imental methods are now available to complete many isobaric quartets. Most of the $T_z = +\frac{3}{2}$ masses are known, and the $T = \frac{3}{2}$ states in the $T_z = +\frac{1}{2}$ and $-\frac{1}{2}$ members can be readily located through (p, He^3) and (p,t) reactions on appropriate targets.[10,12] In addition, the observation of this reaction offers promise that the fourth and fifth members of the $A = 4n$, $T = 2$ quintets can be measured. Taking the $A = 16$ system as an example, at present $T = 2$ states in the $T_z = +2$ (C^{16}), $T_z = +1$ (N^{16}), and $T_z = 0$ (O^{16}) nuclei are known.[10] Next, one can hope to locate $T = 2$ states in the $T_z = -1$ nucleus F^{16} through the reaction $F^{19}(He^3, He^6)F^{16}$ analyzed in a manner similar to that previously used for the $T_z = +1, 0$ isobars, since $\Delta T = \frac{3}{2}$ is allowed in this reaction. Lastly, if He^8 is particle stable,[13] the success of this three-neutron pickup reaction makes it conceivable that the $T = 2$ quintets can be completed by obtaining the mass of the $T_z = +2$ member via a four-neutron pickup reaction, in this case $Ne^{20}(He^4, He^8)Ne^{16}$. The alpha-particle energies which would be required are well within the range of the new variable-energy cyclotrons.

†This work performed under the auspices of the U. S. Atomic Energy Commission.

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MOUNTAIN-ALTITUDE QUEST FOR FRACTIONALLY CHARGED PARTICLES*

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A cosmic-ray search, at a mountain altitude of 8300 feet, has been made for the hypothetical fractionally charged ($\frac{1}{3}e$) particle allowed by the three-dimensional representation as postulated by Gell-Mann[1] and Zweig,[2] who called them "quarks" and "aces," respectively. The experiments at Brookhaven National Laboratory[3] and CERN[4] have shown that if a charge-$\frac{1}{3}e$ quark exists, its mass, M_Q, is such that $M_Q \gtrsim 2$ BeV/c^2. The sea-level cosmic-ray search for $\frac{1}{3}e$ particles of Sunyar, Schwarzschild, and Connors[5] also yielded negative results.

A five-element, liquid-scintillator telescope was employed as shown in Fig. 1. Each scintillator had a nominal size of 18×18×2.5 in.,[3] and was viewed by a 5-inch photomultiplier tube. The area-solid-angle acceptance, $A\Omega$, of the apparatus was 327 cm^2-sr. The last dynode signals of the five photomultiplier tubes

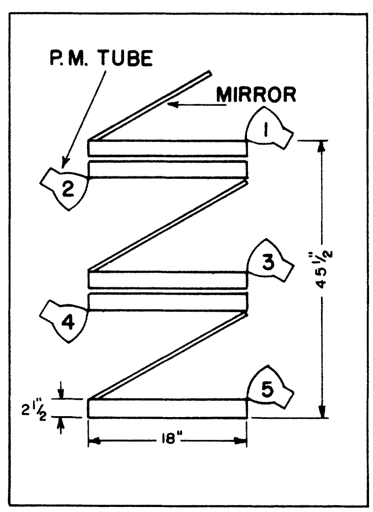

FIG. 1. Arrangement of scintillation counters.

were differentially delayed and connected to the vertical display of an oscilloscope. The anode signals from 1, 2, 4, and 5 were fed into a fourfold coincidence circuit. These same four anode signals were also mixed and fed into the anticoincidence input. The discriminator of the anticoincidence channel was set so that a pulse at any input corresponding to $dE/dx \gtrsim 0.7(dE/dx)_{\min}$ would activate the anticoincidence. The oscilloscope and the recording camera were triggered by this circuit when pulses of sizes corresponding to $0.025 < dE/dx < 0.7$ [in units of $(dE/dx)_{\min}$ for charge e] occurred simultaneously in 1, 2, 4, and 5. Since scintillator 3 had no connection with the triggering requirements, its distributions should not have been affected by possible triggering biases. The data presented were based upon a sensitive time of 237 hours.

Counting efficiencies and pulse-size distributions corresponding to $\frac{1}{3}e$ particles were obtained by the use of masks which allowed only $\frac{1}{9}$ of the incident light to strike the photocathode of each photomultiplier tube.[6] A typical simulated-quark pulse-size distribution is shown in Fig. 2(d). The simulated-quark distributions were used to set scanning limits on the pulses from 1, 2, 4, and 5. Narrowing these limits increased the signal-to-noise ratio of true quark events relative to background events at the cost of reducing the total number of true events. Figures 2(a), 2(b), and 2(c) show pulse-height distributions of the independent (counter 3) pulse with criteria on the selection of pulses 1, 2, 4, 5, such that 96%, 77%, and 55%, respectively, of true quark events would have been accepted.

The shapes of the observed distributions [Figs. 2(a), 2(b), and 2(c)], when compared with a typical simulated-quark distribution [Fig. 2(d)], indicate that most, if not all, of the quarklike pulses are background events. The background contribution in the region where quark pulses would be expected has been estimated by assuming that the shape of the background distribution is insensitive to small changes in the selection criteria on pulses 1, 2, 4, 5. For convenience, an exponential curve was fitted to the 96% distribution [Fig. 2(a)]. In Figs. 2(b) and 2(c) the same exponential is drawn, but normalized to the smaller numbers of events. In each case, the observed distribution seemed consistent with an approximately exponential background distribution. In order to estimate

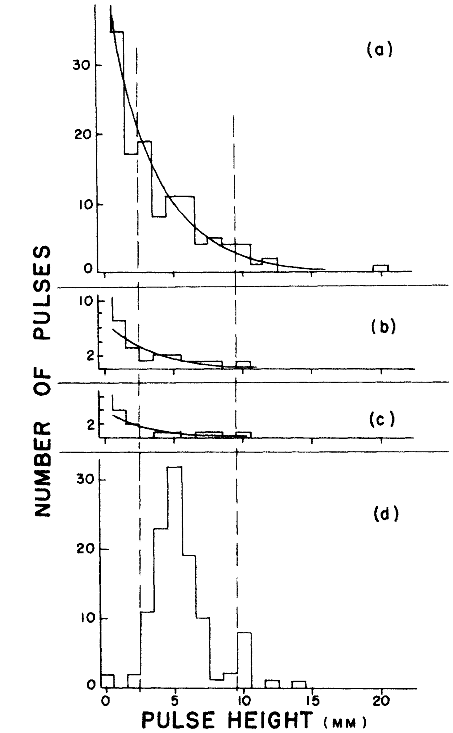

FIG. 2. Pulse-height distributions observed in counter 3. The selection criteria on pulses 1, 2, 4, and 5 would have included (a) 96%, (b) 77%, and (c) 55% of all true quark events. The smooth curve in (a) represents the best fitting exponential. The same exponential, but renormalized, is shown in (b) and (c). A typical simulated-quark distribution is shown in (d) for comparison.

an upper limit on the possible number of true quark pulses present in the data, counter-3 pulses in the 3- to 9-millimeter region were selected for analysis. This region included 88% of the pulses in the simulated-quark distribution for counter 3. In each case [Figs. 2(a), 2(b), and 2(c)], the number of pulses observed in the range 3-9 mm is close to the number expected from the background distribution. As a further check that the pulses of counter 3 in the range 3-9 mm were, indeed, background pulses, the distribution of the accompanying 1, 2, 4, and 5 pulses was examined. This latter distribution, even for the few events remaining in Fig. 2(c), was easily fitted with the same exponential shown in Figs. 2(a), 2(b), and 2(c), which indicates that these pulses were from background events.

The results of the analysis leading to the 90% confidence limit on the upper limit to the mean number of quarks are given in Table I. It is

Table I. Summary of the number of events in the range 3-9 mm where true $\frac{1}{3}e$ quark events would appear.

True quarks accepted by 1, 2, 4, 5 selection criteria (%)	Number of counter-3 pulses observed in the range 3-9 mm	90% confidence upper limit on mean number of pulses in the range 3-9 mm	90% confidence upper limit on mean number of quarks (with background and efficiency corrections)
96	62	75	14
77	8	13.0	4.7
55	4	8.0	4.4

observed that the more selective criteria for pulses 1, 2, 4, and 5 resulted in more restrictive limits to the number of quarks which might have been present. Combining the upper limit of 4.4 quarks given in Table I with the area, solid angle, and sensitive time of the detector, the vertical intensity at 8300 feet of $\frac{1}{3}e$ quarks, I_Q, is less than 1.6×10^{-8} cm^{-2} sec^{-1} sr^{-1} using a 90% confidence limit. The same 90% confidence criteria applied to the one possible event observed by Sunyar, Schwarzschild, and Connors[5] gives $I_Q < 20\times10^{-8}$ cm^{-2} sec^{-1} sr^{-1} at sea level.

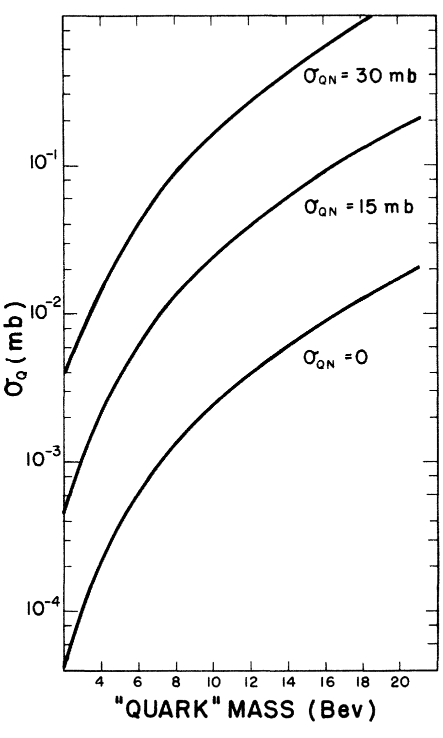

FIG. 3. The 90% confidence upper limit, σ_Q, for quark production in nucleon-nucleon collisions is shown as a function of the assumed quark mass for several choices of σ_{QN}, the effective quark-nucleon cross section for removal or attentuation before reaching the detector.

The upper limit to the production cross section for hypothetical charge-$\frac{1}{3}e$, long-lived quarks can be estimated if one assumes that (a) the cosmic-ray primary proton total energy integral spectrum for 10 BeV $\leq E \leq 10^4$ BeV is given by[7]

$$N(E) = 0.88E^{-1.5} \text{ cm}^2 \text{ sec}^{-1} \text{ sr}^{-1} \ (E \text{ in BeV}); \quad (1)$$

(b) the attenuation mean free path, $1/\mu_p$, of protons in air is 120 g/cm^2; (c) quarks are produced in pairs with a constant cross section per nucleon, σ_Q, for energies above threshold in the reaction $N+N \rightarrow N+N+Q+\bar{Q}$; (d) an average of one quark of charge $\frac{1}{3}e$ is produced per reaction; (e) the removal of quarks from the relativistic energy region of the spectrum, the region in which the detection scheme is sensitive, can be approximated by an attenuation mean free path $1/\mu_Q$; (f) the attenuation of protons and buildup of quark intensity can be described by a simple one-dimensional diffusion equation; and (g) each air nucleus is equivalent to six free nucleons. The resulting dependence of the quark production cross section, σ_Q, on the observed vertical intensity, I_Q, at atmospheric depth, x, is

$$\sigma_Q = 4.1\times10^3 I_Q(\mu_p-\mu_Q)[2(1+M_Q/M_p)^2-1]^{3/2} \times\exp(\mu_Q x)\{1-\exp[-(\mu_p-\mu_Q)x]\}^{-1}. \quad (2)$$

The 90% upper-confidence limit on σ_Q given by Eq. (2) is plotted in Fig. 3 as a function of the assumed quark mass, M_Q, for several choices of the quark-nucleon removal cross section, σ_{QN}.

If the quark is strongly interacting and the production of strange particles is taken as a guide, the production cross section above threshold might be expected to be at most of the order of 0.1 mb. Because the accelerator results[3,4] imply high mass for a hypothetical quark, and because its fractional charge cannot be taken away in collisions with nuclear matter, it seems reasonable to assume that the effective cross section for removal of quarks by energy degradation is less than 15 mb. With these assumptions, a strongly interacting, long-lived, charge-$\frac{1}{3}e$ quark must, if it exists, have a mass such that $M_Q \gtrsim 16$ BeV/c^2. Reducing the assumed quark-production cross section to 0.01 mb, $M_Q \gtrsim 7$ BeV/c^2.

It is a pleasure to thank W. R. Dawes, J. J. Jones, and R. C. Noggle for their help in constructing the apparatus, and K. C. DeLise for assistance in operating the equipment.

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*This work was supported by the National Science Foundation.

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ELECTROMAGNETIC MASS CORRECTIONS IN THE SU(6) SYMMETRY*

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(Received 5 November 1964)

Recently Gürsey and Radicati[1] and Pais[2] have proposed an interesting new theory, SU(6) symmetry, for the strongly interacting particles. In their theory spin and unitary spin are incorporated in the same scheme. This is because the group SU(6) contains both SU(2) and SU(3) as its subgroups. In particular, they have assigned the pseudoscalar octet and the vector nonet to the 35-dimensional representation and the baryon octet and spin-$\frac{3}{2}$ decuplet to the 56-dimensional representation. Some consequences of the SU(6)-symmetry scheme have been investigated,[3,4] and the predictions of the new theory seem to be in agreement with experiments. The aim of this Letter is to obtain further a set of mass relations between the members of various isomultiplets in the limit where the SU(6) symmetry is broken by electromagnetism only. Similar work[5] has, in fact, already been done with the SU(3) group for the octet and decuplet where the electromagnetic mass splittings in these two representations are not related. Since the SU(6) group contains both the octet and the decuplet in its 56-dimensional representation, we expect that the assumption of SU(6) symmetry would relate the electromagnetic mass splittings of the octet and the decuplet and might put further restrictions on the mass relations. These mass relations could then be compared with experimental results, when such information is available. We should mention that the approach of the present work is similar to that of the recent work of Bég, Lee, and Pais,[4] where they have uniquely expressed the magnetic moments of all members of the baryon