A Brief History of the Muon

Sheldon Lee Glashow

In response to "Muons and New Physics" (Vol. 6, No. 3).

To the editors:

My old and dear friend Eduardo de Rafael is a renowned Spanish-French theoretical physicist and a talented amateur pianist. He and his charming English wife live and work in Provence. His superb review of the controversy concerning an apparent departure between observed and calculated values of the muon's magnetic moment leaves little room for criticism, so instead I offer a bit of background.

Carl D. Anderson and Seth Neddermeyer, at Caltech, discovered muons in 1936 by examining the tracks left by cosmic rays as they traversed a cloud chamber flown at high altitude. Anderson, four years before, had discovered positrons, the antiparticles of electrons. Muons were the sixth of what were then regarded as elementary particles, after electrons, positrons, photons, neutrons, and protons. Neutrinos had been postulated by Wolfgang Pauli in 1930, but they were not observed until 1956.

Electrons and muons, generically referred as leptons, are electrically charged particles, as are their neutral counterparts called neutrinos. Today three varieties of charged leptons are known, each with its own neutrino. Leptons do not interact strongly among themselves or with other particles; they seem to be truly elementary. Protons and neutrons, as well as all other strongly interacting particles, are called hadrons. They are not elementary at all, but are made up of quarks which are held together by gluons.

When first discovered, muons were thought to be the particles that had been imagined by Hideki Yukawa in 1934 as the mediators of nuclear forces. Some physicists, including Niels Bohr, dubbed them yukons. But muons were soon found not to interact strongly. Yukawa's hypothetical particles would be discovered among cosmic rays in 1947. They are now called pions. The pion is a hadron made of one quark and one antiquark.

The magnetic moment of any charged lepton is specified by a dimensionless number called g, its gyromagnetic ratio. The equation Paul Dirac famously invented in 1928 implies that $g = 2$, but physicists soon realized that Dirac's "zeroth order" value of g must be modified by calculable quantum electrodynamical radiative corrections. The lowest order contribution to the anomaly was first computed by my thesis advisor Julian Schwinger in 1947: $g - 2 = \alpha / 2\varpi$, for both electrons and muons. The anomaly was a mere tenth of a percent, but its theoretical and measured values agreed.

Since then, theoretical and measured values of the muon magnetic moment anomaly have been determined with ever increasing precision, remaining in lockstep agreement with one another until now. Today they seem to have grown slightly apart. Is this due to experimental error, or computational error, or to physics lying beyond the Standard Model? A recent measurement of $g - 2$ at Fermilab confirms the earlier CERN result, but uncertainty reigns among the most precise attempts to compute $g - 2$ from theory. Because both leptons and hadrons are subject to electroweak forces, higher-order contributions to the muon anomaly which involve virtual hadron loops must be evaluated to achieve computational precision comparable to today's experimental precision, and there's the rub! The strong force, quantum chromodynamics or QCD, cannot be addressed perturbatively, as can the electroweak force. De Rafael mentions two attempts to achieve the required theoretical precision: one is based on lattice QCD, the other on the extrapolation of indirectly relevant experimental data. In the former case, experiment and theory are not in severe conflict; in the latter case they are. Until and unless this theoretical conflict is resolved, we will not know whether or not our Standard Theory needs revision. De Rafael will tell us as soon as the veil is lifted.

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