

indicates the existence of a 27-day recurring period which has thus far been followed through four cycles. Presumably, this variation is associated with a solar phenomenon, characterized by this period, which introduces a modulating effect upon the primary cosmic-ray flux. A detailed discussion of these results will be published later.

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Time Reversal, Charge Conjugation, Magnetic Pole Conjugation, and Parity

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UNTIL recently various theorems on the properties of elementary particles and of nuclei were based on parity arguments whose validity was questioned¹ only rarely. It is now known from the theoretical work of Lee and Yang² and from the experiments of Wu, Ambler, *et al.*³ and of others^{4,5} that the parity arguments are often not valid. Recently some of the properties previously derived from parity arguments have been rederived from other symmetry properties such as time-reversal invariance,^{6,7} invariance under the combined operation (*TCP*) of time reversal, charge conjugation, and parity,⁸⁻¹¹ etc. Landau,⁶ for example, has shown from a time-reversal argument that particles cannot possess electric dipole moments.

However, it should be emphasized that while such arguments are appealing from the point of view of symmetry, they are not necessarily valid. Ultimately the validity of all such symmetry arguments must rest upon experiment. For example, if magnetic monopoles exist and if elementary particles are differently coupled to north and to south poles, the conclusions drawn from the normal symmetry arguments would be modified. Dirac¹² has shown that it is theoretically possible that such magnetic poles should exist and that

their possibility of existence might be related to the experimentally observed quantization of electric charge.

In a theory which includes the effects of magnetic poles, the *TCP* theorem would be replaced by a *TMCP* theorem where *T* represents simple time reversal, *M* magnetic pole conjugation, *C* electric charge conjugation, and *P* simple inversion of space coordinates. It is of course possible to express the theorem in various ways, such as

$$(TM) (MC) (PM) = T' C' P',$$

where *T'* indicates an extended time reversal whose definition includes magnetic pole conjugation as well, *C'* represents conjugation of both electric and magnetic charges, and *P'* represents a parity transformation which includes magnetic pole conjugation as well. This method of writing has the advantage that consistency with Maxwell's equations requires that a simple parity transformation be accompanied by either magnetic pole conjugation or electric charge conjugation (but not both) since otherwise a magnetic field would be a mixture of a vector and a pseudovector depending on its mixed origin from magnetic and electric poles. On the other hand, this requirement would equally well be satisfied if the theorem were written as (*TC*) (*MC*) (*PC*). A still different but equivalent procedure leading to a *TMCP* or equivalent *TC'P* theorem could be based on treating the magnetic charges in the fundamental equations as pseudoscalars with respect to both space and time reflections.

Since the experimental observations of parity non-conservation, it has been generally assumed,^{6,7} pending further experiments,⁷ that there should be invariance under the combination of *P* and *C* together in which case from the usual *TCP* theorem, invariance under *T* alone is inferred. On the other hand, with the possibility of magnetic poles, the above *TMCP* theorem would apply and invariance under *P* and *C* would imply invariance under *T* and *M* together and not each alone. If this were the case, the present proof⁶ for the non-existence of electric dipole moments for particles would no longer apply; an electric dipole moment could be proportional to the product of a magnetic pole and a spin angular momentum in which case each would change sign under *TM*, but their product and resulting electric field would not. A particle (such as all presently observed particles) whose magnetic monopole is zero could still possess an electric dipole moment by the above mechanism provided it were differently coupled to fields of north pole particles than to those of south poles. Such a coupling asymmetry, in addition to making possible the existence of an electric dipole moment, would also imply an added possible particle degeneracy since magnetic pole conjugation alone would provide a transformation to a particle of opposite magnetic pole coupling asymmetry and opposite electric dipole moment while the electric charge would be unaltered.

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