Peter Higgs and François Englert awarded 2013 Nobel Prize in Physics

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The 2013 Nobel Prize in Physics was awarded on October 8 to Peter Higgs and François Englert for providing a theoretical description of how the particles of ordinary matter are imbued with mass. The achievement, a landmark in centuries of inquiry into an understanding of matter, has been celebrated across the globe.

In 1964 Englert, along with Robert Brout (who died in 2011), and Higgs independently proposed a model, now known as the Brout-Englert-Higgs or BEH mechanism, which links mass to a proposed new particle. This particle, explicitly predicted by Higgs and now known as the Higgs boson, inspired a decades-long search capped by its detection last year at the Large Hadron Collider (LHC) operated by physicists at the joint European laboratory of particle physics, CERN.

The award is in recognition of the physicists who began an almost five-decade long search to understand how mass exists and thus complete the Standard Model of particle physics, so far the most advanced understanding of the fundamental constituents of matter and their interactions.

A third team of researchers led by Gerald Guralnik, Carl Hagen and Tom Kibble further developed the BEH mechanism, and their work is included in the theory. Their important work was published after Higgs, Englert and Brout, so they did not share in the prize.

While the search for the Higgs has been ongoing for five decades, it is part of the broader search to understand matter at its most fundamental level, what the ancient Greek philosopher Democritus first labeled the "atom" (that which cannot be cut smaller). In its modern form, this pursuit was initiated in 1909 by Ernest Rutherford when he probed the inner structure of a thin sheet of pure gold by firing particles at it.

At that time, it was thought that the fundamental structure of matter had been finalized in Mendeleev's periodic table of the elements, first formulated in 1869. Using only a single variable, the amount of positive charge contained within each element, Mendeleev classified each pure chemical substance into various groupings, or "families," that all held similar properties. Significantly, his formulation also predicted undiscovered elements and their chemical properties. The predictions were born out with the discoveries of gallium and germanium. Germanium's physical traits differed from their expected values by at most 3 percent.

That these elements were not indivisible was demonstrated in 1897 when physicist J.J. Thomson generated a cathode ray, a beam of negative charge. His experiment demonstrated that this negative charge was in fact a stream of negative particles stripped from atoms and projected through space. These particles, constituents of the atom, became known as electrons.

Immediate questions were raised about the internal structure of atoms. Thomson put forward the idea that the electrons were distributed in a uniform sea of positive charge. It was thought that if a heavy, positively charged particle were shot at a sheet of even a very dense material like gold, such particles would simply pass through.

Rutherford set out to test this hypothesis, but the results he found were radically different than expected. While most of the particles did pass through, some bounced almost directly back at Rutherford. He described it as "the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." He concluded that the internal structure of the atom must be a massive, extremely small, extremely dense and positively charged nucleus surrounded by a very low-density sea of electrons.

The discovery of neutrons occurred after it became apparent that the mass of the nucleus was not generated solely by particles of positive charge—protons—but also by some other neutrally charged particle of almost the same size.

Soon after, a particle that was not part of the internal structure of atoms was proposed, the neutrino. It was first postulated by Wolfgang Pauli in 1930 to explain the underlying process of an observed type of radioactive decay that, according to the understanding of the time, couldn’t happen. Although the physics community was skeptical at the time, especially considering the exotic properties the neutrino was predicted to have, it was directly detected in 1956.

An internal structure to protons and neutrons was suggested eight years later. With the growth of larger and larger particle accelerators in the 1950s and 60s, a great many new particles were discovered that were not constituents of the chemical elements: kaons, muons and pions, to name a few. Unlike the periodic table, however, there was very little understanding of how the traits of each particle compared to the other. Moreover, new particles could not be predicted.

In 1964, Murray Gell-Mann and George Zweig proposed that each of the newly discovered particles were in fact not fundamental, but were instead built by combinations of point particles now called quarks. The two most common quarks are dubbed “up” and “down.” Moreover, experiments done at the Stanford Linear Accelerator Center in 1968 revealed that the proton and neutron shared this internal structure of up and down quarks.

With the discovery of quarks, particle physics finally was able to formulate its own “periodic table,” what has become known as the Standard Model. It is an incredibly powerful tool for predicting and understanding physics at the subatomic level. It categorizes every known particle, their properties and how they interact with each other.

What it does not do, however, is explain the difference in masses of each particle. This is most starkly seen when looking at the particles that govern electromagnetism and radioactive decays, the photon and W and Z bosons respectively. According to the Standard Model, these particles should all be massless, yet only the photon has that property. The BEH mechanism explains how this occurs. (See: “CERN confirms Higgs discovery”)

Moreover, the Higgs boson explains the masses of all the particles in the Standard Model. It provides an answer to one of the last major questions in particle physics. In many ways it is the capstone to more than a century and a half’s worth of inquiry into the most basic nature of matter.

This discovery does not conclude inquiry into the nature of mass, far from it. It marks the beginning of a program to characterize the Higgs particle and integrate that knowledge into deep questions that remain. It has been known for some time that the Standard Model, even with the Higgs boson, does not explain how gravity works on the quantum scale. Nor does the Standard Model give insight into the astrophysical phenomena of dark matter or dark energy, both very real things that are extremely poorly understood.

The discovery and confirmation of the Higgs boson marks a new stage in a process which is effectively endless, as human understanding develops, new insights are made and new and more comprehensive physical models of the universe are built.