MAGNETIC FLUX LINES AS RELATIVISTIC STRINGS

L.J. TASSIE

Department of Theoretical Physics, Research School of Physical Sciences, The Australian National University, Canberra, ACT.2600

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It is suggested that the relativistic string of the dual resonance model of hadrons is a line of quantised magnetic flux. Accordingly, quarks have magnetic charge. Assuming quarks of magnetic charge $+g$, $-2g$, baryons are composed of three quarks. States of one, two, four or five quarks will not normally occur.

The quantisation of magnetic flux in an amount $\frac{1}{2}(2\pi\hbar c/e)$ and the quantisation of electric charge in units of e follows from requiring the same invariance properties under time reversal of both classical and quantum systems [1]. e is used here for the smallest possible electric charge, not necessarily the charge of the electron. Consider the system consisting of a single particle of charge e moving around an impenetrable cylinder which contains magnetic flux. Time reversal without reversal of magnetic flux is a symmetry of this system classically, but because of the Aharonov–Bohm [2] effect it is not a symmetry of this system quantum mechanically unless the magnetic flux contained in the cylinder is $N\frac{1}{2}(2\pi\hbar c/e)$ where N is an integer.

The action integral for a line of quantised magnetic flux is the area of the surface traced out in space-time by the motion of the line [1]. The equation of motion of a quantised flux line obtained by requiring the variation of the action integral to vanish can be written

$$\frac{\partial^2 x_m}{\partial l^2} - \frac{1}{c^2}\frac{\partial^2 x_m}{\partial t^2} = 0 \qquad m = 1 \text{ to } 3$$

where $x_m(l,t)$ are the spatial coordinates at time t of a point of the string labelled by l, and l obeys the condition

$$\sum_{m=1}^{3} \frac{\partial x_m}{\partial l}\frac{\partial x_m}{\partial t} = 0 .$$

Nambu [3] and Susskind [4] have used a model of a relativistic string in obtaining the Veneziano amplitude for strongly interacting particles. Goto [5], Minami [6], and Goddard et al. [7] have shown that the equation of motion of this relativistic string can be obtained from an action integral proportional to the area of the surface swept out by the string. This suggests that the relativistic string should be identified with a line of quantised magnetic flux. As the action of the quantised flux line is the same as the action integral of the relativistic string, all results of the relativistic string can be obtained from the theory of the line of quantised magnetic flux. The important new feature from this identification of relativistic string and flux line is that the relativistic string has a direction, namely the direction of the magnetic flux. A meson is identified with a finite length of string. But the two ends of the string are not equivalent and can be identified as quark and antiquark. See fig. 1a. Thus the quark is also a magnetic monopole, although rather different from the magnetic monopole suggested by Dirac [8].

The baryon consists of a bound state of three quarks as shown in fig. 1c if it is assumed that there are two types of quarks with different magnetic charges $+g$, $-2g$, where $g = \frac{1}{4}\hbar c/e$. The quark of mag-

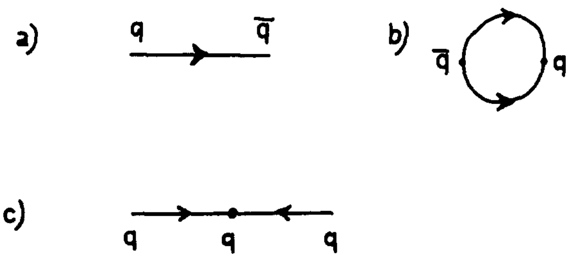

Fig. 1. q and $\bar{q}$ denote quark and antiquark respectively. a) and b) mesons; c) baryon. The arrowheads show the direction of magnetic flux in the quantised flux lines.

netic charge $-2g$ consists of a change of direction of magnetic flux in a line.

With this picture, it is very difficult, if not impossible, to produce a free quark, because it would be the end of an infinitely long string of magnetic flux, and the energy to break the string is only the rest mass of the pion. Similarly states of two, four, five, seven etc. quarks would have infinite magnetic strings attached, and so would not normally be expected to occur. However, if such magnetic monopoles attached to infinitely long strings did occur, they could be detected using a superconducting coil [9]. It should be noted that these magnetic monopoles have no other magnetic field than the strings attached to them. These strings, unlike those of Dirac [8], are observable. Indeed the flux $\frac{1}{2}(2\pi\hbar c/e)$ is that flux for which the Aharonov–Bohm effect [2] is a maximum. Schwinger [10] has previously proposed a model of hadrons in which the quarks are magnetic monopoles of the type proposed by Dirac.

The success of the parton model [11] suggests that in collisions of hadrons, quarks recoil as if weakly bound, although no free quarks are produced. Such behaviour is expected in this picture, as the string attached to the recoiling quark breaks.

Mesons can also be made of a quark of magnetic charge $-2g$ and its antiquark corresponding to the loop structure of fig. 1b. Breaking the two flux lines in such a meson yields a baryon–antibaryon pair.

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