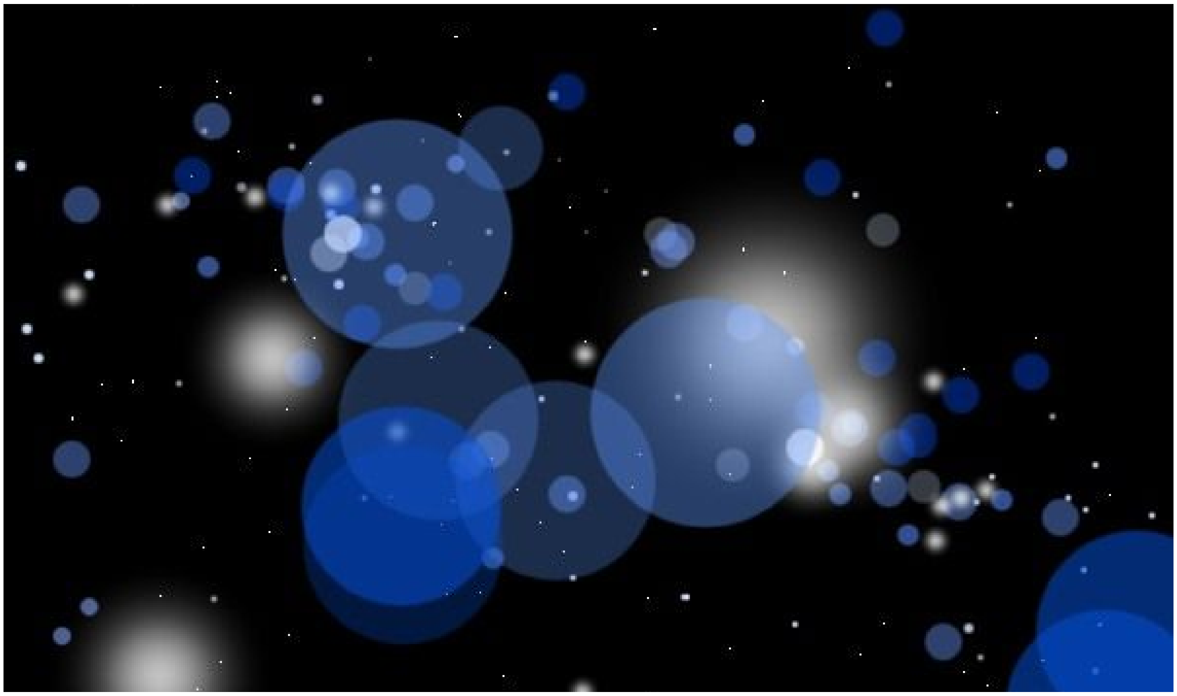
Physics Newsletter

October 2020



Hi guys!

The physics newsletter is back for the new school year, we hope you'll enjoy it! If you'd like to contribute to our next issue, please send an email to the following email addresses by 19th October.

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This edition includes articles on:

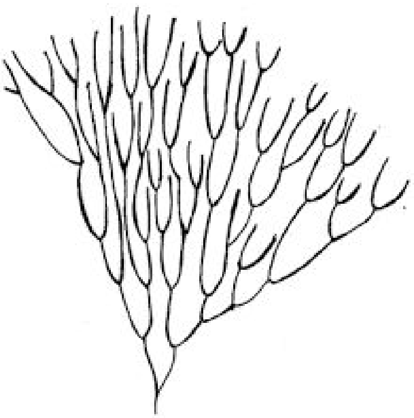
- The physics behind parallel realities
- Particle accelerators

Physics or Fiction? - Parallel Realities

Parallel realities, alternate universes and the multiverse are all common themes in science fiction. These are realities that resemble ours, but are just out of reach; due to being in a far away universe or a timeline that runs simultaneously to our own. Is it possible that these fictitious plot devices have a basis in reality?

Many Worlds and Quantum Mechanics

One way the parallel reality idea manifests itself is through an interpretation of physics' most useful theory - quantum mechanics. Quantum mechanics describes the world of the miniscule- on the scale of protons, neutrons and electrons. It is a theory that is known for being mind-boggling and one of the reasons why is that when certain properties of a quantum object (such as the position of an electron) are measured we get indefinite answers. These can be interpreted as a superposition (or combination) of two different outcomes.



The Many Worlds theory of quantum mechanics solves this murky indefiniteness by postulating that when a measurement is taken, both possible outcomes occur simultaneously, on different branches of reality. It suggests that reality breaks into two different paths when a measurement is taken, one path where one measurement outcome is observed, and another path where the other outcome is observed. A 'measurement' can refer to any interaction between a subatomic particle and its surroundings, therefore if this theory is true, there could be billions of alternate realities as particles interact with their environment constantly.

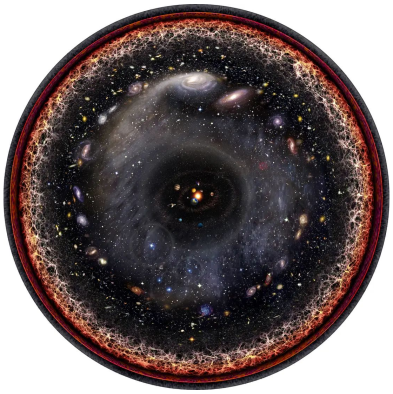
Unfortunately, there is no way of proving this theory to be true or false, as there is no way of communication between the branches of reality, however it is still amazing to consider there could be replicas of each and every one of us on different branches.

Multiple Universes

Another take on alternate realities is the multiverse theory, which envisions multiple universes coexisting side by side as bubbles as part of a wider 'multiverse'. There are two main ways in which this could work.

One is that each smaller bubble universe is similar to our own observable universe, and the 'multiverse' in this idea simply refers to the entire universe as a whole, which is infinitely vast.

An observable universe is the extent of the universe from which we can receive signals, and such a cut-off point exists due to the speed of light. Nothing can travel faster than the speed of light and the universe has existed for a finite period of time (about 13.8 billion years). This means that during the time for which the universe has existed, light (and other electromagnetic radiation such as radio waves) could only have travelled a certain distance - 13.8 billion lightyears. For an observer in space, this results in an observable universe in the shape of a sphere of radius 13.8 billion lightyears, with the observer in the centre. This is due to the fact that if anything, for example a star, outside of this sphere emits light towards the observer, for example Earth, the distance between the star and the Earth is too large for the light to cover within 13.8 billion years. Every location in space has an observable universe around it. In our real universe, the radius of the observable universe is actually about 90 billion lightyears due to the expansion of the universe, however the principle is still the same - this sphere demarcates a dark wall beyond which we cannot see.



This first type of multiverse describes causally disconnected universes, meaning that one of these universes cannot influence another (due to not being able to pass signals between them), however these universes exist within the same spacetime and experience the same laws of physics.

Another multiverse theory depicts a set of bubble universes that each arise from separate big bangs, much like the Big Bang that started our own universe billions of years ago. In this version of the multiverse, it would be possible to have different laws of physics inside each universe, due to them forming independently of each other.

This is possible due to theories about what existed before the Big Bang. One such theory that gives rise to a multiverse is cosmic inflation, in which space expands exponentially for a period of time. During this inflation, the space is unstable and therefore can decay, much like a radioactive isotope. When the decay occurs, energy is released which allows the big bang to happen. Multiple big bangs could therefore occur as space might not decay at the same time everywhere.

There is an even more startling type of multiverse that could possibly exist, in which each universe is described by a different type of mathematical system. This idea comes from the fact that there are some high level mathematical systems that exist and are logically consistent, but do not seem to describe our universe. Some mathematicians and scientists believe that there is no reason for certain systems to be ‘favoured’ (i.e. be real) over others, therefore they must all describe a universe that exists somewhere. Although this is not a completely scientific theory, it is an interesting thought to pursue. -Sai Potturu 13.2

Particle Accelerators

Particle accelerators are one of the most crucial pieces of equipment in the discovery of new physics concepts but what are they and how do they work?

What are particle accelerators?

Particle accelerators are machines which are able to propel charged particles to extremely high speeds, with some accelerators being able to reach speeds that are close to the speed of light (3×10^8 ms^{-1}). In some accelerators, these particles are then collided with either other particles that are travelling in the opposite direction, or a target object.

When the particles have sufficient energy, the energy of the collision can be transformed into new matter (i.e. new particles). This follows Einstein's equation $E=mc^2$, which states that mass is simply a form of stored energy and so mass and energy are interchangeable. The properties of the massive (high mass) particles that are created can be measured, hence increasing our understanding of matter significantly.

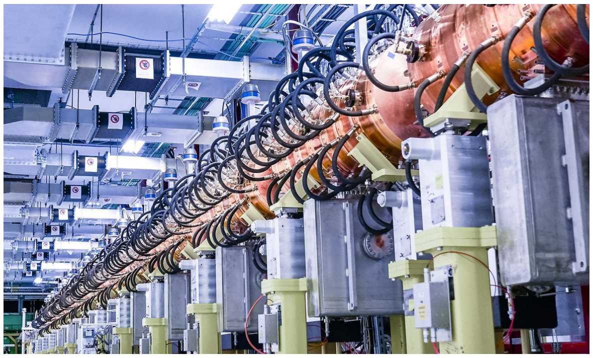
One such particle that was discovered in this way was the antiproton, a particle with the same rest energy and rest mass as the proton, but with a negative charge. This was discovered by colliding high-energy protons with a copper target in Bevatron's accelerator.

Types of Accelerator

There are two types of accelerator: linear and circular. Linear accelerators are those where particles pass once through a linear beam line, whereas in circular accelerators, particles are continuously propelled around a circular track many times.

Circular accelerators have the potential to give particles extremely high amounts of energy, as they gain energy on each rotation. However, the higher the energy of the particles, the stronger the magnetic fields must be to keep them in a circular orbit. This means that as physicists have explored higher energies, accelerators have had to become larger and more expensive.

Circular Accelerator (Super Proton Synchrotron)



Linear Accelerator (LINAC 4)

The ability to give particles such high energies by simply accelerating the particles around the track more times is one key advantage of a circular accelerator. In comparison, in linear accelerators, the only way to reach higher energies is to make the accelerator longer. However, without the need to guide particles around a circular path, linear accelerators don't have to contain such high strength magnets, reducing their cost in this area. High- energy particles also radiate away much more energy in a circular accelerator than a linear one.

How do accelerators work?

Circular accelerators use electromagnetic fields to accelerate and then steer charged particles. There are two key components to this: radiofrequency cavities and magnets. Radiofrequency cavities are metallic chambers spaced at intervals along the accelerator which contain electric fields, alternating between positive and negative charges at a given frequency. This creates electromagnetic waves that can travel in both the forward and reverse direction. Each time a beam of charged particles passes through the electric field in the cavity, the particles gain energy and are accelerated.

The magnets bend the path of the beams of particles, ensuring that they travel in the correct direction. It is crucial that the beams of particles travel inside a vacuum because any air or dust molecules in the path would obstruct the particles, altering their speed and direction, hence interfering with collisions in collider accelerators.

Around the area in which these collisions occur are particle detectors. These can collate information on the particles' speed, momentum, mass and charge, as well as which type of radiation was emitted during a collision, hence allowing the physicists to identify the particles produced in a collision.

The Large Hadron Collider

The Large Hadron Collider (LHC) is currently the most powerful accelerator in the world and it is found in Geneva at CERN (The European Centre for Nuclear Research). Particles travel around a 27km circumference loop at an energy of 6.5TeV , giving a collision energy of 13TeV.

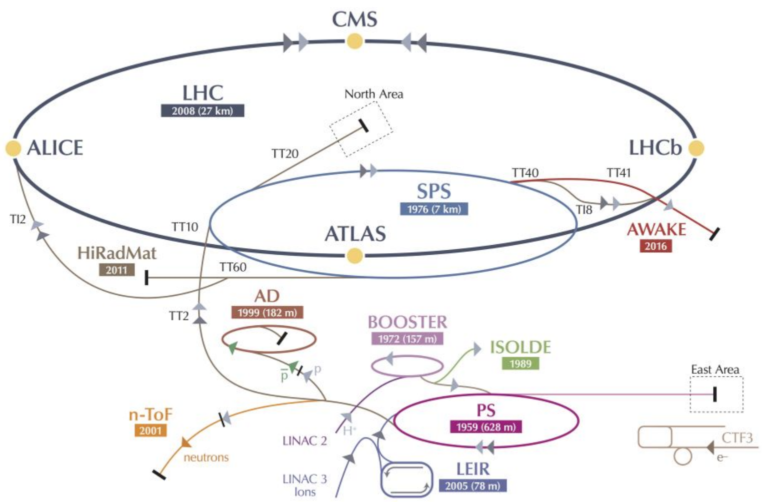
Because the accelerator is able to concentrate this energy at a very particular point, the concentrations of energy gained are close to those that existed just after the Big Bang, meaning that the LHC can be used to investigate the origins of the universe, among many other things.

The main function of the LHC is to accelerate and collide protons, although it is able to collide heavy lead ions too.

For proton acceleration, an electric field is initially used to remove the electrons from hydrogen atoms (1 proton, 1 electron), leaving only a proton. There are approximately 1.2 x10^{11} protons per bunch and 2808 bunches per proton beam.

In order to reach the extremely high speeds of the LHC, a series of successive accelerators is used, each of which raises the energy of the beam of charged particles before passing it onto the next accelerator. This series is: LINAC 2 (50MeV) -> Proton Synchrotron Booster (1.4GeV) -> Proton Synchrotron (25GeV) -> Super Proton Synchrotron (450 GeV) -> LHC.

Here is a link to a tour of the accelerator complex, including the detector zones:

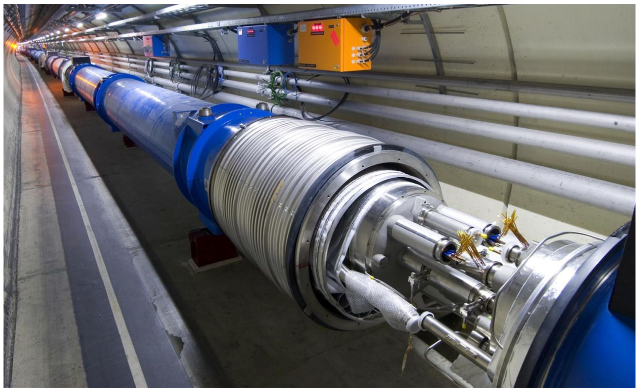


A diagram of all the accelerators, decelerators and detectors at CERN.

https://home.cern/science/accelerators/accelerator-complex/panoramas

Once in the LHC, it takes 20 minutes for the protons to reach their maximum energy of 6.5TeV. Upon reaching this energy, the protons can be collided with other protons travelling in the opposite direction. Typically, 1 billion collisions occur per second in the LHC.

It takes over 9000 extremely powerful electromagnets to keep the particles travelling on the correct course so that these collisions can occur. One type of magnet used is dipoles. These are able to generate magnetic fields of 8.3 tesla, which is more than 100,000 times more powerful than the Earth's magnetic field. To generate a magnetic field of this size, a 11,080A current flows through the magnets, meaning a superconducting coil is necessary so that the current can flow without losing significant amounts of energy to electrical resistance.



Since 2008, when the LHC first came into operation, one of its biggest discoveries has been the Higgs boson in 2012. This was predicted by scientists in 1964, but until 2012 hadn't been formally discovered. This discovery was crucial as it was the only remaining particle of the Standard Model of Physics (which covers the 17 fundamental particles and the forces through which they interact) that hadn't yet been observed.

Future Accelerators

Despite the vast array of accelerators currently in use at CERN, future accelerators are already being designed. This includes the successor to the LHC, the High-Luminosity LHC. Construction of this new accelerator began in 2018 and it is expected to be operational from the end of 2027. The aim of this new accelerator is to increase luminosity by a factor of 10 from that of the LHC. Luminosity is a measure of the number of collisions that occur in a given time, so by increasing this, physicists can study discovered, but relatively unknown phenomena, as well as allowing the potential for currently undiscovered phenomena to be observed. There are also plans for accelerators post 2040, including the Future Circular Collider and the Compact Linear Collider.

One of the main goals for the LHC and future accelerators is to study dark matter. With matter that we know about only accounting for 5% of all matter, studies of dark matter and energy are hugely important and could account for unexplained observations, such as the motion of stars within galaxies. The most common explanation for dark matter is that it is composed of an unknown particle, which it is hoped that accelerators can produce so that it could be studied.

Accelerators in everyday life

Today, more than 30,000 particle accelerators are in operation around the world- with very few being on the scale of the LHC! Fewer than 10% are used for scientific research and only 1% are used in high energy particle physics. Hundreds of industrial processes use particle accelerators. The most common processes include: manufacturing of computer chips/ microelectronics inside smartphones, modification of material properties, pathogen destruction in medical sterilisation and increasing shelf life of food.

Particle accelerators are also crucial in medicine. They have two primary roles here- production of radioisotopes for medical diagnosis and production of beams of electrons, protons and heavier charged particles for medical treatment. One such example is proton therapy in cancer treatment (see newsletter 1), where circular particle accelerators are required to give the protons sufficient energy to be effective against the cancerous cells. Proton-accelerating cyclotrons are also used to produce positron-emitting nuclei which can be used in PET scans, while linear accelerators can be used in the generation of X-rays.

Given the number of ground-breaking discoveries that past accelerators have made, plans for future accelerators at CERN are extremely exciting for scientists, while the development of particle accelerators in other fields means that they may soon become a common sight in everyday life. - Natalie Smith 13.2