20th Century Physics

“Out yonder there was this huge world, which exists independently of us human beings and which stands before us like a great, eternal riddle, at least partially accessible to our inspection and thinking. The contemplation of this world beckoned like a liberation….” – Thank God it did. Over the past century, physicists, namely the owner of this quote, Albert Einstein, have completely revolutionized physics and have transformed the way humanity views the university. The 20th century, deliverer of the Great Depression and both World Wars, also brought six great achievements in the subject of Physics, and these advances have proven to be very valuable in the world of today. The structure of the atom, the discovery of subatomic forces, the vastness of the universe, the history of the universe, quantum mechanics, and Einstein’s theories of relativity are the aforementioned achievements, and each continue to amaze and astound researchers to this day.

The conceptual origin of atoms dates back two-and-a-half millennia ago when the Greeks hypothesized of a smaller structure that made up other larger structures. The irony of the atom’s name was brought out in early 20th century. The word atom means “indivisible,” yet today it can be divided into even smaller parts than just an atom itself. It cannot be the fundamental building block as it used to be thought of because it is composed of even smaller parts (protons, electrons, neutrons). However, it does not end there. Since 1980, scientists have discovered that protons and neutrons are made up of three point-like entities called quarks. These quarks are one-third and two-thirds of the charge of an electron. Science continues to delve deeper and deeper into the structure of matter, dividing it up into smaller and smaller units. Who knows when this process can and will end, but the past century has provided a very clear view of the basic building blocks of all matter, and by doing so, has led to another one of the great achievements of the 1900's: the discovery of subatomic forces.

Gravity, magnetism, and the electric force were the three widely accepted forces in the 18th century. Experiments in the 1800's brought about the combining of the magnetic and electric force into the electromagnetic force, leaving scientists with only two forces. However, true to form, the 20th century led to the discovery of two new fundamental interactions at the subatomic level: the strong nuclear force and the weak sub-nuclear force. The strong nuclear force binds three quarks to form the neutron and the proton. The weak sub-nuclear force can be held responsible for some radioactive decay of nuclei. Now, scientists accept gravity, electromagnetism, the weak interaction, and the strong interaction as the four fundamental forces.

The last century in physics has also expanded the view on the size of the known universe. Thought of only containing hundreds of thousands of stars up to 100,000 light-years away, the universe, thanks to new technology, has revealed how wrong scientists a hundred years ago really were. "Today, astronomers have observed objects that are about 10,000,000,000 light-years away." It may come as a surprise that it was not until the 1920's until the existence of galaxies was discovered. Astronomers have found that many galaxies (up to 10,000) often group together, forming galaxy clusters. Conversely, there are regions in space that hold very few galaxies; these spaces are simply called giant voids. The universe consists of these galaxy clusters and giant voids. The visible universe is thought to hold 50,000,000,000 (fifty-billion) galaxies! The size of the visible universe is thought to be 200 billion trillion kilometers. The 20th century has multiplied our view of the size of the universe by about 200,000 times.

So how did this vast universe come about? Scientists and astronomers have struggled with this question for thousands of years. However, the past century has brought what is perhaps the best answer yet for this question. Scientists believe that the earliest life forms formed about 3 billion years ago as simple microscopic organisms. Even more impressive is the fact that scientists have theorized and calculated a chain of events that they believed to have occurred right after the initial “big bang.” Within one second, for example, positrons and electrons combine and annihilate into photons. For every billion positrons, there is one extra electron, and this electron survives. Within three minutes, the nuclei of lithium and helium are formed. After 300,000 years, atoms form, specifically the atoms of hydrogen, helium, and lithium. The popular theory states that the “universe started as an extremely hot concentration of mass and energy.” As time went by, the universe grew and as a bi-product, “material was dispersed and the universe cooled” (A Century of Discoveries in Physics). Gravity eventually grabbed hold of high concentrations of matter and caused them to collapse into galaxies and stars depending on the scale of the size of the matter. Scientists believe this to have happened about 500,000,000 years after the big bang actually took place. This process of forming galaxies and stars occurs even today, although it is at a slower rate.

Quantum mechanics applies to the world of tiny, microscopic objects such as atoms and electrons. These mechanics behave differently than the classical mechanics of the macroscopic world. One feature of quantum mechanics is uncertainty. The exact position of an electron in an atom is not knowable; however, it can be probabilistically determined. Another feature is discreteness. Using an electron in an atom again as an example, it can only assume particular types of motions (states) and particular values of energy (energy levels). Before the development of quantum mechanics, philosophers believed that because the dynamics of everything was predictable using classical mechanics (i.e. Newton's laws), people's actions were predetermined. Quantum mechanics provides uncertainties, and philosophers now accept that people's actions are not necessarily predetermined.

While the aforementioned achievements may be amazing and impressive, if it were not for Albert Einstein's ambition and research in his theories of relativity, physics as it is known today would simply not exist. At the age of twenty-six, Albert Einstein shattered his fellow physicists' way of thinking. Before his time, physicists believed space as containing a "kind of fixed, invisible substance called the *ether*" (Gardner, 14). They believed it to fill the entire universe, penetrating all material substances. But if it is invisible, how can the movement of anything be measured with respect to it? The answer is simple: by comparing the motion with the motion of a beam of light. In the case of light, the velocity of a beam is not affected by the speed of the object that sends out the beam. Russian astronomers helped prove this in 1955 by measuring light speeds from opposite sides of the sun, one edge moving toward the earth, the other, away. They found that the light from both edges traveled to earth at the same speed. Regardless of its source, the speed of light through empty space is *always* the same, about 3×10^8 meters per second. Physicists in the 19th century believed the *ether wind* to behave just as air does, say, over a moving flatcar, so the velocity of light, measured on a moving object, would definitely be influenced by an ether wind.

Albert Michelson and Edward Morley joined together to attempt to prove this hypothesis correct. Their experiment (the Michelson-Morley experiment) failed. Physicists were so amazed the by the negative results, that they began to form their own theories, one of which was that the earth does not move at all. The best explanation was that the ether is dragged along by the earth, but other experiments ruled this out as well. Albert Einstein, however, had a different thought. The reason Albert Michelson and Edward Morley were unable to detect an ether wind was simple: it did not exist. This theory completely opposed most of Einstein's peers. Consider, for example, an astronaut in a spaceship beside a beam of light. The spaceship he is traveling in is going half the speed of light. If he measured the speed of that beam of light, he would still measure that the beam was passing him at its original speed of 3×10^8 meters per second. Einstein, in his first paper on relativity, points out two "fundamental postulates of his theory:

1) There is no way to tell whether an object is at rest or in a uniform relative motion to a fixed ether.
2) Regardless of the motion of its source, light always moves through empty space with a same constant speed.

Other physicists had played with these two postulates. Lorentz had considered similar ideas, but held fast to an absolute length and time for objects "at rest." Einstein, however, abandoned such a thought. He argued that "there is no meaning to the concepts of absolute length and time" (Gardner, 35). This is the key to Einstein's special theory of relativity.

Rather than try to explain his theory in mathematical jargon, a thought experiment may be more helpful in understanding. Imagine an observer who is standing beside a railroad track. At some distance down the track is a spot, A. At the same distance up the track is a spot, B. Lightning strikes simultaneously at points A and B. How does the observer know these events are simultaneous? Because he sees the two flashes of lightning at the same instant. Since he is midway between the two points and because light speed is a constant, he concluded that the lightning struck simultaneously at A and B.

Now assume that as the lightning strikes, a train is swiftly traveling from point A to B. An observer on the train is exactly opposite the other observer when the lightning flash occurs. Since he is moving toward the flash at B and away from the flash at A, he will see the flash at B first, but knowing that he is in motion, he will consider the speed of light and he too will say that the lightning flashes occurred simultaneously.

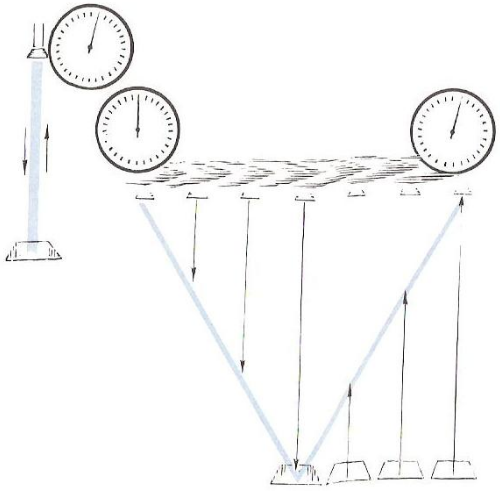
Einstein's postulates, however, leave room to assume that the train is at rest and the ground is moving very quickly under the train's wheels. From this *relative* point of view, the observer on the train will deduce that the flash at B actually did occur before the flash at A. The observer on the ground is now moving toward A and away from B, and he will conclude that flash B actually occurred first. The question of whether or not the flashes of lightning are simultaneous cannot be answered in an absolute way. It all depends on the choice of the reference frame. So the greater the distance between two events, the more difficult it is to actually decide about simultaneity. Einstein's theory makes the bold statement that there is simply no absolute time in the universe that can measure absolute simultaneity. In fact, absolute simultaneity of distant events is a meaningless concept.

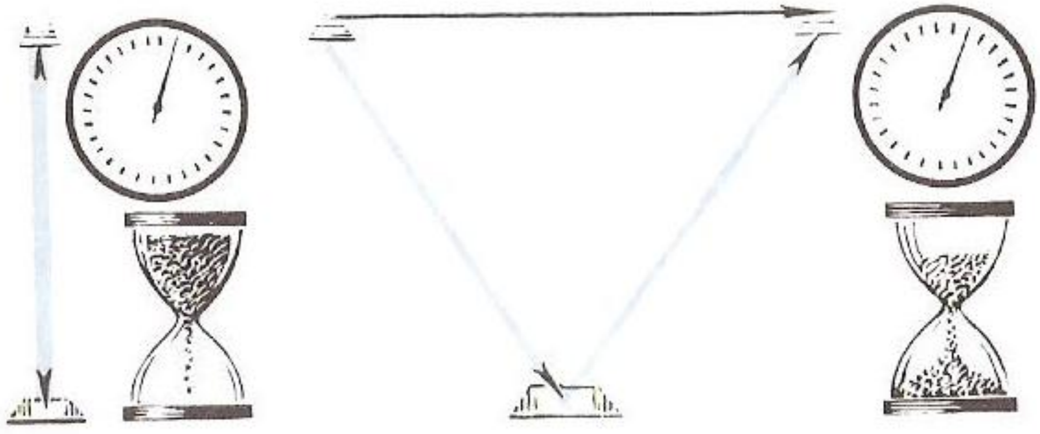
This fall in the concept of simultaneity led to the fall in the concept of time and length as well. When relative speeds are great, changes in length and time are very significant. Imagine, again, two astronauts on two identical ships moving at a high velocity (this velocity will be greater than one-third the speed of light, this being the speed where time and length start to bend significantly). The observer on each ship observes no change in length in his own ship, but when he measures the other ship, he finds it shorter than his own.

In addition to changes in length, each astronaut will find that the clocks on the other's ship are running slower. Say that one astronaut is looking through his spaceship into a porthole of the other spaceship. The two spaceships are passing each other with a speed close to that of the speed of light. As they pass, the non-observing astronaut shoots a beam of light from the ceiling to the floor where it strikes a mirror and travels back to the ceiling again. The observer will see a V-shaped path, while the astronaut who shone the light will simply see a straight line.

If the observer could clock the time it took to travel that V-shaped path, he could divide the length of the path by the time to obtain the speed of light. Say the astronaut who shone the light wanted to measure the speed of light too. He comes up with a shorter length (because his observed light only traveled in a straight line). When he divides this distance by the time it took the beam to go up and down, he will also obtain the speed of light. How? There is only one possible explanation: his clock is slower. This situation is the same either way. If the observer now became the person who shone the light, the previous astronaut would see a V-shaped path and conclude that the other astronaut's clock is slower.

It cannot be deduced that one of these observations was true and one was false. Each is true relative to the observer making their different measurements; as in the train example, to his frame of reference.





(Gardner, 42-43)

If length and time are both relative, and an object’s inertial mass is measured by the force it takes to increase its speed (distance per unit time) by so much per unit time, then inertial mass is also relative. This helps explain why no object can increase its velocity to the speed of light. As, say, a rocket-ship moves faster and faster relative to someone standing still, its relativistic mass keeps increasing proportionally to its decrease in length and time. This will require a much greater force to keep it accelerating, and as the ship moves even faster, the force it takes to accelerate constantly increases. If the speed of light were reached, the observer on the ground would say that the ship had disappeared, yet had acquired an infinite mass and exerted an infinite force with its motors.

Although nothing itself can outrun light, outside an inertial reference frame there are many ways that speeds faster than that of light can be observed. If two ships pass each other at three-fourths the speed of light, an observer on the earth will measure the two ships as passing each other with a relative velocity of one and one-half times the speed of light. However, for the people inside the ship, they would calculate the relative speed of the ships to be less than that of light, thus not exceeding the speed of light. The speed of the ships relative to each other, as seen from the earth, is x plus y, where x is the speed of one ship relative to the earth and y is the speed of the other relative to the earth. As seen by an observer on either ship, the speed of the other ship is

$$(x + y) / (1 + (xy / c^2)),$$

where c is the velocity of light.

Another important concept, which gives birth to the equation Albert Einstein is most famous for, is that under certain conditions mass will change to energy and vice versa. When coffee is made, it gains mass as it heats and loses mass as it cools. These changes are too small to be calculated into any physics. However, the change from mass to energy is not so infinitesimal when a hydrogen bomb explodes. The equation that shows the relation of mass to energy is well-known around the world thanks to Einstein's discoveries: $e = mc^2$, where e is energy, m is mass and c is the speed of light.

Einstein's theory of relativity has been tested thoroughly over the past century, and it would be hard to find a physicist today who disagreed with it. His general theory of relativity provides great insight into the nature of gravity. Heavy masses, such of those as the earth and the sun, cause space-time to curve. An object moving in this space-time would no longer move at a constant speed in a constant direction, it would accelerate. Since forces are defined as things that cause acceleration, the curvature of space-time is accepted to be gravitational force's source.

The 20th century undoubtedly brought new ways of thinking and new ways of analyzing phenomena. Although the discoveries in the 1900's have provided astonishing ideas and insight into humanity's view of the world, these have also left room for the physicists of today to further study each of the six major accomplishments, and who knows if by doing so, they will make even more impressive discoveries of their own.

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