Is This a Quark I See Before Me?

A group at the University of Sydney has found five tracks in high-energy cosmic-ray air showers whose "appearance was that expected for a quark of charge 2/3 *e*." The group, headed by Charles B. A. McCusker, used an array of scintillation counters, which triggered four delayed-expansion cloud chambers when an extensive air shower arrived. Each chamber is expanded 100 millisec after the shower arrives, and the vapor trail is photographed 200 millisec later.

For relativistic particles, to a first approximation the ionization is insensitive to the mass of the particle producing the ions; the number of droplets produced per unit length is proportional to the square of the charge. A quark with 2/3 *e* would produce 4/9 (0.44) the ionization produced by an electron.

The tracks. Since July 1968 the group has photographed more than 600 air showers; four of the tracks had an appearance appropriate for a 2/3 *e* quark.[1] In August of this year McCusker and I. Cairns found a fifth event (see photograph), which they believe greatly strengthens their conclusion. McCusker reported the results at the 11th International Conference on Cosmic Rays in Budapest early in September and in the 22 Sept. issue of *Physical Review Letters*.

In the photograph, tracks 1 to 5 are among nine parallel tracks passing through the chamber; these tracks are considered typical of singly charged relativistic particles. In the midst of the normal tracks is track R. It is well within the illuminated region; so the weakness of the track could not be attributed to poor illumination. Because cloud chambers tend to be differentially sensitive in different parts of the chamber, a weakly ionizing track such as R is more convincing when observed near other normal looking tracks. McCusker and Cairns argue that the reduced ionization cannot be produced by the field-doubling mechanism and conclude that ". . . the only other explanation we can see is that the track is due to a fractionally charged particle."

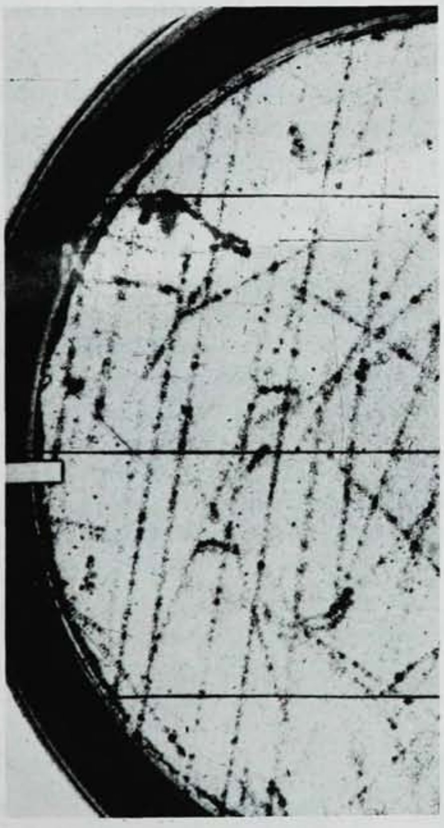
The ratio of the ionization of track R to the tracks of singly charged particles is reported as 0.48 ± 0.05. The response of the air-shower array puts the core of the shower on the cloud chamber; the energy of the primary particle was about 3.5 million GeV. It was not possible to determine the energy required to produce the weakly ionizing track.

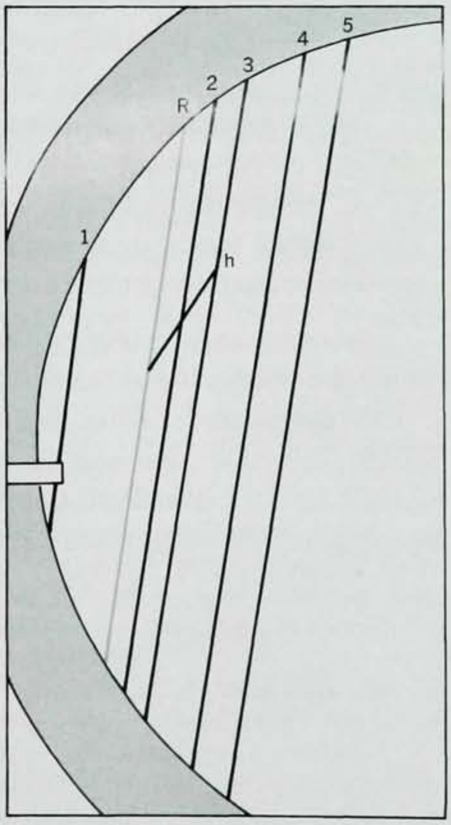
Reaction. The Australian experiment has excited great interest. Of course many feel that further observations are required. Some have suggested, for example, that one should measure the specific ionization for many normal tracks (randomly selected) in the cloud-chamber photographs, to see what the distribution is. The technique of splitting the track into positive and negative parts can provide a check on efficiency of droplet formation and whether or not positive and negative ions are both fully represented in the track.

Since quarks were proposed (independently by Murray Gell-Mann and George Zweig) about five years ago, many have searched for them. But the Sydney group is the first to look in the middle of extensive air showers. In fact most other cosmic-ray experiments deliberately excluded extensive air showers because they would have swamped the detectors.

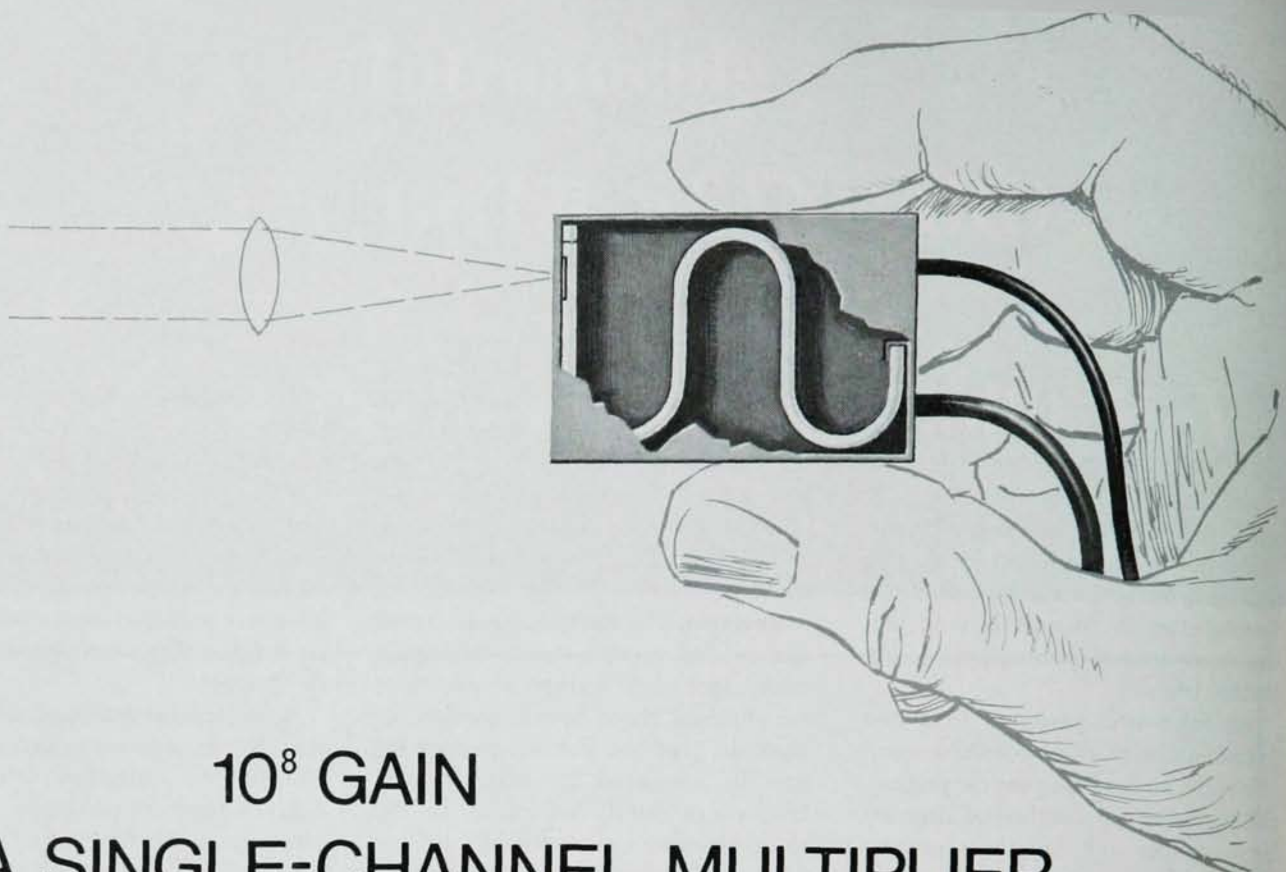
Some experiments used an array of scintillation counters to look for anomalously low ionization. Others used delayed-time coincidence measurements in air showers to find very energetic particles that arrived late because of their large mass. Others looked for quarks in stable matter.

What next? McCusker and his col-





WEAKLY IONIZING TRACK labeled R has "appearance expected for a quark of charge 2/3 *e*," according to C. B. A. McCusker and I. Cairns of the University of Sydney. Cloud-chamber photograph is of event 66 240. Tracks 1 through 5 are part of a parallel beam of singly charged relativistic particles. Track R is parallel to this beam. Track h extended well into and out of the plane of this photograph.



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Reference

1. I. Cairns, C. B. A. McCusker, L. S. Peak, R. L. S. Woolcott, Phys. Rev., to be published.

K-Mesic Atoms Indicate A Nuclear Neutron Skin

A thin skin of neutrons apparently surrounds the nucleus, according to measurements with K-mesic atoms by Clyde E. Wiegand of Lawrence Radiation Laboratory, Berkeley (*Phys. Rev. Lett.* **25**, 1235, 1969). Such atoms offer a new tool for determining the extent of the nuclear wave function.

For many years theorists had suggested that the nuclear surface might be covered with neutrons. But conventional electron-scattering measurements, such as those done by Robert Hofstadter and his collaborators at Stanford, only measure the nuclear charge distribution. By analyzing analog states one can learn if the mean-square-density radius is different for neutrons and protons. There is some evidence for a larger neutron radius, but the conclusions remain controversial.

At much greater distances density falls off exponentially. Because the proton sees a Coulomb barrier, its wave function falls off much more rapidly than that of the neutron. So one would expect to find a larger neutron radius.

Using the external proton beam to make kaons at the 6-GeV Bevatron, Wiegand bombarded a variety of targets to make K-mesic atoms. Because the kaon is about 1000 times as massive as an electron, it forms a hydrogenlike atom in which the orbits are about 1000 times smaller than the ordinary electron shells.

Wiegand observed x-ray emission as the kaon dropped toward the nucleus. The highest-energy x ray observed tells how close the kaon got to the nuclear surface before it was absorbed by the nucleons there. Wiegand made 24 kinds of K-mesic atoms with atomic numbers ranging from $Z = 3$ to 92. Mesic atoms have previously been made using pions and muons, both lighter than kaons.

Wiegand says that his measurements on 24 elements show that the neutrons are distributed in a low-density tail and that the parameters of the tail are relatively insensitive to how you distribute the matter in the center.

Wiegand also observed x rays suggesting the formation of Σ^- hyperonic atoms. With high-Z atoms, he hopes to see a fine structure due to the magnetic moment of Σ^-. With more intense kaon beams and larger germanium detectors of improved resolution, he may be able to measure the Σ^- magnetic moment. (Only two hyperon magnetic moments are known.)

Serpukhov Data Suggest Asymptopia May Be Further Away Than Ever

With 70 GeV available at the Soviet Serpukhov accelerator, a new look into the asymptotic region is possible, and some observers are surprised at the glimpses reported at the Lund International Conference on Elementary Particles in July. Preliminary results suggest that the π^-–p and K^-–p total cross sections may be flattening out as energy increases; many theorists had predicted that these cross sections would go down as energies increased.

In another Serpukhov experiment the p–p differential elastic-scattering cross section shows shrinking of the forward diffraction peak as energy is increasing; this shrinking confirms an earlier trend.

New results from the Serpukhov quark search were reported by L. G. Landsberg's group. They find that if the quark has a mass less than 6 GeV, an average upper limit for the production cross section is 3×10^{-38} cm^2. (The actual cross section varies as a function of energy.)

The total cross-section curves are expected to agree with the Pomeranchuk theorem, originally proposed by Isaak Ya. Pomeranchuk in 1956. The theorem, which follows from the dispersion relations, predicts that in the high-energy limit the cross section for a particle hitting a given target will be equal to that for an antiparticle hitting the same target. For example, in the asymptotic limit, the π^-–p cross section should be the same at the π^+–p cross section.

The Serpukhov experiments, done by a collaboration between CERN and the Serpukhov Institute for High-Energy Physics (IHEP),[1] measured K^-–p, π^-–p and $\bar{p}$–p total cross sections in the range 20–65 GeV/*c*. The antiproton–proton cross sections appear to be falling off and approaching an extrapolated flat proton–proton total cross section.

The somewhat unexpected results are those for pions and kaons: Between 30 and 65 GeV/*c* the experimenters believe the pion cross section has become energy independent within the estimated 0.20 millibarn accuracy; the average value is about 24.4 millibarns. The kaon cross sections also show very little energy dependence over the region investigated; they average about 20.8 millibarns, but the estimated errors are larger.

Extrapolations from higher-accuracy lower-energy data obtained by S. J. Lindenbaum and his collaborators[2] predicted a declining π^-–p cross section, the curve tending towards the π^+–p curve. Regge-pole analyses, such as those made by Vernon Barger and his collaborators,[3] had also led to predictions of a declining π^-–p cross section.

If interpretation of the data is correct, one can explain the flatness of the π^- and K^- curves in several ways: Asymptopia is very far away and the particle and antiparticle cross-section curves are approaching each other very slowly as $1/\log E$ (where E is bombarding energy), for example; the π^+ and K^+ curves could start increasing, because the Pomeranchuk theorem says they must approach the π^- and K^- asymptotes, respectively; or the Pomeranchuk theorem is wrong.

Now information on π^+–p and K^+–p total cross sections in the new range is eagerly awaited.

The proton-proton differential elastic-scattering cross section was measured from 12 to 70 GeV at angles from 1 to 5 milliradians by a Dubna–IHEP collaboration.[4] In the early 1960's Regge-pole advocates predicted that the forward peak in the elastic differential cross section would shrink for both protons and pions. The prediction was verified for p–p scattering in the energy range below 30 GeV, but violated for π–p scattering, thus temporarily damping enthusiasm for Regge poles.

The Serpukhov data show that in the new energy region the rather broad p–p diffraction peak continues to shrink somewhat. Extrapolations from lower energy $\bar{p}$–p elastic differential cross sections show a narrow peak, which is expanding. Because the Pomeranchuk theorem predicts that both peaks will tend toward the same