Particle Physics Research for a Dummy: A Brief History

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"Nothing Exists Except Atoms and Empty Space, Everything Else is Opinion" said Greek Philosopher Democritus, who lived circa 460-370 B.C. How he came to this understanding, which is pretty close to correct in the broad sense, is pretty astonishing. Speaking of astonishing, at least to me, is where research in the field of sub-atomic particles has now taken us and what some of those "opinions" now are.

One of the most interesting areas is in particle physics. The very aim of this research is to prove the "nature of fundamental particles and the space between them". Democritus said pretty much the same thing.Benefits of Research in Particle Physics, P. Allport et al. www.hep.ucl.ac.uk. The goal is to "explore... the nature of matter and of the forces that bind matter together." Id. But are there practical uses and benefits from such research? We shall see....

For years, the field of particle physics has been ruled by what is known as the Standard Model. Sean Carroll, The Particle at the End of the Universe, Penguin Group, USA, Inc., (2012). What that model tells us is that there are a few particles that make up everything. They are actually smaller than atoms and smaller than the protons, neutrons, and electrons that make up an atom. Physicists have identified twelve particles, six quarks and six leptons plus something known as "force carrying" particles to hold the quarks and leptons together.

There are four "forces" that pervade the physical world and work on these particles. They are gravity, electromagnetism, and what are called the “strong force” and the “weak force”. Gravity we all pretty much intuitively understand. Electricity and magnetism even we non-scientists might think we have a handle on. But what about “strong” and “weak” forces?

The “strong force” is what holds particles together inside atoms. That is what we are used to interacting with in our surrounding material world. Then there is a “weaker” force, a weaker interaction that acts between particles as well. I do not think that is intuitively well-grasped, at least not by me, but that does not mean it’s unimportant. Why? This weak force helps protons convert to neutrons, part of turning protons into helium, from where solar energy comes. Yes, that means the weak force helps the sun to shine.

But scientists will always research and tinker and Standard Models always need tweaking. In the 1960’s another fundamental particle was theorized, the “Higgs Boson”, named after physicist Peter Higgs. A boson is a force-carrying particle. Id. at 28. The theory is that the Higgs Boson gives other particles mass. Without mass every other particle would move at the speed of light, just like particles of light, which are called photons. With no mass, elementary particles could not form atoms which could not form molecules and so on. So no stars, planets, plants, rocks, trees, cars, or people, then, without the Higgs boson. Id. at 30.

And now the [a?] Higgs boson has been discovered. On July 9, 2012, a particle accelerator laboratory in Switzerland announced it had found a new particle that looked a lot like what was expected of and is consistent with the

"Higgs Boson". This search was likened to "looking for a bit of hay in a haystack." Carroll at 175.

And all it took to do it was the "largest, most complex machine ever built by human beings." Id at 15. This is the Large Hadron Collider or "LHC," located near Geneva, and operated by CERN, the European Organization for Nuclear Research. CERN is an acronym for the French "Conseil Europeen pour la Recherce Nucleaire." "Hadrons" are the heavy particles, protons and neutrons. Id. at 48. The LHC began operating in 2009, after unsuccessful lawsuits tried to stop it out of fear its operation "might produce world consuming black holes." Id. More about the lawsuit in a bit. But what good is all this? Perhaps a recollection of a scientist's work from a simpler time may provide some perspective.

Scientists have never stopped "playing" and trying to understand how the world around us works. Michael Faraday was a British scientist who flourished in the early 19th century. His experimentation, for example, discovered benzene, later used to manufacture nylon and plastic and decaffeinated coffee. But he is most famous for his work with electricity. See Michael Faraday-God's Power and Electric Power, *Creation* 12, NO. 4 (September 1990).

Here are examples of scientists at play: [I am being somewhat facetious-this was work both mental and physical]. Earlier experiments by Danish scientist Hans Oersted had shown that running an electric current through a wire caused a magnetic field around the wire. Faraday advanced this work by demonstrating this property called "electromagnetism" could also cause a wire to move around a magnet or a magnet move around a wire. Id.

A perhaps apocryphal story has Faraday demonstrating this phenomenon to a young Queen Victoria. When shown the motion produced by the property of electromagnetism, the Queen is reported to have said "well what good is that?" Faraday's response was said to have been "well what good is a baby?—none but it has all the potential in the world." Faraday's work had shown that electrical energy could be translated into mechanical energy. Electric motors are the result of this type of experimentation. Id. This led to the development of the dynamo which could generate large amounts of electricity for industrial use.

But Faraday kept on experimenting. He wanted to try to sort of work in the opposite direction: instead of using electricity to apply a current to a magnet, he tried to generate electricity from magnetism. He succeeded in this effort by moving a magnet in and out of a coil of wire. This property is known as electromagnetic induction. On this principle works that completely useless device – the electronic transformer. I wonder how many of those are within one hundred yards of us tonight. Faraday was the son of a blacksmith and a maid. By playing with magnets, electric current and wire he could produce moving "toys" of no apparent practical use. Until one kept playing, thinking and tinkering, and then, major industrial power supplies can be generated.

Back to the LHC-here is how scientists play today: the LHC is located in a "circular tunnel, with a circumference of 27 kilometers (17 miles) at a depth ranging from 50 to 175 metres (164 to 574 feett) underground". https://en.wikipedia.org/wiki/Large_Hadron_Collider#cit_note-32.

"Inside the accelerator, two high-energy particle beams travel to close to the speed of light before they are made to collide. The beams travel in opposite directions in separate beam pipes – two tubes kept at ultrahigh vacuum. They are guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets. The electromagnets are built from coils of special electric cable that operates in a superconducting state, efficiently conducting electricity without resistance or loss of energy. This requires chilling and magnets to -271.3° C – a temperature colder than outer space. [-455 degrees F]. For this reason, much of the accelerator is connected to a distribution system of liquid helium, which cools the magnets, as well as to other supply services." http://home.cern/topics/large-hadron-collider.

These detectors that look for the particles are incredibly precise (A boson is a force-carrying particle. Id. at 28. A fermion is a matter-carrying particle. Id.) how precise? The Higgs decays in less than a zeptosecond. That's 10 to the negative 21^{st} power by the way. Here's another example of this type of precision.

The LHC used the same tunnel built for its predecessor, the large electron positron collider, the "LEP". Here is what happened during one of its predecessor's experiments. We know the moon exerts a gravitational pull on the earth. This pull caused the tunnel (remember 17 miles in circumference) to stretch and contract about a millimeter each day. The tiny change in the energy of the particles this caused was detected and had to be accounted for. This earlier collider had detectors leaking electrical currents from a nearby high speed "TVG" train.

Here is a little background on why I picked this topic. My brother Bill is a mechanical engineer. He works at the Fermi National Accelerator Laboratory, or Fermilab as it is known, in Batavia, Il. The lab was founded in 1967. This is the foremost American facility. He has been to Switzerland to work with CERN. The particle accelerator at Fermilab is four (4) miles in circumference compared to the LHC's seventeen (17) miles. Until the LHC was built, the Tevatron, as the accelerator at Fermilab is called, was the most powerful particle accelerator in the world. It was operational until September 30, 2011.

There is no other major high energy research particle collider in the United States. Fermilab's greatest discovery was the "top quark." Quarks are what make up protons and neutrons. The top quark is the heaviest.

My brother's specialty is materials science, specifically dealing with superconductivity- or "super-cooling" materials. This is important as to how particle accelerators work because the interior of the pipes that carry the particles to be smashed or collided must be extremely cold.

This is because the pipes must themselves be surrounded by powerful magnets that bend the protons into the correct path for a collision. But how are magnetic fields produced – remember Faraday – electric current is run through a wire. But strong magnetic fields require strong electric current. Since the current must be so strong, in order for the wires to have as little resistance to electric current as possible they must be super-cold. Otherwise, the high current will melt the wires. How cold are we talking about? The LHC is by far the largest refrigerator in the world. The temperature is minus 456°F or 3.4° above absolute zero.

This process is not without risk because this cooling effect is accomplished with the use of liquid helium. If the helium warms up, the wires could stop "superconducting", causing the electric current to heat the wires, which results in heating of the helium which results in heating up the wires..... and so on. The trade term for this event is a "quench", when the helium gets so hot it turns to gas and explodes.

This dangerous event is not just a theory, it happened in 2008 at the LHC. No one fortunately was injured. This happened only nine days after the LHC began operating and resulted in a re-fit and about a year's worth of work before all was deemed safe again. Id at 77.

As discussed earlier the accelerator operates by smashing protons. All the protons used, which will ever be used there, came from a container of hydrogen about the size of a fire extinguisher. There are enough protons to run the accelerator for a billion years, protons being about one ten-trillionth of an inch in diameter. Id at 84-85.

The protons are travelling almost at the speed of light in the accelerator. During its initial 2009-2011 run, they went at 99.999996 the speed of light or 670,616,603 mph. Not that anyone could be hit with such a beam, because it is encased in sealed vacuum tubes, and is one-thousandth of an inch thick, as they collide. But there has been such an accident.

A Soviet scientist was struck in the face by a much less intense beam at a Russian laboratory in 1978. He saw a bright flash, felt no pain, and survived, as most of the protons passed through him. While suffering no mental impairment, he lost hearing in one ear, was scarred by radiation, paralyzed on one side of his face and has an occasional seizure. Id. at 87.

Now to some practical spin-offs from this type of research. The first application to come to mind is in the field of medicine. Particle accelerators are used in cancer therapy, for both diagnosis and treatment. There are seven thousand (7,000) linear accelerators ("linacs") that have treated over thirty million (30,000,000) patients worldwide. There was a small wing at Fermilab where patients volunteered for experimental testing as well.

Medical diagnostics without particle detection technology is now unimaginable. The PET scan is a well-known example. "PET" stands for "Positron Emission Tomography". The scanner detects the result of a collision between a positron and an electron. The result of this is a creation of a gamma ray photon.

Another major use of this technology is in the field of industry. Superconducting material designed for particle accelerators has found its way into cables used to deliver electricity. These cables can carry more power with less loss than ordinary cables. This would take over for copper transmission lines that are near capacity in highly populated areas.

Particle accelerators also use silicon strip detectors and low noise amplifiers. The detectors look for sub-atomic particles in basic research. Low noise amplifiers "LNA's" try to assist in detecting weak signals in extreme temperatures. These are used in industries that need to understand the dynamics of fluid turbulence like long distance oil pipelines.

Bio-medical industrial uses are also aided by the technologies. Bio-medical scientists decipher proteins by using a particle accelerator called a synchrotron. Effective drugs used to fight, for example, AIDS, have been provided by using particle accelerators to study proteins.

I am sure no one here is familiar with a thing called the World Wide Web. Yes, it was developed by particle physicists so they could quickly communicate with colleagues all over the world.

In a similar vein, the Worldwide LHC Computing Grid is a collaboration among computing centers launched in 2007. Its purpose is to analyze the gigantic 15 petabytes of data from the Large Hadron Collider (a petabyte is a million gigabytes). Any endeavor requiring analysis of large amounts of data can benefit. The collisions produce much data-hundreds of millions of events per second. You would have to fill up a thousand hard drives per second to store it all. Id at 110. While gigantic stores of data are saved, most of it is actually discarded, after passing through a "trigger" designed to detect interesting data. Id. at 111. In order for the scientists to analyze this data, who work at universities across the ocean from Geneva, even larger data sharing platforms had to be devised. This is the Worldwide LHC Computing Grid, known as the "Grid".

Superconducting magnets used in accelerators are also being used in magnetically levitating "mag-lev" trains. These are faster and quieter than wheeled trains and may reach velocities kin to a jet aircraft. Magnetic levitation may also be used by Goodyear to "attach" tires that are spherical to the chassis of a car. They are called the Eagle 360. These tires would move in all directions and would contain all sorts of smart tech. I urge anyone who is interested to google "Goodyear spherical tires."

Particle detection technology can also have a national security application. A particle detector can monitor the contents of a nuclear reactor core, for example.

Super-powerful x-ray beams can create the brightest lights on the planet. These can be used in pharmaceutical analysis, protein structure analysis, materials science, and restoration of works of art.

As an aside, while constructing the site where the LHC is a 4th Century Roman villa was discovered, so there has been some archaeological benefit too.

Because my understanding of what I have just written and read to you would fit inside a Higgs boson, I would like to retreat to the familiar. I had mentioned a lawsuit was filed to try to stop the LHC from becoming operational. For some reason, this was filed in federal court in Hawaii. The two plaintiffs, Walter Wagner and Luis Sancho, sued the U.S. Department of Energy, Fermilab, CERN, the National Science Foundation and 100 "Doe" or unknown entities. The pro se plaintiffs advanced these theories about what could happen if the collider became operational:

"Plaintiffs allege that operation of the LHC could potentially trigger various irreversible processes that could lead to the destruction of the Earth." Sancho v. U.S. Dep't of Energy, 578 F. Supp. 2d 1258, 1259 (D. Haw. 2008), aff'd, 392 F. App'x 610 (9th Cir. 2010). "Plaintiffs posit three separate theories regarding the outcome of the LHC particle experiments: (1) the creation of a runaway fusion reaction that would eventually convert all of Earth into a single, large 'strangelet'; (2) the creation of a 'micro black hole' into which the Earth would fall; and (3) the creation of a runaway reaction due to the formation of a 'magnetic monopole'. (*Id.*) Under all of Plaintiffs' theories, the

LHC particle experiments could lead to the end of all mankind. (*Id.*) Plaintiffs do acknowledge, however, that various competing scientific theories exist regarding the outcome of the subatomic collisions to be performed at the LHC. (*Id.* at ¶ 12.)" Id. at 1261.

The defendants referenced the "Review of the Safety of LHC Collisions' [which] state[d] as its conclusion: "There is no basis for any concerns about the consequences of new particles or forms of matter that could possibly be produced by the LHC." Id. at 1262. While the defendants "were involved with the LHC project ... the construction, operation, and management of the LHC [was] the sole responsibility of CERN, an intergovernmental European agency headquartered in Geneva, Switzerland." Id. The suit was dismissed on jurisdictional grounds, not surprisingly.

Of course the plaintiffs appealed. The U. S. District Court's decision was affirmed by the Ninth Circuit Court of Appeals, which held:

"Wagner cannot demonstrate that he has standing. A plaintiff alleging a procedural injury, such as Wagner, must still establish injury in fact. *See Laub v. U.S. Dep't. of Interior,* 342 F.3d 1080, 1086 (9th Cir.2003). Injury in fact requires some "credible threat of harm." *Cent. Delta Water Agency v. United States,* 306 F.3d 938, 950 (9th Cir.2002). At most, Wagner has alleged that experiments at the Large Hadron Collider (the "Collider") have "potential adverse consequences." Speculative fear of future harm does not constitute an injury in fact sufficient to confer standing. *Mayfield,* 599 F.3d at 970."

"Even if Wagner has demonstrated injury in fact, he nevertheless fails to satisfy the causality or redressability prongs set out in *Lujan.* The European Center for Nuclear Research ("CERN") proposed and constructed the Collider, albeit with some U.S. government support. The U.S. government enjoys only observer status on the CERN council, and has no control over CERN or its operations. Accordingly, the alleged injury, destruction of the earth, is in no way attributable to the U.S. government's failure to draft an environmental impact statement." Sancho v. U.S. Dep't of Energy, 392 F. App'x 610, 611 (9th Cir. 2010).

When plaintiff Wagner was interviewed by a British journalist about his claims he was asked:

"So roughly speaking, what are the chances the world is going to be destroyed? Is it one in a million, one in a billion?"

Mr. Wagner responded "Well, the best we can say right now is about a one-in-two chance."

This astonished the journalist: "Hold on a second. It's fifty-fifty?"

Mr. Wagner explained "Yeah, fifty-fifty...if you have something that can happen, and something that won't necessarily happen, it's going to either happen, or it's going to not happen, and, so, the best guess is one in two."

The journalist, John Oliver, replied "I'm not sure that's how probability works, Walter." Carroll at 189.

The future of research in this area is, to put it mildly, mind-boggling. Particle physicists will look into such questions as why is there more matter in the universe than we can observe. What is this "dark matter" and from where does it come? Is the elementary constituent piece of matter not a particle at all or is it like a vibrating string? Hence the term "string theory." Are there different laws of physics than our Standard Model in other dimensions? If there are other dimensions are there other universes? Id. Chapter 12.

So what good is all this? You never know what will result from basic scientific research. Heinrich Hertz was a German physicist and was the first to produce and detect radio waves in 1888. When asked what his discovery would be good for he said "it's of no use whatsoever." When asked if it had any practical application, he said "nothing I guess". Remember that when you use your cell phone, wireless computer, or microwave oven. Id. at 122.

For what it's worth one economist, Edwin Mansfield suggests public spending on basic science has a return of 28 per cent. That's not too bad. It also can inspire others to scientific careers. Id. People come from all over the world to cooperate and work in peace. It is all because of a natural curiosity about the simple-sounding idea of discovering how nature works. Id. at 277. Art and science cross all human boundaries. Id. at 279.

When asked about this particle physics research during a Congressional hearing in 1969, Robert Wilson, the founder of Fermilab, had this to say:

"It has only to do with the respect with which we regard one another, the dignity of man, our love of culture. It has to do with: Are we good painters, good sculptors, good poets? I mean all the things we really venerate in our country and are patriotic about. It has nothing to do directly with defending our country except to make it worth defending." Id. at 270.