Wondrous Physics: The Higgs Field

Edward N. Clarke*

On the 4th of July of 2012, physicists from all over the world celebrated the experimental finding of a small particle called the Higgs boson, which enables something called the Higgs field to interact with the fundamental electrons and quarks that compose matter. The interaction creates the mass of the electron and the quark, and hence the mass of us and of the entire universe.

This finding also brings close to completion what physicists have called the "Standard Model," a not very glitzy name for a very important concept. This model explains how the universe works through its fundamental particles and forces (one force, gravity, remains unaccounted for by the Standard Model).

Among the physical phenomena the Standard Model seeks to explain is mass. For life as we know it, mass is critical. For ordinary purposes, we usually take “mass” to be synonymous with “weight,” but advanced physics requires a more rigorous definition. Mass is “a property of a physical system or body, giving rise to the phenomena of the body's resistance to being accelerated by a force and the strength of its mutual gravitational attraction with other bodies.” Without mass, we humans and the entire universe are virtually nothing.

We and the entire universe are made of huge numbers of atoms from a fairly limited number of elements. If we could shrink ourselves to the size of atoms, we would be amazed to find that atoms look to be mostly empty space. Electrons surround an atomic nucleus, but the electrons and nucleus are tiny little specks in this sea of nothingness. The tiny nucleus is larger than the electrons, but nevertheless tiny, and is made from even tinier protons and neutrons, which in turn are made of even tinier things called quarks and gluons. This reminds me a little bit of nested Russian dolls.

If atoms were really only empty space, we should be able to walk through a wall without any trouble. We cannot do that because the empty space of the atom is filled with an invisible electromagnetic field created by the constant motion of the electrons. That, plus the physical laws that govern the specific energies of the electrons surrounding the nucleus, give the atoms rigidity even though they appear to be empty space. All of this is reasonably well understood within the Standard Model. In addition, we now know that mass is conveyed to the electrons and quarks. But, that process is *not* one of adding mass directly to the electrons and quarks.

The leading theory of how we acquire mass was developed nearly fifty years ago by Peter Higgs of the University of Edinburgh, with contributions from several other physicists.

Higgs postulated an invisible field (which came to be known as a "Higgs field") that creates *mass-like* properties. Metaphorically, it is like taking a light weight (assume zero weight) ping pong ball and putting it into a container of molasses. If you push on the ping pong ball, it is like pushing something heavy because of the mucky viscous molasses. So, according to this theory, our mass and that of the whole universe comes about because we are continuously interacting with the Higgs field. We all share a common Higgs field, much like sharing the same gravitational field, thus making us more closely linked than we have ever realized. The Higgs field would have come into existence shortly after the Big Bang, and remained throughout the entire universe since that time some thirteen or fourteen billion years ago.

Until recently, Higgs's theory lacked experimental confirmation. During the first few months of 2012, though, this confirmation was at last made possible by the giant Large Hadron Collider of the *Conseil Européen pour la Recherche Nucléaire*—or, in English, the European Organization for Nuclear Research, usually referred to by the acronym CERN. More specifically, the Large Hadron Collider detected the Higgs boson particle, the key player in the Higgs field. Research will continue to gain more knowledge of the Higgs field and Higgs particle, with physicists hoping that a flood of new knowledge will be pouring forth during the next few years.

The Large Hadron Collider (LHC) that enabled physicists to detect the Higgs boson particle is the largest, most complex instrument of science ever created. The machine and the experiments conducted with it involve 25,000 physicists from all over the world. Located in a ring shaped cavern about three hundred feet underground and seventeen miles in circumference—yes, seventeen miles—the LHC is located near Geneva, Switzerland, lying partly under France and partly under Switzerland.

In that seventeen-mile circle, two beams of protons are sent in opposite directions inside high vacuum circular tubes. Held in the large circular orbit by means of powerful magnets, the proton beams are accelerated to speeds very close to the speed of light (186,000 miles per second), completing the trip around the circle more than 11,000 times per second. The two beams are then aimed at each other to produce proton collisions at energies of seven trillion electron volts. The precision required for the collision of the two beams can be described as the equivalent of shooting two needles at one another from seven miles apart and having the needles hit head-on, tip-to-tip!

There are four collision detectors placed in four different locations along the seventeen-mile circular accelerator. The precision of the detectors has been metaphorically described as "being like someone drinking water from a fire hose at a fire hydrant while successfully separating out a few small grains of gold in that rushing water with the use of one's teeth" (Riordan). The data from the detectors is analyzed by a giant network of computers located all over the world. Two of the detectors were used to detect the Higgs boson: the detector called ATLAS weighs 7,000 tons, and the detector called CMS weighs 12,500 tons. Both of those detectors independently detected the decay products of the Higgs. That independence was important in the process of verification.

How has it been proven that the Higgs theory is correct?

Particle physicists rely on the brute force experimental process of colliding small fundamental particles at very high velocities and energies, which is why they need an instrument on the scale of the LHC. Upon collision, the particles release anything smaller that may exist within. The energies of collision are high enough to create extremely hot soup-like plasmas of the smallest fundamental particles. In particular, if protons are smashed against each other, the quarks and gluons that make up the protons will create a hot plasma of quarks and gluons, often called a quark soup, which is complex and liquid-like.

Then, if one is lucky (and has great skill and great experimental equipment), nature will do what it did right after the Big Bang. Nature made quarks and gluons and then protons and neutrons and electrons, and, yes, even the Higgs field. Higgs's theory holds that if two protons collide with high energy, short-lived heavy quarks are created, which then lead to and create a particle called the Higgs boson. In 2012, researchers were for the first time able to find evidence of these particles.

Nature is very stingy, however; even with the Large Hadron Collider, the experimenters are getting just one Higgs boson for every 10 billion collisions, and that Higgs boson decays very rapidly as the plasma cools and disappears. But the decay products of Higgs are known from the theory, and those products are what is detected and analyzed. Thus, they do not detect the Higgs particle directly, but detect what might be called the "shadow" of the Higgs particle. Three hundred trillion actual collisions leading to an estimated (this author's estimation) 30,000 Higgs particles and rapid decays were detected and analyzed by the worldwide network of computers before the public announcement of success.

A great deal of demanding work remains to be done. Particles in motion gain energy of motion, and Einstein's law of mass and energy (E=mc2), means that the mass increases if the particles have higher energy. The quarks and gluons that make up the protons and neutrons of the nucleus apparently have high energy because those quarks have much more mass than that given by the original Higgs interaction. The protons and neutrons have mass a thousand times greater than that of the electron. The "rest mass" of the original quarks was only slightly larger than the "rest mass" of the electron. In order to create the long sought-after "Theory of Everything" (the "holy grail" that has been sought for years and years), it will be necessary to describe how the gravitons of gravity (the assumed quanta of gravity), or the warped space/time field of Einstein interact with the Higgs boson particle and the Higgs field. That is one goal for the future.

Long before the experimental verification, many called the Higgs particle the "God particle," somewhat by mistake and with unforeseen consequences. The name came from

American physicist Leon Ledermann, who was writing a book concerned with the theoretical Higgs particle and at first wanted to follow the word "God" with the word "damn". He wanted to use the expletive out of his frustration at not being able to find the Higgs experimentally during his research in the early 1990s. His editor convinced him to drop the word "damn", but for some reason the editor may have decided to hang on to the word "God" (Lisee). Perhaps we shall never really know. Peter Higgs does not like the term because it might be an affront to people of religion. Press coverage of this scientific breakthrough continually referred, however, to the "God particle," so we now live with the name and the confusion it can cause.

Here is one instance of that confusion. *The Christian Century* magazine issue of August 8, 2012, reports theoretical physicist Lawrence M. Krauss from Arizona State University stating that the Higgs boson discovery "posits a new story of creation" independent of religious belief. Krauss went on, "Humans, with their remarkable tools and their remarkable brains, may have taken a giant step toward replacing metaphysical speculation with empirically verifiable knowledge. […] If we can describe the laws of nature back to the beginning of time without any supernatural shenanigans, it becomes clear that you don't need God" (Krauss, Lisee).

I have a friend, George Coyne, who is a Roman Catholic Jesuit and an astronomer. He was head of the Vatican Observatory for 25 years. When I asked him for his reaction to the discovery of the Higgs particle and its impact on religion and belief, he suggested reading a paper by another Jesuit, a friend of his: "Tiny Particle of the Creator," by Guy Consolmagno, S.J., currently curator of meteorites at the Vatican Observatory and also an astronomer. The article was reprinted in several places, but originally appeared in the Catholic newspaper *The Tablet*.

In the article, Father Consolmagno states, "Catholic thinkers from Augustine to Aquinas to John Paul II have been at pains to remind us that there are not two different kinds of truth, one for science and another for religion. But, there are two kinds of questions. One sort are those that have simple and often quantifiable answers: how many, how big, what happen first, what happens next? Science answers this kind of question. [Comment: "simple"? really?]. The second kind of questions, though, are those that we continue to ponder all of our lives, even when we already have answers for them: questions about meaning and beauty and love. Rather than answering them, science can provoke us to ask such questions, illuminating them in a new light. When it does that, science enriches our theology and philosophy without pretending to replace it." Consolmagno says of the discovery of the Higgs, "It's a beautiful piece of science, an illustration of how we humans can progress in our understanding of these unimaginable realms of reality. And it is not over yet." Scientists like Professor Krauss may think the Higgs particle gives them the last word, but clergy like Father Consolmagno are not quite ready to concede.

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*Biographical Note

Edward N. Clarke has an undergraduate degree in engineering from Brown University, masters degrees in Applied Physics and in Engineering Science from Harvard University, and a PhD in Physics from Brown. He served in the U.S. Navy during World War II. He is a founder of the early (1950-1965) U.S. semiconductor industry, serving three different companies and originating twelve early inventions. He co-founded the National Semiconductor Corporation in 1959, which after fifty-two years as a public shareholder owned company was sold to Texas Instruments in 2011. Starting in 1965, he served as a dean, and professor, and director of research at Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts, retiring eighteen years ago. During his latter years at WPI, he led world-wide student projects concerned with the use of solar generated electricity, including the design, construction, and racing of road worthy intercontinental solar racing cars. During retirement he has lectured at Brown and at Nichols College and has continued to assist WPI on energy projects, such as WPI's collaboration with Ghent University of Belgium and Brooklyn Poly of NYU) on a net zero energy solar house for an international competition held in China in the summer of 2013. He has been a member of the Worcester Torch Club for 47 years, making nearly twenty presentations on twenty different topics, and has served several terms as an officer. He received the Distinguished Service Award from the Worcester Club in 2007.