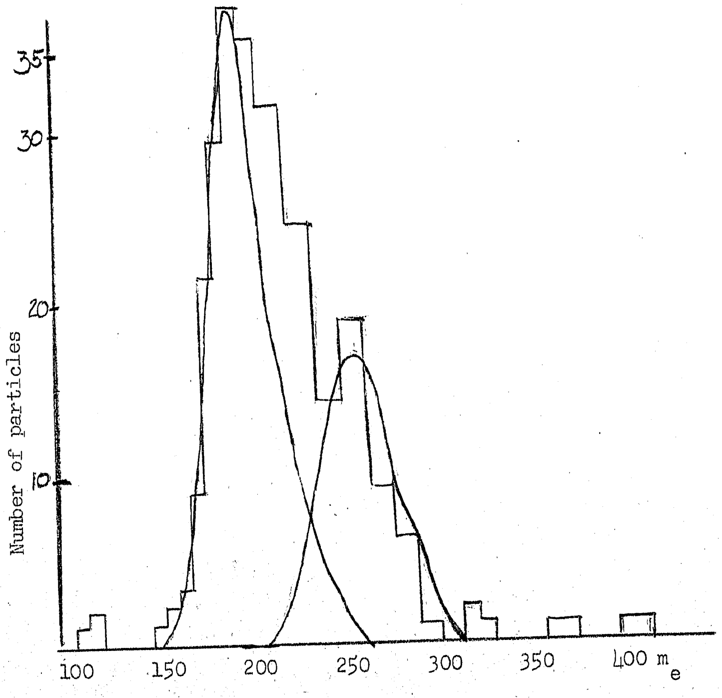


Figure 6. Experiment IV. Spectrum of particles with a mass up to 400 m_e

DISCUSSION OF THE RESULTS OBTAINED

The first conclusion which follows from the results obtained is to the effect that alongside of mesons having a mass of about 215 m_e there are observed, in an amount smaller by 3-5 times, particles having a mass of 260-280 m_e. The curves shown in Figure 2 and 3 indicate the Gaussian distribution of errors, based on calculated mean quadratic deviation $\overline{\Delta} m/m$ = 10 percent, with a distribution peak at the mass value 215 m_e. Inside of the Gaussian curve (Figure 2) are located 146 of the 234 particles forming the distribution curve of particles by mass. More than 60 particles are located outside the confines of this curve. The second Gaussian curve of errors is plotted from the group of particles which do not fit within the first Gaussian curve, with a peak at the mass value of 270 m_e. Within the limits of the second Gaussian curve approximately 75 particles are located.

The distribution by mass of particles having produced delayed coincidences (Experiment II) yields the following. Within the confines of the Gaussian curve, plotted with a peak at the mass value 215 m_e, there are located 37 of the 68 trajectories. A large positive excess is present in the region of mass $>$ 250 m_e (in Experiment II as well as in Experiment IV). This is due to different properties of the particles of the first and second group.

The first group of mesons does not interact with the nucleus and therefore the negative mesons which have stopped in the graphite undergo disintegration more rapidly than they are being entrapped by the nucleus. The second group on the other hand interacts strongly with the nucleus and the negative particles, on stopping, are en-

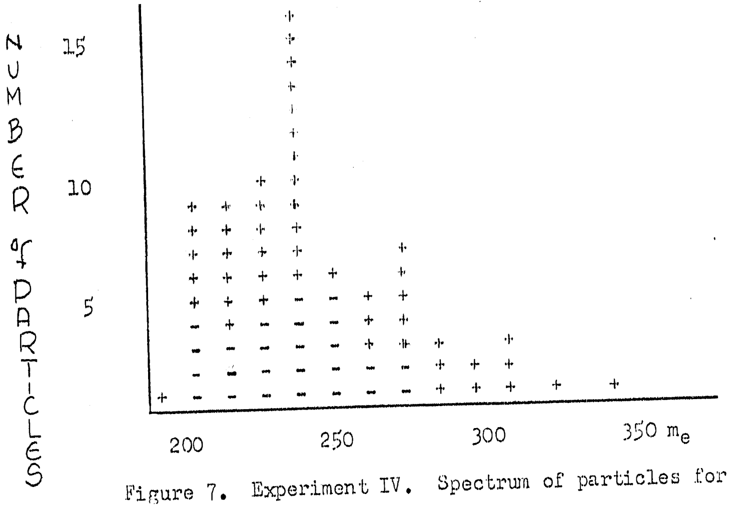


Figure 7. Experiment IV. Spectrum of particles for which disintegration was registered after stopping in the filter. Positive particles are denoted by a + sign, negative by a -

trapped by the nucleus before undergoing disintegration. Thus, separation of two groups of mesons in these experiments is effected not only by mass magnitude but also by another physical property. In Experiment III when a 50 centimeter Pb filter is placed over the unit the obtained curve of particle distribution by mass can be satisfactorily explained by one group of particles, although under these conditions, apparently, a small percentage of admixture of the second group of mesons is present.

Thus, the basic conclusion reached from investigations using a similar method [7] during 1946-1947, as to the existence of particles having a mass greater than that of the μ-meson, is confirmed by experiments conducted at sea level using more nearly perfect and precise equipment.

If one compares these data with those published hitherto, a discrepancy becomes apparent with publications [1-3] in which particles with a mass of 260-280 m_e were not found. Under the conditions of our experiments, the presence of this group of particles is detected as a very clear, one may say, gross effect. The observed discrepancies can be explained by different experimental conditions. Fretter, Brode and Retallack placed above the unit a filter of 25 to 45 centimeters Pb hoping to increase thereby the effect. Peyron et al., for the same purpose, also provided a filter of 72 centimeters Pb, and in some instances decreased it to 24 centimeters Pb.

As can be seen from data of Experiment III, when a filter of 50 centimeters Pb is placed over the unit, the number of particles with masses greater than 250 m_e is considerably smaller than in Experiments II and IV wherein a filter of 10 centimeters Pb was placed over the unit, i.e., on using a thick filter we have to deal only with μ -mesons.

The fact that Peyron et al., were unable to detect the second group of particles is apparently explained by the fact that under conditions most convenient for observation of π-mesons, namely, with a filter of lead having a thickness of about 10 centimeters, their unit was in operation 25 percent of the time and the number of registered particles is insignificant. In recent work [8] conducted without a filter over the unit there were observed a few particles with a mass of about 300 m_e, but because of poor accuracy of mass measurement, the authors cannot on this basis assume that a second group of mesons has been observed. (In the absence of a filter over the unit, generation of interacting mesons can take place in the ceiling, walls, roof and other objects surrounding the top of the unit. With a lifetime of $2 \cdot 10^{-8}$ second, the distances at which these sources are distributed are very essential. It is quite possible that different results can be obtained depending on such usually poorly controlled conditions.)

Adverting to the second region of mass spectrum from 400 m_e and higher, we will compare our data with the results of publications [9, 10, 11].

At sea level under a filter of 10 centimeters Pb, for 450 particles having a mass up to 400 m_e which have been retained in all three filters, we obtained 13 trajectories with a mass greater than 450 m_e, that is, about 3 percent, while of those with a mass of about 1000 m_e -- 1.5 percent. Brode [9] points out that in all the experiments described in the paper, 78 trajectories yielded masses of approximately 215 m_e and 8 trajectories, that is 10 percent, gave masses within 500-800 m_e.

In paper [10] is shown a mass spectrum of cosmic radiation particles determined by deflection in a magnetic field and ionization capacity. The radiation was filtered through 12 centimeters Pb. In this mass spectrum there are 5 particles having a mass of a proton or thereabout, and 8 particles having a mass between 250 and 1800 m_e. Correlation between separate sections of the mass spectrum was determined in this paper by the accepted method of mass determination, which compels a selection of particles within a definite interval of ionization capacity.

For a comparison with our experimental conditions wherein the particles are selected within a definite range interval, one must introduce in the spectrum of Leprince-Ringuet a rating correction (assuming that in the distribution of these particles no substantial predominance exists in the region of short ranges) which yields the following results. For 44 protons there must be 50 mesons with a mass of about 250 m_e and 20 intermediate particles with a mass greater than 500 m_e. On considering only those trajectories of particles with intermediate masses which are expressly selected by the authors, probably as being the most reliable, their number still constitutes 25-30 percent of the number of mesons. At the same time the authors of paper [1], apparently by means of the same Wilson chamber, at the same altitude, selecting under 72 centimeters of Pb those particles which are absorbed in a copper filter, have found that the number of particles having a mass of about 1000 m_e is less than 2 percent. In Experiment III, under 50 centimeters Pb we have obtained a still smaller percentage (1 percent) of particles with such a mass.

When the filter over the unit was removed, Peyron et al., also did not obtain any indication of the existence of particles having a large mass. Apparently, trajectories of heavy particles have been differnetiated by them from trajectories of electrons by ionization capacity. Within the range interval 27-43 grams/square centimeter the mean ionization capacity of particles having a mass of 1000 m_e is 2.1 I_{min}, those of 500 m_e is 1.6 I_{min}, while that of electrons having an impulse of about $2.50 \cdot 10^8$ eV/c is 1.4 I_{min}. It must be pointed out that classification of particles which differ from one another in ionization capacity by only a factor of 1.5, is a most difficult task.

Thus, a comparison of the data obtained by us with those available in the literature does not reveal serious, unexplainable discrepancies. It must be noted that there exists a sharp variance between data shown in paper [1] and those found in the cited publications [9, 10].

Three trajectories which yielded, by curvature in the magnetic field and ionization capacity, the mass values 800-1000 m_e, were observed in the Wilson chamber by Butler et al., [11]. The unit was provided with a control block selecting the penetrating showers and was in operation 800 hours.

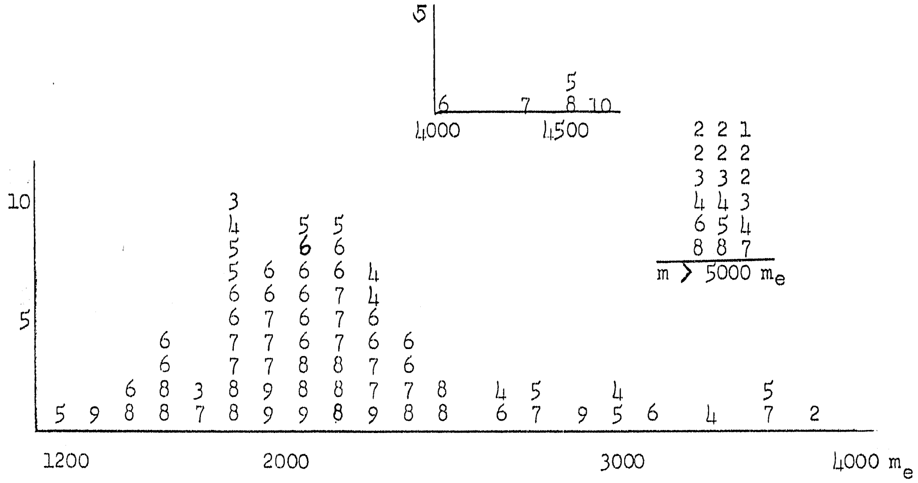
On introducing a rating correction analagous to that used in connection with the data of Leprince-Ringuet, and one for the luminosity of the apparatus, one finds that the number of particles with a mass of 1000 m_e which we have observed is considerably smaller than that derived from the data of this publication.

In conclusion, let us consider the question of the nature of trajectories of negative particles having very large impulses. As was stated in connection with the description of these trajectories, they cannot be explained by leaks, since trajectories stopped in the last filter are observed in just as many instances as those not stopped in the last filter. On most rigorous approach these trajectories can be explained only as being trajectories of particles stopped in the filters. Their number is small but in four instances obtained with a low efficacy counter switched in, it produced few discharges, namely, 3, 5, 2, 3, on the average 3.25. Mesons with a mass up to 240 m_e which stopped within the range interval 9.6-11.6 centimeters C, that is possessing an ionization capacity 1.34 I_{min} yielded an average number of discharges amounting to 3.7 ± ± 0.23. At the same time in the case of protons stopped in all three filters in Experiment IV, the average number of discharges is equal

6.5 ± 0.35. For 62 protons (particles having yielded masses from 1300 to 2900 m_e) there were only 2 instances of three discharges, all the remaining ones producing more than three discharges (Figure 8). If the negative particles were particles heavier than the proton, and they should be such from impulse and range, then one must expect a still smaller percentage of triple discharges in the case of these particles than in the case of the protons, whereas, actually, the exactly opposite effect takes place.

Thus, it can be definitely assumed that these trajectories of negative particles are caused by stops resulting from non-ionization decelerating action. As was stated above, the section in cases of such action is $\sim 10^{-28}$ centimeter square, if hard μ-mesons are involved. However, for non-interacting mesons even this section must be too large and therefore it appears more acceptable to assume that these are stops of π-mesons. Such considerations are further supported by the fact that in Experiment III, that is under 50 centimeters Pb, not a single one of these trajectories was observed. If this is not fortuitous then the stopped negative particles possessing great impulses cannot be μ-mesons, since their number cannot be appreciably changed by introduction of the 50 centimeter Pb filter. An analagous phenomenon is also observed in the case of positive particles. Among these, in Experiment IV, there are 18 trajectories corresponding to a mass greater than 5000 m_e.

In ten cases out of eighteen the number of discharges of the low efficacy counter does not exceed three (the average being 3.8), that is, particles of this entire group have low ionization capacity and have sustained stopping as a result of sharp energy losses on nuclear collisions; apparently, the greatest portion of them are protons, while a smaller portion are positive π-mesons, corresponding to the number of negative ones. Figure 1 shows a case of non-ionization loss of energy by a rapid positive particle. In the filter under row VI the particle has formed a star. Nine out of 21 trajectories of positive particles which yielded a calculated mass value of 5000 m_e have produced similar stars in the filters.



Received for publication

3 March 1951

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