$(m_N{}^2+m_Y{}^2)$ with a free parameter s_0. A fit can be improved if one varies s_0 at different energies. The parameters which were determined by minimizing the sum of χ^2 for the differential cross section and spin correlations at 2.5 GeV/c are shown in Table II. The details of the calculations and predictions at various energies will be discussed elsewhere. The curve drawn in Fig. 1(a) and Table III shows the predictions of the differential cross section and spin correlations at our incident momentum. The C_{ij}'s are the weighted average over the whole t range.

In spite of the fairly good fit to the over-all data, there is only qualitative agreement with the spin-correlation parameters. In view of the statistical uncertainty, this result should not be interpreted as indicating a defect in the model, but rather as a statement that judgment should be deferred until a high-statistics determination of the correlations has been made.

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Lightly Ionizing Particles in Air-Shower Cores*

I. Cairns, C. B. A. McCusker, L. S. Peak, and R. L. S. Woolcott

Cornell-Sydney University Astronomy Center, Physics Department, The University of Sydney, Australia

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A search for quarks has been made in the cores of air showers of mean primary energy $\sim 4\times 10^{15}$ eV. Four tracks whose specific ionization is about half that of a fast singly charged particle are described. Various mechanisms that might simulate a quarklike track are considered. The most probable of these is that of the separation of the $\pm$ ion columns in the clearing field, and evidence for and against this explanation is considered. If the particles are assumed to be quarks, a rough production rate can be deduced. This is compared with the limits set by earlier experiments. A decisive experiment to search for quarks of charge $\pm\frac{1}{3}e$ is proposed.

INTRODUCTION

It is well known that the many experiments designed to observe quarks at energies up to ~ 100 GeV have failed to find any.[1] However, much higher energies are available in air showers. Moreover, several groups[2–5] have reported finding transverse momenta in air showers greater than the normal value of ~ 0.5 GeV/c by at least a factor of 10. Since the interaction time is essentially fixed at r_0/c sec (where r_0 is the proton diameter and c the velocity of light), this implies the existence of a force much stronger than the normal "strong" force. This force might be that involved in quark-quark interactions.

Technically, the search for quarks in air-shower cores presents some difficulties. One may use either the anticipated large rest mass of the quark or else its possibly fractional electric charge. The first may cause the quark to arrive a little later than the bulk of the particles in the shower; the second will produce a specific ionization of 4/9 or 1/9 that of a singly charged particle. One then has the problem of picking out one particle of less than normal ionization from between 100 and 50 000 "normal" particles per square meter.

EXPERIMENTAL METHOD

In the 1930's, the specific ionization of cosmic-ray particles was measured by Hazen[6] and by Corson and Brode[7] using the delayed expansion of a Wilson cloud chamber. The cloud chamber was triggered by the passage of the particle whose ionization was to be measured through a suitable Geiger-counter array but a delay was inserted into the system so that the ion column had time to diffuse. If conditions were suitable the expansion then produced a droplet on each individual ion. These were then photographed and the specific ionization determined. We have used this method with a trigger selecting air showers.

In all, four Wilson cloud chambers made for us[8] were employed. All were 30 cm in diam. Three were 20 cm deep; the fourth was 10 cm deep. The three deep chambers were adequately shielded by a 15-cm-thick lead shield. The shallow chamber was unshielded. All four chambers had an illuminated depth of 5 cm. They were in the same hut and within 3 m of the Sydney

* Work supported by the Science Foundation within the University of Sydney, the Australian Universities Research Grant Committee, and the U. S. Air Force Office of Scientific Research under Contract No. AF 49(638)-842.

[1] T. Massam, CERN Report No. 68-24, 1968 (unpublished).

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[3] S. Miyake, K. Hinotani, M. Ito, S. Kino, H. Sasaki, H. Yoshii, H. Sakuyama, and E. Kato, Can. J. Phys. **46**, 25 (1968).

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[5] C. B. A. McCusker, L. S. Peak, and M. H. Rathgeber, Phys. Rev. **177**, 1902 (1969).

[6] W. E. Hazen, in *Cloud Chamber Photographs*, edited by G. D. Rochester and J. G. Wilson (Pergamon Press Ltd., London, 1952), pp. 4 and 5.

[7] D. R. Corson and R. B. Brode, Phys. Rev. **53**, 773 (1938).

[8] The Wilson cloud chambers were made for us by J. Daly of Dublin.

64-scintillator array.[9] This consists of 64 41×41×10-cm unshielded plastic scintillators in a chessboardlike array. It is triggered by the coincidence of three small Geiger-counter trays at the apices of an ~2-m triangle just under the light roof of the hut. The cloud chambers shared this trigger. In addition to the scintillators the array has four trays, each of 48 150-cm² Geiger counters at various distances up to 55 m. The hut is temperature controlled to (21±0.5)°C. The cloud chambers have an orthodox filling of 1.4 atm of argon and a saturated vapor of 70–30% alcohol-water.

When a shower produced a coincidence, the 300-V clearing field between the front and back plates of the cloud chambers was removed within 1 msec; 100 msec later the expansion was initiated. This was complete after another 20 msec, 100 msec after that the lights were flashed, and then for the next 4 min a normal recycling program was followed.

Early in the experiment we observed the effect of different expansion delays on the width of tracks of single muons. A delay from 0 to 800 msec could be inserted between the master pulse and the initiation of the expansion. There is also a small additional time between the initiation of the expansion and the beginning of droplet formation. The results are shown in Figs. 1 and 2. Figure 1 shows two tracks, one taken at 65-msec delay and the other at 450-msec delay. The difference in width is obvious. In Fig. 2, we have plotted mean track widths against the square root of the inserted delay time. A straight line with a small intercept

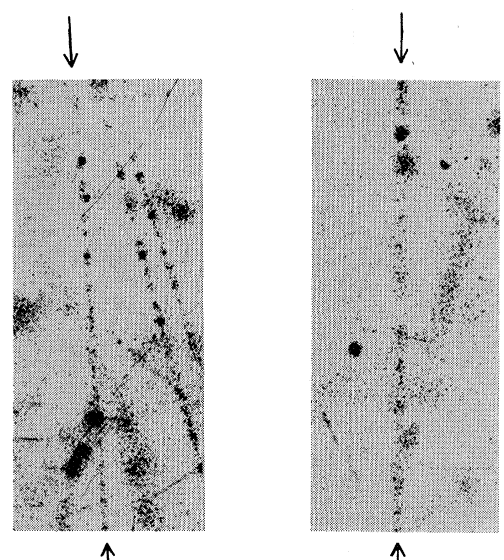

FIG. 1. Two negative prints of cloud-chamber photographs of muons with expansion delays of 65 and 450 msec, respectively.

[9] A. D. Bray, D. F. Crawford, D. L. Jauncey, C. B. A. McCusker, P. C. Poole, M. H. Rathgeber, J. Ulrichs, R. H. Wand, M. M. Winn, and A. Ueda, Nuovo Cimento 32, 827 (1964).

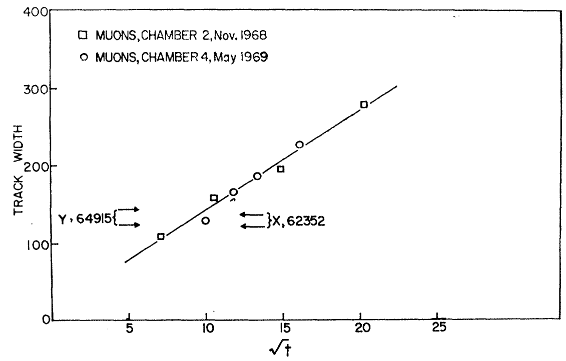

FIG. 2. Graph of mean track width in eyepiece units (1 eyepiece unit=0.0145 mm) against $\sqrt{t}$, where t is the expansion delay time in msec, for muon tracks in two of the cloud chambers. The widths (with ±1-standard-deviation error bars) of two of the light tracks are also shown.

at zero inserted delay time (being the small additional time mentioned above) is a good fit to the experimental points.

In a second subsidiary experiment we inserted a variable delay into the circuit, which removed the clearing field. We then took a number of photographs of muons with delays of 0 to 1600 msec between the passage of the particle and the removal of the clearing field, with no subsequent delay before the expansion. The separation of the positive and negative columns was measured with a Zeiss N2 stereoscope fitted with a parallax bar using half-life-size enlargements of the 35-mm negatives. This separation was found to be linear with t and gave a mean ionic mobility of 0.3 (cm/sec)/(V/cm). The established value for alcohol vapor is 0.36 (cm/sec)/(V/cm).[10]

Using an extensive-air-shower trigger, we have now run the array from July 1968 to July 1969, recording ~5500 air showers. These showers have a mean size of about 5×10^5 particles at sea level, which corresponds to an average total primary energy of about 5×10^6 GeV.

RESULTS

Four photographs showing tracks that seem to be less ionized than the track of a fast singly-charged particle are discussed here.

In Fig. 3, we reproduce stereo views of event 62 352. Tracks 1, a, and b are typical tracks of fast singly charged particles. Track X appears less ionizing. It is towards the back of the illuminated region. We have measured the positions of all four tracks and of various tracks in other events close in time. These include two tracks in event 62 348 which straddle the position of X. These positions are shown in Fig. 4 together with a photograph of event 62 348. Track X appears to be about 1 cm in front of the back edge of the illuminated region. The widths of tracks 1, a, b, and X were measured directly on the negative using a Leitz scanning

[10] E. V. Condon and H. Odishaw, *Handbook of Physics* (McGraw-Hill Book Co., New York, 1958), pp. 4–161, Table 10.1.

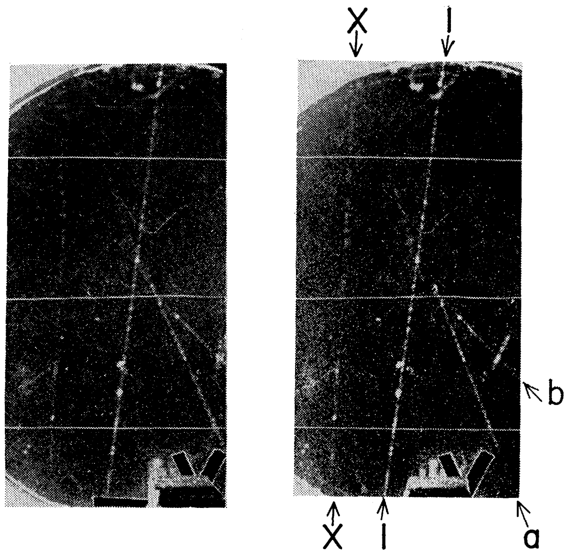

FIG. 3. Stereophotographs of event 62 352. The tracks labeled 1, *a*, and *b* are of fast singly charged particles. *X* is the lightly ionized track.

microscope with a $2\frac{1}{2}$ times objective and a 10× micrometer eyepiece. All widths are the same within the measurement errors and correspond to a delay of 100 msec.

The specific ionization I of tracks X and 1 were compared by counting the number of drops in $\frac{1}{2}$-cm intervals on the half-size enlargment. Intervals including a δ ray were omitted. Since the number of δ rays on 1 is greater than X, this tends to give an overestimate of the ratio of the specific ionization of X to the specific ionization of 1. The count was made by five independent observers and their results averaged. The mean ratio I_X/I_1 was found to be 0.58 ± 0.05. The mean total number of droplets in the track X was 200 and the track (1) 330. We estimate the number of δ rays on track X to be nine. In an equal length of track 1 we find 19 δ rays. It is worth noting that, although this picture appears very uncluttered, the particle density at the cloud chamber was $\sim$300 particles/m^2. Unfortunately the Geiger and scintillator arrays were out of action during this event.

The second of the tracks occurred in event 64 358 in chamber III under 15 cm of lead. It is reproduced in Fig. 5. The lead shield has completely removed the electronic component and there is no contemporary track of a fast single charged particle in the picture. Fortunately, such a track does occur in the previous event, 64 357, and we have compared the ionizations of these two tracks. The ratio $I_{64\,358}/I_{64\,357}$ is 0.58 ± 0.12. The candidate track in event 64 358 is $1\frac{1}{2}$ cm behind the front edge of the illuminated zone (which is 5 cm

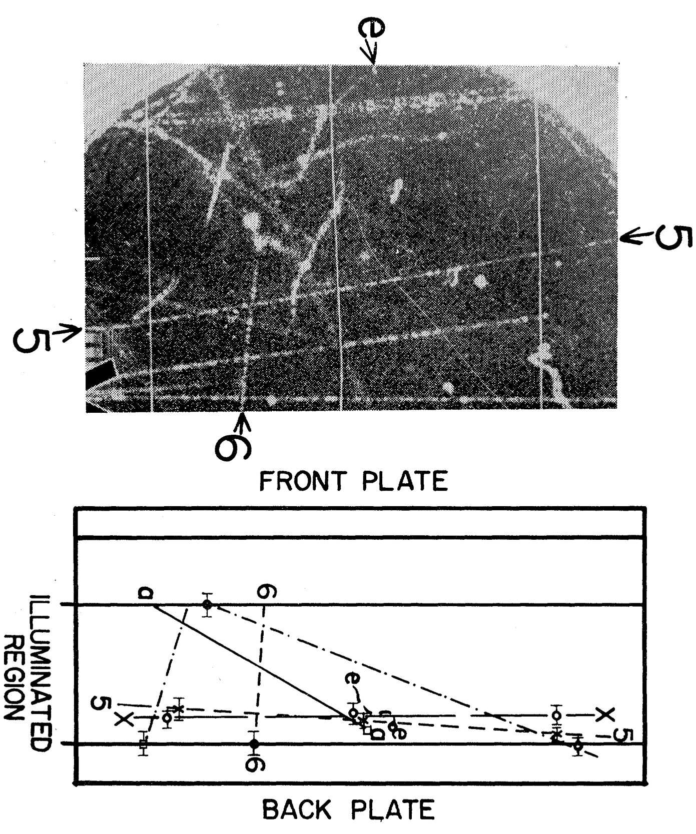

FIG. 4. Event 62 348 and a side elevation of the cloud chamber showing the positions of several tracks with respect to the illuminated volume.

deep). It is, for instance, behind the post-expansion slow-electron track to the left of it in the bottom half of the picture. Its width is the correct width for a 100-msec delay. The particle causing the track passed through 15 cm of lead without any visible interaction.

The third event, 64 915, is shown as a stereoscopic pair in Fig. 6. The mean width of track 2 as measured by five different observers was 128±9 divisions. This is consistent with the expected value for 100-msec delay. The mean width for track Y is 135±9 divisions. The mean ratio of the specific ionizations of the two tracks I_Y/I_2 is 0.46±0.08. The mean total number of drops counted along track Y was 130 and along on track 2 was 280. We estimate the number of δ rays along Y to be four and along an equal length of 2 to be 12. Track Y is well placed with respect to the illuminated region. It enters that region from the front at the top and almost reaches the back of the region at the bottom. For most of its length it has well-illuminated tracks on both sides of it, in front of it and behind it. There are a considerable number of contemporary tracks at minimum ionization in the picture. The Geiger array gave a shower size of $\sim 1.5\times 10^5$ particles and a shower-core position close to the cloud chambers. The 64-scintillator map is shown in Fig. 7 and suggests a core on or close to the 64-scintillator array. Comparison with our detailed Monte Carlo simulations of air showers[5] in just this energy region suggests that the primary particle was a proton or an α particle of total energy $\sim 2\times 10^6$ GeV. The particle density at the cloud chamber was ~ 2000 particles/m^2. If we take the main core to be on the cloud chamber, then the subcore on the 64-scintillator array gives a transverse momentum of 2.3 GeV/c. Only a minority of showers triggering the array have cores which fall on the 64-scintillator array, and only a minority of these show a transverse momentum >0.5 GeV/c. The over-all probability of any one shower being a "high p_t" event is ~ 0.001.

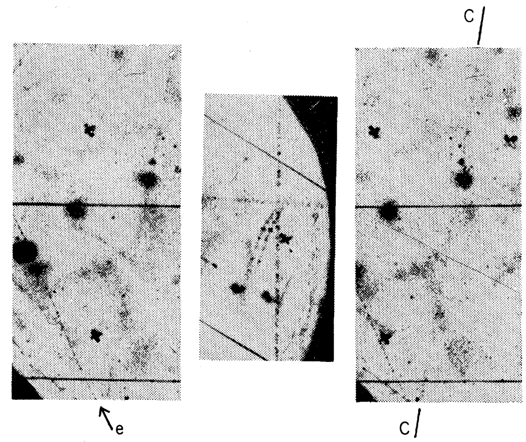

FIG. 5. Stereoscopic photographs of the lightly ionized track in event 64 358. The post-expansion track of a slow electron in the bottom left-hand corner is further forward than track C. The inset is of the track of a fast singly charged particle in event 64 357.

The fourth track occurred in event 65 677 and is shown in Fig. 8. This track, labeled Q, passes from front to back of the illuminated region and has well-illuminated tracks, e.g., track I and track e, on either side of it. Its width is 123±16 units. The width of track I is 122±16. The count gives a ratio I_Q/I_I of 0.46. The total number of drops counted in track Q was 94. We estimate three δ rays on Q and seven on an equal length of track I. Several of the tracks in the chamber are parallel to Q. Some weeks before this event the clearing field in chamber IV had been reduced by a factor of 2 to 15 V/cm, the value of the field in the other chambers. The density at the cloud chamber was 900 particles/m^2.

DISCUSSION

One way in which a singly charged particle may simulate a fractionally charged particle is by straightforward statistical fluctuation. We have examined over

FIG. 6. Stereoscopic pair of photographs of event 64 915. The track labeled Y is lightly ionized. Tracks 1–3 are those of fast singly charged particles (as are many other tracks in the photograph). Tracks D_1 and D_2 are the two halves of an old field-doubled track.

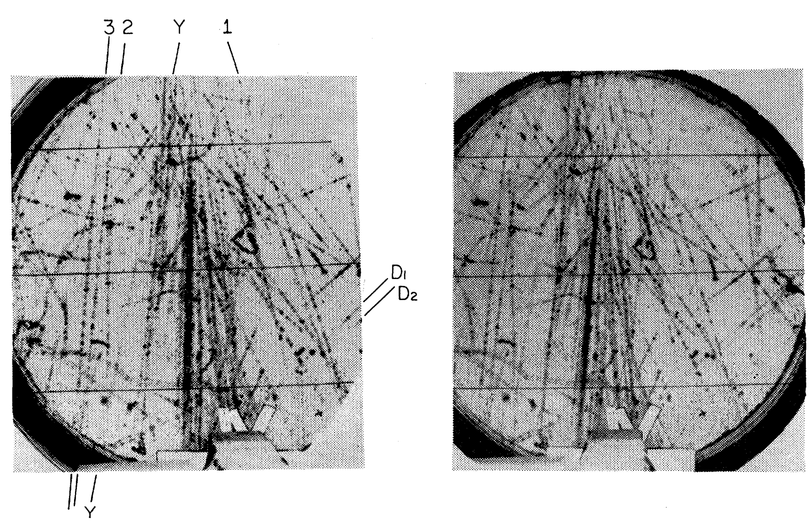

TABLE I. Expected width of the four tracks if they are one-half of a field-doubled track. The final column gives the measured widths. The errors are single standard deviations.

Event number	Clearing field (V/cm)	Minimum possible separation of the two columns (cm)	Necessary time in clearing field (msec)	Expected width (eyepiece units)[a]	Measured width (eyepiece units)[a]
62 352	30	0.7	36	164	128± 9
64 358	15	1.1	122	207	131±13
64 915	30	5.0	278	266	135± 9
65 677	15	4.5	500	334	123±16

[a] 1 eyepiece unit = 0.0145 mm.

55 000 tracks, so even comparatively rare occurrences must be considered. However, in a typical case, track Y, we find 130 droplets in the intervals not containing δ rays. In a similar interval of a track due to a singly charged particle we find 280 drops. This value is well established by counting a large number of tracks due to singly charged particles. Thus to simulate a 4/9 ionization, we need a fluctuation of 9 standard deviations, and this is improbable even in 55 000 samples.

Faint tracks are sometimes reported by the scanners, which upon further examination are shown to be tracks of singly charged particles which are not properly illuminated. This certainly cannot be the case for tracks Y and Q, which cross the illuminated region from front to back, and we believe it not to be so for tracks X and C.

Tracks are sometimes seen which are the positive or negative halves of tracks so old that the corresponding ion column has been moved out the illuminated region by the clearing field. Generally, these are easily recognized by the fact that their width is much greater than that due to a 100-msec delay. We have, of course, produced such doubled tracks in our subsidiary experiments using a delayed removal of the clearing field. As mentioned earlier, we have shown that the separation increases linearly with the time between the passage of the particle and the removal of the clearing field [giving a mean ionic mobility of 0.3 (cm/sec)/(V/cm)], and that the width of the track increases as the square root of the time between the passage of the particle and the onset of droplet formation. During these experiments we were not able to simulate tracks such as the four tracks discussed which had no visible partner and yet had a small width.

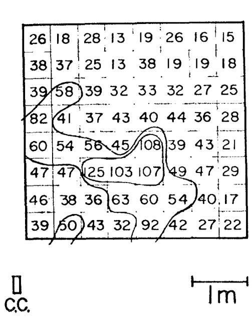

FIG. 7. 64-scintillator array response to event 64 915. The number of particles passing through each scintillator is shown. Density contour lines at 50 and 100 particles per scintillator have been drawn in. c.c. stands for cloud chamber.

To investigate the possibility that this is the explanation of our tracks we have carried out the following procedure. We assumed that the other half of the track was just outside the illuminated region. From the measured position of the visible half, we then found the necessary drift in the clearing field and from the measured ionic mobility, the time that the track must have spent in the clearing field. This time, added to the 100-msec delay between the removal of the clearing field and the onset of the expansion, gave us the diffusion time. We then derived the expected width of the track from our experimentally determined relationship between it and this delay time. The results for the four tracks are given in Table I and are compared with the observed widths. It is worth noting that the expected width for the track in 65 677 is greater than the observed width for the 450-msec muon track in Fig. 1. Note also that the track-doubling mechanism should not reduce the δ-ray count on a track.

There is one physical mechanism that can produce tracks of less than minimum ionization. This is the Chudakoff[11] effect—the very close separation of an electron-positron pair just after their creation. If the γ-ray energy is considerable, this separation may be maintained at $<10^{-8}$ cm over a sufficiently long path length for a reduced ionization to be observed. This path length for track Y is at least 10 cm, so θ, the angle of emission of the e^+-e^- pair, must be $<10^{-9}$ rad; θ is given by

$$\theta = 4(m_0c^2/E_\gamma)F(E'/E_\gamma),$$

where E' is the energy of the lower-energy electron and E_γ is the energy of the γ ray. $F(E'/E_\gamma)$ is the Borsellino function. The minimum value of F is unity; hence in our case $E_\gamma > 2\times10^{15}$ eV. Since the energy of the shower primary at the top of the atmosphere was 2×10^{15} eV, this is obviously impossible.

COMPARISON WITH OTHER EXPERIMENTS

If we assume, for the moment, that all four tracks are due to quarks, we can estimate the frequency of quark ($\pm\frac{2}{3}e$) production in atmospheric cascades initiated by primary particles of mean energy $\gtrsim 4\times10^{15}$ eV. The flux of such particles at the top of the atmo-

[11] A. E. Chudakoff, Izv. Akad. Nauk USSR **19**, 651 (1955).

sphere is 5×10^{-7} particles/m² sec sr.[12] The effective area of a cloud chamber is 125 cm² and the acceptance angle of the air-shower detector is $\sim$0.6 sr. If n is the number of quarks ($\pm\frac{2}{3}e$) per shower then we expected $\sim n/10$ per cloud chamber per year. We have run for $\sim$1 yr and hence get $n\simeq10$.

It is obvious that if quarks are produced only at energies greater than $\sim10^{14}$ eV, they cannot be detected by either accelerator or low-energy cosmic-ray experiments. They will, however, be stopped in the earth and may accumulate. The number accumulated will be $2\pi n(5\times10^{-7})4\pi r_e^2 t_{\mathrm{acc}}$, where r_e is the radius of the earth and t_{acc} the accumulation time. t_{acc} has often been taken to be approximately the age of the earth, particularly for negative quarks. The reason for this is straightforward. If a negative quark were stopped by matter, it would quickly fall through the electron shells around the nearest nucleus and take up its own K-shell position around that nucleus. Since its mass is expected to be large, the K shell would be within the nucleus. Since it can only be annihilated by a $+\frac{2}{3}e$ antiquark, which would be strongly repelled by the positive charge on the nucleus, it would appear to be in a particularly safe position.

Several groups have looked for such negatively charged atoms, and so far the lowest upper limit on their frequency seems to have been set by Chupka, Schiffer, and Stephens,[13] who may have obtained as low as one quark per 10^{27} nucleons for sea water. If we take t_{acc} as the age of the earth, our expected concentration is much higher than this, being between one per 10^{24} nucleons and one per 10^{21} nucleons, depending on the depth to which quarks are allowed to spread. Thus, unless $t_{\mathrm{acc}}\ll$earth's age, the tracks we observe can hardly be due to quarks, since it seems very unlikely that the experiment of Chupka *et al.* could have missed such a comparatively large concentration.

However, it has been pointed out[14] that there is a mechanism that may greatly shorten t_{acc}, particularly for air and sea water. The quark atom is always charged, generally with a charge of $-\frac{2}{3}e$. Thus, it is much more influenced by electric fields than by the earth's gravitational field. The normal electric field of the earth is $\sim$100 V/m, driving negative charges upwards. In thunderstorms this is greatly increased. The earth is continually swept by $\sim$2000 thunderstorms. A quark atom, even if it forms part of a fairly large dust grain, will be swept up into the ionosphere. McDowell and Hasted have proposed that the quark atoms are trapped there, but there also seems to be a finite possibility that they will be swept into interplanetary space via the solar wind.[15] In any case, the mechanism reduces the accumulation time for quarks trapped in the atmosphere to $\ll$1 yr. For those stopped in the ocean it will be of the order of 1 yr, and for quarks stopped in dirt and rock it will be determined by the transpiration rate of plants or by the erosion rate.

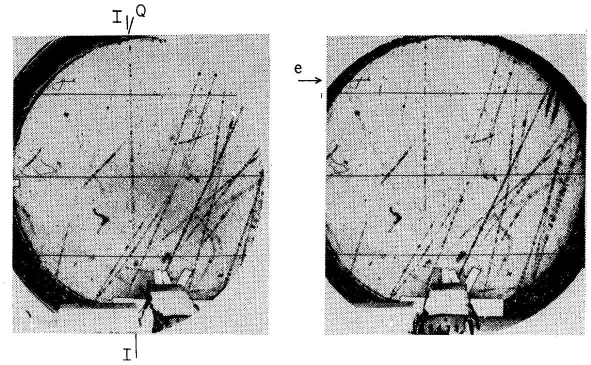

FIG. 8. Stereoscopic pair of photographs of event 65 677. The track Q is lightly ionizing. Track I is that of a fast singly charged particle (as are many other tracks in the picture). Track e is a well-illuminated slow-electron track.

The experiment of Chupka *et al.* also looked for quarks in meteoric material, but if quarks are produced only at energies greater than 10^{14} eV there will be a negligible accumulation in such small bodies.

Experiments on massive delayed particles in air showers are obviously relevant to the present experiment. Bjrnboe *et al.*[16] found no such particles. Dardo, Penengo, and Sitte[17] produced evidence both for their existence and for an interaction mean free path of 420_{-45}^{+253} g/cm². Obviously the particle producing the track in event 64 358 is penetrating.

CONCLUSION

In 1 yr, we have examined about 55 000 particles in 5500 air showers of mean primary energy $\sim4\times10^{15}$ eV. Four tracks have been found whose specific ionization is significantly less than that of tracks of fast singly charged particles. Their observed widths seem to be much less than the widths expected if they are field-doubled tracks. We have been unable to reproduce such tracks by field doubling under the conditions of our experiment. Nevertheless, it might be possible to produce such tracks by the combination of a much higher clearing field and shorter expansion delay. However, the simulation by this means of a track of one-ninth the ionization of a fast singly charged particle would seem to be impossible. Under the conditions of the present experiment such a track would be very difficult to detect. However, by using a cloud chamber

[12] H. R. Allan, R. F. W. Beamish, W. M. Glencross, D. M. Thomson, and R. D. Wills, Proc. Phys. Soc. (London) **79**, 1170 (1962).

[13] W. A. Chupka, J. P. Schiffer, and C. W. Stephens, Phys. Rev. Letters **17**, 60 (1966).

[14] M. R. C. McDowell and J. B. Hasted, Nature **214**, 235 (1967).

[15] I. Axford, J. Geophys. Res. **73**, 6855 (1968).

[16] J. Bjrnboe, S. Damgard, K. Hansen, B. K. Chatterjee, P. Grieder, A. Klovning, E. Lillethun, and B. Peters, Nuovo Cimento **53B**, 1073 (1968).

[17] M. Dardo, P. Penengo, and K. Sitte, Nuovo Cimento **58A**, 59 (1968).

operating at nine times the present pressure, this difficulty would be avoided. We are building such a chamber at present.

Note added in proof. Most of the particles in an air-shower core are on the plateau of the ionization curve. Some, however, may be on the minimum of the curve, which for argon has a specific ionization 1.4 times less than the plateau. A fluctuation from this value to 0.44 I_{plateau} is obviously more likely. However, the electrons which constitute the great majority of particles in an air-shower core will all be on the plateau (their critical energy in air is 100 MeV). The number of muons in an air shower core is small ($N\mu/Ne$ within 1 m of the core is <0.001) and they will mostly be of high energy. The hadrons close to the core are generally extremely energetic; on our 64 scintillater array we have seen many of energy >5000 GeV.

If n is the number of drops counted on the candidate track, the necessary fluctuation is $0.43n/(1.43n)^{1/2}$ standard deviations. We take n rather than $\frac{1}{2}n$ as our basic sample because in our counting procedure we counted as one drop any conglomeration of two or more droplets up to our δ-ray limit. The probability of such large fluctuations occurring from such a small population is negligible.

ACKNOWLEDGMENTS

We are indebted to our colleagues in the School of Physics for their help and criticism, particularly to Dr. H. B. Ogelman, now with NASA; to A. Bakich and D. Nelson, who ran the scintillator and Geiger arrays; and to our scanners Miss Rosemary Roberts and Miss Audrey Castleman. We are very grateful to Professor H. Messel for the facilities provided.

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Reaction $\pi^+n \rightarrow K^+K^-p$ at 2.7 GeV/c*

A. F. GARFINKEL, S. LICHTMAN, R. J. MILLER,† AND R. B. WILLMANN
Purdue University, Lafayette, Indiana 47907

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A sample of 101 events of the reaction $\pi^+n \rightarrow K^+K^-p$ has been isolated in a study of π^+d interactions at 2.7 GeV/c. A strong $Y_0^*(1520)$ signal is seen, but the K^+K^- spectrum shows no enhancements. The absence of a significant threshold enhancement in the K^+K^- system may be anomalous.

THE reaction

$$\pi^+d \rightarrow p_s pK^+K^-, \tag{1}$$

where p_s is the spectator proton, has been studied at an incident pion momentum of 2.7 GeV/c. The two-body mass spectra of the pK^+K^- were analyzed for decays of resonances. We found a strong $Y_0^*(1520)$ signal but no conclusive evidence of resonance production in the K^+K^- (or K^+p) spectra. In particular, there is no indication of ϕ production or of a threshold enhancement in the K^+K^- spectrum. In principle, the same physical information is obtainable from a study of the charge-symmetric reaction

$$\pi^-p \rightarrow nK^0\bar{K}^0. \tag{2}$$

In practice, only $nK_1^0K_1^0$ events are analyzable in reaction (2), so it provides data in only the $C=+1$ component of the $(K\bar{K})^0$ system. One can also obtain information relevant to the coupling of the $I=0$ $K\bar{K}$ system to pions from the reactions

$$\pi^+d \rightarrow p_s pK_1^0K_2^0, \tag{3}$$

$$\pi^+d \rightarrow p_s pK_1^0K_1^0, \tag{4}$$

which are analyzable and contain both $C=+1$ and $C=-1$ states of $(K\bar{K}^0)$, as with reaction (1). However, reactions (1), (3), and (4) may not be physically identical since, for example, Y_0^* production is possible in (1) and not (3) or (4). Moreover, interference between an $I=0$ s-wave $K\bar{K}$ state and an $I=1$ s-wave $K\bar{K}$ state, both with $C=+1$, could enhance either reaction (1) or (4) and deplete the other.[1]

The data were obtained from an exposure of 100 000 pictures in the LRL 72-in. deuterium bubble chamber. The total beam track length is such that one $p_s pK^+K^-$ event with a visible spectator proton corresponds to a cross section of 1 μb for all reaction-(1) events.

Events in the final state $p_s pK^+K^-$ were isolated in a systematic study of all four-prong events which contain at least one proton which stops in the bubble chamber.[2] Measured events which have three-momentum balance among the visible tracks were considered candidates for reaction (1). We then calculated

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† Present address: Rutherford High Energy Laboratory, Berkshire, England.

[1] The possible existence of such an effect has also been noted by H. J. Lipkin, Phys. Rev. **176**, 1709 (1968).

[2] Details of the scanning and measuring procedures are given by R. J. Miller, S. Lichtman, and R. B. Willmann, Phys. Rev. **178**, 2061 (1969); also see R. J. Miller, Ph.D. thesis, Purdue University, 1968 (unpublished).

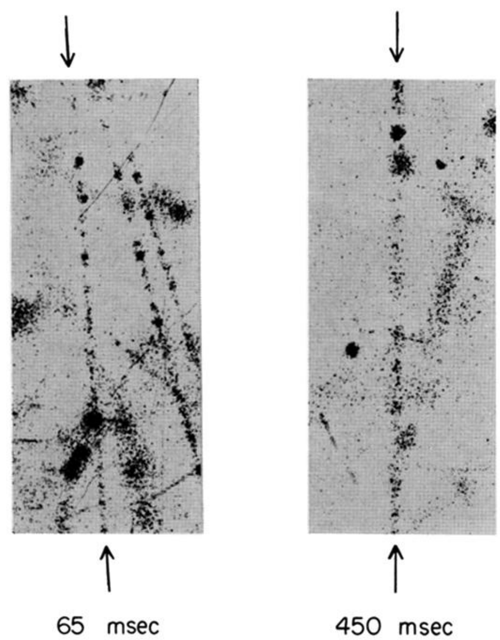

FIG. 1. Two negative prints of cloud-chamber photographs of muons with expansion delays of 65 and 450 msec, respectively.

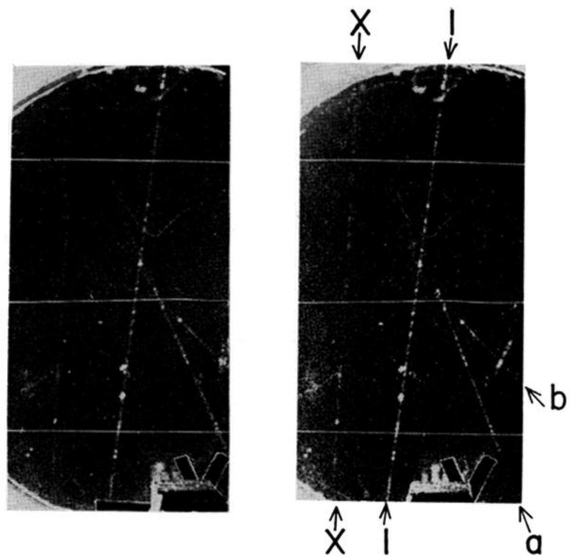

FIG. 3. Stereophotographs of event 62 352. The tracks labeled 1, *a*, and *b* are of fast singly charged particles. *X* is the lightly ionized track.

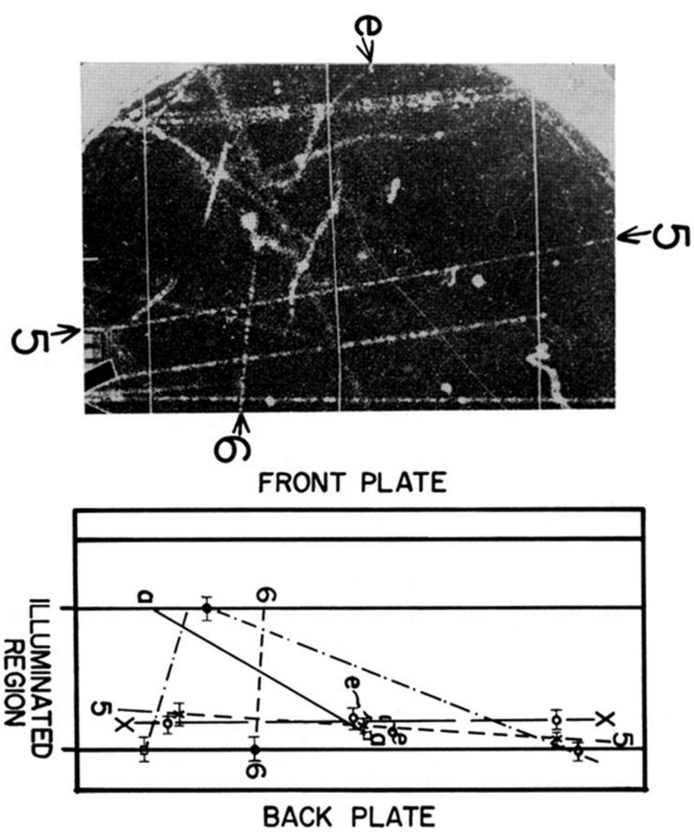

Fig. 4. Event 62 348 and a side elevation of the cloud chamber showing the positions of several tracks with respect to the illuminated volume.

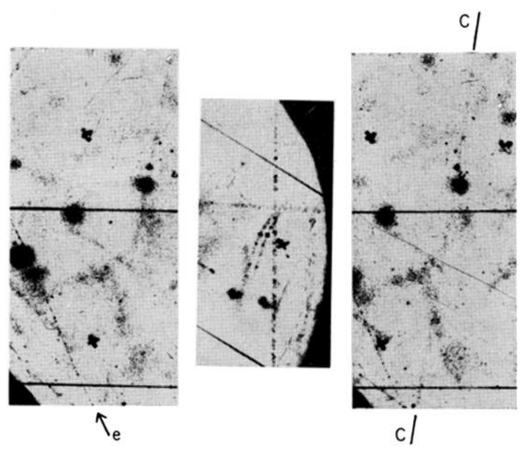

FIG. 5. Stereoscopic photographs of the lightly ionized track in event 64 358. The post-expansion track of a slow electron in the bottom left-hand corner is further forward than track *C*. The inset is of the track of a fast singly charged particle in event 64 357.

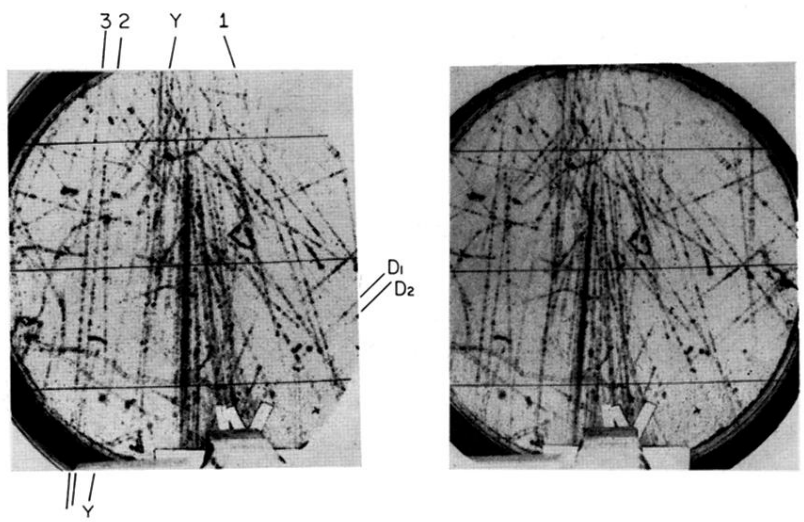

FIG. 6. Stereoscopic pair of photographs of event 64 915. The track labeled Y is lightly ionized. Tracks 1–3 are those of fast singly charged particles (as are many other tracks in the photograph). Tracks D_1 and D_2 are the two halves of an old field-doubled track.

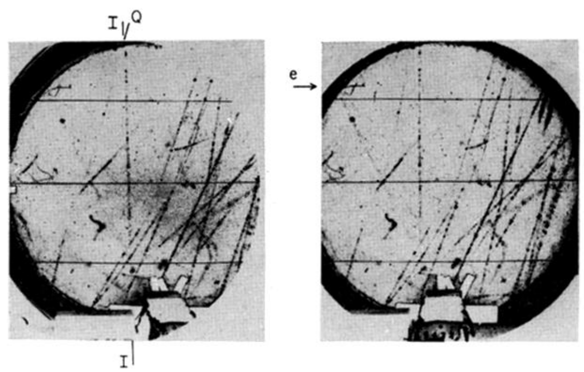

FIG. 8. Stereoscopic pair of photographs of event 65 677. The track Q is lightly ionizing. Track I is that of a fast singly charged particle (as are many other tracks in the picture). Track e is a well-illuminated slow-electron track.