

# Life in the Higgs condensate, where electrons have mass

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The particle recently discovered by the CMS and ATLAS collaborations at CERN is almost certainly a Higgs boson, fulfilling a quest that can be traced back to three seminal high-energy papers of 1964, but which is intimately connected to ideas in other areas of physics that go back much further. In 1935, Fritz and Heinz London effectively gave mass to the photon in a superconductor, and thereby provided a macroscopic explanation of the Meissner effect – the expulsion of a magnetic field from a superconductor. In 1963, Philip Anderson pointed out another important aspect: A would-be zero-mass Nambu-Goldstone boson in a superconductor is effectively eaten by the photon to become a finite-mass longitudinal mode, which appears as a plasmon in a nonrelativistic treatment. In 1964, realistic models with Lorentz invariance and nonabelian gauge fields were formulated by Englert and Brout, by Higgs, and by Guralnik, Hagen, and Kibble. Finally, Weinberg recognized that a Yukawa interaction with the Higgs field would give masses to fermions like the electron in the fully developed electroweak theory. The Higgs condensate is thus responsible for the masses both of the gauge bosons which are carriers of the weak nuclear force and of fermions like electrons, but in different ways. The radius of an electron's orbit in the ground state of a hydrogen atom is inversely proportional to the electron mass, and similar results hold for other atoms. So if the mass of an electron were zero there would be no atoms, and the formation of ordinary matter would be impossible without the Higgs condensate. (However, about 99% of the mass of an atom or human body results from the kinetic energy of quarks and gluons as they whiz around relativistically inside the protons and neutrons.) It is a true demonstration of the unity of physics that the Meissner effect in a superconducting metal and the short range of the weak nuclear force in the universe have the same origin: In each case the vector bosons (photons or W and Z bosons) grow masses because they are coupled to a field which forms a condensate at low temperature, as the metal is cooled in the laboratory or the universe expands and cools after the Big Bang. Because of a quadratic divergence of radiative corrections to its mass, the Higgs boson appears to require new physics such as supersymmetry, potentially opening the door to a plethora of new effects and new particles, such as a dark-matter candidate. It is also connected to grand unification of the forces of nature, with various high-energy symmetry breakings which presumably involve condensation of Higgs-like fields. Finally, the cosmological constant and dark energy problems are yet again associated with the Higgs field, whose condensation should produce an enormous negative vacuum energy. Instead of acting as an endpoint for physics, and a mere capstone of the Standard Model, the Higgs boson is thus a harbinger of exciting new physics.