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The Mass of Cosmic-Ray Mesotrons

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The range of mesotrons in lead as a function of their momentum was determined in an experiment in which two simultaneously expanded counter-controlled cloud chambers were used. The upper chamber was in a magnetic field of 5300 gauss, while the lower, which was vertically in line, contained eight ½-inch thick lead plates. The range of a particle that stopped in one of the plates in the lower chamber, together with the $H\rho$ as measured in the upper chamber, suffice to determine the mass. Data for 26 particles have been obtained which indicate that, within the experimental error, the masses of mesotrons as measured in this experiment are all consistent with a *unique* rest mass of 202 times the rest mass of an electron. Statistical and systematic errors are analyzed.

INTRODUCTION

THE determination of the mass of individual cosmic-ray mesotrons has been accomplished in several ways, all involving measurement of the momentum of the particle and indirect measurement of the velocity or energy. The momentum is found by measuring the curvature of the mesotron track in a cloud chamber in a magnetic field. The velocity is determined by measurement of a quantity such as ionization, range, or momentum loss that theoretically depends on the velocity or energy of the particle. Wheeler and Ladenburg[1] discussed the various methods and gave the results of all observations up to the date of their paper. Subsequently, Johnson and Shutt,[2] Nielsen and Powell,[3] LePrince-Ringuet,[4] D. J. Hughes,[5] and Chaudhuri[6] (with a statistical method) have published additional values of the mass. Most of the values center around approximately 200 electron masses (m_e). The total number of reasonably reliable determinations to date is about 25.

The range-momentum relationship for cosmic-ray mesotrons was first investigated experimentally by J. C. Street[7] during a time when the existence of the particle was being established. He used two cloud chambers, one in a magnetic field of 7000 gauss, the second vertically in line below, and containing three one-cm thick lead plates. Since the apparatus was counter-controlled, he could observe the curvature of a particle in the upper chamber and its range in lead in the simultaneously expanded lower chamber. Between the two chambers there was an additional three cm of lead. With this arrangement, Street was able to show that the penetrating particles had masses much larger than those of electrons, but less than protons. He noticed, however, that "many" of the particles disappeared from view and were apparently stopped before they reached the end of their theoretical range, and he concluded that the mesotrons evidently suffered large anomalous energy losses near the end of their range.

Since measurement of the mass of mesotrons by the comparison of momentum and range depends on the assumption that the individual energy losses are very small compared to the energy of the particle, it seemed worth while to repeat Street's experiment under better conditions in order to verify or disprove the straggling in range that he observed. If the straggling is not observed, the data can be used to determine the masses of the individual particles observed.

THE EXPERIMENTAL APPARATUS

The upper cloud chamber, in which the momentum of the particle was determined, was 12 inches in diameter and three inches deep. It was filled with argon at 1.15 atmospheres and con-

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[1] J. A. Wheeler and R. Ladenburg, Phys. Rev. **60**, 754 (1941).

[2] T. H. Johnson and R. P. Shutt, Phys. Rev. **61**, 380 (1942).

[3] C. E. Nielsen and W. M. Powell, Phys. Rev. **63**, 384 (1943).

[4] LePrince-Ringuet and M. Lheritier, Comptes rendus **219**, 618 (1944).

[5] D. J. Hughes, Phys. Rev. **69**, 371 (1946).

[6] Chaudhuri, Ind. J. Phys. **18**, 57 (1944).

[7] J. C. Street, J. Frank. Inst. **227**, 765 (1939).

tained a 1:3 mixture of water and ethyl alcohol in sufficient quantity to keep the expansion ratio at about 10 percent, but the chamber was not saturated with the vapor. The cloud chamber was placed in a magnetic field of 5300 gauss provided by the Carnegie magnet. The clearing field in the chamber was maintained with 67 volts between the slightly aluminized front glass and the metal back plate. The drops that condensed on the positive and negative ions were thus separated into two vertical columns. In order to check the condensation efficiency, two pictures were taken of the upper chamber, one straight on, for the observation of curvature, and one from the side for the observation of the separated ion columns. Light for the photographs was provided by argon-filled capillary flash tubes through each of which condensers of 150 microfarads charged to 1800 volts were discharged. The illuminated region was one inch deep and 12 inches long. The front camera lens was set at f:4.0 for most of the pictures, while the side camera was set at f:6.3. Eastman Super XX or Ansco Ultra-Speed film was used.

It was found that the temperature of the upper cloud chamber had to be maintained uniform within 0.5°C in order to prevent turbulence of the tracks caused by the convection currents. Since the cloud chamber was directly in contact with the back pole-face of the magnet, it was necessary to control the temperature of the magnet as well as a jacket around the main part of the cloud chamber. Residual turbulence was largely responsible for the errors in measurement of curvature.

The lower cloud chamber was 16 inches in diameter and nine inches deep, and contained eight $\frac{1}{2}$-inch thick lead plates. These were placed on 1.5-inch centers so that the length of track visible between each pair of plates was about one inch. The plates were tilted in the chamber so that the camera viewed them edge on in all sections. The camera was a specially made stereoscopic camera using two Leitz f:4.5, 13.5-cm lenses tilted to converge in the illuminated region. The film used was 127 size (1.81 inches), Ansco Superpan Press, obtained in 100-ft. rolls. The pictures thus obtained were square and made use of the full angular field of the lenses. It was necessary to use a 45° front-aluminized mirror and to take the picture at 90° from the axis of the chamber because of structural features of the magnet mounting. The clearing field in the lower chamber was maintained by about 20 volts between the plates. It was shorted when the counters tripped but there was a residual field which continued to separate the columns of ions until the ions were fixed by the expansion. This resulted in doubling of horizontal and slanted tracks and doubling of ion clusters along vertical tracks. Measurement of the distance between doubled clusters or tracks gave a very good indication of the age of the track. This distance depends directly on the delay time t and thus permits a more accurate measurement of the track than the width of the diffuse track which depends on $t^{\frac{1}{2}}$.

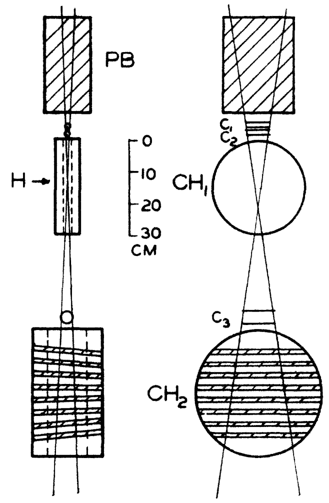

FIG. 1. A schematic drawing of the two cloud chambers Ch_1 and Ch_2. The chambers were simultaneously expanded upon the passage of a particle through counters C_1, C_2, and C_3. The momentum of the particle was determined in the upper chamber, and the range in lead determined in the lower chamber. The dotted lines indicate the extent of the illuminated region.

The illuminated region in the lower chamber was three inches wide at first but was later increased to five inches. The lights were G. E. flash tubes FT22, xenon filled, flashed on 150 μf at 1800 volts.

The over-all experimental set-up is shown in Fig. 1. The chambers were expanded upon the passage of a charged particle through the triple-coincidence Geiger counters, which defined a region in the lower chamber considerably narrower than the light beam. The lead over the upper counters served to select penetrating particles and to increase the number stopping in the lower chamber. The increase in the number of slow mesotrons was predicted by Rose[8] and is primarily caused by the fact that the decay of mesotrons in the lead is small compared to the decay in an equivalent thickness of air.

OBSERVATIONS

Approximately three pictures per hour were taken with the counter arrangement that was used. Of the approximately 2100 pictures that showed counter-controlled tracks, 83 percent showed particles that went through all of the lead plates in the lower chamber. With few exceptions, these particles were also visible in the upper chamber and had momenta large enough so that the observed penetration was expected. Some of these particles exhibited considerable scattering in the lower cloud chamber, which resulted in a lateral component of range. In some cases the track remained in the illuminated region and could be seen in all segments, but, if the scattering was such as to take the particle out of the illuminated region, the track would be lost to view. Sixteen particles were observed to scatter out the side of the chamber before reaching the last lead plate. Thus it was to be expected that some of the particles would be lost out of the illuminated region, especially in the lower part of the chamber. These could usually be distinguished in the stereoscopic view by the forward or backward direction of the track and the fading due to decreased illumination.

About 7 percent of the singly occurring counter-controlled tracks were observed to terminate in the lower cloud chamber. In most cases, especially in the upper part of the chamber, there was no doubt that the particle did stop. A conclusive observation in some cases was the density of ionization over the plate in which the particle was stopped. If this was noticeably greater than normal, the residual range of the particle was less than the thickness of the lead plate.

In some cases, however, when the ionization was normal but the particle was near the edge of the illuminated region, the scattering in a single plate might have been enough to remove the track from the illuminated region. This was fairly common below the 6th, 7th, and 8th plates and posed a problem in the selection of data. Unless a particle that disappeared under the 6th, 7th, or 8th plates was clearly in the center of the illuminated region or had strong ionization, only a minimum value of its range was given.

Some slow protons were observed. These ionized several times normal in the upper chamber and stopped in the first or second plate of the lower chamber. The heavy ionization and large radius of curvature in the upper chamber were sufficient for easy identification. Of the total of four singly-occurring protons observed, three stopped in the first plate and one in the second. This is evidence for the belief that the slow protons observed at sea level are locally produced and are not part of the tail of an energy distribution; otherwise protons stopping in the other plates might have been expected.

Electrons entering the lower chamber were distinguished by the showers that they made on interaction with the lead. Mesotrons stopping in the first lead plate are indistinguishable from electrons, however, and there is a small but finite probability that an electron might penetrate the first plate and stop in the second without visible multiplication. All data resulting from particles that were stopped in the third plate and were accompanied by other particles were also rejected as possibly being electrons. An example of a mesotron which stopped in the lower chamber is shown in Fig. 2.

REDUCTIONS OF OBSERVATIONS

In order to determine the momentum of the particle in the upper chamber, the magnetic field (H), the radius of the curvature on the film, and the magnification factor of the camera must be measured. The magnetic field was measured by a flip coil of 130 turns-cm^2 connected to a ballistic galvanometer, and was independently checked by a group from the Radiation Laboratory under the direction of W. M. Powell. The magnetic field was uniform to less than 1 percent over a 20-cm diameter, and was measured as a function of the scale reading of an ammeter connected in the field coils. Records of this scale reading were kept during the course of the experiment so that the

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[8] M. E. Rose, J. Frank. Inst. **236**, 9 (1943).

magnetic field was known. Its value was approximately 5300 gauss.

The radius of curvature of the track on the film was determined by plotting the coordinates of the track as viewed in a microscope with a traveling stage. If the displacement from a straight line is plotted on a large scale compared to the distance along the track, the resulting curve should be a section of an ellipse. Any deviation from the elliptical shape indicates spurious effects such as turbulence or scattering in the gas. From observation of these curves, it was determined that turbulence was serious if the temperature of the cloud chamber was not carefully controlled. It was difficult to observe zero field tracks because of the thermal equilibrium maintained between the magnet and cloud chamber.

After the track had been plotted and found to conform to the elliptical (or approximately parabolic) curve, the curvature was calculated by smoothing the points and using the sagitta formula or by fitting a curve to the observed points by the method of least squares. If the track departed appreciably from the elliptical curve, it was rejected as unreliable. Several criteria are available to check the reliability of the various tracks. The plotted points were compared with a family of parabolas drawn on transparent plastic, so that even small deviations were easily visible. If many of the points varied from the parabolic shape by more than the usual error of setting the cross-hairs or if a general trend away from the parabolas was shown, it was clear that the track was turbulent. Calculation of the radii of curvature of various sections of the track and comparison of the results was useful in rejecting turbulent tracks. Observation of other tracks on the same strip, including many that were not deviated by the magnetic field, provided another means of checking turbulence. Tracks whose radii of curvature varied along their length by more than 10 percent due to turbulence were rejected in the final analysis of data included in Table I.

Once the curvature on the film was found, it was necessary to know the factor to convert this to curvature in the chamber. The magnification factor of the camera lens was measured by photographing a piece of millimeter cross-section paper back of a 0.5-inch glass plate corresponding

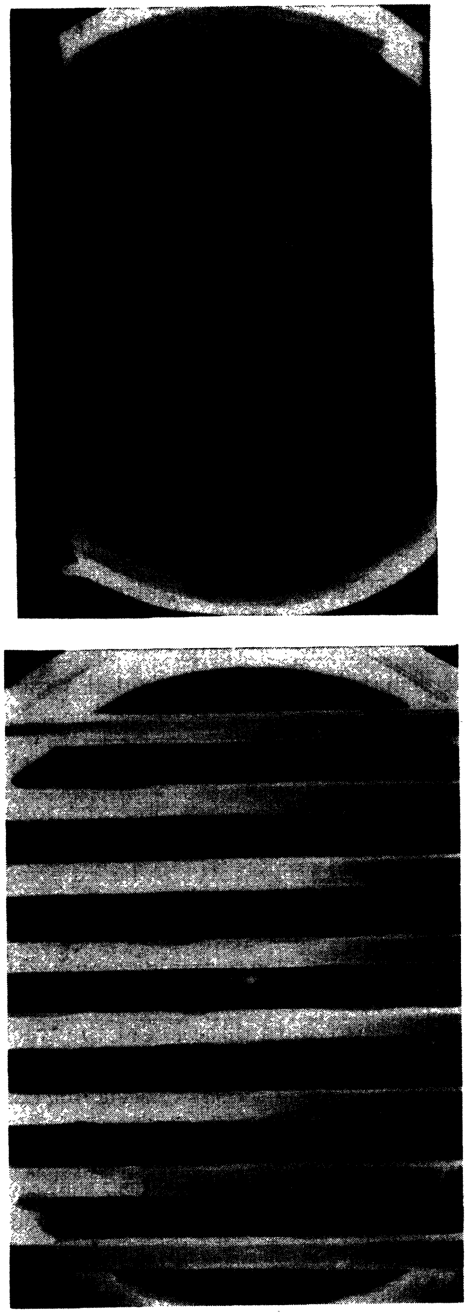

FIG. 2. A mesotron with $H\rho = 820\times 10^3$ gauss-cm in the upper chamber was stopped in the sixth lead plate with no increase in ionization above the plate. 7.90 cm$<$range$<$9.62 cm. Its mass was 244 ± 37. The slanted tracks appear doubled because of the residual clearing field. The track of the particle in the lower chamber illustrates the possibility of scattering out of the illuminated region if the scattering were toward the front or back instead of toward the side. In the actual apparatus the chambers were separated by a distance equal to two diameters of the upper chamber.

to the front glass. The cross-section paper was placed in the center of the illuminated region, with the chamber removed. Measurement of the pattern on the film gave a factor of 8.05 for conversion of length on the film to length in the cloud chamber. The factor for the side camera varied somewhat over the region and hence was plotted as a function of position in the chamber.

Most of the particles that stopped in the lower chamber had radii of curvature in the chamber of between 1 and 2 meters, or 125 to 250 mm on the film. The displacements of the center of the track from a straight line varied between 0.3 mm and 0.8 mm on the film, depending on the curvature and the length of track usable for measurement.

In order to find the range of the particle after it left the upper chamber, it was necessary to identify the plate in which it appeared to stop and to calculate the amount of lead through which it had gone. There was a considerable amount of material between the chambers: the glass wall, the copper jacket on the upper chamber, the lower counter (which has copper and glass walls), a mirror over the lower chamber, and the glass wall of the lower chamber. By means of the equations for energy loss in various materials given by Rossi and Greisen,[9] it is possible to calculate the thickness of lead equivalent to all of this material. The value obtained was 0.55 inch Pb (equivalent) and this was added to the amount of lead traversed in the lower chamber. A second correction that must be made is for the additional material penetrated when the particle was scattered or went through the lower chamber at an angle. This correction was usually fairly small and was roughly calculated by measuring the projected angles on the film. The residual range of a particle after it entered the plate in which it stopped is of course unknown but observation of the ionization over the plate helped to determine this residual range. If the particle had twice or more normal ionization, it was assumed that it stopped in the first half of the plate. If its ionization was normal, the uncertainty was taken as the full thickness of the plate since an apparent lack of increase of ionization may be caused only by poor illumination.

RESULTS OF RANGE-MOMENTUM OBSERVATIONS

A graph showing all the particles that stopped or appeared to stop in the chamber is given in Fig. 3. The circles represent particles for which the $H\rho$ and range are both known with relatively high accuracy. The crosses are those for which the range is known but the $H\rho$ is uncertain, because of turbulence. The vertical lines represent particles that disappeared from view under a certain plate but mostly appeared to be scattered or located in such a way that they were leaving the illuminated region. Thus only a lower limit on range was set. It is seen that, for the most part, the particles that were certain in both $H\rho$ and range group together quite well, giving the impression that for most mesotrons the $H\rho$-range relation involves no serious straggling. There were two particles whose range seemed anomalously long for the $H\rho$ measured but in these cases the chamber had been turbulent and the error in the measurement of curvature had been large. These particles are represented by crosses which fall below and to the left of the circles on the graph. Some of the particles represented by vertical lines on the right half of the graph may actually have had anomalously short ranges, but in view of the large angle scattering which has occasionally been observed this is not considered likely. If, on the other hand, these particles had large mass compared to other mesotrons, the ionization before stopping should in all cases be heavier and this was not observed.

The results agree with Street's to the extent that many particles did disappear in the chamber

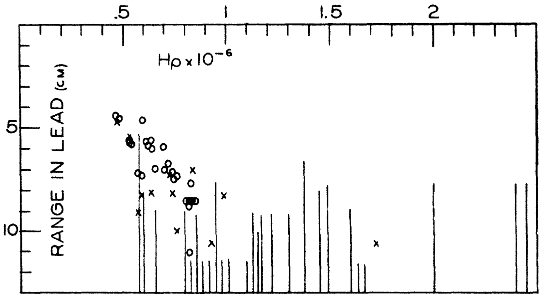

FIG. 3. Graph showing range and $H\rho$ for all particles that *appeared* to stop in the lower chamber. Circles represent particles for which both $H\rho$ and range were accurately determined. Crosses indicate that the $H\rho$ was uncertain, and the vertical lines indicate that the range could only be given a minimum value.

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[9] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 240 (1941).

but with the stereoscopic pictures and wide illuminated region in the present experiment it seems possible to attribute most of this effect to scattering in the lead.

MASS DETERMINATION

Since the effect of straggling in range does not seem to be very important, it is possible to make mass determinations for the particles for which $H\rho$ and range are known. A magnified section of the $H\rho$ range plot is shown in Fig. 4. The curves for different masses are the theoretical curves as given by Wheeler and Ladenburg, with constants evaluated from stopping-power experiments. The lines plotted on the diagram are the data for the various stopped particles, with the horizontal projection of each line representing the estimated uncertainty in $H\rho$ and the vertical projection representing the uncertainty in range.

It is seen that, within the experimental error, the masses lie between 142 and 264 electron masses. The weighted average of masses thus determined is 202. In Table I the individual data are given, together with estimated probable errors.

TABLE I. Summary of data.

Track No.	Range in lead (cm) min	Range in lead (cm) max	Ionization increase	$H\rho\times 10^{-3}$ (gauss-cm)	Mass, probable error	Sign
137–19	5.29	5.92	Yes	529±45	160±26	−
165–1	6.50	7.80	No	668±43	199±33	−
165–10	5.25	5.90	Yes	610±60	212±35	−
168–17	5.44	7.24	No	598±43	180±33	−
180–5	6.50	7.80	No	576±43	142±32	+
182–5	3.94	5.21	No	592±27	238±30	+
190–27	4.16	4.85	Yes	480±54	164±38	+
202–26	7.77	9.11	No	840±32	264±28	+
210–6	7.77	9.10	No	830±65	260±42	+
212–8	5.34	6.00	Yes	536±65	163±35	−
215–23	7.80	9.06	No	814±43	250±30	−
218–13	7.90	8.59	Yes	760±21	222±18	+
218–37	6.60	7.35	Yes	700±54	225±32	−
219–25	6.65	8.25	No	749±43	242±37	−
222–31	4.32	5.71	No	530±21	180±26	+
224–30	4.01	4.70	Yes	460±21	157±16	+
226–17	6.60	7.24	Yes	652±43	195±28	+
226–20	5.21	6.48	No	620±27	209±30	−
231–10	5.24	6.55	No	694±21	258±28	+
232–16	6.53	8.05	No	589±21	143±28	+
234–4	5.24	5.86	Yes	633±21	228±19	+
237–8	7.87	9.65	No	809±44	237±35	−
244–11	6.55	7.82	No	760±43	258±35	+
244–20	10.70	11.42	Yes	820±43	183±21	+
244–33	6.75	8.43	No	739±43	230±37	−
245–32	7.90	9.62	No	820±43	244±37	+

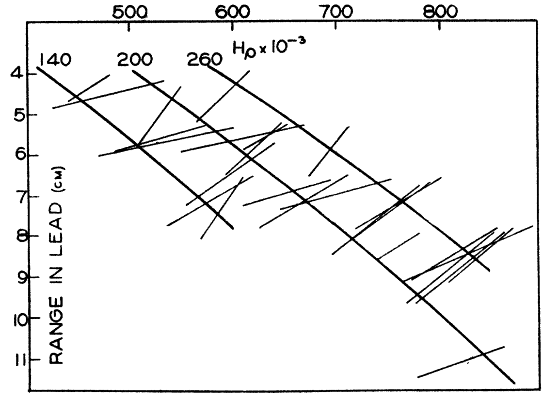

FIG. 4. Graph showing data for particles for which $H\rho$ and range were accurately determined. The curves are the calculated range-momentum relationships for mesotrons of mass 140, 200, and 260 electron masses. Each line represents the data for an individual particle, with the horizontal projection giving the uncertainty in $H\rho$, the vertical projection giving the uncertainty in range.

ERRORS

The errors in the determination of $H\rho$ come from:

1. Measurement of magnetic field. The uncertainty in this measurement is probably about two percent due to all causes: calibration, current measurement, flip coil, etc. The systematic error in H is probably not more than one percent.

2. Measurement of magnification factor. The error in this is less than one percent, but it is also a possible source of systematic error.

3. Measurement of curvature on the film. The statistical error in setting the cross hairs on the track was about two percent. The error due to turbulence in the cloud chamber was in many cases considerably more than this, was very difficult to estimate, and was likely to be systematic. The usual procedure was to observe the appearance of other tracks on the same strip of film, since turbulence was obvious in tracks that were very little bent by the magnetic field. The plotted displacement of the track, which should be nearly parabolic when plotted on a large scale, was also compared with true parabolas to see if there was any skew or off-center motion before the picture was taken.

4. Scattering in the upper chamber. E. J. Williams[10] has given a formula for the spurious radius of curvature produced by scattering in the gas of the upper chamber. If ρ is the true radius of curvature and ρ_s is the apparent radius of curvature due to scattering, the expression reduces to $\rho_s/\rho = H/109$ for the present conditions. Since H is approximately 5300, $\rho_s = 49\rho$. Thus the error caused by scattering in the argon is about two percent, and is not systematic.

The general conclusion was that the uncertainty in $H\rho$ in the majority of the tracks varied

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[10] E. J. Williams, Phys. Rev. 58, 298 (1940).

from ±5 percent to ±10 percent. Tracks with uncertainty greater than this due to turbulence were plotted as crosses on Fig. 3 and rejected for Fig. 4.

The uncertainty in range due to scattering out of the illuminated area has already been discussed, but may cause a systematic error in the final result. For particles that remain in the illuminated area, the uncertainty has been fixed at 0.25 inch of lead for those particles that appear to ionize heavily before they enter the plate and 0.5 inch of lead for those that appear to ionize normally. Those that appear normal may, of course, scatter as they enter the lead and traverse a distance greater than 0.5 inch before stopping. The average angle of scattering of such a particle is about 8° so the correction due to this is not large and has been neglected.

The systematic error introduced by selection of data is more serious. It is possible that some of the particles included in Table I did not actually stop but were scattered out of the illuminated region. This would result in the assignment of a spuriously high mass to those particles, and a resultant systematic error in the average.

The error in mass is thus compounded from the uncertainties in $H\rho$ and range. The maximum value of mass consistent with a given set of data was calculated using the maximum $H\rho$ and minimum range, while the minimum value of mass was calculated using the minimum $H\rho$ and maximum range. Since it is unlikely that the uncertainties in $H\rho$ and range would add in this way, the value assigned to the "probable" error of each observation of mass was about 30 percent less than the maximum error.

CONCLUSIONS

The large straggling of cosmic-ray mesotrons observed by Street has not been confirmed, and it is likely that his results are explained by scattering of particles out of the illuminated region of his lower cloud chamber. Even in the present experiment, with a relatively much larger illuminated region, loss of particles due to scattering is still observed.

Since the momentum of the particles that definitely stop in the lower chamber is known, the masses of the individual particles can be obtained from the range-momentum relationship given by Wheeler and Ladenburg.[1] This gives a number of mass determinations with values ranging from 142 to 264 m_e.

It was of interest to determine whether the data were consistent with a unique mass or whether a distribution of masses must be assumed to explain the spread of values. Let us make use of the criteria of internal and external consistency as given by R. T. Birge.[11] From the estimated errors of individual observations we can assign weights to each observation which are inversely proportional to the square of the estimated error of each observation. We then calculate the weighted average $M=202$. The residuals are calculated by taking the difference between M and the observed value. From these residuals the probable error of a given observation of unit weight based on external consistency can be calculated.

It was found that the ratio of the probable error based on external consistency to the probable "internal" error was very nearly unity. This means that the observations agree among themselves about as well as was to be expected from their individual probable errors.

It is clear, then, that assuming a unique mass of 202 is quite consistent with the data obtained.

The fact that the above statistical analysis of the data can be made is a direct consequence of the fact that a relatively large number of mass determinations have been made in the same experiment. In previous experiments the number of data have been much smaller and no such analysis could be made.

We can now estimate the probable error of the weighted average of all observations. If we use the estimated error for external consistency, the probable error of the weighted average is about ±5.

It should be emphasized, however, that the systematic errors in this experiment are probably somewhat larger than the statistical uncertainty and that, although the uniqueness of the mass seems well established, a more accurate determination of the absolute value of the mass awaits experimental refinements.

The magnet, together with its cloud chamber

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[11] R. T. Birge, Phys. Rev. 40, 207 (1932).

and auxiliary equipment, was designed and built by Professor R. B. Brode in 1940 and 1941 expressly for the measurement of the mesotron mass. Funds for this equipment were made available by a grant from the Carnegie Institution of Washington. The lower cloud chamber and its camera were built by Professor W. E. Hazen, who suggested the experiment and to whom I am deeply indebted for constant instruction and encouragement. Professor R. T. Birge was very helpful in connection with the statistical analysis of the data.

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Low Energy Alpha-Particles from Radium

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The large alpha-ray spectrograph and the sensitive track method of detection, as used for studying the polonium alpha-particles, have been used to investigate the alpha-ray spectrum of radium. Thin and uniform radium sources were freshly prepared by depositing radium carbonate on platinum rods, using a modified method of Hahn and Meitner. Microscopic examination has revealed a line at 4.615 Mev, which is identifiable with that found by Rosenblum. From 0.5 to 0.9 Mev below the main line five previously unknown groups have been found. The intensities of the first line and of these last ones are, respectively, about 1800 and 50–20, if the intensity of the main line is set as 100,000. As in the polonium case, if the particle groups come from the nucleus as all experiments have indicated, the ordinary alpha-decay theory is in serious disagreement with the experiments, for the theoretical intensity varies with energy much more rapidly than the observed intensity. Therefore, a mechanism other than a simple penetration through the static potential barrier may be needed. Attempt has been made to explain these results by assuming a strong interaction between the outgoing particle and the rest of the nucleus. This interaction may imply a transfer of kinetic energy from the particle to the residual nucleus, which will then make the decay probability appear much larger. The total probability of decay and the resultant excitation of the nucleus are discussed in terms of this tentative mechanism.

I. INTRODUCTION

MORE than a year ago we found a series of weak alpha-particle groups[1] in the energy region below the polonium main alpha-ray line. If these alpha-particle groups are assumed to come from within the polonium nuclei, as all experiments have indicated, leaving the lead nuclei in different excited states, they may be then correlated with the gamma-rays from Po. In general the intensities and energies of these groups are found to be of the similar order of magnitude to those of the gamma-ray lines from Po as found by Bothe. However, the intensities of these groups are quite out of line with the predictions of the ordinary alpha-decay theory which assumes penetration through a static potential barrier. For this reason it is of interest to study similar effects in other radioactive nuclei which have different main decay periods and different α-particle energies. The present paper reports the results of an examination of the α-particle spectrum of radium.

II. EXPERIMENTAL

Because of the longer decay period of radium and the activity of its decay products the work with radium is much more troublesome than with polonium. On the one hand, short exposure times require relatively thick sources entailing α-particle straggling. On the other hand, long exposure with thinner sources introduces difficulties caused by background from contamination of the chamber near the source box and from the α-particles from the decay products. A compromise between these evils was necessary.

To prevent contamination of the whole apparatus with emanation the old radon must be driven out before the preparation of the source and the radon developed in the source during

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[1] W. Y. Chang, Phys. Rev. 69, 60 (1946).

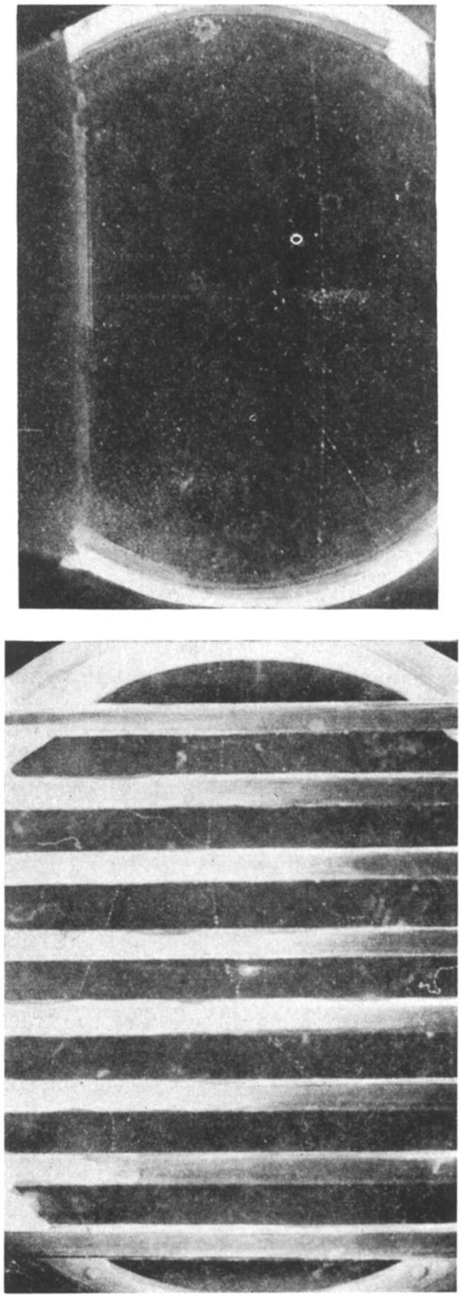

FIG. 2. A mesotron with $H\rho=820\times10^3$ gauss-cm in the upper chamber was stopped in the sixth lead plate with no increase in ionization above the plate. $7.90\text{ cm}<\text{range}<9.62\text{ cm}$. Its mass was 244 ± 37. The slanted tracks appear doubled because of the residual clearing field. The track of the particle in the lower chamber illustrates the possibility of scattering out of the illuminated region if the scattering were toward the front or back instead of toward the side. In the actual apparatus the chambers were separated by a distance equal to two diameters of the upper chamber.