PROCEEDINGS OF THE ROYAL SOCIETY A | MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Proc. R. Soc. Lond. A 1954 **221**, 394-405
doi: 10.1098/rspa.1954.0032

for his advice and encouragement; and Miss A. Peddie, Miss D. B. Woodhouse, Mrs E. Birchall, Mrs J. Cunliffe and Mrs E. R. Lock for their careful searching of the plates. The event was found by Mrs J. Cunliffe.

One of us (J.V.M.) is indebted to the Department of Scientific and Industrial Research for a maintenance grant and the other (W.O.L.) to the Imperial Chemical Industries for a Research Fellowship.

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A search for nuclear disintegrations produced by slow negative heavy mesons

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[Plate 14]

This paper describes the preliminary results of a search for evidence of the nuclear interactions of negative heavy mesons. A qualitative analysis is given of the possible characteristics of their interactions and the appearance these might be expected to have in photographic emulsions. 37 ml. of emulsion, in which are recorded 10000 stars and 1200 slow π-mesons, have been completely examined. In the conditions of exposure, such a volume should contain six examples, with good geometry, of the decay of heavy mesons. Mass measurements have been carried out, by the range/scattering method, on 417 tracks of σ-mesons. In addition, 1800 σ-mesons, observed in 42 ml. of emulsion, have been examined. No disintegrations which can be attributed to heavy mesons have been found. The results suggest that some of the negative heavy mesons, on being brought to rest in photographic emulsions, behave in a manner qualitatively different from that of negative π-particles. Possible explanations for this result are suggested.

1. Statement of the problem

It is now known that heavy mesons† are produced directly in high-energy nuclear encounters; the evidence has been discussed in detail by several authors. This result suggests that at least some types of heavy mesons have integral spin and possess strong nuclear interaction, but it does not provide decisive proof for

† Throughout this paper, the term 'heavy meson' is used to denote some or all of the various types of charged particles, the τ-, κ- and χ-mesons, of mass $\sim 1000 m_e$ observed in photographic emulsions. The symbol B is used to denote a heavy meson irrespective of the particle type of particle involved.

this view. Thus, among other alternatives, heavy mesons might be the decay products of short-lived particles, or they might be produced in nucleon-nucleon collisions as one of a pair of particles. Daniel, Davies, Mulvey & Perkins (1952) have shown that fast, heavy mesons, produced in high-energy nuclear interactions, have a mean free path in photographic emulsions closely similar to the value for nucleons. It is thus reasonable to conclude that at least some types of these particles are strongly interacting.

Wilson-chamber studies of charged *V*-particles show that both positively and negatively charged heavy mesons exist, and that they occur in comparable numbers. Thus, the Manchester Group working at the Pic-du-Midi (Armenteros, Barker, Butler, Cachon & York 1952; Barker, Butler, Sowerby & York 1952) have reported that amongst twenty-seven charged *V*-particles, ten were positive, eleven were negative and six were indeterminate in sign. Recent Pasadena results (York, Leighton & Bjornerud, private communication) indicate a considerable negative excess. There appears to be considerable similarity between the charged *V*-particles and the κ- and χ-mesons. It is therefore reasonable to assume that the charged heavy mesons arrested in photographic emulsions are made up of positive and negative particles in approximately equal numbers.

The above considerations suggest that the heavy mesons brought to rest in plates exposed to cosmic radiation should contain some negative particles which might be expected to give evidence of their interaction with nuclei. In fact, very few events which can be attributed to such a process have been observed. More than forty examples which are undoubtedly due to the decay of heavy mesons have been reported. Further, an additional forty events have been observed in this laboratory, most of which are believed to be due to the decay of κ- or χ-mesons, but in which the tracks are too short to allow a definite identification. These numbers are in striking contrast with the few events, hitherto reported, which can be attributed to nuclear capture processes. The question therefore arises as to the fate of the negative particles.

The disintegrations resulting from the nuclear capture of heavy mesons may have characteristics which cause them to be confused with events of a more common type, so that they are often not recognized. It was therefore decided to re-examine certain types of events, recorded in the plates available in this laboratory, to see whether any of them could be interpreted as due to negative heavy mesons.

In this paper the possible characteristics of the nuclear interactions of heavy mesons are first discussed. These considerations gave a guide to the types of events to which particular attention should be directed in making the search. The observations which followed are described in §3. The criteria which any event must satisfy if it is to be accepted as due to a negative heavy meson are established in §4, whilst §5 contains a discussion of possible explanations of the failure to observe any positive evidence for nuclear interactions of the type sought. A description is given in the appendix of an event which was observed whilst scanning for heavy mesons and which at first appeared to represent the nuclear capture of a negative heavy particle. More extensive measurements do not confirm this interpretation.

2. Possible characteristics of the interactions of heavy mesons with nuclei

Detailed theoretical calculations concerning the nuclear capture of slow mesons are both arduous and highly speculative, for they involve parameters which, at present, can only be conjectured. It is, however, possible to obtain a simple picture of disintegrations induced by negative heavy mesons on the basis of the concepts used to describe the nuclear capture of π- and μ-mesons and our knowledge of nucleon-nucleon processes. These considerations provide the only guide available at present. The expected interactions can be divided into two types which may be represented

$$B^- + p + N \rightarrow n + N + Q, \tag{1}$$

and

$$B^- + p \rightarrow n + B^0 + Q, \tag{2}$$

where B^- represents a negative heavy meson, B^0 a neutral particle, p a proton, n a neutron, N a nucleon and Q the energy released in the centre-of-mass system. It is possible that the meson may interact with several nucleons, but, for the present discussion, it is sufficient to consider only one or two. Interactions of the type represented by equation (1) are similar to those involved in the capture of negative π-mesons by all nuclei other than hydrogen, whilst those given by equation (2) are characteristic of the capture of negative π-mesons by hydrogen, and of negative μ-mesons by all nuclei. A process of type (2) is only possible if $m_{B^-} - m_{B^0} > m_n - m_p$.

Process (1)

For process (1) to occur, the heavy meson must be of zero or integral spin. In a reaction of this type, all the energy corresponding to the rest-mass of the heavy meson (~ 600 MeV) is made available in the centre-of-mass system of the interacting nucleons, an amount sufficient for the creation of three π-mesons. By comparing the final state densities (Fermi 1950), it is possible to obtain rough estimates of the relative probability that 0, 1, 2 or 3 π-mesons will be created. Such calculations have been made by Menon (1952) and Yamaguchi (private communication). It is then found that the capture of a κ-meson, of mass $\sim 1250 m_e$, could result in the emission of one or more π-mesons in 70 % of the interactions. In the capture of τ-particles, of mass $\sim 980 m_e$, the corresponding value is 50 %.

Estimates of the above type must be regarded as very tentative. Yamaguchi has pointed out that they will depend, among other features, on the statistical weight of the charge states and the overlapping of the wave functions of the initial and final nucleons. It appears, however, that if these features are taken into account, the expected number of secondary π-mesons is increased rather than diminished. With an interaction of the type envisaged, therefore, it appears that there will be a high probability of producing secondary π-mesons.

In the light of these considerations, we can now speculate on the characteristics of the disintegration produced in a photographic emulsion as a result of an interaction of the above type. When no mesons are created, the two nucleons will each have a kinetic energy of about 200 or 300 MeV. In some cases, these nucleons will disrupt the nucleus in which they originate. The resultant disintegration would then appear as a 'star' in the emulsion. Estimates of the 'nuclear transparency' for neutrons can be made on the basis of the optical model proposed by Fernbach, Serber & Taylor (1949).

On this picture, the two 300 MeV neutrons, which might be produced by the capture of a heavy meson by a silver nucleus, would have a probability of $\sim 0{\cdot}5$ of being absorbed in the parent nucleus. Such an absorption will lead to the general excitation of the nucleus and the emission of several nucleons.

From cosmic-ray and accelerator experiments, it is known that stars produced by nucleons of kinetic energy 200 to 300 MeV, consist, on the average, of five or six prongs. In many instances, stars of such a type would be classified by scanners among commonly observed disintegrations due to fast particles, which are generally referred to as 'evaporation stars'. In all but very favourable cases it is highly probable that the track of an incoming meson would be mistaken for that of an emitted proton of relatively low velocity.

If a π-meson is produced as a result of an interaction of type (1), there is a finite probability, especially in the case of heavy elements, that it will be reabsorbed in the same nucleus. If so, the resultant star will be similar to those produced when no mesons are created. If the created mesons escape, the residual excitation in the nucleus will be very much smaller than in the previous examples, and the resultant 'stars' will have correspondingly fewer prongs. Such disintegrations would, in many instances, be classed as three- or four-prong 'evaporation stars', one of the tracks being that of the incoming heavy meson, and some of the others due to outgoing π-mesons; they might also be wrongly identified as σ-stars.

Process (2)

For the type of interaction given by equation (2), the heavy meson can be either a boson or a fermion. In either case, in order to conserve energy and momentum, the neutral particle must carry away a large fraction of the rest-energy of the meson. Using a Fermi gas model for a nucleon, Yamaguchi has calculated the energy gain of the nucleon, following a process of type (2). The calculations are similar to those carried out by Wheeler (1949) in the case of the nuclear capture of μ-mesons. Yamaguchi considered the two cases in which B^0 has either a vanishing rest-mass or $B^0 \equiv \pi^0$. The variation of the energy gain of the nucleon was found to be closely similar for the two assumptions. For the nuclear capture of a τ-meson, the excitation energy lies in the interval from about 20 to 140 MeV, with a maximum probability at about 80 MeV; for capture of a κ-meson, of rest-mass $\sim 1250 m_e$, the excitation energy varies from 50 to 200 MeV, with a maximum probability at about 140 MeV. In some cases the interacting nucleon may escape without imparting any of the energy to the rest of the nucleus. These results indicate that for process (2) the excitation energy would be approximately equal to that following the nuclear capture of slow π-mesons. The resulting stars would thus be similar to σ-stars and would, in many instances, be classified among them. Alternatively, they might appear among small evaporation stars, if the scanner failed to identify the incoming heavy meson.

It should be remarked that the expected excitation energy depends on the assumed mass of the neutral particle of equation (2). In particular, if the neutral particle has a mass nearly equal to that of the charged meson, the resulting excitation might be so small that it would be very difficult to observe the disintegration.

3. Experimental results

The above considerations suggested that disintegrations due to the nuclear capture of heavy mesons might have been recorded among events in the following categories: (*a*) σ-stars, (*b*) 'evaporation stars', (*c*) stars from which slow π-mesons are emitted. Such events were therefore subjected to a close scrutiny.

(*a*) σ-*stars*

Stars with less than seven black 'prongs', in which one of the tracks is heavily scattered, and apparently due to a particle approaching the point of disintegration, are classified as σ-stars.

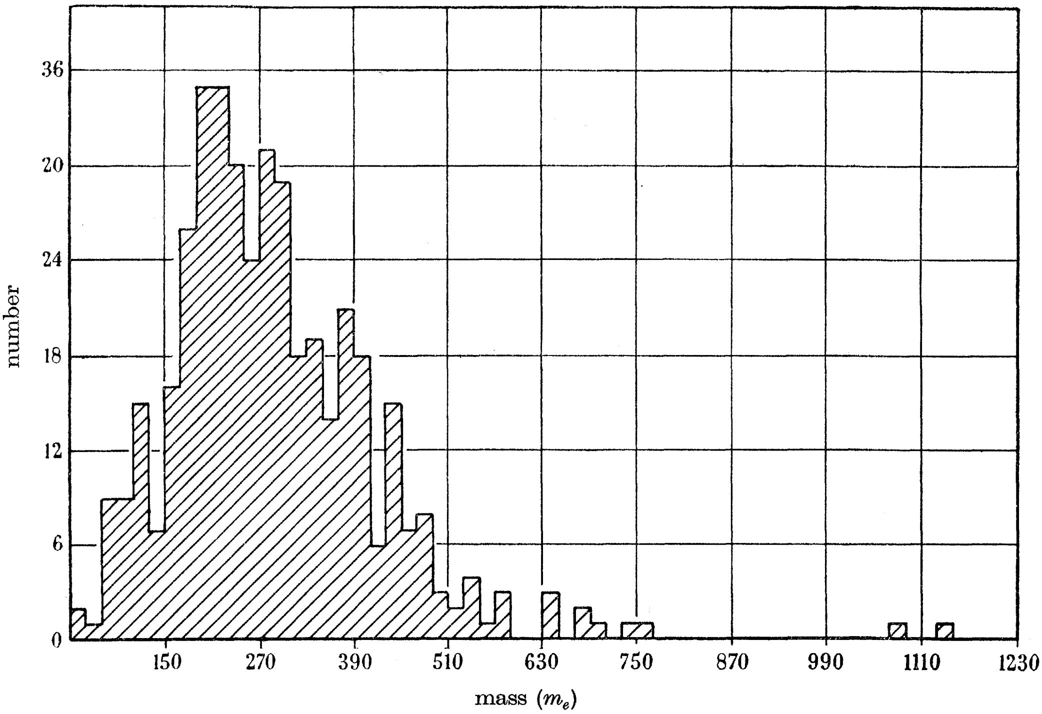


Figure 42. Mass distribution of 417 σ-mesons. All track lengths $\geqslant 400\mu$.

Mass measurements have been carried out on 417 tracks, of length $\geqslant 400\mu$, produced by σ-mesons. The events were found both in plates exposed at high altitudes with balloons, at geomagnetic latitudes $\sim 55°$ N, and at mountain altitudes under absorbers; at geomagnetic latitudes 47° N. In several of these plates, examples of the decay of heavy mesons had already been observed.

The method used for measuring the mass of the σ-mesons was the range-scattering method ($\bar{\alpha}R$) described by Menon & Rochat (1951), which is the most convenient for a survey of this nature. For such an extensive series of measurements, the gap count-range method is unsuitable as it involves elaborate calibration. The mass spectrum obtained by the $(\hat{\alpha}R)$ method is shown in figure 42.

A few tracks among the 417 gave high mass values, and these were re-examined by the δ-ray-range (Dainton & Fowler, p. 414) and gap count-range methods. In no case was a track found to give consistently high mass values by all three methods. The two highest values shown in figure 42 were obtained on short, steep tracks. It is of interest to discuss briefly the spread in the mass values shown in the figure. On tracks of π-mesons of length $\sim 400\,\mu$, the standard deviation in the mass determination is 50 %, corresponding to the limited number of independent cells available for the determination of the scattering parameter. In addition, with heavy scattered tracks of this length, large systematic fluctuations arise as a result of corrections necessary for dip. The results of Menon (1952) show that the spread in the mass values is greatly reduced when the measurements are confined to tracks of length $\geqslant 1$ mm and $\geqslant 2$ mm.

In order to extend these observations, about 3000 more σ-stars were examined in the same batches of plates. In most cases one can exclude the possibility that an incoming track was produced by a heavy meson from a scrutiny of its characteristics, particularly the rate of change of multiple scattering, grain density and δ-ray density along the track. In cases where the possibility of a heavy meson could not be excluded by visual examination the mass was measured. In all cases a mass consistent with that of the π-meson was obtained.

On the basis of these measurements we have no evidence for the presence, even in small numbers, of particles more massive than the π-meson among the σ-mesons recorded in this laboratory.

(*b*) *Evaporation stars*

It is reasonable to conjecture that the capture of a heavy meson may sometimes result in its rest energy being distributed amongst several nucleons, and a scanner may find it difficult to distinguish the incoming track of the heavy meson from the low-energy outgoing 'evaporation' fragments resulting from the disintegration. About 10 000 evaporation stars, found in ~ 37 ml. of emulsion, have been examined, and in none of them does there appear to be an incoming slow particle. Of the 3000 σ-stars which had been examined (cf. last section) 1200 were found in the same volume as these 10 000 evaporation stars. In the same plates, fifteen examples of heavy meson decay had already been observed (Menon 1952; Menon & O'Ceallaigh, p. 292).

(*c*) *Stars with ejected slow π-mesons*

Since slow π-mesons may sometimes emerge from disintegrations produced by heavy mesons, sixty stars from which slow π-mesons were ejected were scrutinized. In every example the ejected meson came to rest in the same emulsion. Each star was examined for evidence of an ingoing heavy meson and none was found.

The above approach is of limited significance because the emerging π-particle may commonly be of considerable range so that it leaves the emulsion. The results of an earlier series of observations, in which π-mesons, emerging from nuclear disintegrations were identified by measurements of scattering and grain density, were therefore examined. 1360 stars recorded in 75 ml. of emulsion from which identified π-mesons emerged were selected for study. In only seventy-six of them was the apparent release of energy consistent with the view that they were produced by the nuclear capture of a heavy meson, and in none of these was there any indication of an entering slow particle. In identifying the ejected π-mesons in these events, only tracks longer than 3 mm were accepted for measurement. Because of geometrical factors, this has the consequence that only about 7% of the emitted π-mesons were identified. It follows that an effective volume equal to $75 \times \frac{7}{100} \simeq 5$ ml. of emulsion was closely examined for events of this type. A large proportion of the events in which the track of the associated π-meson is too short for positive identification will, however, have been scrutinized during the examination of 'evaporation stars'.

Of the evaporation stars, and those involving the emission of slow π-mesons, only events in which the total excitation energy was less than ~ 600 MeV have been accepted for close examination. Only stars of size smaller than $14+0$, $8+1$ and $4+2$ have thus been considered, where the first figure indicates the number of heavy tracks, and the second figure the number of shower particles involved. The numerical values are based on Le Couteur's (1950) paper on nuclear evaporation.

4. Analysis of the results

In the exposures which have been examined for disintegrations produced by heavy mesons, using the approach described in §3, the ratio $R = (N_\pi/N_B)_{\text{stopped}} \sim 200$ (Menon 1952), where N_B is the observed number of decaying heavy mesons and N_π the total number of slow mesons in the same volume which either produce σ-stars or suffer μ decay. N_B refers to the number of heavy mesons which produce tracks long enough to allow a positive identification of the mesons. There are others present which produce shorter tracks, and if they are also taken into account, R is found to lie between 80 and 100.

In 37 ml. of emulsion containing 1200 π-mesons at the end of their range, we should expect about twelve decaying heavy mesons to be present, six of which should provide positive evidence of identification. If all such events are due to the decay of positive particles, it would be reasonable to expect twelve similar negative particles, about six of which should give tracks long enough to allow mass measurements. None has been found. The statistical probability of finding no events when six are expected is $2{\cdot}5 \times 10^{-3}$. We may therefore reject the assumption that stars due to capture of negative heavy mesons occur with the same frequency as the heavy particles which decay. We are therefore led to assume, tentatively, either that some of the decaying particles are negative or that the negative particles, on interacting with nuclei, produce effects difficult to detect with the present experimental methods. In either case, some of the heavy mesons appear to behave in a manner different from negative π-particles. The volume of emulsion examined completely is not sufficient for us to give quantitative figures on these possibilities.

In view of the possibility that the nuclear interactions of heavy mesons are sometimes difficult to observe, we have examined a number of events referred to as 'protons with blobs'. Three examples of such events are shown in photomicrographs of figure 43, plate 14. Superficially they appear to be tracks produced by particles in the mass range 1000 to 2000m_e; at the point where the particles come to rest in the emulsion, they appear to produce a rudimentary track of restricted range or a thickening. It is known that about 10 % of negative π-mesons produce 'blobs' when they are brought to rest in emulsion (Menon, Muirhead & Rochat 1950). Mass measurements have therefore been carried out on all the tracks classified as 'protons with blobs'. Of eleven measured examples, ten gave values of mass consistent with that of a proton or a heavy meson within the statistical errors of the measurement. The remaining example (shown in figure 43*c*, plate 14) gave a mass of $500 \pm 300 m_e$ by the range-scattering method; the mass as determined by the gap count-range method is, however, consistent with that of a heavy meson or a proton. Only 700μ of track was available for measurement, since the particle went out of observation at the glass-emulsion interface. This length is too short for any definite conclusions to be drawn.

Events have been reported from time to time which have been interpreted as due to the nuclear capture of negative heavy mesons, but hitherto no example has been found in which the evidence is decisive. In no case has it been possible for the investigators to give a reliable estimate of the mass of the heavy meson, and in some the direction of motion of the assumed heavy particle is ambiguous. An event must necessarily satisfy certain minimum criteria before it can be accepted as a heavy meson-induced disintegration. First, it should be possible to establish beyond doubt that the supposed primary particle approached the event. Secondly, it should be possible either to obtain a reliable estimate for the mass of the primary particle and show that it is different, at a high level of statistical significance from the mass of the π-meson, or to show that the observed energy of the resultant disintegration is greater than 140 MeV, i.e. the rest energy of the π-meson. It is also necessary that all details of the event should be internally consistent. It is interesting to note that no event reported so far satisfies strictly the above criteria. This is surprising when one considers the large number of accurately measured examples (~ 40) of heavy meson decay which have been reported, many of which have been found by casual observation, and not as a result of systematic scanning.

On the basis of these considerations, we conclude that a considerable fraction of negative heavy mesons, on being brought to rest in photographic emulsions, do not produce easily observable disintegrations. They thus appear to behave in a manner qualitatively different from that of negative π-mesons.

There is other evidence which is suggestive of these conclusions although it is of small statistical weight. Among the slow π-mesons ejected from nuclear disintegrations, the number of negative particles greatly exceeds that of the positive. Thus, in this laboratory, we have observed a ratio $(N_\sigma/N_{\pi\rightarrow\mu})_{\text{ejected}} \sim 10 \pm 2$. This result is readily explained in terms of the effect of the Coulomb field of the nucleus. The positive π-meson has to penetrate a Coulomb barrier and gains energy as a result of the electric repulsion, whereas the negative π-meson can emerge with low kinetic energies.

It is reasonable to assume that similar effects will operate in the case of heavy mesons. If so, the observed number of slow negative particles ejected should be greater than the corresponding number of the positive. In contradiction with these expectations, most of the examples of ejected heavy mesons which have been observed hitherto (Levi Setti & Tomasini 1952; Isachsen, Vangen & Sørensen 1953; Ceccarelli, Dallaporta, Merlin, Quareni & Zorn, p. 386; Crussard, Leprince-Ringuet, Morellet, Orkin-Lecourtois & Trembley 1953) suffer decay.

This evidence also suggests that negative heavy mesons ejected from nuclear explosions do not commonly produce observable disintegrations on being brought to rest, or that they suffer decay in preference to nuclear capture.

5. Discussion

Menon *et al.* (1950) have shown that, when a negative π-meson suffers nuclear capture, one may consider its rest energy as being distributed among a cluster of nucleons, the number of nucleons involved generally being two, but, particularly in the case of heavy nuclei, sometimes more. This may be explained in terms of the fact that the Compton wave-length of the π-meson is of the same order of magnitude as the nuclear radius. One would thus expect a number of neighbouring nucleons to take part in the primary process. On the basis of such a general argument, Bruno (1949) considered the primary interaction to affect a spherical volume, of radius $r = \hbar/m_\pi c$, with the capturing nucleon at its centre. This value of r will be reduced by a factor of 4 in the case of heavy mesons, since $m_B/m_\pi \sim 4$; the volume of interaction may therefore be reduced by a factor of 64. In view of the large release of energy, it is possible that the influence of nuclear binding is negligible, and the negative heavy meson may thus interact with an individual nucleon, as though it were a free particle, and not within a nucleus. An interaction of type (2) would then be indicated.

As has already been remarked, if the neutral secondary involved has a mass nearly equal to that of the primary heavy meson—if it be a V_2^0 for instance—the energy released in the disintegration would be very small, and it would therefore be difficult to detect. But in such an event, the neutral secondary, B^0, would necessarily have the same spin and be as strongly interacting as the negative meson, B^-, and should frequently be re-absorbed, especially in the case of heavy nuclei. Such a process would lead to a greater nuclear excitation. It is, of course, possible that more than one neutral particle is involved in reaction (2), with a corresponding reduction in the average energy transmitted to the nucleus. The created neutral secondaries could then be non-interacting particles of half-integral spin.

As an alternative explanation, it may be suggested that heavy mesons are associated with nuclear forces which are velocity-dependent. If so, it would be possible to reconcile the apparent copious production of these particles at high energies, and their geometrical cross-section for interactions when travelling fast, with their apparent failure to interact with nuclei when brought to rest.

It is not necessary, however, even if the present results can be established by observations of greater statistical weight, to postulate new physical processes such as those considered above. The lifetimes of the particles, and the actual time involved in the capture process, may be of such magnitudes that most of the negative mesons decay before interacting with nuclei. The lifetimes of the heavy mesons are not yet accurately known, but limits can be estimated. The ratio of the number of heavy mesons produced in nuclear explosions to the number observed to be arrested in emulsions, compared to the corresponding numbers for π-mesons (Daniel & Perkins, p. 351; Menon 1952), suggests that the lifetime is not less than 10^{-10} s. Barker *et al.* (1952), on the basis of the Pic-du-Midi data on charged V-particles, estimate the lifetime of the particles to lie between 10^{-8} and 10^{-10} s. Astbury, Chippindale, Millar, Newth, Page, Rytz & Sahiar (1952) conclude that at least one type of heavy meson must have a lifetime greater than 4×10^{-9} s.

The time taken by mesons to be slowed down and captured into Bohr orbits of low quantum number—from which nuclear absorption usually takes place—has been discussed by a number of authors. Fermi, Teller & Weisskopf (1947) and Fermi & Teller (1947) predicted that in condensed materials the 'time of approach' should be of the order of 10^{-13} s, except possibly for insulators for which $Z < 6$. These authors treated the stopping material as a degenerate electron gas. They did not carry out calculations for the case of a crystalline medium. This has been discussed by Mott (1949) and Rosenberg (1949), who have confirmed these results in a qualitative manner.

A summary of the treatment made by Fermi & Teller has been given by Marshak (1952). The loss of energy by mesons before nuclear capture may be divided into the following three epochs: (*a*) the fast meson is first slowed down, through ionization, to an energy of a few keV, when its velocity is similar to that of the valence electrons; (*b*) it is then reduced from an energy of a few keV to zero energy, when it is captured into Bohr orbits of high quantum number round the nucleus; during this period it loses energy by inelastic collisions with electrons of the degenerate electron gas; (*c*) lastly, it undergoes Auger and radiative transitions and jumps from the high Bohr orbits to lower ones from which nuclear capture takes place.

The times computed for epochs (*a*) and (*c*) appear to be generally accepted. There is, however, some controversy regarding the time taken in epoch (*b*). For instance, Huby (1949) has pointed out that in insulators, mesons may be 'trapped' for a long time in bound orbits. In such orbits the meson will be unable to lose energy rapidly, if the loss per collision is smaller than the 'Brillouin gap'. This 'trapping' becomes more important for heavy mesons, since for a given meson energy the maximum energy transfer to electrons, per collision, is less than for lighter particles. The actual trapping time depends critically on a number of parameters. Thus, according to Huby, though normal times of approach for heavy mesons may be of the order of 10^{-13} to 10^{-12} s, in certain circumstances one might expect trapping times up to 10^{-5} s.

It is possible that 'trapping' does occur in the case of a certain fraction of negative B-particles arrested in photographic emulsions, but it is difficult to see how it could be generally true of all negative heavy mesons. According to Fermi (1952) and Marshak (1952), such considerations might at the most increase the time of approach by a factor of 10.

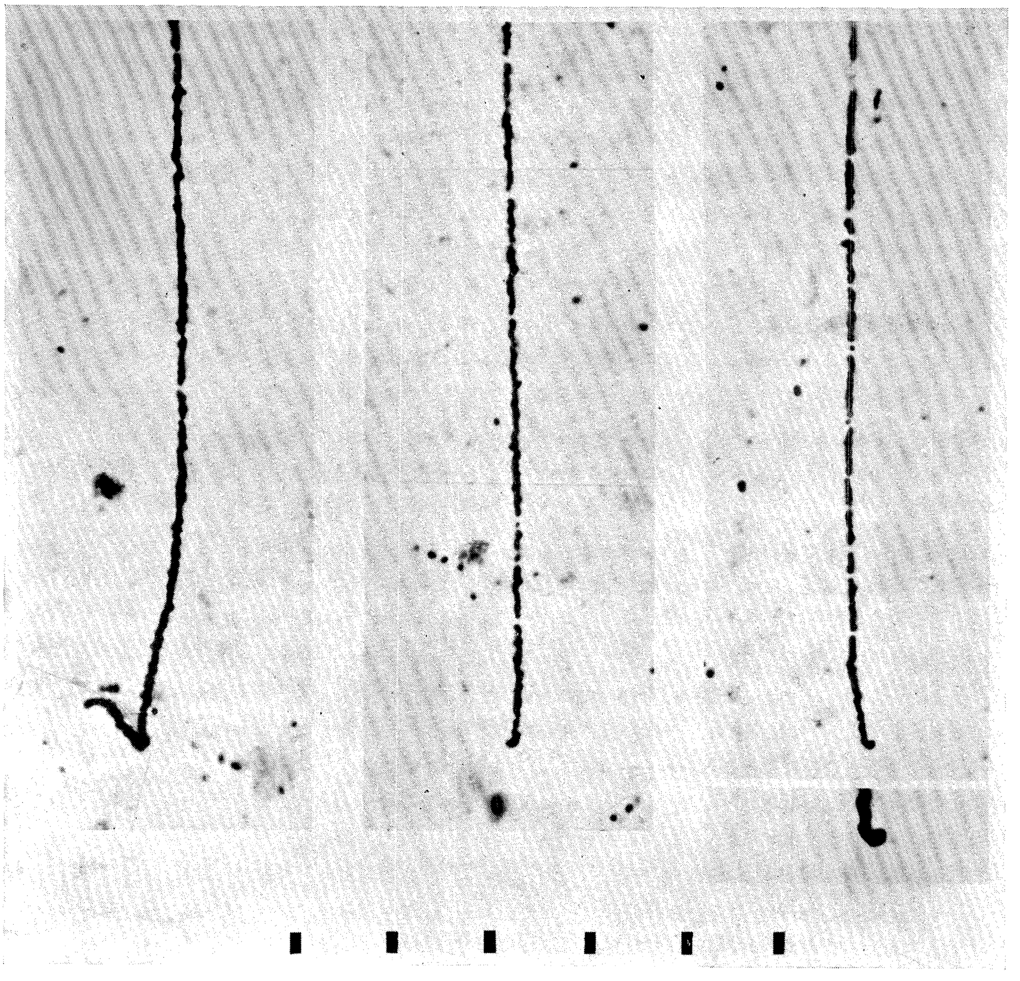
Because of the uncertainties involved, both in the lifetimes of the B-particles and in their times of approach, it is possible to admit that negative heavy mesons commonly decay instead of being captured. Indeed, the time of approach may only have to be increased to $\sim 10^{-9}$ s for competition between decay and capture to be serious.

If negative heavy mesons do not produce observable interactions when they come to rest in condensed media, they will be exceedingly difficult to detect amongst the large numbers of slow protons. An additional means of selection would then have to be used. In the case of multi-plate cloud chambers (cf. observations on S-particles: (Bridge & Annis 1951; Annis, Bridge, Courant, Olbert & Rossi 1952; Bridge, Peyrou, Rossi & Safford, private communication), this selection can, of course, be the determination of track curvature in an additional cloud chamber employing a magnetic field. For nuclear emulsions, the method of magnetic deflexion could be tried, but would involve the use of high magnetic fields. In both these cases, one could select out the negative particles. A simpler approach would be to examine the tracks of slow particles which come to rest in emulsions, and which are ejected from nuclear disintegrations. By suitable selection, the numbers of protons per heavy meson could be reduced. With the use of stripped emulsions (Powell 1953), it should be possible to obtain a large number of tracks of sufficient length for accurate determinations of the masses of the particles, and also to determine the sign of the charge from the behaviour of the charged secondaries at the end of their range. These two features would enable a statistically significant analysis to be made. In addition, this would provide information on the relative numbers of 'ejected' heavy mesons which decay, which produce nuclear disintegrations, and which come to rest in emulsion without producing any observable effect.

We wish to express our gratitude to Professor C. F. Powell, F.R.S., for the hospitality and facilities of his laboratory. We are indebted to Dr Y. Yamaguchi of the Osaka City University, Japan, for communicating to us his unpublished calculations and for valuable comments. We would also like to thank Miss Rosemary Mitchell, Mrs June Cowie, Miss Anne Littlejohns and Mrs D. M. Ford for assistance during various stages of this investigation. Two of us wish to acknowledge financial assistance from the following bodies: The University of Cape Town (M.W.F.) and the United States Educational Commission in the United Kingdom (G.G.H.).

Appendix

At the Discussion Meeting we reported an event which could be interpreted as a star produced by the nuclear capture of a negative heavy meson. The event appeared similar to the (κ, χ) decays normally observed in emulsions. The primary track had a total length of $1700\,\mu$ in two facing plates. No accurate mass measurements are possible, however, on account of the steepness of the track. Scattering, gap density and δ-ray measurements are consistent with the assumption that the



a *b* *c*

FIGURE 43

(*Facing p.* 404)

track was produced by a heavy meson travelling towards the event, and which was at, or near, the end of its range at the event. The probability that it was caused by an outgoing proton emitted from a two-particle star, is less than 1 in 10^5.

Preliminary measurements on the track of the secondary particle gave values of $g^* \sim 1{\cdot}35$ and $p\beta \sim 300$ MeV/c, which indicated that it was very much heavier than a π-meson. It was tentatively assumed to be a proton. Careful calibration of the grain density on this particular plate has revealed irregularities which make it impossible to give any reliable estimate for g^*. The available data suggest that $g^* < 1{\cdot}3$ and probably of the order of $\sim 1{\cdot}0$. If so, there is a strong possibility that the secondary particle is a π- or a μ-meson. In this case, the event could be an example of a heavy meson decay, or a heavy meson induced star resulting in the production of one charged particle, a π-meson.

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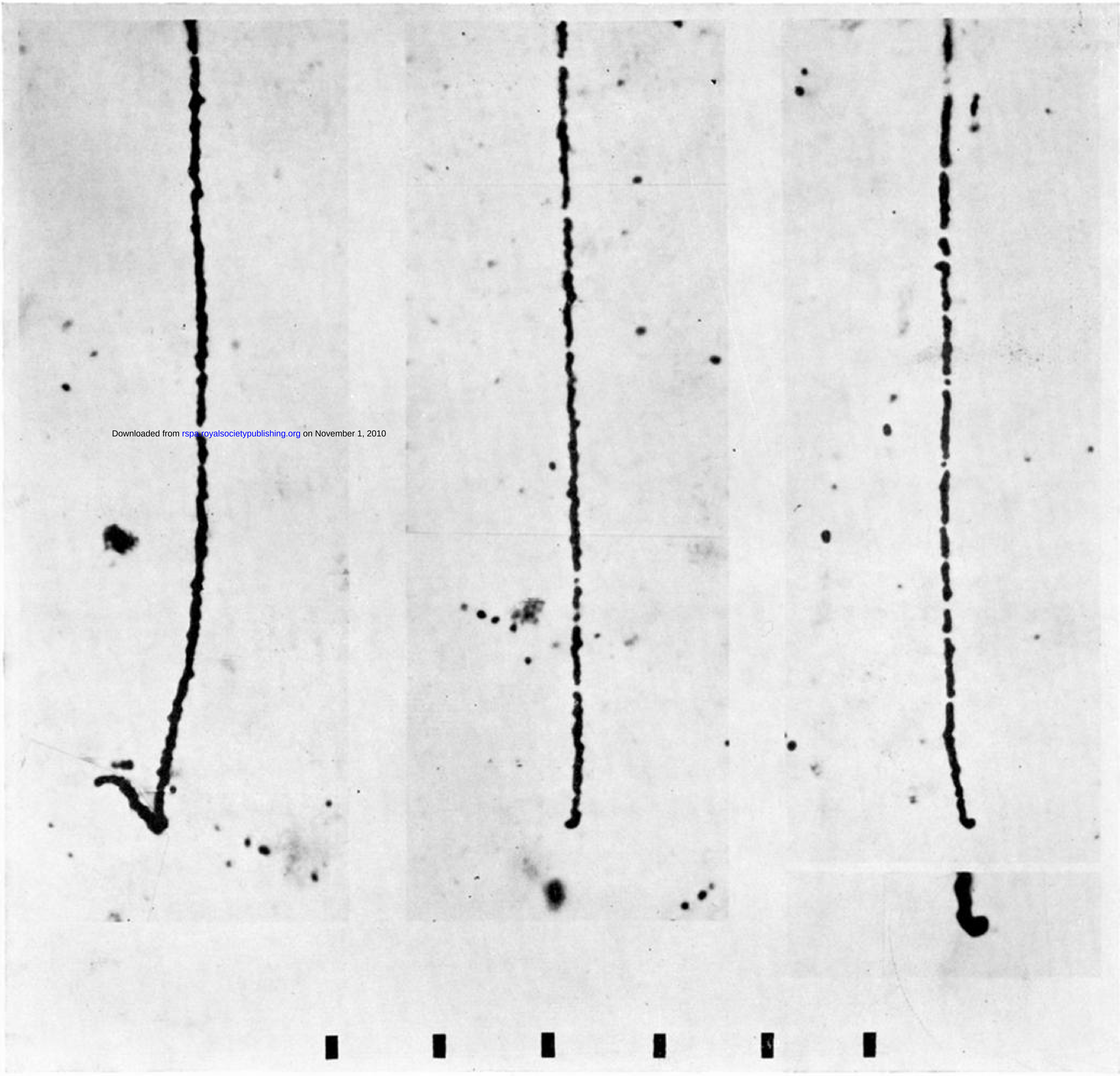

a *b* *c*

FIGURE 43