Using (1) to (5) one easily obtains

$$\begin{aligned} C_1 \vee C_2 &= C_1 \wedge C_2 \\ P \vee W &= P \wedge W \end{aligned} \tag{6}$$

But this implies equivalence of particle and wave concepts using the two-valued interpretation, an undesirable result, since one knows particles and waves are not the same. While the calculus is still quite valid, it does elucidate in mathematical terms the fact that a dilemma is likely to arise if two physical concepts are associated with a single entity.

The problem now looks generally similar to the specific one posed by Carnap (1958) in a mathematical context, and Carnap's solution can be used. That is, one introduces modality operators. If $\Box$ is the modal necessity operator in a revised version of the calculus, and (1) to (5) are appropriately modified, one has, for instance, $\Box(C_1 \rightarrow E)$ but not $\Box(E \rightarrow C_1)$.

Thus one never arrives at $\Box(P = W)$, so there is not strict equivalence between particle and wave in the new calculus. The result suggests, though in no way proves, that the use of modalities and strict implication could be appropriate and have a direct significance in a precise axiomatisation of physics.

Reference

Carnap, R. (1958). *Introduction to Symbolic Logic*, p. 41. Dover, New York.

* * *

Mechanism for Yielding Particles of Non-integral Charge

P. C. M. YOCK and R. C. JOHNSON*

The University of Auckland,
Auckland, New Zealand

Received: 22 *October* 1969

Recently, McCusker & Cairns (1969) and Cairns *et al.* (1969) have reported the observation of charged particles with charges less than that of the electron. The particles were produced in cosmic-ray interactions above 10^{14} eV. The purpose of this Letter is to point out that this observation is consistent with the existence of fundamental particles with masses of only a few GeV, and with charges much greater than, but not integral multiples of, the electronic charge.

The starting point of the discussion is the unified six-quark field theory that has recently been proposed by one of us (Yock, 1969). In this theory the observed particles are assumed to be the 'nearly neutral' bound states of a set of six fundamental particles [we refer to them as 'quarks' for a reason stated previously (Yock, 1969)] whose (bare) charges are g_0, $2g_0$, $3g_0$, $4g_0$ and $g_0 + e_0$ and $4g_0 + e_0$

* On leave from The University of Surrey, Guildford, England.

respectively. Here, e_0 denotes the (bare) positron charge. Given the value of e_0, the magnitude of g_0 is fixed by the requirement that vacuum polarization be finite. This provides an eigenvalue equation for $g_0{}^2/4\pi^2$. Although the precise value of the root of this equation has not yet been determined, it is known (Yock, 1969; Baker & Johnson, 1969) that it must be of order unity. From this we estimate that

$$g_0{}^2 \approx 10^3 e_0{}^2 \tag{1}$$

We furthermore assume, in this Letter, that the root of the eigenvalue equation is such that g_0/e_0 is not an integer. As a result the types of nearly neutral states that are expected to be produced in cosmic ray interactions fall naturally into two classes.

There are those containing just a few quarks arranged so that their g_0's cancel. These, the so-called 'hadronically neutral' states, may be identified with the commonly observed particles. The details of this identification are not crucial to the contents of this Letter and will be discussed in a further publication. We merely quote here two typical examples:

$$\begin{aligned} p &= 4_+\overline{2}\,\overline{2} \\ \Omega^- &= 2\overline{1_0\,1_+} \end{aligned} \tag{2}$$

Here the notation is as follows: 4_+ denotes the quark of charge $4g_0 + e_0$, $\bar{2}$ the antiquark of charge $-2g_0$, and $\overline{1_0}$ the antiquark of charge $-g_0$, etc.

The second class of nearly neutral states is constructed in the following manner. Suppose the solution of the vacuum polarization eigenvalue equation is, for example,

$$g_0 = 30{\cdot}7 \ldots e_0 \tag{3}$$

[Note that this is consistent with equation (1).] Then a nearly neutral state can be constructed from one quark of charge g_0 and thirty electrons. The charge of this bound state would be 0·7 ... times the charge of the positron. A second example from this class is the following state consisting of 746 quarks:

$$X = \overline{31_+}\, \underbrace{4_+\overline{2}\,\overline{2}\; 4_+\overline{2}\,\overline{2} \cdots 4_+\overline{2}\,\overline{2}}_{124 \text{ protons}}\; \underbrace{4_0\overline{2}\,\overline{2}\; 4_0\overline{2}\,\overline{2} \cdots 4_0\overline{2}\,\overline{2}}_{124 \text{ neutrons}} \tag{4}$$

What would the properties of particle X be? It would be stable. Its charge would be 0·2 ... times the charge of the positron. Its binding would be somewhat stronger than that typically observed in nuclei. Its radius would be about 10^{-12} cm, and its mass would be in the vicinity of 200 GeV. Its creation would require a laboratory energy of $\geqslant 10^{14}$ eV. It would be a penetrating particle.

Obviously, many bound states can be constructed in the six-quark theory with properties similar to those of the X. Our proposal is that the particles discovered by McCusker & Cairns (1969) may be such states.

Acknowledgements

The authors have benefited from discussion with E. R. Collins, E. A. Johnson and R. F. Keam. One of the authors (P.C.M.Y.) thanks B. T. Feld and K. Johnson for helpful correspondence.

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