# NEW EVIDENCE FOR A PARTICLE OF MASS ~ 525 $m_e$

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**ABSTRACT.** While photographing stopped muons in a multiplate cloud chamber at Calcutta (sea level 12°N) nine pictures were obtained in which the rate of change of ionisation of the particles and their residual ranges were not compatible with that shown either by mu-mesons or by protons. Their mass values were obtained by measuring their change in ionisation in the successive gaps and their decrease in residual ranges. Ionisation was measured by drop counting. It was found that five of these particles gave an average mass value $528 \pm 34$ $m_e$ and the remaining four an average of $280 \pm 21$ $m_e$. The close proximity of the latter value with the pion mass is a strong indication for the correctness of the method employed. A probable decay event of the particle of mass ~ 528 $m_e$ has also been given.

## 1. INTRODUCTION

The experiments of Alikhanyan *et al.* (1948) and his collaborators at an altitude of 3250 mertes with several sets of G.M. counters and lead absorbers placed in a magnetic field indicated for the first time the possible existence of mesons of various masses as deduced from their magnetic deflections and residual ranges. The same group of workers also confirmed this evidence from observations in photographic plates In 1952 a few events were obtained by Shapire (1952) and Perkins (1952) in photographic emulsions in which a primary particle of mass ~ 525 $m_e$ was observed to undergo a small deflection after which the average scattering of the particle increased two fold pointing to a decrease in mass by a factor of two. These authors interpreted the data as the decay of a particle which was called $\zeta^{\pm}$ according to the mode

$$\zeta^{\pm} \rightarrow \pi^{\pm} + \pi^0 + Q(\text{a few Mev}) \tag{1}$$

Later, Daniel and Perkins (1954) stated that all such events, except only one, could be explained as a normal spread of mass values centred on the pion mass. There were, furthermore, three cases obtained by Leighton and Wanlass (1952) in a cloud chamber operated in a magnetic field where a visual estimate of ionisation and measured momentum gave the mass value $450 \pm 150$, $550 \pm 150$, $750 \pm 150$ of which the first two are highly incompatible with either the pion or the $K$-meson mass. Three doubtful cases of the existence of such particles have been reported by Inoki *et al.* (1957) from the study of slow meson masses.

Recently an investigation was carried out by the authors (1957) to determine the slow meson intensity at Calcutta (12°N) by stopping these particles in a multiplate cloud chamber fitted with five half inch Cu-plates and triggered by a three-fold coincidence cum anti-coincidence method. In course of analysis of the pictures nine cases were observed, where the change in ionisation of the track of the particle from gap to gap was much slower than that of a normal mu-meson but more rapid than that of a proton or a $K$-meson. The ionisation produced by these particles was estimated by drop counting in the different gaps and the mass of each particle was determined by two methods, which although slightly inter-dependent, help to reduce the statistical error. It is found that five of these particles exhibit a mean value of mass $528 \pm 34$ $m_e$ and the remaining four a mean value $280 \pm 21$ $m_e$. The close proximity of the mass value of the second group with the pion mass appears to be a strong evidence for the correctness of the method. A preliminary report has been given by the authors (1958) in *Science and Culture,* March, 1958.

## 2. THE METHOD

The change in ionisation of a singly charged particle on passing through a certain thickness of matter can be easily converted into the corresponding change in $p/\mu( = \beta/\sqrt{1-\beta^2})$ of the particle from one side of the plate to the other from the $I/I_m$—$p/\mu$ curves (figure 1). We then use the following equation of Rossi and Greisen (1941) valid for a small momentum interval.

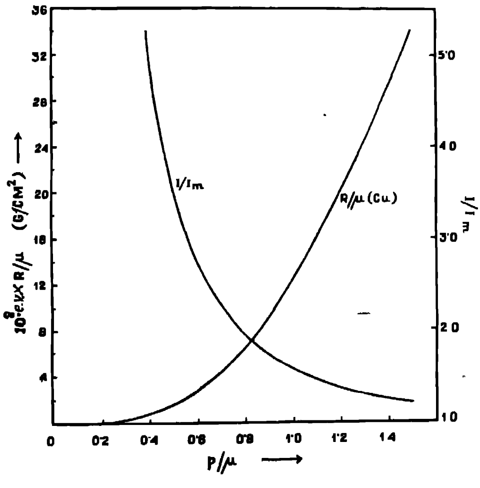

Fig. 1.

$$\Delta R = R\left(\frac{p_2}{\mu}\right) - R\left(\frac{p_1}{\mu}\right) = \frac{M}{2CB}\left[\frac{(p_2/\mu)^2+2}{\{(p_2/\mu)^2+1\}^{\frac{1}{2}}} - \frac{(p_1/\mu)^2+2}{\{(p/\mu)^2+1\}^{\frac{1}{2}}}\right] \quad \cdots \quad (2)$$

where $\Delta R$ is the thickness in g/cm$^2$ of the plate, on passing through which the ionisation of the particle changes by such an amount as to reduce the value of its $p/\mu$ from $p_2/\mu$ to $p_1/\mu$. $M$ is its mass in electron mass units, $C$ is a constant for the material used and $B$ is a slowly varying function of $p/\mu$. For copper, the material used in this cloud chamber,

$$C = 6.84 \times 10^{-2} \text{ and } B = 15.71+9.21 \log_{10}(p/\mu) - \frac{2}{1+(p/\mu)^{-2}}$$

It should be noted that $\Delta R$ is known accurately and the accuracy of the value of the mass determined from equation (2) essentially depends on the accuracy with which the ionisation of the particle can be measured in the different gaps and the number of gaps available for such measurement. It should also be emphasised that this method of mass determination is quite unsuitable for very heavy particles, such as protons where the change in ionisation from plate to plate is quite small and also for very light particles such as mu-mesons where the number of gaps available for measurement (after $I/I_m > 1.5$) is one or atmost two. But, for a particle of mass $\sim 500\ \mathrm{m}_e$, the change in $I/I_m$ as well as the number of gaps in which such changes can be estimated are optimum for the determination of the mass from equation (2).

First of all drop counting was made on thirty selected mu-meson tracks of uniform minimum ionisation which showed less than 0.5° of scattering in all the five half inch copper plates inside the chamber. They were obtained by triggering the chamber with 3-fold coincidence only. The track in each gap was divided into about thirty cells of length equal to the width of the track and the number of drops in each cell was counted after magnifying the track to eight times its actual dimension at the time of formation. Back-ground counts of silver grains were made on both sides of the track at the same time and subtracted from the total counts per cell on the track. The statistical fluctuation of the background counts was small and uniform and the overall statistical error in the final counts per cell of the thirty minimum ionisation tracks was less than 6%. Whenever a portion of minimum ionisation track was available in the picture containing the heavy track, drop counts were made on it and found to agree with the value obtained from the measurement on the thirty mu-meson tracks. The cloud chamber pressure, the delay of light flash, and the developing procedure of the film were kept uniformly constant throughout the experiment. Out of about five hundred particles stopped inside the cloud chamber the rate of change of ionisation in the successive gaps was apparently smaller than that of mu-mesons in nine cases. Seven of the particles stopped in the fourth plate and two in the third plate and in each of them drop counts were made on both the stereo views in all the gaps Back ground counts made on the same negative on the two sides of the track were

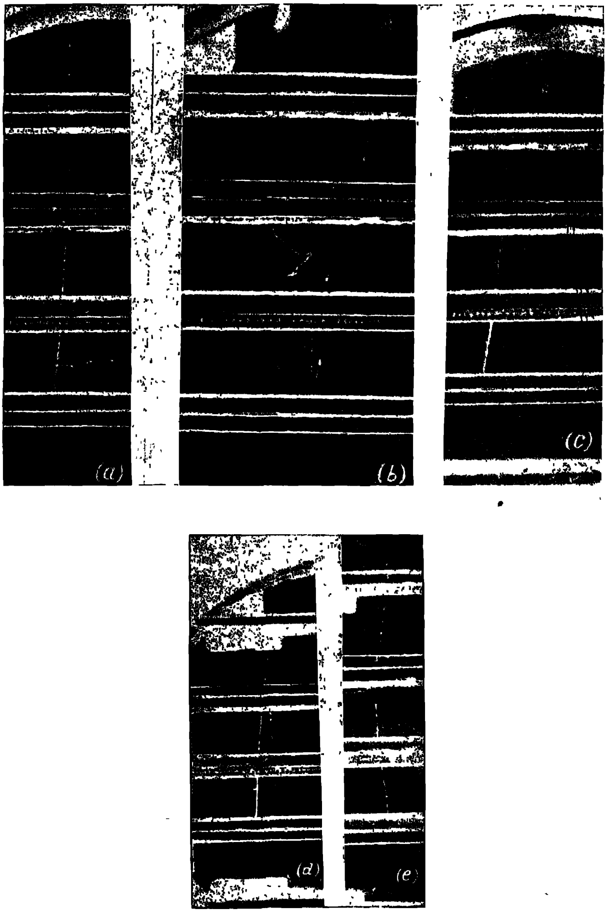

Fig. 2.

then subtracted and the resulting number of drops per unit cell found out. The ratio of the average count in any gap to the average count for the thirty mu-meson tracks was taken to be the ionisation of the particle in that gap. The chamber gas was argon and the number of ion-pairs produced per cell was so high that the error due to overlap of drop images was more than fifteen per cent when the track showed more than three times minimum ionisation and no attempt at estimation of ionisation was made above this value. The values of ionisation of the nine particles in the different gaps obtained in this way are given in Table I.

All the five tracks of the heavy particles are shown in figure 2(a), (b), (c) (d) and (e) and two of the lighter tracks which gave mass values close to the pion mass are shown in figure 3(a), (b) of which the latter shows a visible decay electron. It will be seen from Table I, that although seven of the nine particles stopped in the fourth plate, ionisation measurements in the fourth gap were too high to be measured in two cases. Measurements on the first gap of those tracks which were near minimum in those portions were not carried out extensively. Measurement in gap 2 of picture no. 11505 could not be made owing to the distorted nature of the track in this gap.

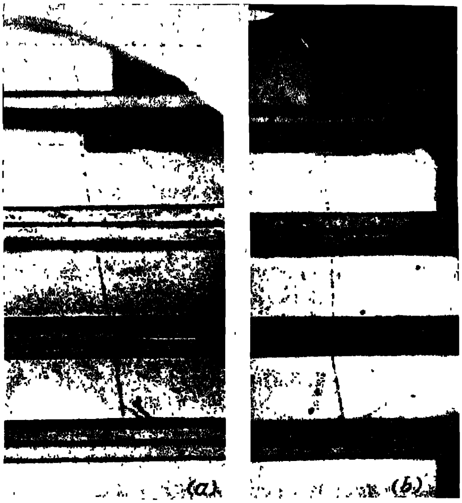

Fig. 3.

All these ionisation estimates were then converted into $p/\mu$ values from the $I/I_m$—$p/\mu$ curve (figure 1) valid for an argon filled chamber. From Table I we find that at least three such $p/\mu$ values were available for each particle which provided us with three independent estimates (12, 23, 13) of the mass value from equation 2. Obviously $p/\mu$ values have asymmetric statistical errors and so

## TABLE I

Ionisation estimates of nine particles

| Picture number | Value of $I/I_m$ above plate number | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 11505 | 1.46 ± 0.15 | | 2.02 ± 0.18 | 2.92 ± 0.22 |
| 12050 | | 1.61 ± 0.13 | 1.01 ± 0.18 | 2.54 ± 0.20 |
| 8610 | 1.52 ± 0.14 | 1.70 ± 0.17 | 2.65 ± 0 23 | |
| 2700 | 1.59 ± 0.16 | 1.94 ± 0.18 | 2.60 ± 0.20 | |
| 3705 | | 1.47 ± 0.17 | 1.79 ± 0.19 | 2.31 ± 0.20 |
| 1605 | 1.33 ± 0.11 | 1 57 ± 0.12 | 2.74 ± 0.21 | |
| 12616 | 1.40 ± 0.12 | 1.66 ± 0.14 | 2.70 ± 0.20 | |
| 1715 | | 1.32 ± 0.11 | 1.65 ± 0.14 | 3.18 ± 0.32 |
| 3700 | | 1.34 ± 0.18 | 1.76 ± 0.20 | 3.11 ± 0 34 |

also these three individual mass values, which together with their six extreme values were combined to obtain an average mass for the particle and its standard deviation. These average values are shown in column two of Table II.

It is well known that apart from the error in counting and the error due to overlap of the drops in highly ionising tracks, the ionisation process itself is a statistically fluctuating phenomenon, and the correction due to this was incorporated in the following way. The $p/\mu$ values obtained for the various gaps were converted to $R/\mu$ values for Cu (shown in figure 1) and then for each gap the total expected residual range of the particle was found out from the mean value of the mass obtained for that particle in the above manner and its $R/\mu$ value for that gap. In this way the expected residual ranges of a particular particle after each of three gaps were known from the ionisation in these gaps and since the thickness of each plate is known accurately, the data gave us the mean expected range of the particle in the plate in which it stopped. It should be noted that in obtaining the range of the particle in the *last plate* we have taken into account the ionisation of the particle in at least three gaps and the mean of this range is given in column 3 of Table II. The experimental residual range at any gap is now fixed, being the total matter subsequently passed through by the particle plus its mean range in the last plate as obtained above.

If we now combine the $R/\mu$ values as obtained from figure 1 from the ionisation estimates of the particle in each gap with its experimental residual range corresponding to that gap we shall get a value of the mass of the particle. We have given in column 4, Table II, the mass values obtained by the second method.

The two mass values thus obtained for each particle are then combined and the mean with its standard deviation given in the fifth column. It will be seen that the mean values obtained for the first five particles (first group) are highly incompatible with the mass of a pion or a $K$-meson, whereas the mean values obtained for the last four particles (second group) are quite consistent with the pion-mass. We have lastly assumed that the particles in the first group have actually the same mass and so also those in the second group and a grand mean for the two groups is given in the last column with its *probable error* as computed from the whole data for that group.

TABLE II

Mass values of the nine particles

| Picture number | $\Delta R$—$\Delta(p/\mu)$ method $m_e$ | Range in last plate (g/cm$^2$ of Cu) | $R$–$R/\mu$ method $m_e$ | Mean mass $m_e$ | Grand mean $m_e$ |
|---|---|---|---|---|---|
| 11505 | 538 ± 171 | 8.5 | 607 ± 141 | 572 ± 91 | |
| 12505 | 568 ± 120 | 11.0 | 610 ± 120 | 589 ± 65 | |
| 8610 | 484 ± 210 | 0.7 | 573 ± 210 | 528 ± 123 | 528 ± 34 |
| 2700 | 483 ± 187 | 0 | 584 ± 156 | 533 ± 103 | |
| 3705 | 416 ± 156 | 8.6 | 426 ± 102 | 421 ± 76 | |
| 1605 | 250 ± 70 | 4.1 | 259 ± 45 | 254 ± 21 | |
| 12615 | 317 ± 69 | 4.8 | 328 ± 65 | 322 ± 26 | |
| 1715 | 256 ± 65 | 2.8 | 273 ± 61 | 264 ± 26 | 280 ± 21 |
| 3700 | 271 ± 79 | 3.0 | 291 ± 85 | 281 ± 32 | |

Annis, Bridge and Olbert (1953) have indicated a method of rough estimation of mass of particles stopping inside a multiplate cloud chamber by measuring the projected angle of multiple scattering in a certain plate and the residual range of the particle at that plate. The values of the product $\eta^2 = \phi^2 R^{2\alpha}$ for each plate was computed, where $\phi$ is the projected angle of scattering in a certain plate, $R$ the residual range at the scattering plate and $\alpha = 0.55$ for all elements. The average value of $\eta^2$ for a large number of scatterings is found out and then equated to a theoretical expression which is a function of the mass of the particle, the thickness of the scattering material and a factor which is constant for a particular scatterer. Although this method is not very accurate even when at least seven or more scattering angles are available, we made an attempt to find in this way the mass of the particle in group one above by measuring the three projected angles of scattering and the residual ranges. The final mean value of the mass so determined is 537 $m_e$ with an as symmetric statistical error of nearly 20 per cent, if we assume that all the particles in group one are of the same mass, and exclude the scattering of the particle 2(b), 12505 in the third plate which is too high to be due to multiple scattering. The general agreement of this value with the grand mean of group one particles in Table II is a strong support for the contention that the particles do exhibit a mass value $\sim 525m_e$.

Lastly, we want to mention that if the particle actually has a decay mode given by equation (1) it will be hard to observe the charged decay product in a multiplate cloud chamber since the resulting $\pi\pm$ will have a small range. The $\pi^0$ can however under suitable conditions be recognised by its subsequent decay into two photons and their resultant electron cascade. It is very interesting to note that the stopping of the particle (12505) in figure 2(b) in the fourth plate results in a heavy particle coming up towards the right which is stopped in the first plate it enters into and there is a pair of soft electrons towards the left. The heavy particle may be interpreted as the low energy pion and the pair of electrons the effect of $\pi^0$. Alikhanyan *et al.* (1956) have also observed a pair of electrons coming out in two cases from the point of stopping of such a particle. These authors further report that particles of mass $\sim 550m_e$ always appeared singly in their chamber and this agrees well with our observations that all the five particles have entered the chamber unaccompanied by any secondary.

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