DETERMINATION OF THE LIFE OF THE MESOTRON.

By N. N. Das Gupta, *M.Sc.* (*Cal.*), *Ph.D.* (*Lond.*) *and* P. C. Bhattacharya, *M.Sc.* (*Cal.*), *University College of Science, Calcutta.*

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Introduction.

In an attempt to explain the short-range nuclear forces and the anomalous magnetic moments of the neutron and the proton, Yukawa (1935) postulated the existence of heavy particles of mass intermediate between those of electrons and protons. These particles are supposed to be radioactive, so that after a very short time τ, they decay into ordinary electrons and neutrinos. In this respect these heavy electrons or the mesotrons, as they are now called, are quite unique, because while all other fundamental particles are stable they have an extremely short life. It was pointed out by Bhabha (1938*a*) that from the considerations of relativity, the time of disintegration of a mesotron will be longer when the particle is in motion. The life of a particle of total energy E and rest mass μ is given by

$$\tau = \tau_0 \, E/\mu c^2 \qquad \qquad (1)$$

where τ_0 is the life of a particle at rest.

There are still serious difficulties associated with the heavy electron theory of nuclear forces; however, the actual proof of the existence of such particles in Nature is furnished by numerous cosmic ray experiments. It now seems certain that the penetrating part of the cosmic raidation at sea level consists of particles lighter than protons but heavier than electrons. Although it is not yet clear whether the mass of all these particles is the same or it varies continuously or even makes quantum jumps as postulated by Bhabha (1938*b*) and Neddermeyer (1938), it will be interesting to see how far cosmic particles agree in their properties with the nuclear particles postulated by Yukawa. As a first step towards establishing this identity it is necessary to verify whether the mesotrons found in cosmic rays are themselves radioactive as demanded by Yukawa's theory.

Until recently the cloud chamber evidence was rather against the existence of a radioactive decay of mesotrons. Thus Maier-Leibnitz (1939), Neddermeyer and Anderson (1938) and Nishina, Takeuchi and Ichimiya (1939) observed altogether 7 mesotron tracks where the mesotron appeared to come to rest within the chamber, but no trace of the disintegration electron into which it is supposed to decay was visible. Montgomery, Ramsay, Cowie and

Montgomery (1939) attempted to find evidence of disintegration of mesotrons by counting coincidences between the mesotrons which are stopped by a lead plate and the decay electrons which emerge out of the lower surface of the plate. The results were entirely negative.

Very recently in the photographs taken in a randomly operated large cloud chamber, Williams and Roberts (1940) have found clear evidence for the disintegration of mesotrons. They have recorded photographically two cases in which mesotrons come to rest within the chamber, and then give rise to high-energy electrons. A similar case was reported somewhat earlier by Maier-Leibnitz (1938) although the track of the disintegration electron in this case was not so clear.

On account of the rarity of the phenomenon such direct evidence of the disintegration of individual mesotrons are very few. There are, however, various indirect evidences. Follett and Crawshaw (1936), Ehmert (1937) and Auger, Ehrenfest, Freon and Fournier (1937) found that for the same mass of the absorber, mesotrons seemed to be absorbed more in rarefied substances than in dense materials. According to Euler and Heisenberg (1938) these anomalies can be explained to be due to the instability of the mesotrons predicted by Yukawa. In order to penetrate the same mass, mesotrons have to traverse longer distances in rarefied gases like air than in condensed substances like water or lead. In dense materials the range as defined by the energy loss by ionisation may be less than the free path of mesotrons ($L = c\tau$), so that no mesotron is lost due to decay. In gases, on the other hand, the range is of the same order as the mean free path L. Some of the mesotrons therefore decay on their way and there is an increased apparent absorption. It should be mentioned here that according to Fermi (1940), a part of the mass absorption anomalies may be explained to be due to the effect of density of a material on ionisation loss of a fast particle. According to this idea for a very fast mesotron ($E > 10^9$ e.v.), with equal masses of the absorbing material, the energy loss in rarefied substances is greater than that in a condensed material. This difference increases with the kinetic energy of the particle. However, such an effect is inadequate to explain the total mass absorption anomaly actually observed and one has to fall back upon the disintegration hypothesis.

Blackett (1938*a*) showed that it is possible to estimate the life of the mesotron based on the differential absorption of the penetrating component in rarefied and condensed materials as well as from altitude and seasonal variation of cosmic ray intensities. The different methods of determination of the life of the mesotron based on these ideas have been summarised by Rossi (1939). He further showed that the shape of the energy spectrum of the mesotrons at sea level is influenced by the disintegration of the mesotrons. A comparison of the shape of the observed sea level spectrum with the theoretical one seems to justify the disintegration hypothesis. In the following table a summary is given of the work carried out so far, together with the methods used and the results of determination of τ_0.

TABLE I.

A Summary of the Previous Work on Determination of τ_0.

Observer	Date	Method used	τ_0 in secs.
Blackett	1938(*a*)	Inclination Anomaly and Mass Absorption Anomaly in Water and Lead.	$1{\cdot}7 \times 10^{-6}$
,, ...	1938(*b*)	Temperature Effect	$3{\cdot}4 \times 10^{-6}$
Bernardini, Ferretti *et al.*	1940	Altitude Effect at 3·4 Km. and 0·5 Km.	$5{\cdot}0 \times 10^{-6}$
,, ,,	..	Inclination Anomaly	$4{\cdot}0 \times 10^{-6}$
Clay, Gemert and Clay.	1939	Variation of Ionisation at Different Depths of Water.	$2{\cdot}0 \times 10^{-6}$
Euler and Heisenberg	1938	Ratio of Intensities under thick Layers of Air and Water.	$2{\cdot}7 \times 10^{-6}$
Johnson and Pomerantz.	1939	Mass Absorption Anomaly in Water and Air.	$2{\cdot}6 \times 10^{-6}$
Nielsen, Morgan *et al.*	1940	Altitude Effect and Attenuation Factor.	$1{\cdot}2 \times 10^{-6}$
Pomerantz ..	1940	Zenith Angle Effect at Sea Level, Integral Method.	$3{\cdot}4 \times 10^{-6}$
,, ..	..	Zenith Angle Effect, Differential Method.	$2{\cdot}6 \times 10^{-6}$
,, ..	..	Ratio of Disintegration Electrons to Mesotrons.	$6{\cdot}0 \times 10^{-6}$
Rossi, Hilberg and Hoag	1940	Mass Absorption Anomaly in Air and Carbon.	$2{\cdot}0 \times 10^{-6}$
Rossi	1938	Mass Absorption Anomaly in Water and Lead.	$2{\cdot}0 \times 10^{-6}$

On account of the great importance attached to the radioactive decay of mesotrons as well as of the large variation in the values of τ_0 obtained by different workers, it was decided to carry out some independent measurements in tropical latitudes.

The present paper describes measurements of the vertical and inclined intensities at Calcutta (approximately at sea level and magnetic latitude 12°N.) and at Darjeeling (height above sea level 2·2 Km., magnetic latitude 16°N.). We have also estimated the proportion of the disintegration electrons to the mesotrons at the two stations. From these measurements, τ_0 the life of the mesotron at rest has been determined by three independent methods, viz.: (*a*) altitude effect, (*b*) zenith angle effect, and (*c*) ratio of disintegration electrons to mesotrons.

APPARATUS AND EXPERIMENTAL PROCEDURE.

In the series of experiments described below we have counted coincidences between four Geiger Müller counters in the same vertical plane with their axes pointing magnetic east-west. The two lower counters were shielded by 10 cms. Pb on all sides to cut off the soft component. In order to measure the absorption in lead additional slabs of any required thickness could be placed between the lower counters and the upper. The correction due to accidental coincidences and showers was determined by displacing the second and the third counters from the common axis as shown in figs. 1 and 2. With this arrangement no single particle could excite all counters simultaneously. This correction varied from about 2 coincidences per hour with no interposed lead to 0·6 coincidence per hour with an interposed lead shield of 10 cms.

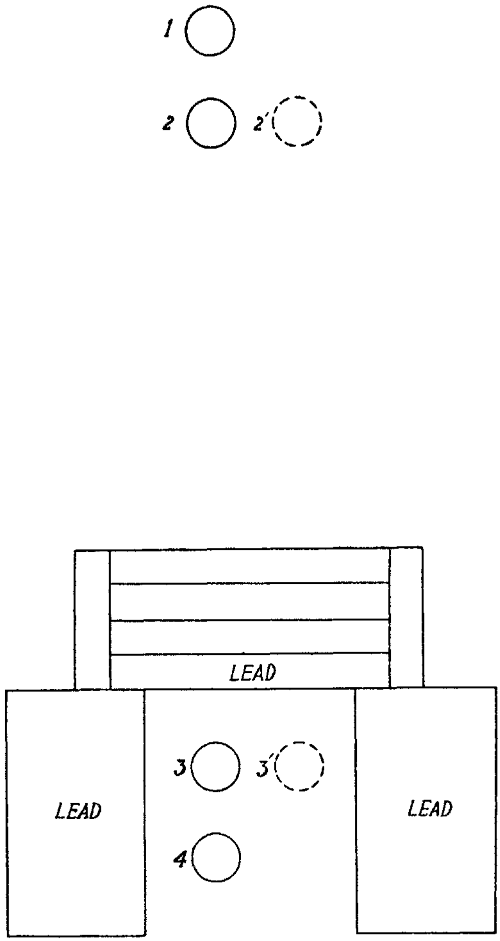

FIG. 1.

This was mainly due to showers as the accidental coincidence rate was negligible, the resolving time of the circuit being only $1{\cdot}2 \times 10^{-4}$ sec. In order to measure the inclined intensities, the counter telescope was tilted at 40° to the zenith towards the north.

The principle of these experiments is to compare cosmic ray intensities under the same mass of the absorber traversed in two different directions, so that the actual lengths of paths are different. Since the mass is the same, the ionisation loss will be the same for the two cases and any additional absorption which is observed along the longer track can only be due to decay.

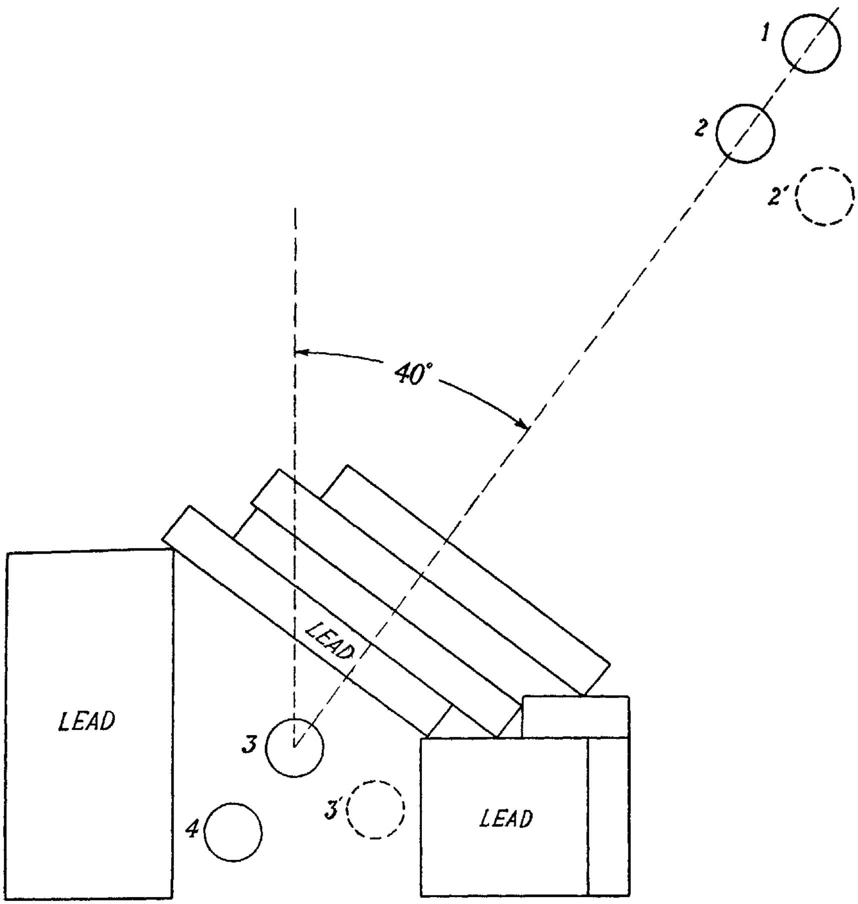

FIG. 2.

If l be the excess path traversed by mesotrons in one case over the other, and N and N_0 be the intensities observed in the two cases, then the mean free path is given by the equation

$$L = \frac{l}{\log \frac{N_0}{N}} \quad \ldots \quad (2)$$

For the determination of L we have used two different methods.

(a) Determination of L from Altitude Effect, i.e. from the Variation of the Vertical Intensity with Height.

We have compared the vertical intensity of the mesotrons at Calcutta (elevation 200 ft., geomagnetic latitude 12°N.) with the vertical intensity at Darjeeling (elevation 2·2 Km., geomagnetic latitude 16° 30′N.). The effect of the small difference in geomagnetic latitude may be neglected as the maximum latitude effect at sea level, due to a change of latitude from 40°N. to 0°, is not more than 10 per cent according to Compton (1937) and Thomson (1938). In the measurement of the vertical intensity at Darjeeling we have used an additional lead screen equivalent in stopping power to the layer of air between Calcutta and Darjeeling. The mass of this layer is given directly by the difference in atmospheric pressure between Calcutta and Darjeeling, i.e. 1028 − 784 or 244 gms./cm.^{2} which is equivalent in stopping power to about 34 cms. of Pb. In this calculation the stopping power of air is assumed to be 1·58 times that of Pb, as given by Bethe, Bloch, Bhabha formula (1938*b*) for ionisation loss. 10 cms. of Pb are always used between the counter system as shown in fig. (1) to filter out the soft component. Hence the vertical intensity under 10 cms. Pb at Calcutta is compared with that at Darjeeling under 44 cms. The total mass traversed by the rays is then the same in both cases, but the actual paths differ in length. In this case the excess path l traversed by the vertical rays at Calcutta is clearly the difference in height above sea level between Calcutta and Darjeeling, that is, $2{\cdot}2 \times 10^5$ cm. With $l = 2{\cdot}2 \times 10^5$ cm. and the measured values of N and N_0 i.e. the intensities at Calcutta and Darjeeling, the mean free path L may be calculated by means of equation (2).

(b) Determination of L from Zenith Angle Effect, i.e. from the Vertical and Inclined Intensities at the Same Station.

For the determination of L in a different way we compared the intensity of the inclined rays ($\theta = 40°$) at Darjeeling with the vertical rays at the same station with an additional layer of Pb between counter system to compensate for the excess mass along the inclined direction. Since the mass traversed by the vertical rays at Darjeeling is about 784 gms./cm.^{2} the rays inclined at angle 40° to the zenith have to penetrate an excess mass of 784 (sec 40° − 1), i.e. about 244 gms./cm.^{2} of air over the vertical rays. This excess mass is compensated if the vertical intensity of mesotrons is measured under an extra lead absorber 34 cms. thick. The vertical path through the air and the lead absorber and the inclined path through the air then differ only in actual length but not in stopping power. The ratio of the two intensities therefore indicates the mean free path of the mesotrons in air as in the previous case. Hence the vertical intensity of mesotrons at Darjeeling under 44 cms. of Pb was compared with the intensity under 10 cms. at an angle of inclination 40°

to the zenith. The excess path l traversed by the inclined rays in this case is given by

$$l = (Z'_m - Z_1) \sec \theta - (Z_m - Z_1) = 7{\cdot}7 \text{ Km.} \quad \ldots \quad \ldots \quad (3)$$

where Z_1 is the height of Darjeeling above sea level, and Z'_m the height of formation of mesotrons incident at an inclination 40° to the zenith.

It is generally assumed that mesotrons are formed in the atmosphere when the mass traversed by the primary rays is about one-tenth of the total mass of the atmosphere. The validity of this hypothesis has been proved by the recent baloon experiments mentioned later in detail. On this assumption the height of formation (Z_m) of the vertically coming rays is about 18·4 Km. and that for the rays inclined at an angle of 40° to the zenith (Z'_m) is 20·5 Km. Substituting the values of Z_m, Z'_m and $\sec\theta$ in equation (3) the excess path l in the case of the inclined rays is found to be about 7·7 Km. As before with this value of l and the measured values of the vertical and the inclined intensities, the mean free path for decay may be calculated from equation (2).

Results.

The results of determination of the mesotron intensity under the conditions mentioned above are given in the following table. For each case the number of showers recorded per hour was determined by the method of displacement of counters as indicated in figures 1 and 2. The shower rate thus obtained was subtracted from the total number of mesotrons recorded per hour. The corrected mesotron intensity is given in column V, Table II.

Table II.

Results of Measurements.

Observation	Station	Angle to the zenith	Amount of lead between counters	Number of mesotrons recorded per hour, after deducting the correction due to showers
1	Calcutta	0°	10 cms.	$16{\cdot}0 \pm {\cdot}48$
2	Darjeeling	0°	44 cms.	$20{\cdot}0 \pm {\cdot}50$
3	Darjeeling	40°N.	10 cms.	$14{\cdot}8 \pm {\cdot}57$

From the results given in Table II it is evident that the vertical mesotron intensity measured under the same mass of the absorber decreases from about 20 to 16 per hour due to a change of height above the sea level by 2·2 Km. Similarly, a tilt of the counter telescope by 40 degrees from the zenith at Darjeeling reduces the intensity of the penetrating component from 20 to 14·8, although the excess mass traversed in each case is compensated by additional absorbers. In both the cases the decrease is much greater than the limits of statistical errors. With the assumption that the reduction of intensities is due to decay of mesotrons along the longer tracks, the mean free paths of these particles have been calculated with the help of equation (2) and are indicated in the third column of Table III.

The mean free path is related to the rest life of a mesotron by means of the equation,

$$L = \frac{c\tau_0 E}{\mu c^2} \quad \text{or} \quad \tau_0 = \frac{L\mu c^2}{cE} \qquad \dots \quad \dots \quad \dots \quad (4)$$

where E is the total energy of the mesotrons considered.

The mesotrons recorded in our measurements are those having energies greater than a certain minimum required to penetrate the ten cms. lead screen which is always present. Assuming $\mu = 160m$, i.e. $\mu c^2 = 8\times 10^7$ e.v. it follows from the consideration of ionisation loss of mesotrons in lead $E_{min} = 2\times 10^8$ e.v. In calculating the average energy of the mesotron spectrum at sea level we have, therefore, to consider a lower limit of 2×10^8 e.v.

No measurement of complete energy spectrum at our latitude is available. We have assumed an average energy of $1{\cdot}3\times 10^9$ e.v. which is deducible from the measurements of Blackett (1937) and Wilson (1939). On account of the uncertainty in the actual values of the mass and the average energy of the mesotron beam it is probable that uncertainty in τ_0 is greater than that in L. However, any changes found later in the exact values of these two quantities will produce a corresponding change in the value of τ_0 which can be easily allowed for.

For the determination of τ_0 from the measurement of the vertical intensity at Calcutta and Darjeeling we require the average energy of the mesotrons at Darjeeling. This may be obtained by adding to the energy at the sea level the amount spent in ionisation in traversing the column of air between Calcutta and Darjeeling.

Thus $\qquad \bar{E}_a = (1{\cdot}3+2\times 10^{-3}\times 244)\ 10^9 = 1{\cdot}8\times 10^9$ e.v.

For the second case we require not the energy in the place where the particles are actually observed but the average along their tracks. This may be obtained from the formula given by Rossi (1939) and we derive the following average energy for the second case.

$$\bar{E}_b = 2{\cdot}7\times 10^9 \text{ e.v.}$$

The values of $\bar{E}$ are given in Table III together with those of L. τ_0 calculated for each value of L is indicated in the last column of Table III.

TABLE III.

Calculation of τ_0.

Method	Data used	L in Km.	$\bar{E}$ in 10^9 e.v.	τ_0 in 10^{-6} secs.
Altitude Effect ..	1 and 2	$9{\cdot}86\pm 3{\cdot}4$	1·8	$1{\cdot}46\pm{\cdot}51$
Zenith Angle Effect ..	2 and 3	$25{\cdot}7\pm 6{\cdot}8$	2·7	$2{\cdot}57\pm{\cdot}68$

It will be found from the table that the values of τ_0 obtained by the two different methods are in agreement with each other within rather large statistical errors. The mean value of τ_0 is about 2×10^{-6} secs.

In the next section are described the results of determination of τ_0 by an entirely different method, i.e. from the ratio of disintegration electrons to mesotrons at Calcutta and Darjeeling. It is very satisfactory that τ_0 comes out again to be about 2×10^{-6} secs.

Determination of τ_0 from the Ratio of Disintegration Electrons to Mesotrons.

Euler and Heisenberg (1938) deduced the following relation for the proportion of the disintegration electrons to mesotrons.

$$k = \frac{9X_0 \mu c^2}{8\tau_0 \, cE_c} + \frac{\mu c^2}{2ah} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

where X_0 the characteristic unit for air $= 275$ m., E_c is the critical energy for air $1 \cdot 5 \times 10^8$ e.v., h the depth below the top of the atmosphere in gm./cm.^{2}, a the energy loss by mesotrons per gm. of air (about 2×10^6 e.v.). Substituting the values of the quantities involved

$$\tau_0 = \frac{5.50 \times 10^{-7}}{(k - 20/h)} \text{ secs.} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5a)$$

In the present experiment τ_0 was obtained by determining the ratio (k) of the disintegration electrons to mesotrons at Darjeeling and Calcutta. The values of τ_0 thus obtained agree within the limits of experimental errors with the previous determinations. This serves as a check on the correctness of the determination of τ_0 by the former methods.

For the determination of k we measured the complete absorption curve of cosmic rays in lead, both at Darjeeling and at Calcutta. The results which are given in Table IV are shown plotted graphically in fig. 3.

Table IV.

Absorption in Lead of the Vertical Cosmic Ray Intensity at Calcutta and Darjeeling.

Thickness of interposed lead absorber	0 cm.	2 cms.	5 cms.	10 cms.	20 cms.	30 cms.	44 cms.
Intensity at Darjeeling..	$39 \pm \cdot 75$	$34 \cdot 2 \pm \cdot 95$	$25 \cdot 6 \pm \cdot 80$	$23 \cdot 4 \pm \cdot 50$	$22 \cdot 6 \pm \cdot 55$	$20 \cdot 6 \pm \cdot 50$	$20 \cdot 0 \pm \cdot 50$
Intensity at Calcutta ..	$21 \cdot 6 \pm \cdot 95$	$21 \cdot 0 \pm \cdot 80$	$17 \cdot 3 \pm \cdot 80$	$16 \cdot 0 \pm \cdot 48$	$14 \cdot 9 \pm \cdot 80$	$15 \cdot 4 \pm \cdot 70$	

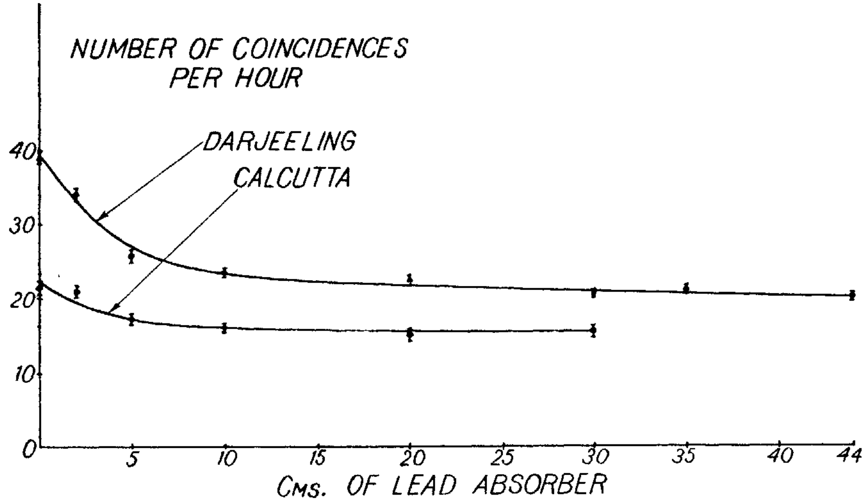

FIG. 3.

From fig. 3 it is evident that the total intensity of cosmic rays increases by a factor 1·82 due to a change of height of 2·2 Km. from Calcutta to Darjeeling. Also the proportion of the soft component to the hard increases from 33·4 per cent to 74 per cent between these two stations.

The soft component at any place consists of the disintegration electrons (D), knock-on shower electrons (K) and the cascade electrons due to primaries (P). Hence if we denote the total soft component by E,

$$E = D+K+P \quad \ldots\ldots\ldots\ldots \quad (6)$$

In order to determine the fraction of the intensity due to the decay electrons alone (D) we must subtract from the total intensity (E) the effects due to the cascade multiplication and knock-on showers ($P+K$).

From the calculations of Bhabha (1938*b*) the number of knock-on secondaries that accompany mesotrons of energy 10^{10} e.v. is about 7 per cent of the number of mesotrons. If the average mesotron energy is 10^9 e.v. the proportion reduces to 5 per cent.

The number of electrons expected at Calcutta and Darjeeling due to the cascade multiplication of the primaries can be calculated in the following way. In the characteristic units of the radiation theory the distance of Calcutta from the top of the atmosphere is given by $l = 29$, and for Darjeeling $l = 23$. We have next to fix the other parameter, viz. the logarithmic ratio of the energies of the primary and the cascade electrons. Due to the presence of the earth's magnetic field only those electrons may be incident on the surface of the atmosphere which have energies exceeding a certain minimum given by

$$E_\phi = 1{\cdot}9 \times 10^{10} \cos^4 \phi \text{ e.v.} \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

where ϕ is the magnetic latitude of the place. For Calcutta where the magnetic latitude is about 12°N. the minimum energy of the incident electrons is about

$1 \cdot 7 \times 10^{10}$ e.v. Only particles with energy greater than $1 \cdot 7 \times 10^{10}$ e.v. can be incident on the top of the atmosphere at Calcutta. Presumably a bulk of these will have energies just above this minimum limit. If we make the assumption that all the incident particles have energies approximately equal to $1 \cdot 7 \times 10^{10}$ e.v., then since the critical energy for air is $1 \cdot 5 \times 10^{8}$ e.v.,

$$y = \log (E'/E_c) \approx 5 \quad \text{.. .. .. ..} \quad (8)$$

Bowen, Millikan and Neher (1938) found that the total vertical energy flux at our latitude is 10^9 e.v. per cm.^{2} per sec. This is the total energy carried by the cosmic particles per square cm. per sec. directly overhead at Calcutta. Assuming that all the cosmic particles incident on the surface of our atmosphere have energies equal to the magnetic limit $1 \cdot 7 \times 10^{10}$ e.v. we calculate the number of particles incident per sec. per sq. cm. to be about 0·058. Since some of the cosmic particles will have energies greater than this minimum value, the above estimate gives the upper limit of the number of particles incident per sec. Johnson (1938) estimates that a more probable number is 0·032. This represents the number of primary particles incident per cm.^{2} per sec. The problem now is to find out how they will multiply in the successive layers of the atmosphere and in particular what intensities are to be expected at Calcutta and Darjeeling.

If F $(E'O)$ be the spectrum of the primary particles whose energies exceed E' and z (l, y) the number of the cascade electrons produced by one primary particle at a depth l and defined by the logarithmic ratio of the energies y, then the intensities of the soft electrons to be expected at Calcutta and Darjeeling after multiplication in the layer of air above these two stations is given by

$$F(E, l) = \int_{E' = E\phi}^{\infty} z(ly) \frac{-\partial F}{\partial E'} \, dE' \quad \text{.. .. ..} \quad (9)$$

An exact solution of this equation is difficult and moreover the distribution of the primary electrons is not known with any accuracy. But we can make a simplified calculation on the previous assumption that the energy of all the primary particles is the same. Then from the theories of Bhabha and Heitler (1937), since

$$\left.\begin{array}{llll} \text{for} & l = 29, & y = 5, & z(l, y) = 7 \cdot 5 \; 10^{-4} \\ \text{for} & l = 23, & y = 5, & z(l, y) = 0 \cdot 03 \end{array}\right\} \quad \text{.. ..} \quad (10)$$

the calculated number of the cascade electrons above an energy of $1 \cdot 5 \times 10^{8}$ e.v. expected at Calcutta and Darjeeling are 0·086 and 3·4 per hour. Taking into account Arley's correction (1938) for the number of slow electrons and the limited solid angle of the apparatus, the number of soft electrons expected to be recorded with our apparatus are about 7 and 0·2 per hour.

It is possible to estimate from the above results the number of ordinary electrons due to decay of mesotrons. The results of these calculations are contained in the following table. The number of mesotrons incident per hour (M) and the total intensity (E) of the soft component at the two stations are given in columns II and III respectively. The estimated values of the number of knock-on electrons (K) and the primary cascade (P), obtained as mentioned before, are given in the next two columns. The number of disintegration electrons (D) has been obtained by subtracting ($K+P$) from (E). The two ratios of the disintegration electrons to mesotrons have been given in column VII, and the corresponding values of τ_0 in the last column.

TABLE V.

Station	Number of mesotrons per hr. M	Number of electrons per hour E	Knock-on electrons per hour $K = \cdot 05M$	Cascade electrons due to primaries P	Disintegration electrons per hour D	Ratio of disintegration electron to mesotrons $k = D/M$	τ_0 in 10^{-6} secs.
Darjeeling	$23\cdot5 \pm \cdot87$	$16\cdot0 \pm \cdot64$	1·15	7·00	$7\cdot85 \pm \cdot64$	$\cdot33 \pm \cdot06$	$1\cdot8 \pm \cdot3$
Calcutta	$16\cdot5 \pm \cdot48$	$6\cdot0 \pm \cdot17$	·82	·20	$4\cdot98 \pm \cdot17$	$\cdot30 \pm \cdot02$	$2\cdot0 \pm \cdot2$

DISCUSSION.

In deriving the life of the mesotrons we had to make the following assumptions. It was assumed that mesotrons are the secondaries produced by the primary cosmic particles at a height above the sea level where the mass traversed by the primaries is about $\frac{1}{10}$ of the total mass of the atmosphere. This assumption, which was originally made by Euler and Heisenberg, is based on the observation of Millikan, Neher and Bowen (1937) that at a depth of about 1 metre of water below the top of the atmosphere, the primaries are absorbed more than could be accounted for by the cascade theory. It appears that at this height the primaries are absorbed by some other mechanism besides the formation of cascade showers. This additional loss of energy is believed to be due to the formation of mesotrons. Although the exact processes which lead to the creation of mesotrons are not yet clear, the recent baloon experiments of Schien, Jesse, and Wollan (1940) and Dymond (1940) seem to confirm these ideas in a striking manner. The variation of the mesotron intensity with height above the sea level indicates that the mesotron intensity reaches a maximum value at a pressure of 8 cm. Hg, after which the intensity decreases again with height.

The determination of τ_0 from the altitude effect is independent of any assumption regarding the height of formation of mesotrons and also of the assumption of the isotropy of the radiation. It is possibly more correct than the other determination. The agreement between the results obtained by the three methods is therefore very satisfactory.

The second serious assumption in the determination of τ_0 is that the mass of the mesotrons is constant and is about 160 electron masses. The present experimental evidence on this point indicates that the mass lies between wide limits, 100–250 electron masses. While it is not impossible that the mass varies according to quantum laws, the experimental errors in the various determinations of mass are so great that they do not exclude the possibility of mesotrons having a fixed mass. We have provisionally assumed a fixed mass of 160 m. A similar assumption has been made regarding the average energy of the mesotron spectrum at Calcutta which is also not known very accurately. Any changes in the exact values of μ and $\bar{E}$ that are found to be necessary in the light of future experiments will introduce a corresponding change in τ_0. This can be easily allowed for.

We have neglected the correction mentioned by Fermi (1940) as this, if present, can account for only a small fraction of the total effect. The results of the present experiment therefore give conclusive evidence about the disintegration of mesotrons.

It is with great pleasure the writers record their sincere thanks to Prof. M. N. Saha, F.R.S., for providing facilities for this work at Darjeeling and at Calcutta and also for his continued interest in this work. The writers are also indebted to Mr. K. S. Manian for making the counters used in these experiments. We also wish to record our appreciation of the constant help rendered by Mr. B. P. Dutt, Lecturer in Physics, St. Paul's School, Darjeeling.

Summary.

The radioactive decay of the mesotron is confirmed by a series of measurements carried out at Calcutta and at Darjeeling (2·2 Km. 16°N., geomagnetic latitude). The vertical intensity of the mesotron at Calcutta has been compared with that at Darjeeling under additional lead blocks equivalent to the mass of air between the two stations. We have also compared the vertical intensity at Darjeeling under 44 cms. of lead with that at an inclined direction of 40° to the zenith. Under this condition the mass traversed by the vertical and inclined rays is the same. From these as well as from the ratio of the soft to the hard component at the two stations, the life of the mesotron at rest is deduced to be about $2{\cdot}0 \times 10^{-6}$ sec. This is comparable with the results obtained previously by different observers.

References.

Arley, 1938, *Proc. Roy. Soc.*, A *168*, 545.
Auger, Ehrenfest, Freon and Fournier, 1937, *Comptes Rendus*, *204*, 257.
Bernardini, Feretti *et al*, 1940, *Phys. Rev.*, *57*, 945.
Bhabha, 1938(*a*), *Nature*, *141*, 117.
" 1938(*b*), *Proc. Roy. Soc.*, A *164*, 257.
Bhabha and Heitler, 1937, *Proc. Roy. Soc.*, A *159*, 432.
Blackett, 1937, *Proc. Roy. Soc.*, A *159*, 1.

Blackett, 1938(*a*), *Nature*, *142*, 692, 992.
,, 1938(*b*), *Phys. Rev.*, *54*, 973.
Bowen, Millikan and Neher, 1937, *Phys. Rev.*, *52*, 80.
,, ,, ,, 1938, *Phys. Rev.*, *53*, 217.
Clay, Gemert and Clay, 1939, *Physica*, *6*, 184.
Compton, 1937, *Phys. Rev.*, *52*, 799.
Dymond, 1939, *Nature*, *144*, 782.
Ehmert, 1937, *Zeits. Phys.*, *106*, 758.
Euler and Heisenberg, 1938, *Ergeb. der Exakt Naturwiss*, *17*, 1.
Fermi, 1940, *Phys. Rev.*, *57*, 491.
Follett and Crawshaw, 1936, *Proc. Roy. Soc.*, A *155*, 554.
Johnson, 1938, *Phys. Rev.*, *53*, 499.
Johnson and Pomerantz, 1939, *Phys. Rev.*, *55*, 104.
Maier-Leibnitz, 1938, *Naturwiss*, *29*, 677.
,, ,, 1939, *Zeits. Phys.*, *112*, 569.
Montgomery, Ramsay, Cowie and Montgomery, 1939, *Phys. Rev.*, *55*, 1117.
Neddermeyer, 1938, *Phys. Rev.*, *53*, 102.
Neddermeyer and Anderson, 1938, *Phys. Rev.*, *54*, 88.
Nielsen, Nordheim, Ryerson and Morgan, 1940, *Phys. Rev.*, *57*, 158.
Nishina, Takeuchi and Ichimiya, 1939, *Phys. Rev.*, *55*, 585.
Pomerantz, 1940, *Phys. Rev.*, *57*, 3.
Rossi, 1938, *Nature*, *142*, 993.
Rossi, Hilberg and Hoag, 1940, *Phys. Rev.*, *57*, 461.
Rossi, 1939, *Rev. Mod. Phys.*, *11*, 297.
Schien, Jesse and Wollan, 1940, *Phys. Rev.*, *57*, 847.
Thomson, 1938, *Phys. Rev.*, *54*, 93.
Williams and Roberts, 1940, *Nature*, *145*, 102, 818.
Wilson, 1939, *Proc. Roy. Soc.*, A *172*, 517.
Yukawa, 1935, *Proc. Phys. Math. Soc. Japan*, *17*, 48.