Shoulders of Giants: The Scientific Influence of Isaac Newton

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Personal Life

Sir Isaac Newton was a highly influential English scientist who paved the way in mathematics, physics, chemistry, astronomy. Not only was he a key figure in the scientific revolution, he is also famous for many remarkable talents and observations. Newton is best known for his discoveries on optics, universal gravitation, the laws of motion, and the development of calculus.

Newton was born in Woolsthorpe, Lincolnshire at Woolsthorpe Manor on Christmas Day, 25 December 1642, according to the Julian Calendar (NS 4 January, 1643). Newton attended The King's School in Grantham and excelled in his studies receiving top rankings from an early age. His mother was widowed again and wanted to make a farmer out of Newton, which he had no passion for. The master of The King's School urged his mother to send him back to school to further his education, Newton continued to demonstrate his talents by creating sundials and windmill models.

After completion of his preliminary education at The King's School, Newton went on to Trinity College, Cambridge in 1661. He paid for his education by being a Sizar for a few years, until he received a scholarship that would pay for four more years of education. Upon his arrival, the Scientific Revolution of the 17th century had already made way at Cambridge through monumental astronomers; Nicolaus Copernicus and Johannes Kepler. During his time at Cambridge University Newton became highly interested in mathematics, optics, physics and astronomy. Cambridge used the teachings of Aristotle's philosophy while Newton attended the campus. However, he was more interested in the theories of modern philosophers such as Descartes, and astronomers such as Galileo and Thomas Street. While attending, the Great plague hit and temporarily closed the campus, Newton returned to Woolsthorpe, which ended up being quite beneficial. He used this time away from Cambridge to focus on the method of infinitesimal calculus, set foundations for his theory of light and color, and gained significant insight into the laws of planetary motion. His observations during this time ultimately led him to the publication of *Principia*. It is also said the famous "apple incident" occurred during this time. Although it is mostly believed to be a myth, the theory of gravitation is supposedly due to Newton witnessing an apple's fall from a tree. In his early years at Cambridge Newton created a notebook *Quaestiones Quaedam Philosophicae* where he kept a journal of natural and mechanical philosophy where he would then test his experiments on each question that he had. Newton eventually returned to Cambridge and was elected as a fellow of Trinity, although he was not recognized as an extraordinary student. Two years after his return at Cambridge he was appointed second Lucasian professor of mathematics. At the young age of 27 Newton received his Masters of the Arts degree from Cambridge and was elected Member of Parliament for Cambridge University in 1689.

Although Newton had already achieved countless scientific accomplishments, he did not stop there. Newton's creation of the reflecting telescope ultimately led him to becoming a fellow of the Royal Society in 1672. In 1696 Newton moved to London when he was appointed the Warden of the Royal Mint, then soon after became the Master of the Royal Mint in 1699. He held this position until his death in 1726. He was said to be very dedicated and took his duties very seriously. Newton and Robert Hooke had an ongoing bitter rivalry, stemming from either jealousy or competition. Hooke had made accusations that Newton had plagiarized his first edition of Principia and they had an ongoing battle until Hooke retired in 1703, when Newton finally became the President of the Royal Society. In 1705 Newton was knighted by the Queen

Anne in Cambridge, which would be one of his last greatest triumphs, although his legacy would continue to live on.

Personality

Isaac Newton once said, “I can calculate the motion of heavenly bodies, but not the madness of people”. He was born only 3 months after the death of his affluent father. His mother eventually remarried, and it is said that Newton was not fond of his new stepfather, the Reverend Barnabas Smith. When Newton was three years old his mother moved to another town with her new husband, leaving him to live with his grandmother, Margery Ayscough. He hated his stepfather, which may have led to the aggressive and antisocial behavior prevalent throughout his life. Due to his mother’s extended absence, Newton did not have much of a childhood. Upon her return when he was 10 years old, she took him out of school to become a farmer. He failed miserably at farming. Newton probably began to develop aggression issues due to the trauma of feeling that his mother had abandoned him. Some scientists have argued that his intellectual ambition was partly due to a perceived need of regained confidence. Regardless of specific effects, his mother was absolutely an overshadowing figure in his life.

Newton’s theological ambitions and anti-Trinitarian beliefs possibly developed because he longed to replace the lack of parental love with the love of God, but also viewed Him as a new rival. In Newton’s writing, he referred to himself as Jehovah, the holy one. Newton’s religious views lead him to study the nature of the world, and he believed that ancient philosophers and religious leaders had gained insight into the true nature of the universe. In the eyes of Isaac Newton, worshipping God was a fundamental sin. He rejected many doctrines of the Orthodox Church, and did not believe people went to either heaven or hell after death. He did not believe in pre-existence of Christ, but saw God as creator. Newton spent a great amount of time studying the bible trying to discover hidden messages potentially within. “He estimated that the world would end no later than 2060”.

Looking at the national survey of families and households, there is range of sociability behavior for adults who grew up without one or both parents. Compared to those raised with parents, they have less frequent social interaction with relatives, and the difference is greater among those who lived apart from both parents. In 1662, he admitted to have physically abused his sister, and purportedly made threats of arson to his mother and stepfather. Although, William Stukeley, one of his first biographers, remembered having seen him laugh often and said he possessed “natural pleasantness of temper”. He was considered reclusive, keeping a small circle of acquaintances later in life. He stayed in the company of close friends like the Swiss mathematician Fatio de Duillier, and his half-niece Catherine Barton. The extremely socially inept behavior continued throughout his whole life. There is no evidence that Newton was ever involved in a romantic relationship with either a woman or man. He devoted his entire life to studying and discovering incredible things, commonly staying up late and eating very little. Often absorbed in thought, Newton did not care or pay attention to things many things surrounding him.

Newton famously suffered from multiple nervous breakdowns during his life, caused by both professional disputes and personal loss. The breakdowns were so severe that he experienced paranoid delusions and even sent threating letters to friends and colleagues. As if this weren’t enough, he also suffered from intense insomnia, poor digestion, and deep depression. Characteristic of newton’s personality was his remarkable fear of critique, which resulted in a hesitation to publish new work. He developed his vision of Calculus earlier than Gottfried Wilhelm Leibniz, but published his work later. When colleagues insinuated he may have stolen these ideas, Newton became offended enough to threaten completely leave the scientific community. Those who worked with Newton described him as very fearful, cautious, and immensely suspicious of others. Many of his personality traits have led psychologists to speculate that he may have suffered from a number of psychological disorders, including manic-depression, obsessive compulsive disorder, and Asperger's syndrome. However, despite an emotionally distressing childhood and a number of obvious personal issues, Isaac Newton was still able to achieve more in his lifetime than almost any of his contemporaries, and many of these have survived the test of time and held their place in the world of physics.

Optics

While still a student at Cambridge in 1664, Isaac Newton began to read the respected works of Robert Boyle and Robert Hooke on optics and light. These topics peaked Newton's interest, leading him to inspect the phenomena of color and optics (Hall, 2014). Although he may have begun his own research into the nature of light while still attending Cambridge, the majority was certainly completed during an 18-month hiatus, after the school closed temporarily because of the Great Plague that had been devastating England

Utilizing a series of precise experiments and observations, including his *experimentum cruces* (Figure 1), Newton found proof of his hypotheses on the composition of light (Weisstein, 2015). The famous crucial experiment let a narrow beam of sunlight into a dark room, allowing it to pass through a prism and break into the color spectrum on a board with a small aperture. This adjustable opening allowed a chosen color to pass beyond the board, into another prism. The second prism would refract the color to another board, and while it retained the same angle of refraction, the color was never further broken apart (Westfall, 2014). The primary purpose of this experiment was to show that visible white light is composed of different colors; it is heterogeneous. However, these colors are primary and cannot be broken down further; they are homogeneous. Newton also demonstrated that colors of the visible light spectrum correspond to an observed and quantifiable degree of refraction. When a beam of colored light was continuously refracted through a number of prisms, the angle at which it was refracted remained the same.

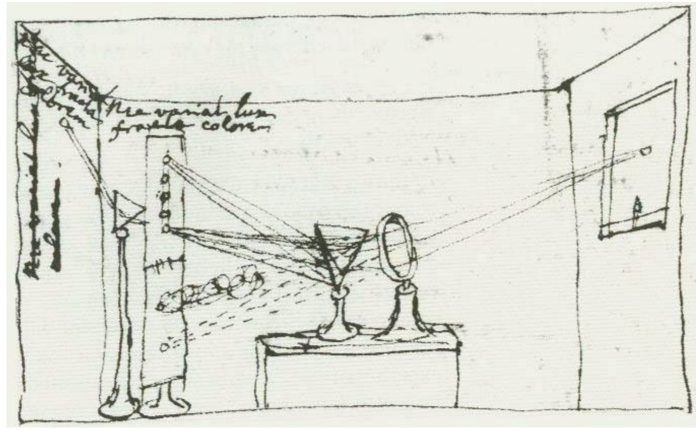

FIGURE 1: NEWTON'S ORIGINAL SKETCH FOR HIS CRUCIAL EXPERIMENT

A common issue with refracting telescopic lenses at the time was that of chromatic aberration, also known as color fringing. Chromatic aberration is a problem that occurs when a lens is unable to focus different wavelengths of color at the same position in the focal plane, giving the image a fuzzy appearance and something of a colored outline. Newton knew that this phenomenon was linked to his research on light and color, and creation of an alternative would aid his theories on white light refraction. Because it was thought chromatic aberration could not be eliminated from lenses, he turned to the concept of a reflecting telescope as an alternative and constructed the first one in history (Figure 2) (Isaac Newton, 2015). The basic design of Newton's

FIGURE 2: NEWTON'S ORIGINAL REFLECTING TELESCOPE

reflecting telescope is still utilized today, and remains perhaps the most widely used style of telescope for amateur astronomers.

It should be noted that Newton's work with light was greatly influenced by his belief that light was corpuscular; composed of immutable particles of matter. We know today that light acts as both a wave and particle, but a photon is not exactly what Newton had in mind and the overwhelmingly accepted theory at the time was that of light travelling and behaving as a wave. Although views of light as generally corpuscular greatly influenced his incredible discoveries on color, they certainly contributed to the conflicts between Newton and the greater scientific community at the time (Westfall, 2014).

The Royal Society took notice of the reflecting telescope and asked for a demonstration in 1671. The attention encouraged Newton to publish his notes on optics, light and color the following year. However, the response was only partially positive. Among the loudest dissenting members of the Royal Academy was Robert Hooke, who considered himself a master in optics and held strong that light was composed of waves. Hooke wrote a spiteful and condescending critique of the young and relatively unknown Newton, attacking everything from his methodology to the seemingly proven conclusions. Although others had questioned the work, including Christiaan Huygens, Hooke's opinion stood out due to his association with the Royal Society and great respect in the field of optics (Isaac Newton, 2015). Newton went into a rage, rabidly defending his theories while attempting to publicly humiliate his newfound arch nemesis. It is this exchange that sparked a famous rivalry between the two natural philosophers.

After the dramatic conflict surrounding his first paper had partially subsided, and only because he thought his theory of color had been accepted by some critics, Newton once again began studying and writing on optics. In a paper examining the color phenomena in thin films, he sought to explain the colors of solid bodies by showing light can be analyzed by reflection as well as refraction. Within this work, he discovered the concentric colored rings appearing in the very thin film of air between a lens and flat sheet of glass—now aptly named Netwon's rings—including the change of distance between rings relative to the thickness of the film of air (Westfall, 2014). Ironically, the concentric rings named after him are a product of the same wave nature of light that Newton disagreed with. Either way, this paper was sent to the Royal Society along with another on the properties of light. The content of this attached work once again ignited conflict between rivals.

Robert Hooke made claims that Newton's second paper contained ideas that had been stolen from him. Still utterly unable to positively respond to criticism, Newton threw yet another tantrum. However, the situation with Hooke was kept relatively under control through the exchange of some passive-aggressive correspondence. It was the addition of other dissent, conflict, and personal turmoil that pushed Newton to a breaking point. Additional exchanges on the theory of colors were taking place with both English Jesuits in Liege and respected continental scientists. Between their critique of his methods, insinuation that his conclusions were mistaken, and the aforementioned conflict with Hooke, Isaac Newton underwent a complete nervous breakdown. This, combined with the death of his mother, led to a six year withdrawal from almost any intellectual correspondence (Westfall, 2014).

Although the majority of *Opticks* had been written before 1692, its release was delayed until 1704, the year after Robert Hooke's death. The book consisted of some revised lectures, his 1675 paper, and a minor amount of additional material. Perhaps because he waited until the majority of his critics had died, the *Opticks* became Newton's most widely read work. Beyond the popularity of the contents, it practically created a model for experimental physics throughout the 18th century. Despite the melodramatic conflict surrounding his work with light and color, Newton inadvertently changed the scientific process through his optical research. The utilization of definitions and principles, combined with the use of propositions, theorems, and proof by careful and quantifiable experiment set a new standard for physics that has led to the rigor of modern scientific research.

Mathematics

Mathematics took up an extensive amount of Newton's time. "The origin of Newton's interest in mathematics can be traced to his undergraduate days at Cambridge. Here Newton became acquainted with a number of contemporary works, including an edition of Descartes *Géométrie*, John Wallis' *Arithmetica Infinitorum*, and other works by prominent mathematicians." Hatch, R. (1999, November 30). During the years of 1665 and 1666, Newton made so many discoveries that this time period has been called Isaacs "Anni Miracles" meaning year of miracles.

This was the period during which, having been sent home from college because of the Plague epidemic, Newton occupied his time by inventing calculus, discovering the chromatic composition of light, and conceiving of the inverse-square law of universal gravitation. Of course, it must be remembered that in later life Newton was embroiled with priority disputes, most notably with Robert Hooke over optics and the inverse-square law of gravity, and with Leibniz over the Calculus. Thus, it was always in Newton's self-interest to place his discoveries as early as possible. The documentary evidence suggests that, at least with regard to mechanics and gravitation, his ideas hadn't actually reached a coherent state until much later, around 1685-1687, when he was actually composing the Principia.

Newton supposedly composed the mathematical inverse square law. This law states that energy dispersed equally from its source without limit will lose or gain potency depending on the distance from the source. The specific energies that apply to Newton's inverse square law include gravity, electric fields, light, sound, and radiation. The way Newton represented this loss of concentration of energy is $I=P/A$ where I is equal to the observed energy's intensity or concentration, P is equal to the total power output of the source, and A represents the surface area of a sphere of radius r is $A=4\pi r2$. A practical use for this in today's world is that a photographer can move closer or farther away, from the source they are attempting to capture, in order to change the intensity of the photo without changing the exposure time. In retrospect, the photographer can increase the exposure time by 4 to increase the intensity of the source 2 times.

Another important and notable discovery Newton made was his advancements on the Binomial Theorem, but there is common misconception. Newton was not the first to describe a formula for binomial expansions, or multiplying out any expression of the form $(a + b)n$. We know, for example, that Islamic mathematician al-Karaji (d. 1029) constructed a table of binomial coefficients up to $(a+b)5$ (that is, Pascal's triangle), and later Muslim mathematicians credited him with discovering the formula for the expansion of $(a + b)n$. Furthermore, in a now lost work, Omar Khayyam (1048-1131) apparently gave a method for finding nth roots based on the binomial expansion and binomial coefficients. Ancient Indian and Chinese mathematicians also knew the binomial theorem. And in Europe, already a century before Newton's birth, Blaise Pascal's Treatise on the Arithmetical Triangle provided a handy way to generate binomial coefficients. All of these methods for binomial expansion, however, work only for positive integer values of n.

Newton discovered a formula that works with not only a few numbers, but rather every single whole number and every single fraction in the number line. This formula is (a+b)n = an + nan-1b + [n(n-1)an-2b2] / 2! + [n(n-1)(n-2)an-3b3] / 3! + . . . + bn. This is a very useful discovery because it "generalizes Pascal's work with binomial coefficients and expansions far beyond the limits of his triangle." In addition, it "develops the idea of infinite series as a basis for calculus and establishes the need for mathematical rigor."

As with many of his breakthroughs, Newton battled other notable mathematicians concerning the creation of new mathematical concepts. He claimed to have discovered calculus sometime between 1665 and 1666 but as stated earlier, he didn't document his discoveries until around 1687. In 1684, a continental mathematician by the name of Gottfried Leibniz happened to publish a paper showing that he had discovered calculus, thereby making him the official discoverer. Each man wanted to be known for the incredible work, and each had a fair argument. The conflict that developed between Newton and Leibniz was no struggle between two mismatched enemies contesting over the rights to use scientific material, as in the Newton-Flamsteed dispute; nor was it based upon jealousy and petty rivalry. Leibniz was a world-class intellectual who had blossomed from an early age.

"It may be argued that there was insufficient room for two such geniuses living simultaneously and that a conflict was inevitable." White, M. (1997). Newton is still one considered one of the smartest and accomplished physicists/mathematicians that has ever lived and was one of the greatest contributors to math and science as we know it today. We now know that Newton and Leibniz discovered calculus each on their own behalf. Rather than assuming one stole the idea from another we now understand the ways each man discovered calculus were entirely independent of one another.

Mechanics & Gravitation

FIGURE 3: ILLUSTRATION OF ISAAC NEWTON

Newton's work in the field of classical mechanics was arguably some of the most revolutionary and influential work of the seventeenth century, and some might argue, quite possibly some of the greatest scientific contributions of all time. In his book titled *Philosophiae Naturalis Principia Mathematica* or better known as *Pricipia* that he released in 1687, Newton developed the basic principles of modern physics along with the concepts of universal gravitation, and the laws of motion, which have remained at the forefront of science for centuries to come.

Newtonian mechanics provided an explanation for a wide range of celestial and terrestrial phenomena. These mechanics were the study of causal relationship, in the natural world, between force, mass, and motion. Newton developed a set of universal principles that were both elegant and very simple to help predict and explain the motion of objects in the natural world. In the *Pricipia*, Newton built upon some other works by great mathematicians and philosophers such as Aristotle, Galileo, Descartes and Kepler, without whom none of Newton's work could have been possible. Perhaps it was best summed up by Thomas Reid in his book *Philosophical Works* when he said "Sir Isaac Newton, the greatest of natural philosophers, has given an example well worthy of imitation, by laying down the common principles or axioms on which the reasoning's in natural philosophy are built. . . . [In this way,] a solid foundation is laid in that science, and a noble superstructure is laid upon it, about which there is now no more dispute or controversy among men of knowledge than there is about the conclusions of mathematics (Reid, 1967).

Among the many theories in his book there were three that stood out the most and have shaped the world as we know it. These have come to be known as Newton's Laws of Motion. The first of these laws states that "An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force." This law is often called the "law of inertia". According to some this law had already been in print for almost 45 years in a book released by Pierre Gassendi called *De Motu Impresso a Motoe Translato*. However, it was Newton's law that introduced the idea of force, and that was the key. The reason this law is so important is that it allows us to know with a certainty how things will react in our world at any given time. This has helped us immensely in all areas of our society such as safety, astronomy, engineering, architecture, air and space travel. Under his first law a moving object's inertia is related to the speed of the object as caused by the net force acting upon it and the mass of the object. The greater the speed of a moving object, the more inertia it has (Figure 4). An objects mass depends on the kinds and number of atoms contained in the object. The greater the mass of a moving object, the more inertia it has. Newton's first law leads directly into his second.

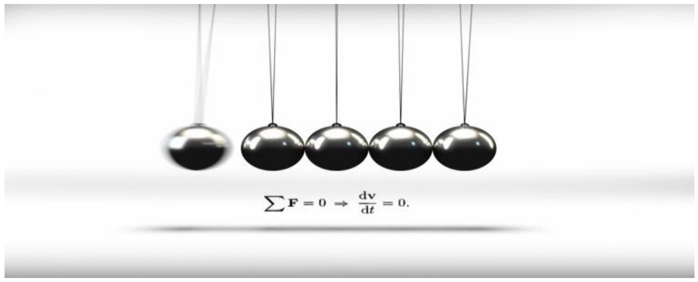

FIGURE 4: REPRESENTATION OF NEWTON'S FIRST LAW.

In Newton's second law he states "The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object" and was originally stated as F= rate of change of momentum, and is better known as F=ma (Figure 5). This was not only one of the most important rules of nature, it was also important because it introduced one of the most important fundamental concepts in science and that is mass. The more mass an object has the more difficult it is to change its state. The mass of an object is a key factor in determining the effect of force upon an object. Mass is one of the factors that inhibits acceleration and motion. It also gives us a mathematical definition of the relationship between net force and acceleration. Yet, mass is not the only influence on acceleration, there is also net force. Net force is directly proportional to acceleration, whereas mass is inversely proportional to acceleration.

There are other factors to consider when one is implementing these laws such as friction. Friction is a force that acts on materials that are in contact with one another. The type of materials in contact affects how much friction occurs. Friction, similar to mass, works to decrease the acceleration of an object and can be caused by both liquids and fluids. You can see this affect when trying to slide an object over ice, compared to sliding an object over sand or gravel. One of the biggest changes this law had was it completely changed the understanding of the effect on gravity on a free falling object. This idea was being worked on by Aristotle and Galileo but they were unable to explain why gravity worked the same on falling object, this is when Newton came out with his second law.

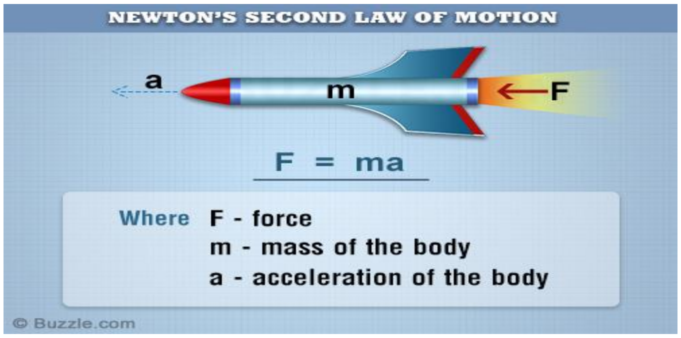

FIGURE 5: REPRESENTATION OF NEWTON'S SECOND LAW

In Newton's second Law he continued with explaining that a force acting on an object causes acceleration and acceleration is a change in motion. He also explains why a force acting on a moving object causes acceleration and the interrelationship of the force with the object. This law was very important because it provides us with a mathematical method for determining force, acceleration and mass of an object. Many say this was the most important of all three of Newton's Laws. His second law leads into his third where Newton looks at the interaction between an accelerating object, the force affecting it, and the objects effected by it.

Newton's third law states "To every action there is always opposed an equal reaction; or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts." Newton's Third Law of Motion, translated from the Principia's Latin. This law is better known as the "law of action and reaction". In this law Newton explains that if one object applies force to a second object, the first object is affected by the second object with an equal and opposite force. This law also gave us the understanding that a force is not merely a push or a pull it is a mutual reaction between two bodies (Figure 6). This third law was crucial as it provides us with all the required information to describe the motion involved in any given situation.

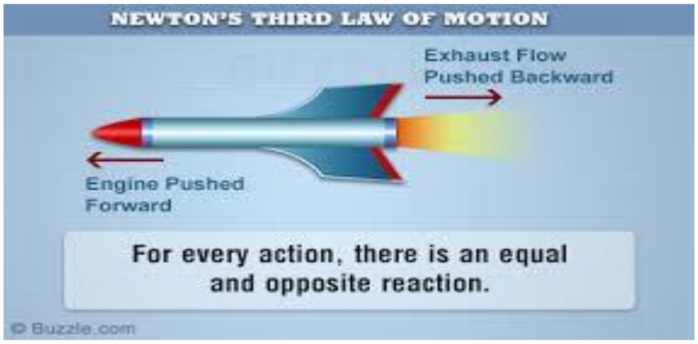

FIGURE 6: REPRESENTATION OF NEWTON'S THIRD LAW

Newton's Laws were crucial in not only mechanics but in physics as a whole. Too understand a physical process we must understand it through the forces acting and then from there form an equation of motion. With Newton's Laws it is now possible to do this. Newton would not have been able to do this without the work of other great mathematicians, philosophers and great minds dating back to the early Greeks. But it was Newton that supplied us with the Mathematical formulas that were crucial. His Laws have shaped the world as we know it and have laid a foundation for other greats to continue to understand everything from our world to the outer regions of space.

Conclusion

Although many laypeople are unaware, Sir Isaac Newton struggled with many personal and public issues. He suffered from crippling emotional turmoil, while constantly battling the expectations and judgments of his peers. Despite all of this, he was still able to utterly change not only humanity's collective scientific knowledge, but the very way that science was done. It could be said that Newton was one of the last Renaissance Men, as he studied and mastered numerous fields of research. On top of the outlying studies of alchemy and religion, his work in optics challenged the status quo, while offering revolutionary ideas and devices never before seen. Although it was challenged, he created mathematical concepts that still stand as the foundation of physics today. Of course, most famously, Newton conceived a fundamental law of gravitation that remained unchanged for centuries, until Albert Einstein's theory of general relativity.

Newton can simultaneously be viewed as one of the founders of our modern study of science. His rigorous use of repeatable experiment and quantifiable results aided in the paradigm shift of physics, from a natural philosophy—an "armchair science"—to the world-changing unification of theory and experiment we know today. He is famously quoted as stating, "If I have seen further, it is by standing on the shoulders of giants." This statement comes off as somewhat ironic coming from him. Of all the giants on whose shoulders we stand to peer out into the scientific frontier, Isaac Newton's stand higher than nearly all others.

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