References

Baker, M. and Johnson, K. (1969). *Physical Review* (to be published).
Cairns, I., McCusker, C. B. A., Peak, L. S. and Woolcott, R. L. S. (1969). *Physical Review* (to be published).
McCusker, C. B. A. and Cairns, I. (1969). *Physical Review Letters*, **23**, 658.
Yock, P. C. M. (1969). *International Journal of Theoretical Physics*, Vol. 2, No. 3, p. 247.

* * *

Possible Production Mechanism for the Particles Discovered by McCusker *et al.*

P. C. M. YOCK

The University of Auckland, Auckland, New Zealand

Received: 28 *October* 1969

Recently, the author (Yock, 1969) has proposed a six-quark theory of the elementary particles, which theory has been shown (Yock & Johnson, 1969) to allow in principle for the existence of charged particles whose charges (in magnitude) are less than that of the proton. The purpose of this Letter is to comment specifically on a realistic production mechanism for such particles in the light of the recent observation by McCusker & Cairns (1969) and Cairns *et al.* (1969) of lightly ionizing particles in extensive air showers.

The discussion is based on the six-quark theory mentioned above. The reader is referred to the original papers (Yock, 1969; Yock & Johnson, 1970) for the details of this theory, as well as for the nomenclature used below.

We consider a collision between an energetic (one million GeV say) cosmic-particle and an atomic nucleus high in the earth's atmosphere. Normally, some tens of pions are created in such collisions. Thus some tens of bound quark–antiquark pairs may be expected to be created in a typical collision. If the cosmic-ray energy is great enough, one or more of these quark–antiquark pairs may be created with a relative kinetic energy that is sufficient to overcome the strong Coulombic attraction that normally binds them. [We recall here that quarks are assumed to have *large* (and *non-integral*) charges in the six-quark theory.] In what follows we focus attention specifically on the free antiquark of an unbound pair. The Lorentz transformation from the centre-of-mass system to the laboratory system will ensure that its direction is very nearly forward in the laboratory system. Also, in the laboratory system, its energy will be high. We attempt in this Letter to trace the history of such an antiquark (which, we recall, has large *negative* charge) as it traverses the earth's atmosphere.

Because of its large charge it quickly decelerates. As it decelerates it reduces its charge by picking up atmospheric nuclei (or segments of them). This charge reducing process presumably continues until the net charge lies between $+\frac{1}{2}e$ and

$-\frac{1}{2}e$. The end-product that reaches the earth's surface is thus a massive and lightly ionizing particle of the variety that has been discussed by Yock & Johnson (1970). Its arrival at the earth's surface is delayed with respect to the arrival of the leading shower particles, and its direction may be significantly different from them. These features may be not inconsistent with the observations of McCusker (1969).

One qualification of the above scenario is necessary. If the free antiquark created in the original cosmic-ray interaction happens to be of the $\bar{4}$ variety, then it would be annihilated by a type-4 quark at its first nuclear encounter. (We recall here that the quark configuration of the nucleon is $4\bar{2}\bar{2}$ in the six-quark Theory.) The residue of such an annihilation process would be a moderately energetic nucleus with two type-$\bar{2}$ 'unbalanced' antiquarks attached to it. This object would traverse the earth's atmosphere in the manner outlined above. Thus it would decelerate and pick up atmospheric nuclei to become finally a massive and lightly ionizing particle.

A more quantitative description of the above phenomena, together with a discussion of the fate of free quarks created in cosmic-ray interactions, will be reported in a forthcoming publication.

Acknowledgements

The author thanks C. B. A. McCusker and M. H. Rathgeber for discussion.

References

Cairns, I., McCusker, C. B. A., Peak, L. S. and Woolcott, R. L. S. (1969). *Physical Review* (in press).
McCusker, C. B. A. and Cairns, I. (1969). *Physical Review Letters*, **23**, 658.
Yock, P. C. M. (1969). *International Journal of Theoretical Physics*, Vol. 2, No. 3, p. 247.
Yock, P. C. M. and Johnson, R. C. (1970). *International Journal of Theoretical Physics*, Vol. 3, No. 1, p. 80.

Errata

(1) Vol. 2, No. 3 (1969), pp. 319–323. Dr. Browne has stated that he considers equation (15) is 'unnecessary to assume'. Further, he states $(\mathbf{v} \times \mathbf{a}/c)^2 \rightarrow \mathbf{a}^2$ is incorrect and does not follow from (9). A more detailed commentary on *The Implicit Spin Magnetic and Electric Moments of an Electron* is not available at present, but intending readers should take heed. There are a number of trivial miswritings.

(2) Vol. 2, No. 3 (1969), pp. 247–254. *Unified Field Theory of Quarks and Electrons*. In the caption to Figure 2, β_μ should be B_μ.