Magnetic Monopole

What is the reason that the magnitude of charge of the electron and proton are exactly the same? Why are the charges of all particles integer multiples of 1.602177×10^{-19} coulombs? Is there a principle behind the quantisation of electric charge?

Dirac observed that Maxwell's electrodynamics in the source free region has a subtle symmetry of duality. The equations are invariant when electric and magnetic fields are interchanged. ($E \rightarrow B$, $B \rightarrow -E$). However the known sources for E and B are electric charges and electric currents only. If the electric-magnetic duality symmetry is to be complete there must be magnetic charges or magnetic monopoles, the analogue of electric charges, as well.

In his classic 1931 paper and subsequent treatment in his 1948 paper, Dirac pointed out that quantum mechanics required the magnetic monopole strength g to be constrained by the quantisation relation: eg $= n/2$, $n = 0, 1, 2, \ldots$ where e and g are expressed in dimensionless units of the electric and magnetic charges. (In this unit $e^2/4\pi = \alpha = 1/137$). An elegant derivation of this result was given by Saha (*Indian J.Phys.* 10, 141, 1936) when he noted that a *static* pair of electric charge e and magnetic monopole g separated by d comes associated with a net angular momentum $eg\,\hat{d}$, that resides in the electric and magnetic fields, since the electromagnetic angular momentum density is $r \times (E \times B)$. The quantisation rule follows from the requirement that the angular momentum is quantised in half integral units of $\hbar$ (which we have set equal to 1 in our units). The quantisation of electric charge can be then understood as due to the possible existence of a monopole of strength g somewhere!

In electrodynamics, Dirac had to postulate the presence of sources in the form of magnetic monopoles; there is really no compulsion to have them. However, in theories that are now regarded as possible candidate theory of all forces, it is interesting that they may emerge as inevitable solutions. Gerhard 't Hooft and A M Polyakov discovered them in gauge theories that are in a sense generalisations of the familiar notion of gauge invariance of electromagnetism. Indeed Salam and Weinberg succeeded in combining electromagnetism and weak interactions to construct the electroweak gauge theory. These theories have in addition to photons, that mediate the electromagnetic forces, massive analogues $W^{\pm}$ and Z that play the role of carriers of weak interactions. A grander unification attempted by Georgi and Glashow, Pati and Salam, etc. combines this with the strong interactions and this has more species of force carriers. In such theories, we will have as solutions monopoles that are finite energy composites, made up of these species of gauge fields as ingredients. It is possible to estimate their energy content to be of the order $M_X / e^2 \cong g^2 M_X$, where M_X is the typical mass of the heavy vector bosons that is believed to be about 10^{16} times the nucleon mass. This makes the monopole very heavy and hence inconceivable to be produced in any of our present day or yet to be developed particle accelerators.

Perhaps they were produced in the very early instants after the big bang that initiated our universe, since at that time the universe must have been hot enough to create the monopole – anti-monopole pairs. So spotting a monopole would be like seeing the relic of early universe.

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