International Congress on Cosmic Radiation at Bagneres de Bigorre

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THE International Congress on Cosmic Radiation held at Bagneres de Bigorre, near the Pic du Midi in the French Pyrenees July 6–12 proved to be an exceptionally well-planned and fruitful meeting. Organized by the University of Toulouse and sponsored by the International Union of Pure and Applied Physics with the support of UNESCO, the Congress attracted nearly two hundred physicists from twenty-three countries. Comparatively unhurried presentations and discussions were made possible by restricting the scope of the meeting to the field of "elementary" particles and high-energy interactions. The leisurely atmosphere contributed much to the success of the Congress.

New results on K-mesons and hyperons,[1] as well as reports on improved techniques for measuring their properties, were presented in six sessions which comprised the program of the first three days. These meetings, presided over by Professors Blackett, Leighton, Peters, Reynolds, Leprince-Ringuet, and Amaldi, were equally divided between papers on cloud chamber observations and those on experiments with nuclear emulsions. The fourth day was spent visiting the Observatory of the Pic du Midi where a notable attraction was the double cloud chamber installed by the École Polytechnique Laboratory. A morning session on high-energy interactions, presided over by Professor Bhabha, concluded the presentation of experimental results. The final three sessions were distinguished by the recapitulations of Professors Powell, Fretter, and Rossi, who deftly tied together many loose strands and outlined the pressing problems which remain.

This report attempts to summarize many of the results presented at Bagneres, with emphasis on the subject of unstable particles, to which the Congress was mainly devoted. It gives the impressions of a single observer, hence cannot pretend to do justice to all the noteworthy communications which were presented.

In summarizing the work on unstable particles, we shall first discuss those less massive than nucleons, and then the hyperons, charged as well as neutral.

[1] Unstable particles intermediate in mass between proton and deuteron. This group includes the V_1^0 which decays into a proton and π. A revised, rational nomenclature for the unstable particles was proposed by a group at Bagneres. The author had adopted the new notation for the present report, but then learned that some of the names were still under discussion by the recommending group. Accordingly, most of the familiar nomenclature is retained here; new names are used only in the absence of older ones.

K-Mesons

We shall use the term K-mesons to denote particles, whether charged or neutral, with masses intermediate between those of the π-meson and the nucleon. These are sometimes observed to decay in flight (V-events) and sometimes to decay or undergo nuclear capture after coming to rest (S-events). Alternatively, their presence may be deduced without evidence of decay or nuclear capture, from mass measurements on the primary track alone.

The existence of at least three types of K-mesons, subject to the following modes of decay, seems very likely:

$$\tau^{\pm} \rightarrow \pi^{\pm} + \pi^{\pm} + \pi^{\mp} + Q \qquad (1)$$

$$\kappa^{\pm} \rightarrow \mu^{\pm} + 2 \text{ neutral particles} + Q \qquad (2)^{2}$$

$$V_4^0 \rightarrow \pi^{+} + \pi^{-} + Q. \qquad (3)$$

(1) may be considered almost certain; and (2) and (3) are very probable. Most of our information about τ and κ mesons comes from tracks in emulsions, whereas our knowledge of V_4^0 mesons derives from cloud chamber observations.

A fourth type of K-particle probably decays according to the scheme:

$$\chi^{\pm} \rightarrow \pi^{\pm} + \text{neutral particle} + Q \qquad (4)$$

It appears possible that all four K-mesons have a mass close to 970 m_e, but this is more firmly established for the τ-meson than for the others. In fact, one of the unsolved puzzles of the Congress was the question as to whether the various mass measurements on K-particles can be reconciled with a single mass, i.e., that of the τ-meson.

V_4^0-Mesons. Convincing evidence for a neutral particle with mass indistinguishable from that of the τ was presented by Thompson of Indiana University. He found a group of neutral V-events characterized by the decay scheme (3) and the energy release 214 ± 5 Mev. This Q value implies a mass of 971 ± 10 m_e for the parent V_4^0 meson.[3] Barker of Manchester, Bridge of MIT, and Gregory of École Polytechnique reported cloud chamber observations consistent with Thompson's.

An estimate of the lifetime of V_2^0 particles was

[2] κ (kappa)-mesons should not be confused with the more inclusive category, K-mesons, of which the kappas are a special class.

[3] The suggestion of a "V_2^0" which decays into two light mesons, probably pions, had previously been made by Butler and his collaborators of Manchester. However, the more definite quantitative properties which could be assigned to the Indiana V-events led to the designation V_4^0.

given by Astbury of Manchester, who used the symbol "$V_2{}^0$" to designate all neutral V-events which do not conform to the $V_1{}^0$ scheme. These may, however, be presumed to consist largely of $V_4{}^0$ mesons. The mean life of $1.7^{+2.0}_{-0.6} \times 10^{-10}$ was based on an assumed Q value of 160 Mev. Since, however, the calculated lifetime decreases with increasing Q, the best value for $V_4{}^0$ mesons would seem to be lower than the one given. On the other hand, the selection of long tracks, which permit a better determination of momentum, tends to introduce a bias against the longer-lived particles which decay near the bottom of the cloud chamber.

There does not yet appear to be good evidence for the 3-body decay of a neutral K-meson (or τ^0) into two charged and one neutral pion.

Charged K-Mesons. Knowledge about the nature of these particles stems mainly from two sources, direct mass measurement on the primary tracks and the identification and momentum distribution of their secondaries. We shall first discuss those K-mesons which decay with the emission of a single charged secondary, then we shall briefly review the better known $\tau^{\pm}$-mesons.

Masses of Charged K-Mesons. Mass measurements on charged particles observed in nuclear emulsions differ according as the particles come to rest or are relatively fast. In the former case (S-events) an important parameter is the residual range, as a function of which one measures the changing ionization or multiple coulomb scattering. For fast particles one must rely on the latter two quantities, which usually are nearly constant along the available length of track. At the Bagneres Congress, six groups presented results on K-particles which stopped in emulsions—Bristol, Bombay, Brussels, Cornell-Rochester, Milan-Genoa, and Paris. Mass determinations on fast K-mesons emitted from stars and "jets" were made at two laboratories, Bristol and the Naval Research Laboratory in Washington.

Menon and O'Ceallaigh, of Bristol, found that if one considers the measurements on the primaries alone, these are consistent with a unique mass of 1100 m_e for stopped charged K-mesons (other than τ).[4] Similar results, suggesting masses in excess of 1000 m_e, were reported by Bonetti for the Milan-Genoa group. On the other hand, measurements which strongly indicate a mass close to that of the τ were described by Mrs. Dilworth (Brussels), Peters (Bombay), Crussard (École Polytechnique, Paris), and Kaplon (for the Cornell and Rochester groups).

Reviewing the mass distribution of fast meson-shower particles observed at Bristol, Perkins stated that the results are consistent with a single mass of about 1200 m_e. He considered it unlikely that it could be less than 1100 m_e, citing the fact that only one value as low as 955 ± 120 m_e was observed. Shapiro reported the latest mass measurements at NRL on moderately fast $(0.5 < \beta < 0.75)$ K-mesons created in fundamental interactions (i.e., stars consisting of thin or gray tracks only). A mean value of 1115 ± 90 m_e was deduced from the three long tracks in which the ionization exceeded twice the minimum. Thus good precision could be expected both in velocity, from ionization, and the quantity $p\beta$, from scattering. A single example with a mass of 895 ± 140 m_e was also reported.

In cloud chambers, mass estimates on K-mesons, whether in V-events or S-events, have hitherto been subject to rather large error. A notable improvement has been introduced with the double cloud chamber arrangement of the École Polytechnique. The tracks are magnetically bent in the upper chamber, and the particle has a good chance of stopping in the lower, multiplate chamber, thus yielding range as well as momentum. In addition, the nature and interactions of the secondaries can be studied in the lower chamber. Lagarrigue cited four mass determinations on S-primaries, the mean of three of these being 922 ± 41 m_e. It is interesting that the cloud chamber results of Leprince-Ringuet's group agree with the emulsion results from the same laboratory in assigning a mass < 1000 m_e to the stopped K-mesons.

Secondaries of Charged K-Mesons: Evidence for Kappa and Chi Mesons. That some of the charged secondaries are mu mesons appears definitely established. The best recent example, described by Renardier, was found in a stripped-emulsion stack at Bristol. The secondary had been followed through 18 layers with a track length of 3 mm in each, and its mass was found to be 203 ± 8 m_e. Several additional muon secondaries were observed at Bristol, and one each at Milan and Paris. These muons show a wide spread in momentum, indicating a three-body decay. Thus as Menon pointed out, the existence of a kappa meson which disintegrates according to scheme (2) seems fairly sure, although the nature of the neutral particles is still uncertain. He stated that the mass of the kappa very probably exceeds 1000 m_e.

Menon also asserted that there is strong but not yet decisive evidence for the presence of π mesons among the secondaries of K-particles. At least three good examples of pions have been found. These, as well as a few more apparent pi secondaries, have $p\beta$ values (from multiple scattering) which cluster close together with a weighted mean of 179 ± 7 Mev/c. These results led the Bristol group to suggest the existence of a chi meson which, unlike the kappa, undergoes 2-body decay. There are indications that the chi mass is somewhat less than 1000 m_e, and that the mass of the neutral secondary is less than 300 m_e. Thus one is tempted, at least provisionally, to identify the chi with the tau, and to assume that it undergoes an alternative mode of decay in which only one charged pion is emitted rather than three.

From cloud chamber observations on charged V-events and S-events,[5] further data are available on

[4] See, however, discussion of secondaries below.

[5] These terms refer to phenomenological appearance, not to definite particles. Thus, V-events and S-events may, for example, involve hyperons, as well as K-mesons. However, the discussion in this section is confined to the evidence bearing on K-mesons.

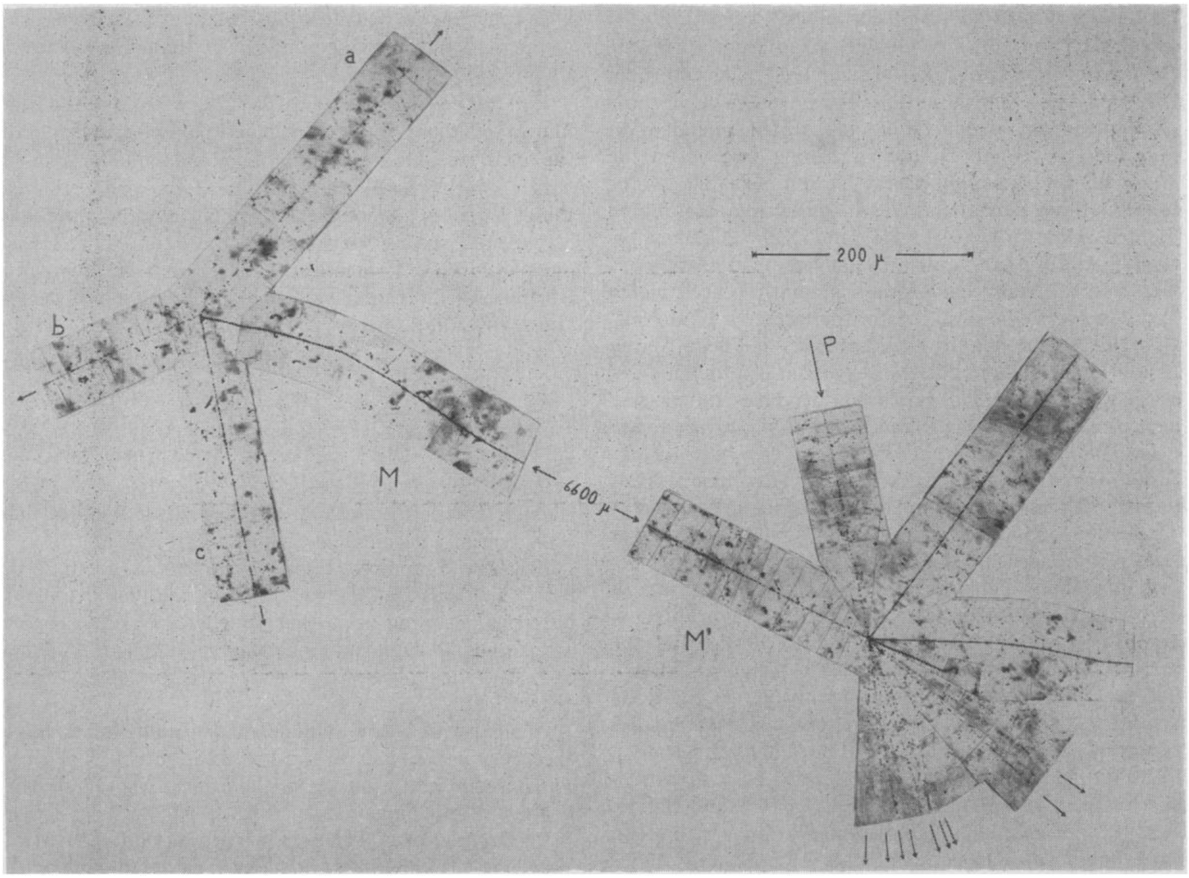

FIG. 1. *Emission of a Tau Meson from a Shower Star.* This photomicrograph shows the first published evidence for the direct production of a tau meson (singly charged particle of mass 970 m_e) in a high-energy nuclear disintegration. The incident particle P collided with a target nucleus in a sensitive photographic emulsion, 1200 μ thick, exposed to the cosmic radiation at an altitude of 30 km. The tau particle M′ came to rest after traversing about 7 mm of emulsion; it then decayed into three pions, a, b, c. In addition to the relatively slow heavy meson, a shower of fast particles, attributable mainly to π-mesons, was also generated. Courtesy of M. Ceccarelli, N. Dallaporta, M. Merlin, G. Quareni, and G. T. Zorn, University of Padua. (*Il Nuovo Cimento,* **10**, 681 [1953]).

the K-mesons and their secondaries. Thus Butler observed that the $V^{\pm}$ particles seen at Manchester are probably a mixture of kappa and chi mesons. Most of their secondaries have a transverse momentum consistent with ~ 200 Mev/c, but some have nearly one-half of this value. Leighton stated that the peak of the mass distribution for the $V^{\pm}$ particles studied at the California Institute of Technology, occurs at ~ 950 m_e, and the transverse momenta are distributed around 150–200 Mev/c. Thompson said that the Indiana data permit the assignment of an upper mass limit of 1200 m_e, and lower limits of 970 or 940 m_e, respectively, for assumed decay into pion or muon.

Rossi noted that charged secondaries of S-events in the MIT multiplate cloud chamber have been followed through 950 g/cm² of Pb—approximately 6 mean free paths—without any clear indication of a nuclear event. Since these secondary particles are light[6] mesons, they are very likely to be muons, but the possible occurrence of pi secondaries in cloud chamber S-events cannot be ruled out. The MIT S-secondaries have a momentum distribution which clusters around 200 Mev/c.

[6] The term "light meson" is here used collectively for pions or muons.

Observations bearing on the nature of the neutral secondaries are scarce. There was special interest, therefore, in the evidence presented by Rossi that photons with 100–200 Mev energy are associated with some of the S-decays. Four cases have been observed in the MIT cloud chamber in which small electron showers appear about 180° from the direction of emission of the charged secondary. In all four examples, the electron tracks lie within a 15° cone, and in two of these, within 5°. This argues against a π^0 secondary, since the most probable spread in the electron progeny would then be about 30°. Thus the neutral secondary in these S-events is probably a gamma ray. However, this cannot be true of all the S-events unless the energy of the gamma ray in those is very low.

Negative K-Mesons. Since evidence for negative K-mesons has hitherto been elusive, one of the striking communications was that of Peters, who described four examples of K-mesons captured by nuclei after coming to rest. The observations were made by the

Bombay group in an "emulsion block" consisting of a set of stripped emulsions, each 600 microns thick. Of the four events, two involved primary tracks too short for good mass determination. However, each of these slow primaries produced a star which included an outgoing pi meson. In the remaining two stars, the track of the captured heavy meson was 2.5 cm or longer, thus permitting mass measurements which yielded values of 1010 ± 150 and 840 ± 200, respectively. A different result was given by Friedlander, who told of an extensive and systematic search which had been carried out at Bristol for negative K-mesons. No definite evidence for such particles had been found. Powell suggested a possible explanation for this result: if the K^-, when captured, produces an observable star in only a small fraction of cases, as the muon does, this would help account for the observations. Schein reported that several possible examples of negative K-mesons had been observed at Chicago.

τ-Meson. The properties of this K-meson are better known than those of the others, largely because its decay into three charged light mesons yields a wealth of quantitative information from any favorable example of τ decay. There is now little doubt that the three light mesons are all pions. The τ mass is known within a few electron masses to be 967 m_e, and its mean life exceeds 10^{-10} sec. For the τ decay, Amaldi reported an energy release of 76 ± 1.7 Mev and Peters, 72.2 ± 0.8 Mev. Estimates of the ratio of τ to π production were also given: Amaldi, 3.5×10^{-3}, and Peters, 1.0 ± 0.7 per cent. The latter figure was for a balloon exposure at geomagnetic latitude 19°.

Observations of τ-mesons in Wilson chambers are still unusual: two were described at Bagneres. A τ for which each of the three secondaries traversed at least four plates of the cloud chamber at Washington University was reported by Sard. Another, possibly the first tau demonstrated to have negative sign, was observed, according to Leighton, in the new Pasadena 4-chamber arrangement. The experimental results on the τ-meson were capped with a theoretical discussion by Dalitz of Birmingham on the modes of decay of this particle which are expected according to the pseudoscalar, vector, and pseudovector theories.

Direct Emission from Stars. Examples of the emission of identifiable types of K-mesons from stars have been slowly accumulating. Thus, the direct emission of kappa mesons was cited by Bonetti of Milan. The group at Padua has observed the ejection of a τ-meson from a star (Fig. 1). Independent evidence for the emission of K-mesons from stars has come from Bristol, Oslo, and NRL. A large fraction of the Bristol observations were made on "jets." The Washington group concentrated on stars lacking evaporation tracks and hence attributable to "fundamental-type" collisions.

Hyperons

In the domain of unstable particles intermediate in mass between proton and deuteron, two developments are particularly noteworthy—the evidence for charged hyperons, including those observed in V-particle cascades, and the growing number of emulsion observations of $V_1{}^0$ decays.

$V_1{}^0$ Particles. The neutral $V_1{}^0$ is of course the best known of these "super-nucleon" particles, nearly all the information deriving from cloud chambers until very recently. Armenteros reviewed the properties of these particles. Among the various groups reporting $V_1{}^0$ results at the Congress—Manchester, MIT, Pasadena, Indiana, Princeton, École Polytechnique, and Göttingen—there was consensus on the mode of decay and the Q-value, i.e.,

$$V_1{}^0 \rightarrow P + \pi^- + (37 \pm 2)\,\text{Mev} \tag{5}$$

Page of Manchester reviewed the lifetime measurements on the $V_1{}^0$ and arrived at a mean life of $3.3^{+0.9}_{-0.5} \times 10^{-10}$ sec, based on what he considered the best available data, those of Cal Tech, MIT, and Manchester. Bartlett's method of calculating the lifetime was generally accepted as the most suitable.

Leighton remarked that the Pasadena group still regards as possible the existence of another group of particles decaying according to scheme (5) except for a different Q-value and possibly a different lifetime. Cal Tech has observed a concentration of Q-values near 75 Mev.

It is also noteworthy that many laboratories have observed occasional examples of neutral V-decays which seem incompatible with either the $V_1{}^0$ or the $V_4{}^0$ described above.

V^0 Production. The rate of production of neutral V-events (of all kinds) increases rather slowly with the energy of the associated shower, according to Deutschmann of Göttingen. On the other hand, Reynolds reported a rise of about a factor of 7 between 2 and 20 Bev. Deutschmann estimated that only 20 per cent of the V^0 particles decaying in a cloud chamber are actually observed, and concluded that one V^0 is produced for every 8 ± 2 showers. He remarked that owing to the large fraction of V^0 events which are missed, there is no decisive evidence against Pais' suggestion that V^0 particles are produced in pairs. Newth of Manchester stated that in showers with energy $\sim 5 \times 10^{10}$ ev, V^0 are produced at a rate about 3 per cent that of charged shower particles, and at least one-half of the V^0 are $V_2{}^0$. Thompson found a similar relative rate of $V_1{}^0/V_2{}^0$ production, for energies between 10^9 and 10^{10} ev. Reynolds reported on the energy distribution of the $V_1{}^0$ particles. At least 25 per cent of Princeton's $V_1{}^0$, he said, have an energy less than 400 Mev.

Schein of Chicago described several examples of apparent $V_1{}^0$ production by 227 Mev π^--mesons. He cited experimental precautions and tests which indicate that the observed events are neither neutron-induced stars nor due to back-scattered pions originating in the π^--beam. However, he pointed out that further work will be required before the $V_1{}^0$ interpretation of these events can be considered conclusive.

$V_1{}^0$ in Emulsions. After several years in which only

one or two isolated V^0-events had been observed in emulsions, a surprising total of some twenty apparent examples found in this medium were reported to the Congress by Yasin of Bristol, Amaldi of Rome, Peters of Bombay, Bonetti of the Milan-Genoa group, and Teucher of Bern. The necessity of distinguishing between true V^0 decays and phenomenologically similar events such as 2-prong stars due to neutrons, was generally recognized. Some of the reported examples of V^0 were subject to the criticism of lacking sufficiently rigorous evidence for this distinction. However, in a substantial number of the observations, the secondary products were identified as proton and pion, respectively, and the Q-value agreed with that of the V_1^0($\sim$ 37 Mev) within experimental error. Admitting that one can hardly be sure of the V^0 identity of any isolated event, a systematic study can lead to reliable data on V^0 in emulsions. Thus, as Powell observed, if a collection of 2-prong stars has been examined for proton-pion pairs, and the Q-values computed, assuming 2-body decay, then the appearance of a closely bunched set of Q-values suggests that one is in fact observing a homogeneous group of V^0-type decays.

V^0 in Nuclear Fragments. The emission of an unstable nuclear fragment which apparently contained a V_1^0 particle, first noted by Danysz, has also been reported from Imperial College and the École Polytechnique. Upon coming to rest the fragment decays with the emission of a proton, or alternatively of a proton and pion. Crussard described the Paris observation, and Ney reported a similar event observed by Freier at Minnesota. Sard of Washington University in St. Louis summarized the theoretical considerations of his colleagues Cheston and Primakoff on bound V-particle decay. They estimate the mean life for "nonmesonic" decay of V-particles embedded in light nuclear fragments as 10^{-11} to 10^{-12} sec. This time is sufficiently long to allow the fragment to come to rest. They also discuss the possibility of a "V-deuteron," a neutron bound to a V-particle, which would decay in 10^{-10} sec according to one of the schemes

$$\begin{aligned}&\rightarrow p+n+175\text{ Mev}\\ \text{``V-deuteron''}&\rightarrow p+p+\pi^-+35\text{ Mev}\\ &\rightarrow p+n+\pi^-+35\text{ Mev}\end{aligned}\qquad(6)$$

Although no observation of a charged V-deuteron was reported at the Congress, the Bombay group has measured a 2-prong event which, if correctly interpreted as a V^0 event, may represent a "neutral V-deuteron" which decays into a deuteron and a π^- with a Q of $\sim$ 90 Mev.

Charged Hyperons. Evidence for singly charged hyperons was of three types: tracks in emulsions of slow (stopped) and fast particles; and V-particle cascades in cloud chambers. Three observations were discussed by Levi-Setti of Milan. The first two had slow primaries 16 mm and 1.25 mm long, respectively, with mass values of 2370 ± 280 m_e and 2300 ± 780 m_e, respectively. The fast singly charged secondary in each case left the emulsion after too short a path to permit identification. However, from the grain density of their tracks it was inferred that they are probably light mesons. The third example had a primary track of 0.9 mm, too short to allow mass estimation, but its secondary track, 1.67 mm long, could be identified as due to a proton which terminated in the emulsion. Assuming a decay of the type

$$H^+ \rightarrow P + \pi^0 + Q \qquad (7)$$

a mass of 2320 m_e and a Q of 115 Mev were calculated for this event.[7]

An example of a charged hyperon which decays just before it comes to rest with the emission of $\pi^\pm$ was analyzed by Peters, Lal, and Yash-Pal. The primary track was 19.3 mm and the secondary 14 mm long, the mass evaluation being 2520 ± 400 m_e and 330 ± 60 m_e, respectively. The event can be interpreted in terms of a decay scheme symmetric with respect to (7), i.e.,

$$H^\pm \rightarrow \text{neutron} + \pi^\pm + Q \qquad (8)$$

where $Q = 135 \pm 35$ Mev.[8] A decay of a hyperon in flight with the apparent emission of a pion was reported by Ceccarelli and Merlin of Padua.

Shapiro reported the following observation by the group at the Naval Research Laboratory in Washington. A moderately fast singly charged particle of mass 2560 ± 500 m_e was emitted from a fundamental collision apparently of the p-p type. Its track, 18.6 mm long, displayed an ionization of 2.25 times the "plateau" value, hence well above the insensitive region of minimum ionization. Thirty-four tracks of protons and pions of comparable lengths and grain densities were used for calibration.

V-Particle Cascades. A phenomenon of exceptional interest is the V-particle cascade observed in cloud chambers. Until recently there has been but one example, that of the Manchester group. Butler reviewed the characteristics of this original event: somewhat below and near the decay point of a V^- occurs the vertex of a V^0. The event can be interpreted as the decay of the charged V into a V^0 and a light charged meson. It was not possible, however, to identify the type of V^0. Leighton reported three new examples observed at Pasadena. These provided important evidence for the genetic relation between the V^- hyperon and the V^0; moreover, the V^0 is identified as a V_1^0, i.e., one which decays according to (5). The charged secondary is a π or μ meson. Thus the following 2-body decay scheme was suggested:

$$V^- \rightarrow V_1^0 + (\pi^- \text{ or } \mu^-) + Q \qquad (10)$$

Selection Rules. A timely contribution by Michel of

[7] The decay of a charged hyperon into a proton, observed in one of the Pasadena cloud chambers, was reported at the Rochester Conference in December, 1952. A similar event has been observed by Bridge and Annis.

[8] The NRL group, King, Seeman, and Shapiro, have recently observed an example similar to that of Peters. They suggest, however, as an alternative to scheme (8), the mode of decay

$$H^\pm \rightarrow V_1^0 + \pi^\pm + Q \qquad (9)$$

Support for (9) is provided by cascade V-particle events which led the Pasadena group to postulate scheme (10) (see below). Rather direct evidence thus exists for the emission of a V_1^0 as a neutral decay product of a hyperon, whereas there seems to be no corresponding evidence for a secondary neutron.

Paris was a list of selection rules which must be obeyed by any proposed decay scheme.

High-Energy Interactions and Meson Production

Kaplon of Rochester reported that there is apparently no strong dependence at very high energies ($\sim 10^{13}$ ev) of meson-shower multiplicity on the size of the target nucleus. Hoang, of the École Polytechnique, described a study of "jets" made in collaboration with the Brussels and Milan groups. When the shower multiplicity is plotted against total energy, the showers appear to separate into two groups, one in which the multiplicity goes up steeply with energy, and another in which it increases very slowly. One interpretation offered is that the high-multiplicity showers arise in "head-on" collisions, and the other showers in glancing collisions in which only a fraction of the energy in the CM system is expended in meson production. An alternative explanation is that the nature of the primary generating particle differs for the two categories. Bhabha of the Tata Institute and Janossy of Budapest cautioned that additional data are required to establish a clear separation into two groups.

Jets and K Production. Mulvey of Bristol described an extremely energetic jet, the core of which had been followed through twenty emulsions. A study of electron pairs in the core led to a ratio of 0.25 ± 0.1 neutral pions to charged shower particles. Since the ratio of neutral to charged pions is approximately 0.5, the ratio of charged pions to all charged shower particles was inferred to be 0.5 ± 0.25. Of the remaining 50 per cent of shower tracks in the jet, ~ 10 per cent were attributed to knock-on protons and ~ 40 per cent to K-mesons.

Haber-Schaim of Rehovot, Isreal, presented theoretical considerations on the relative production of K- and π-mesons according to Fermi's theory, under the alternative assumptions that only pions are Yukawa particles, and that K-mesons are also nuclear-force particles.

Nucleon Pairs, Stars, Jets. Schein called attention to the expected creation of nucleon-antinucleon pairs in collisions of sufficiently high energy, and reported a search for negative protons and their annihilation. No such evidence was found. Cosyns of Brussels found some 200 directionally correlated pairs of mesons, protons, or mesons and protons emerging from stars. Of these he considered that only ten were likely to be accidental. Moreno of Rome studied a group of jets, assuming independence of energy and angular distribution of the secondaries in the CM system. Calculations were made according to the Fermi and Heisenberg theories of multiple meson production.

Multiple Meson Production. Bhabha presented an alternative theory in which the production depends in a crucial manner on the meson field of the nucleon. Assume that a nucleon consists of a massive center of radius ρ containing a fraction $(1-\varepsilon)$ of the nucleon mass, plus a surrounding meson field which contains the rest of the mass, εM. In a collision of two nucleons the fraction of energy which goes into meson production depends on ε and ρ. If the meson field is due to pions alone, ε cannot exceed 0.1. If heavier mesons (e.g., $\sim 1000\ m_e$) are considered to be nuclear-force particles, then ε may be as large as ~ 0.5. The ratio of types of particles produced depends strongly on ε. According to Bhabha's theory, the energy needed to create a pair of heavy mesons is higher than in Fermi's theory.

Underground Phenomena. A review of cosmic ray phenomena underground was given by Amaldi, in which the cross sections for production of neutrons, stars, penetrating showers, and pairs of penetrating particles were examined critically. The nature of the last of these phenomena had for some time eluded explanation, as the cross section for their production appeared to exceed that of stars observed underground, and this precluded their interpretation as particles originating in penetrating shower-stars. With a large array of counters, Amaldi and his collaborators found that the cross section for production of penetrating pairs is smaller than that for the generation of penetrating showers. Thus the underground pairs need not be considered a special phenomenon, but their origin can be ascribed to shower stars generated by the electromagnetic interaction of mu mesons with nuclei.

Lovati described underground experiments of the Milan group using cloud chambers. Their results on penetrating pairs are compatible with Amaldi's. They also found that the penetrating particles in question are strongly interacting, therefore not muons. Because the muon component is often accompanied by strongly interacting particles, it is difficult to be certain that a given interaction observed underground is due directly to a muon.

Progress in Methods of Measurement

Among recent instrumental advances, two were considered exceptionally noteworthy. One of these, the double cloud chamber of Leprince-Ringuet's group at the Pic du Midi, has been described above. Details were given by Johnston and others of the Paris group. A similar arrangement has been set up by the Princeton group under Reynolds. The other major development is the successful application of blocks of stripped emulsion, notably by the Bombay group, to the study of heavy unstable particles. Techniques for mounting "pellicles" on glass before development, so as to minimize swelling and distortion, had been developed at the Naval Research Laboratory in Washington, and at Bristol. At the Congress, these techniques were described by Fowler and discussed by Shapiro. Peters told of an accurate, though laborious, method of microscopic alignment which expedites the following of tracks from one emulsion layer to the next.

Cerenkov Detector for Heavy Mesons. A promising method of enhancing the detection efficiency for heavy mesons, and measuring their lifetime, particularly in

S-events, was reported by Hyams of Manchester. A cloud chamber contains a set of Pb plates and a Cerenkov detector. Above the chamber is a Pb absorber of variable thickness, another Cerenkov detector, and some counters. The apparatus is designed to discriminate against electrons, light mesons, and protons, leaving a reasonable chance of detecting heavy mesons.

Other Cloud Chamber Techniques. Braddick described photometric measurements of ionization in cloud chambers. The relative transmissions (photographic densities) of two tracks were used as an index of relative ionizations. Barker discussed the methods of cloud chamber measurement employed at Manchester. Thompson described the new magnetic chamber at Indiana, designed for studying high-energy processes, and the procedure used to measure track curvature with precision. The upper limit of detectable momentum is 5×10^{10} ev/c. Chanson of the École Polytechnique, Bridge of MIT, and Ballario of Rome discussed cloud chamber techniques in use at these laboratories.

Relativistic Rise in Ionization Loss in Emulsions. Shapiro reported an investigation, in collaboration with Stiller at NRL, of the relativistic rise in ionization loss in nuclear emulsions. It was found that the "plateau" value of ionization lies 14 ± 3 per cent above the minimum. At energies γ between 10 and 100 rest masses their data are entirely consistent with the slow rate of rise predicted by the Fermi-Halpern-Hall-Sternheimer theory. At extremely high velocities, the ionization saturates at $\gamma > 100$ and maintains its plateau value at least as far as $\gamma = 3500$. Electrons mesons, and protons show the same variation in AgBr grain density with velocity.

Multiple Scattering. D'Espagnat of Paris presented an analysis of the multiple coulomb scattering technique in emulsions with a discussion of "noise" elmination, and of optimum cell lengths for minimizing error. For the identification of stopped particles in emulsions, the variation of multiple scattering with residual range makes it desirable to employ a "constant-sagitta" method of scattering which utilizes the range-energy relation for known particles. This technique has been employed at Brussels, Milan, Paris, and Bombay. Mrs. Dilworth-Occhialini explained the basic advantages of the constant-sagitta method: it is simpler to compute the straight average of the second differences; the "noise level" is practically independent of the (varying) cell length; and cutoff for large single scatters is determined over the whole length of track once for all.

Gaps, Photoelectric Measurement in Emulsions. An alternative to the scattering vs. range method for stopped tracks is, of course, that of ionization vs. range. For the dense tracks of arrested particles, however, grain counting is impractical and one must rely on other means of measuring the ionization. Two methods were described to the Congress. One, involving measurements on the gaps in dense tracks, was analyzed in detail by O'Ceallaigh who collaborated with the Bristol group. He measured mean lengths of gaps exceeding a given lower limit (e.g., $\sim 0.5\ \mu$), having determined that the mere counting of gaps is not a very useful procedure. A second method, which has been used successfully at the École Polytechnique, is a photoelectric instrument described by Morellet and Kayas. This apparatus appears to represent a notable advance in the art of photoelectric track measurements, pioneered by Demers, Blau, von Friesen and Kristiansson, and Ceccarelli and Zorn.

"Erosion" by Hypo. Occhialini discussed the problem of "erosion" of surface layers by hypo solutions—a defect sometimes encountered with thick emulsions, which require very long fixing times. The addition of Ag salts to the thiosulfate bath mitigates the trouble.

Meeting concurrently with some sessions of the Congress, was a conference on Astrophysical and Geophysical Correlations. A lucid summary of the proceedings of that conference was given by Vallarta of Mexico during the final session.

In their concluding remarks, President Blackett and Secretary Leprince-Ringuet reviewed the advances reported at Bagneres and pointed to the wide horizons which lie ahead in cosmic-ray research.[9] A rising vote of thanks was tendered by the Congress to those who had labored so effectively for its success, notably Prof. Leprince-Ringuet, Dr. Gregory and Dr. Peyrou, and the staff of the École Polytechnique, Director Rösch of the Pic du Midi Observatory and his staff, and Dr. Daudin who had organized the auxiliary meeting on astrophysical correlations.

[9] The reader who wishes background information on the new unstable cosmic-ray particles is referred to a review article by G. D. Rochester and C. C. Butler in *Reports on Progress in Physics*, **xvi**, 364 (1953). A useful bibliography is included.