Isaac Newton

Sydney Srinivas

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Foreword

If there is a historical figure that remains ever present in modern day life, especially for an engineer, scientist or mathematician, it is Isaac Newton. So much that we teach and learn, and so many of the things around us, depend upon the insight that Newton shared with the world in his book Philosophiæ Naturalis Principia Mathematica. As one of the lucky few who have experienced weightlessness in Earth orbit, I was keenly aware that my entire trip was an expression of Newton's Laws. The challenge of spaceflight and the ingenuity that makes it possible are completely based in the physics and mathematics that Newton discovered and invented. During the last spacewalk to build the International Space Station, I found myself above the highest point on the structure looking down on the incredible feat of engineering and the entire Earth below. Newton famously once said, "if I have seen further, it is by standing on the shoulder of giants." At this moment, I distinctly recall thinking of Newton, and that this was "floating on the shoulders of giants." It's quite astonishing how much our world today is shaped by the insights of one man who lived three centuries ago.

While many biographies have been written about Newton. The allure to rediscover Newton and his times is an indication of the magnificent persona that he was. In this book, Sydney Srinivas (at the University of Sydney we call him Srin) captures a seminal period in human history, when the idea of science was born as a branch of study separate from philosophy and alchemy. Newton stands out for being a pioneer in the experimental method of studying science, which is akin to the scientific method used to this day!

Srin's biography of Newton is concise yet comprehensive and very enjoyable to read. The book is divided into two sections: The Life and Times of Newton, and Newton's Scientific Discoveries. This approach works very well for several reasons: The first part weaves together the fascinating story of Newton's life and times, and it does so without being distracted by theoretical concepts or scientific explanations. The reader can enjoy the evolution of the person, Isaac Newton, as an individual in society and as a scientist. The second part gives a wonderful account of Newton's most important scientific discoveries, theories, laws and mathematical insights. Like me, many engineers and scientists will be tempted to skip ahead and indulge in this terrific summary with just the right level of math to explain the concepts clearly, while keeping it accessible to the largest possible audience.

The author's idea is not to write the most authoritative biography of Newton but to write one that gives a holistic insight into the complex human mind that was at once genius, larger than life and yet, very human, with all its frailties and idiosyncrasies. As a biographer, Srin is clearly enamored by Newton and passionate in his writing. He also has the objectivity to view the subject from a distance and examine Newton from multiple perspectives. No doubt that Srin's account of Newton's life and contributions will be thoroughly enjoyed by countless readers, who will find themselves propelled to explore and discover more about Newton's scientific contributions.

Greg Chamitoff, Ph.D.
Former NASA Astronaut
Professor of Aerospace Engineering

Preface

We usually say that achieving something great requires meditation, concentration, unity of purpose, singleness of mind and devotion to work. Isaac Newton had each of these qualities in abundant measure. His life was a meditation upon gravity, light, mathematics, alchemy and theology. That led to major discoveries, theories and laws which are basic to modern science. When he was developing his theories he frequently forgot food and sleep. He would lose his way to the Great Hall of Trinity College in Cambridge where he used to dine. When he realised it, he did not continue to the table but returned to his room to study.

Great people take their studies and endeavours to sublime heights. They are not satisfied with a superficial or profitable goal. They penetrate to the very heart of the matter. Isaac Newton was a perfect example. His life is an invitation for writers to explore. He took pains to reach the truth. His was a dedicated interest in pursuit of truth, in sharp contrast to general research today which is mostly grant driven. I have attempted to bring out the greatness of Newton in the introduction to this book and shall not say more here.

This book is honoured with a foreword written by Prof. Gregory Chamitoff, one of the astronauts who spent six months in the International Space Station. He is also the Lawrence Hargrave Professor of Aerospace Engineering at the University of Sydney. Newton explored gravity, which we have all experienced. Here is a gentleman who has experienced zero gravity as well. Thank you, Greg.

This book is the third of my series published by Prism Books Pvt Ltd., the others being *Srinivasa Ramanujan* and *Albert Einstein*. These two books have been very well received by readers both in India and Australia. My hope is that Isaac Newton will be accorded the same welcome.

Encouragement to write this book came from Pranesh Siravara, my publisher. Once I completed the first draft, I read it to the members of the *Open Genre Group* at the New South Wales Writers Centre in Sydney - Pascal Adolphe, Zita Fogarty, Helen Lyne, Silda May, Don Morison, Alita Tanswell, and Aleit Woodward. I am indebted to them for their advice and suggestions.

Brian Bell, Chakravarthy Madhusudana and M Suryanarayana Prabhu read the draft word by word and suggested many changes and improvements. A big Thank You to each of them.

Shubha Srikanth has done a great job of editing this book. Subba Lakshmi from Prism coordinated the production and Compuprint Services, Chennai did the design of the book. Thanks to each of them.

I thank my wife Usha for her unending patience, encouragement and of course, wonderful food.

Sydney Srinivas
Sydney, April 6, 2017

About the Author

Born in India (1946), K. Srinivas (who writes under the penname of *Sydney Srinivas*), obtained his Ph.D from the Department of Mechanical Engineering, Indian Institute of Science, Bangalore in 1976. Later he worked at the University of Sydney in the School of Aerospace, Mechanical and Mechatronic Engineering for over three decades. He also worked at the Universitat Karlsruhe in Germany, and the Universities of Tokyo, Niigata and Tohoku in Japan.

Srinivas has written extensively on topics related to science. He has published about science and written several fictional works in Kannada and English. His articles have been published in several newspapers and magazines. He has also produced programs for the community television and Radio 2RRR in Sydney. He is now retired and lives in Sydney.

Srinivas is the author of 'Srinivasa Ramanujan', and 'Albert Einstein' published by Prism Books Private Limited in 2012 and 2015. He has also written biographies of nine scientists in Kannada.

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PART 2

The Glory of Isaac Newton

Isaac Newton is beyond doubt one of the greatest scientists that humankind has ever known; in fact, many believe he is the greatest! Today, the quality of any publication, particularly scientific, is measured by its impact on the area of knowledge, usually determined by the number of citations it has received. Applying this yardstick to Newton's achievements, one stands amazed. If everyone who referred to and applied his laws and theories were to have cited his work, he would have amassed billions of citations! Nevertheless, history took a turn because of his findings.

Newton gave us a model of the physical universe, which is valid even today. Most importantly, he gave us *inductivism*, a better method to *do* science – observe, hypothesize, experiment and then accept or reject the hypothesis. His method expelled the Aristotelian way of studying, in which contemplation and exercise of reason alone mattered; in which, every object and phenomenon could be explained through abstract reasoning; the way the universe behaved, being, of course, the will of God! With Newton's entry, out went superstition; what the Church said about the universe and its functioning mattered little. Science came of age. It came to be based on facts, which were verifiable through experimentation. *This* was *Scientific Revolution*. Nobel laureate Steven Weinberg quotes the historian Hugh Trevor-Roper, "The success of Newton's theories eventually led to the end of burning witches."

Newton would have been surprised and a trifle annoyed perhaps, if he were to be asked, "Are you a scientist?". Though the word, *science*, existed during his time, it did not have the meaning that has been ascribed to it today. He would have been happier if he was thought of as a *Natural Philosopher*.

All of Newton's thoughts, works and experiments relating to motion of bodies and light found coherent expression in *Principia Mathematica and Opticks,* his groundbreaking works. Newton's Three Laws of Motion, as we refer to them today, are delineated in *Principia Mathematica,* the Bible for even contemporary scientists and engineers. He devised these laws to explain and govern all motion, from vehicular to planetary. *Opticks* details his study of light, its structure and properties, his mathematical contributions and his views on the universe. Not many of us are aware that scientific concepts that we use today, such as mass and velocity were first defined by Newton. *Principia Mathematica and Opticks* continue to be the pillars upon which the discipline of physical science has evolved.

His interests were multifarious. His intellect spread its tentacles from physics to explore mathematics too. He introduced calculus. He worked with infinite series, especially the general binomial expansion. He had his own say in algebra and number theory, classical and analytic geometry, finite differences, classification of curves, methods of computation and approximation, and even probability.

Scientists engaged themselves intellectually and academically with Newton's theories of motion and gravity even when he was alive. And the engagement with them hasn't waned. Although Newton's theories are unanimously accepted, knowledge always evolves. Other masters modified and built upon the foundations laid by Newton. Albert Einstein, two hundred years later, identified a loophole in the theory. He demonstrated that space and time are relative and not absolute entities as Newton had believed.

But Einstein never dismissed Newton's scientific corpus; he only showed that Newton's theory was not applicable at high speeds, which, however, we may not encounter in daily life. Einstein's tribute to Newton reveals the far-reaching impact of Newton's findings. Einstein said, "Let no one suppose, however, that the mighty work of Newton can really be superseded by (Relativity) or any other theory. His great and lucid ideas will retain their unique significance for all time as the foundation of our whole modern conceptual structure in the sphere of natural philosophy." Einstein revered Newton, and his portrait was the only one he retained on the wall above his desk in his office at Princeton. "Fortunate Newton," he exclaimed, "happy childhood of science. Nature to him was an open book. He stands before us strong, certain, and alone."

To quote the celebrated Irish novelist, John Banville, from his review of the book *Isaac Newton* written by James Gleick, "It is not too much to say that our world was founded by Newton." Well, some of the facts that Newton revealed to us were already known. Galileo Galilei had already spoken of phenomena such as inertia and gravity. He knew that any object left to itself in air would fall down. Kepler, Copernicus and others had calculated trajectories of planets. Newton's greatness was that he synthesized all this information, often only conjectures, and gave us mathematical formulae to prove and calculate physical phenomena of interest; gravity, for example. Gravity was no longer a cloudy concept; a formula was now available to calculate its effects. Newton's Laws of Motion help calculate precisely parameters such as force and acceleration. In the words of Gleick, "He made knowledge a thing of substance: quantitative and exact." This exactitude is his contribution to science that changed the course of scientific study.

Every so often, market research agencies such as ranking.com conduct opinion surveys to establish the ten most influential people of the world. The results are surprising; Isaac Newton has always been among the top three, at second or third place after Mohammed or Jesus in the first. It is quite understandable why religious leaders make it to the list. But Newton, a scientist, makes it! Newton's work and its impact are universally accepted.

Science was only a part of Newton's agenda. He was interested in many other pursuits – alchemy, the occult, the Bible and God. He was not like the modern scientist who seldom needs a God. Newton believed in God. Watching Newton would barely give the impression of a scientist at work.

He appeared more like a magician, or a wizard invoking demons. Oft times, he could even be mistaken for a theologian involved in scriptures and in seeking truth. Michael White has titled his book, Isaac Newton: The Last Sorcerer. Wouldn't you have expected him to be called the first scientist?

What sort of a human being was he? We usually have our own imagined profile of a scientist. We associate dignity and virtue. Newton was far from that ideal image. He was human, like the rest of us. He was an egotist who was engaged in perpetual battles with other scientists. Rob Iliffe, an authority on Newton and the Director of the Newton Papers Project at Oxford University, points out, "Newton had what even his friends believed to be an innately suspicious temper that could erupt when his status, honour or competence was threatened. He went to any length to see that his name always came up, to ensure that the voices of other scientists, however great they may be, were silenced. Respect for other's opinion was totally absent. He suffered from bouts of insecurity, dangerous pride and even mental instability". But the spark of ingenuity surpassed all this. It is not difficult to pardon Newton for all his sins! He was a sublime genius.

Newton's family had no academic qualifications to talk about. Newton was the first of the generation of Newtons who could sign his name! His mother would have been happier had he taken to farming rather than to books. There was even an attempt to withdraw him from school. As destiny would have it, he not only studied in schools and gained university education, but excelled in academic and professional life too. He became a professor, Master of the Mint, a Member of Parliament, a knight, the President of the Royal Society and he received a funeral, the likes of which is reserved for royalty and heads of state. The inscription on his grave reads, "Mortals rejoice that there has existed such and so great an ornament of the human race!"

When asked about which scientist he'd like to meet, Neil de Grasse Tyson, the famous astronomer and TV presenter, said, "Isaac Newton. No question about it. The smartest person ever to walk the face of this earth.

The man was connected to the universe in spooky ways. He discovered the Laws of Motion, Laws of Gravity, Laws of Optics. Then he turned 26."

Science would not have been what it is, if there had not been a Galileo or a Newton, any more than music would be what it is, if Mozart or Beethoven had never lived. The greatness of Isaac Newton has been spelled out very well by the Swiss philosopher and writer, Jean-Jacques Rousseau in his *Discourse on the Sciences and Arts (1st Discourse) and Polemics*, "Those whom nature destined to make her disciples have no need of teachers. Bacon, Descartes, Newton — these tutors of the human race had no need of tutors themselves, and what guides could have led them to those places where their vast genius carried them? It is the task of this small number of people to raise monuments to the glory of the human mind."

Childhood

Woolsthorpe-by-Colsterworth is a small village in the Lincolnshire County, about 150 kilometers to the North of London. Grantham, the nearest town is about 12 kilometers away (Fig. 1). One among the numerous villages that raised sheep, none would have guessed

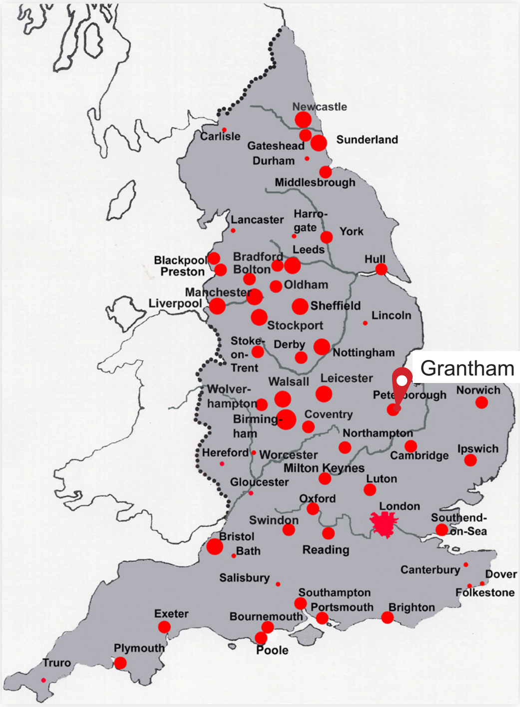


Fig. 1 Map of UK showing Grantham.

in the mid 17th century that it would stand out on the world map one day. Here lived the Newton family, whose main occupation was farming. Education was way below on the priority list. Isaac Newton's father, also called Isaac, signed his will '*XXX'!* One of his ancestors had bought a big house called Woolsthorpe Manor in the village (Fig. 2). This was the house where Isaac Newton, the scientist, was born. Built of gray limestone it is a massive building, which has been preserved and is now a museum.

Fig. 2 Woolsthorpe Manor where Isaac Newton was born.

Newton Senior was married to Hannah Ayscough who came from a family where the men were educated. Perhaps, Newton Jr. owed his superior intellect and inclination to education to his mother's family. It is a pity that Newton Sr. died in October 1642, only six months after his marriage. He was 36 and was said to be sick of body though mentally fit. However, Hannah was already pregnant. Not much is known about him except that he was, 'wild, extravagant and weak'.

Isaac Newton was born a premature baby, on Christmas Day, 1642. It is a coincidence that Galileo Galilei, Italian astronomer and physicist, aged 80 died the same year. A similar coincidence in science history is the birth of Albert Einstein in the year 1879, which also marked the death of

James Clerk Maxwell, Scottish mathematical physicist. Both Newton and Einstein continued the scientific relay race after receiving the baton from Galileo and Maxwell respectively.

Infant Isaac was tiny; very few expected that he would survive. A bolster was needed to keep his head over his shoulder. People joked that the infant could be placed within a quart pot, which holds about a litre and half of water. It is said that two women were sent by his mother to fetch medicine or a midwife from a neighbouring village. The two started no doubt, but on their way, sat down by the roadside, engrossed in some interesting conversation. They assumed the infant would not survive and hence the medicine or midwife would be of no use. Little did they know that the infant would become a world-famous scientist! Hannah too did not believe that the infant would survive. She waited for a week until January 1, 1643 before christening him.

It turns out that Isaac was a rich child. His father had left a sizable property consisting of more than £450, 234 sheep, 46 head of cattle and goats and other goods worth £ 140, apart from the huge ancestral house. In contrast, an average farmer of those days would have owned about £ 100 and 40 sheep.

Hannah Remarries

Hannah was 30 years old when Isaac was born. She attracted the attention of Reverend Barnabas Smith, the rector in North Witham. He was a wealthy 63-year-old widower of six months. The two married in 1646 and Hannah moved to North Witham to be with her new husband. Barnabas insisted that Isaac should not join the couple. Hannah had to leave Isaac in Woolsthorpe Manor. Hannah's mother, Margery Ayscough was brought in to take care of him. As a marriage deal, Hannah demanded and obtained from Smith a sizeable land that added to her wealth.

Barnabas was an Oxford graduate with B.A. and M.A. degrees and he was inclined towards academics and education. He had a large notebook of more than 1000 pages, in which he made extensive notes. A book was a valuable possession in those days when paper was very expensive. Isaac called it the 'Waste Book' in view of the number of blank pages in it. Barnabas owned a library of about 200 books mostly on theology. Isaac inherited all of these.

His mother's remarriage had a devastating effect on Isaac. Historians claim that he was deeply traumatized by his separation from his mother and dislike towards his stepfather. Some of Isaac's writings in his note-books give us a glimpse into his emotional turmoil. One of the entries reads – *Brother. Bastard … Benjamite … Father. Fornicator*. Later in 1662, Isaac listed some of the sins (see Appendix B for List of Sins) he committed – *Making pies on Sunday nights. Threatening my father and mother Smith to burne them and the house over them.* Newton had no affectionate recollections of his grandmother. In fact, her death went almost unnoticed. Joel Levy observes, "As an adult Newton was withdrawn, moody, intense and prone to fits of rage and long harboured grudges."

Barnabas Smith did not live for too long after his marriage to Hannah; he died in 1653 at 71. Consequently, Hannah acquired more wealth, becoming one of the richest in the area. She had three children from Smith – Mary, Benjamin and Hannah. That his step brother's name was Benjamin explains what Isaac wrote about his brother (*Brother. Bastard … Benjamite … Father)*. Widowed again, Hannah returned to Woolsthorpe Manor with her three new children. It is difficult to judge whether Isaac welcomed this reunion with his mother. Historians believe he was unhappy. There is a reference to *punching his sister* in his list of sins (see Appendix B for list of sins). However, he lived with his half-brother and sisters only for two years. He was admitted to a school in Grantham and he moved away.

There are no records of Isaac's early education. The only known facts are that he was sent to day schools in neighbouring villages of Skillington and Stoke. Many of Isaac's aunts, uncles and cousins lived in villages around Woolsthorpe. But he remained aloof and did not develop intimacy with any of them. As the famous biographer, Richard Westfall notes, "The lonely boyhood was the first chapter in a long career of isolation."

At Kings School in Grantham

In 1655, Isaac had turned 12 and was deemed to be of the right age to go to a grammar school. He was sent to King's School in Grantham, also called Free Grammar School of Edward VI. Established some 300 years before Newton, it was about 11 *km* from Woolsthorpe. The school was a single room that housed 80 students (Fig. 3) and was headed by Henry Stokes, a Cambridge alumnus. Latin and Greek were part of the curriculum at the grammar school. Mathematics was hardly taught and yet Isaac invented calculus within four years of leaving this school!

Stokes apparently introduced students to simple arithmetic calculations that would be of use to a farmer, such as measurement of areas, volumes, surveying etc. The study of the Bible was mandatory. The many books on theology in Barnabas Smith's library may have kindled his interest in theology and the Bible. With the help of his teacher, Isaac read books that were available in the church near his school. We will see later that Newton was as interested in theology as in natural philosophy.

Fig. 3 King's School in Grantham where Newton studied.

As it was difficult for Isaac to commute from Woolsthorpe to Grantham every day, he lodged in the house of John Clark, who owned an apothecary business on the main street of Grantham (Fig. 4). Clark had no children of his own; his wife had two sons, Arthur and Edward, and a daughter, Catherine Storer by a previous marriage. Isaac apparently did not get along with her boys either.

William Stuckeley, Isaac's friend at school who wrote Isaac's memoirs later in life, points out that Isaac preferred the company of girls. He showed some affection towards Catherine Storer, though short-lived and forgotten. In fact, this was possibly the only romance Isaac Newton ever developed in his life. One boyish mischief that Isaac enjoyed was stealing cherry cobs, bread and butter from Edward and Arthur. This act too, makes it to his list of sins (see Appendix B for List of Sins).

To quote Westfall, Isaac remained '...*a sober, silent, thinking lad who never was known; scarce to play with boys abroad'*. To start with, Isaac was not considered a bright boy. He ranked lowest in a class of 80.

Fig. 4 Clark's Apothecary, today. This is where Newton stayed as a student in Grantham.

Although, Isaac appeared dim-witted initially, his classmates began to recognize his superior intelligence over course of time, which resulted in hatred rather than admiration.

A very interesting incident took place one day. On his way to school, a boy, possibly Arthur Storer, kicked Isaac in the belly. Isaac mustered all his courage and challenged the boy to a duel after class. A well-arranged fight took place in the churchyard opposite the school in Grantham. It is said that Isaac beat the boy until he declared that he would fight no more. Isaac pulled him by the ear and thrust his face against the side of the church. This enmity however was limited to childhood. In later life, Arthur collaborated with Newton in his astronomical ventures and Edward Storer became a tenant in Woolsthorpe Manor.

This duel was a turning point in Isaac's life. He resolved to beat academically the boy whom he had beaten in the duel. In fact, he defeated not just that boy but the entire school. He stood first. As a celebration, he etched his name on every bench in the school. An etching of his signature on the window remains to date (Fig. 5).

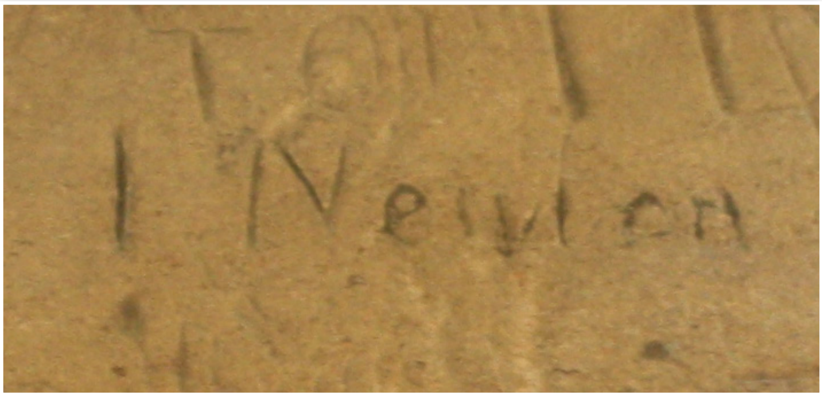


Fig. 5 Newton's signature on the window sill of the school.

Making Gadgets

Isaac had an extraordinary interest and skill in mechanical work. He was a very good carpenter and liked fabricating small gadgets. He spent all his pocket money on buying saws, chisels, hammers and other such tools.

Fabricating something in his room was more rewarding than the fun and frolic of playing with other boys. He made a dollhouse with furniture for Catherine Storer and built himself a four-wheeled cart in which he could sit and propel himself.

Isaac was a keen observer. He was fascinated by mechanical structures. A windmill was under construction in Grantham (Fig. 6). The villagers who had only seen water mills until then were excited at the sight of this new machine. While they treated it as an exciting novelty, Isaac observed it very carefully.

Fig. 6 Wind Mill near Grantham.

He built a model whose blades turned with the help of sails. He amused himself into thinking, 'why not power it with a mouse rather than wind?' He built a treadmill and made a mouse run on it for a cob of corn. The motion of the mouse on the treadmill operated the windmill. Newton's model amused the villagers more than the big windmill!

A kite soaring in the sky is the ultimate fascination for any child. Isaac was no exception. His curiosity and interest got the better of him and he comprehended the functions of the various parts of a kite, the sail, the spine, the tail and so on. He determined the correct proportions of these various parts and the exact points to attach the strings. He lit a lantern and joined it to one of his kites. The villagers were amazed to see a flying lantern. He made lanterns out of crimped paper and carried them in his pocket. He also made several wooden clocks, one of them powered by trickling water.

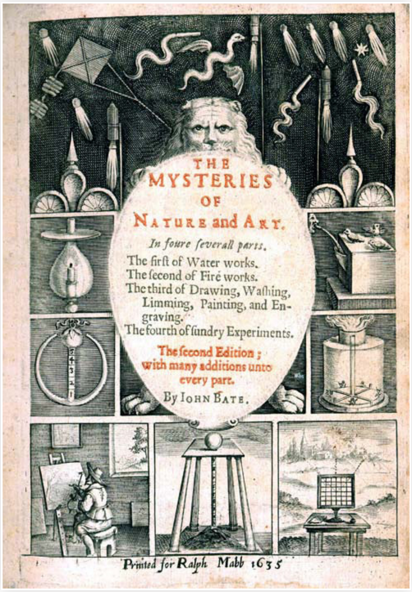


Fig. 7 The book – Mysteries of Nature and Art by John Bate.

Isaac's inspiration and reference for his art came from a book entitled *The Mysteries of Nature and Art* by John Bate, a Welsh theologian and philosopher of the 15^{th} century (Fig. 7). This book, divided into four parts dealt with water works, fireworks, drawing, colouring, painting and engraving, and a description of diverse experiments. His brilliance and originality in building such contrivances stood him apart from other children of his age. Even while he played with other boys he must have exercised his mind with questions about gadgets. Playing for the sake of play alone was a futile activity for him. His classmates found him cunning enough to exploit friendship for gain.

Isaac was not content with borrowed knowledge from books. He wanted to see and experience everything for himself. As a sixteen year old, he contemplated and carried out an experiment to measure the speed of wind. It was a stormy day; he jumped with the wind and then against the wind. He compared his leaps with the ones he had made on a calm day. He determined that the storm was 'a foot stronger'. Of course, we may dismiss such an experiment, but we have to bear in mind that he was only a young lad and yet he had thought of conducting an experiment to ascertain knowledge.

The sun-dial (Fig. 8) was another contraption that attracted Isaac when he was only nine years old. The one in the Colsterworth church is said to be the handiwork of Isaac. He placed many dials in Clark's house. These would show time accurately to a quarter of an hour. His expertise was such that by looking at the dial and the shadow he could tell even the day of the month. Not to mention, the villagers and his own family consulted his dials. Even in his later years, Newton

Fig. 8 Sun-dial near his school.

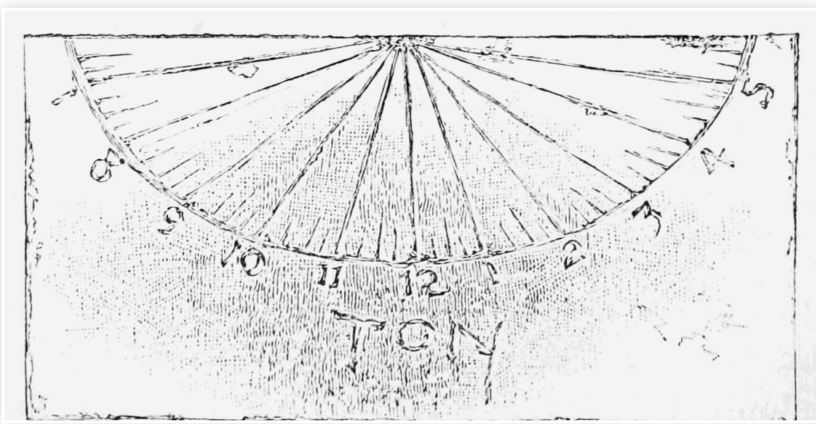


Fig. 9 Isaac Newton's Sun-dial in the Royal Society.

looked at shadows to tell the time. One of the dials that he placed in Woolsthorpe Manor is now in the possession of the Royal Society in London (Fig. 9).

He also had a natural flair for drawing and sketching. He filled his room walls in Clark's house with charcoal sketches of birds, beasts, men, ships and plants. Portraits of John Donne, Charles I and schoolmaster

Stokes also adorned the walls. Geometry found its place too. Lines, triangles and circles were etched on the wall. These were clear indications of the direction in which Newton's imagination would run.

Too much involvement in such activity made Isaac neglect other subjects and he fell behind in class. Stokes, the schoolmaster, had to caution him. After that, Isaac picked up his studies and again stood first.

Isaac, thirteen now, took extensive notes in a book. In it are found entries related to drawing, catching birds, making inks of different colours etc. Scholars like Westfall have noted that the notebook contains information about contraptions such as windmills and sundials, and about colour, light and stargazing. This habit remained with him throughout his life. He copied whatever he read. It is said that he could not read anything without a pen and paper!

Organising and *categorising* information were two important skills that Isaac developed from his school days. He would gather information by reading and observation. He would then organize the data, ask questions about it, record it neatly in his notebook, and finally set forth to seek answers in the style of a true rationalist.

As we know, Isaac was boarding at John Clark's house. Clark was a practicing apothecary and his laboratory was right below his house. Isaac, who spent time at the apothecary, acquainted himself with chemicals, solutions, lotions, powders and such. The knowledge he thus obtained may not have been directly useful for his future alchemical endeavors, but he did acquire the art of mixing chemicals and handling them. It was like an apprenticeship.

Isaac wrote in one of his notebooks, called the Latin Exercise Book, which he purchased for two and a half pence - *A little fellow; my poore help; He is paile; There is no room for me to sit; In the top of the house - in the bottom of hell; What imployment is he fit for? What is hee good for? I will make an end. I cannot but weepe. I know not what to doe.* He did not forget to write *Isaacus Newton hunc librum possidet* (translated as - Isaac Newton owns this book).

Back to the Farm

In 1659, when Isaac was seventeen years of age, his mother Hannah thought he should return home and manage the estate. Learning in a school was not necessary in her opinion. There were things more urgent at home that required his attention. From books, Stokes and school, Isaac returned to the family farm to be with sheep, cattle and pigs.

A servant was appointed to help Isaac and teach him his new responsibilities. This change was disastrous for Newton. Isaac would be sent to watch the sheep. He would leave the sheep to fend for themselves and would engage in building a water wheel or a dam across the brook. He would never notice a broken fence. The sheep would stray into the neighbouring farm and feed on the corn. It was for Hannah to make good the losses. It has been recorded, for example, that on October 28, 1659, Newton was fined 3s 4d.

A distraught mother tried Isaac at trading. He was sent with a servant to a market to sell some family produce and procure something for the house. Isaac found a way out. He bribed the servant and made him do all the transactions while he spent his time with a book or a gadget. If the market took place in Grantham, it was to Isaac's advantage. He could escape to Clark's house or the school. Heaps of books awaited him.

Usually, Isaac went to such markets by horse. Once on his way back, like every other rider, he dismounted to climb a steep hill. When at the top of the hill, riders usually remounted the horse, but Isaac simply forgot to do so. Engrossed in some deep thought, he walked with the horse all the way home. On another occasion, it is said that the horse slipped his bridle and went home by itself. The servants at Woolsthorpe had a tough time with a lad who was not in the least interested in farming and so absent minded that he forgot to take his meals. They said in unison- *Isaac unfit for farm, fit only for varsity.* A glimpse into what Isaac felt about this life is evident from his list of sins - *Refusing to go to the close at my mother's command, Falling out with the servants* and such (refer Appendix B for List of Sins).

There were two people who understood the situation and were sympathetic of the young lad. One was Hannah's brother Reverend William Ayscough and the other, schoolmaster Stokes. The two warned Hannah that any attempt to train Isaac in farming would fail. Watching sheep, herding cattle and shoveling dung were not tasks befitting his interests. He was bound to be a scholar. His talents were being wasted. He should be sent back to school. Stokes offered to waive the forty shilling fees and offered him boarding at his house (Apothecary John Clark had had enough of Isaac!). Hannah had to yield. Science had its way. In 1660, after nine months of 'farming life' in Woolsthorpe, Isaac returned to the grammar school in Grantham.

Back at School

The lion was back in his domain. Clark's intention was to train Isaac for a university education. Isaac excelled. He exceeded the expectations of schoolmaster Stokes. When he completed school education at Grantham, schoolmaster Stokes stood Isaac in front of the assembly of boys and said, "Isaac is an example for you. You should all become like him." As he spoke, tears rolled down his cheeks. Even the other boys broke into tears.

At Cambridge

Isaac left Woolsthorpe Manor in 1662 and made his way to Cambridge to enroll himself in the university. This was a unanimous decision among his well-wishers, schoolmaster Stokes, Isaac's Uncle William and apothecary Clark's brother, Humphrey Babington. Each of them had some affiliation with Cambridge University, Trinity College in particular.

The university was established by King Henry III about 400 years before. It was one of the most prestigious institutions in Europe, and remains so to this day. Trinity College (Fig. 10 and Fig. 11) had the unique distinction of nurturing 32 of the 96 Nobel Prize winners of Cambridge University by the year of 2015. The prominence of Cambridge is evident, when we consider the number of illustrious scientists who have been associated with it. Some of these men of distinction include: Francis Bacon (father of empiricism and scientific method), J. J. Thomson (discovered electron), Ernest Rutherford (nuclear physicist), Sir John Cockcroft (discovered neutron), James Clerk Maxwell (electromagnetic theorist), Ernest Walton (split the atom), Henry Cavendish (discovered hydrogen), Charles Darwin (Theory of Evolution), Alan Turing (pioneer of modern computer), Francis Crick and James Watson (discovered the DNA structure), Paul Dirac (Quantum Mechanics), John Herschel & Sir Arthur Eddington (astronomers), Lord Kelvin (Thermodynamics), Sir Jagadish Chandra Bose (Radio Science) and Amartya Sen (Economics).

To this list, we can add celebrated poets such as Tennyson and Byron, social scientists, economists, artists, politicians and prime ministers (six from Britain alone).

Fig. 10 Inside View of Trinity College showing the Hall.

Fig. 11 Entrance to Trinity College.

Cambridge, a small town with a population of about 7000, of which 3000 were students and graduates, was the intellectual hub of 17th century England. River Cam that courses through the city is flanked by several colleges including Trinity.

Isaac had to clear two levels of assessment to enroll at Cambridge. First, he had to gain admission to the college; for which he had to attend an interview to be conducted by the senior dean and head lecturer. Isaac cleared the interview effortlessly and was admitted to the college. However, admission to college did not entail admission into the university where he sought to obtain a degree. He had to go through the matriculation process. College merely meant a place like a hostel where scholars pursuing different disciplines stayed and boarded. There were many in Trinity College who did not seek a degree and therefore just boarded. Isaac successfully matriculated and officially entered the university by taking an oath and paying the required fees. His name found its place in the university's matriculation book. In the words of Westfall – *For whatever reason, on 5 June 1661, the famousest college in the university, quite unaware, admitted its famousest student*. He remained here for several years to come.

In preparation for his university life, he shopped for clothes, shoes, a lock for his desk, a quart bottle, ink, candles and a chamber pot. For his recreation, he bought a chessboard and became a member of the tennis club. Thus, sheep, cattle, pigs and dung vanished from his view. Now it was books and more books; scholars and scholarship.

Isaac - a Subsizar

At Cambridge, students were categorised as Fellow Commoners, Pensioners, Sizars and Subsizars. Fellow Commoners were wealthy people who enjoyed many privileges such as occupying the top of the table for meals. Pensioners were affluent. Below them in hierarchy were the sizars and subsizars, no better than second-class citizens and the college called them *scholars paupers, qui nominentur Sizatores*. Though they were 'servants' to others, there was a distinction between sizars and subsizars.

Sizars served masters and fellows of the college while the subsizars served fellow students. Both sizars and subsizars did all the menial jobs such as cleaning, polishing shoes, combing the commoner's hair, carrying wood to the heaters, fetching food from the buttery, even emptying the chamber pot. Isaac was a subsizar.

Why did Isaac demote himself to such a low level? His mother was rich by all standards. She had an annual income of more than £700. But she allowed him only £10 per year while the college fees cost £10 to £15 a year. Perhaps she did not approve of Isaac studying in a university. Farming was her priority. There is also a belief that Isaac went to Trinity specifically to be Babington's sizar. Isaac had an ulterior motive. The latter was in Trinity only four or five weeks in a year! This meant Isaac would get considerable time to study.

Intellectual Separation

Many factors distinguished Isaac from his peers at college. By comparison, he was far more intelligent than the rest. Although rich, his mother provided a very small allowance. He lived beyond his means. He bought and flaunted expensive clothes, lent money to pensioners, his bed maker and other colleagues. He was about a year older than the rest and that seemed enough reason to consider himself superior. He hardly had any friends. It appears that no one has ever said, "I was a classmate of Newton in Cambridge." None of his classmates influenced him. The one exception is John Wickins, perhaps a pensioner, who joined Trinity in 1663. By then Isaac had completed 18 months of solitary existence in Trinity.

Wickins' son recalls his father explaining the circumstances under which the two met for the first time. John was not happy with his roommate and accidentally entered Isaac's chambers where he sat solitary and dejected. They found that they shared the same dejection and decided to shake it off and become friends. Westfall opines that even this friendship was ambiguous. In his words - *The sober, silent, thinking lad of Grantham had become the solitary and dejected scholar of Cambridge.*

In 1662, Isaac was struck by a moral crisis. He was plagued by a sense of guilt, doubt and self-denigration. He listed down 'sins' (see Appendix B for List of Sins) he had committed up to Whitsunday in 1662 and started another list for the ones he committed thereafter. He wrote his list in cipher using a system of shorthand. However, he seems to have discontinued his list very soon.

A Tutor

Every student in the university was assigned a tutor who could be approached for help. Isaac's tutor, Benjamin Pulleyn tutored a total of 57 students for a four-year term. Isaac, it seems, did not bother his tutor, for he never liked him. In fact, the latter was also happy to be left alone. Students were not allowed to visit the coffee clubs and the library of three thousand books at Cambridge unless accompanied by a tutor. It is not known whether Isaac was accompanied by his tutor Pulleyn on his visits to the library or whether he had found other ways to gain entry.

Masters of Science before Newton

Even before Isaac entered the portals of Cambridge, he was abreast of contemporary developments in science and astronomy. Now that he had access to books, Isaac read with interest many great masters such as Nicolaus Copernicus, Johannes Kepler and Robert Boyle (known for Boyle's Law of Gases) and Sir Francis Bacon.

A brief account of the contributions of these masters is given below. This will help us understand and analyze the context within which Newton operated, the influences that triggered his imagination, and the systems of knowledge that ripened the atmosphere for the birth of his genius.

Aristotle (384 – 322 BC) and Scholasticism

Cambridge in the 17th century was no longer an institution churning out graduates fit for state or religious duties. The curriculum was based on the scholasticism of the Middle Ages that advocated pure abstract reasoning as the only mode of acquiring knowledge. However, the modern concept of ascertaining facts through experimentation, observation and hypothesis had not yet entered the curriculum.

Fig. 12 Aristotle.

Students were guided in the footsteps of the Greek philosopher Aristotle (Fig. 12). According to him, every substance was composed of four basic elements, namely earth, water, air and fire. Motion was the change in the properties of a substance, in terms of the ratio of the constituting elements. Almost every occurrence in the universe was a consequence of motion – child growing into man, water boiling in a pot, fruit ripening, a plant flowering, a stone falling. Besides, there was a causal factor for every motion. Nothing can move by itself. Every motion thus could be traced back to the first motion, the prime mover of which was, God. This theory had the approval of Christian theology and it is not hard to see why.

In this philosophy, there was no room to explain the mechanism of motion, let alone measure and quantify it. According to the Greeks, mathematics was reserved for calculations concerning the heavens. It was not to be misused for earthly events such as the dropping of a stone or the flight of a bird.

Isaac read Aristotle and made notes in Greek. Curiously, he wrote in the first few pages of the book. He left many blank pages and continued writing only at the end of the book. Did he intend to contemplate more on Aristotle and fill these pages later? No one knows.

Claudius Ptolemy (90 AD to 168 AD)

One of the earliest names that we come across in mathematics and astronomy is that of Claudius Ptolemy. He lived in Alexandria and wrote several treatises, which were important to European and Islamic science. His version of astronomy placed the earth at the centre of the universe around which the heaven moved.

Nicolaus Copernicus (1473 – 1543)

Science had to wait for more than a thousand years after Ptolemy, to stumble upon the truth about the universe. Nicolaus Copernicus (Fig. 13) was the game changer. Born in Poland, he studied at the universities of Cracow, Bologna, Padua and Ferrara,

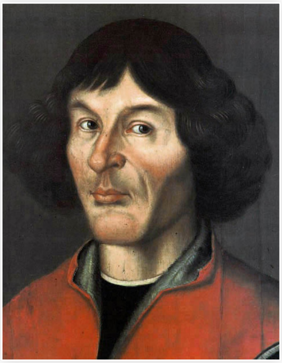


Fig. 13 Nicolaus Copernicus.

travelled all over Italy and other European countries with well-known astronomers. He challenged the geocentric conception of the universe and proposed the heliocentric system in which planets went around the sun in circular orbits. The Church felt threatened for its supremacy would collapse if the earth wasn't the centre after all. It banned his second book *De Revolution ibus Orbium Coelestium. The minister in charge, Martin Luther declared, This fool wants to turn the whole art of astronomy upside down.*

Johannes Kepler (1571 – 1630)

Fig. 14 Johannes Kepler.

Born in Germany, Johannes Kepler (Fig. 14) was interested in science as a young boy. At the age of six, he watched a comet with his mother, and at nine, observed a lunar eclipse. He studied the theories of Copernicus and Ptolemy at the University of Tubingen and became a Copernican and upheld the heliocentric theory. He became an assistant to the well-known astronomer Tyco Brahe in Prague. Kepler disproved, with the help of mathematics, especially geometry, Copernicus' proposition that planetary orbits were circular, and established that they were, in fact, elliptical; thus evolved the three Laws of Kepler. He also showed that moving planets swept out equal areas in equal times.

Kepler's Laws proved very helpful for Newton while he was working on his theories detailed in *Principia* and are outlined in Part 2 of the book.

Galileo Galilei (1564 – 1642)

Galileo Galilei (Fig. 15), a great mathematician and astronomer was born in Pisa, Italy. Although he enrolled at the University of Pisa to study medicine, he soon switched to physics and astronomy. He built a telescope and viewed the heavens. Startling were his findings! Jupiter

Fig. 15 Galileo Galilei.

had satellites; the moon was not a poetic smooth surface; it had hills and valleys. He also supported Copernicus' heliocentric theory for which, the Church placed him under house arrest. The same Church rendered an apology in 1992!

Galileo gave mankind the Experimental Method and advocated experiments to prove or disprove a theory. He, for the first time, showed that mathematical expressions could explain many celestial phenomena. Newton continued in his footsteps and mathematically explained many natural events and occurrences. He conceived the concept of inertia proposing that objects have a tendency to remain in motion or remain stationary.

Galileo performed his famous experiments supposedly at the inclined tower of Pisa and repeated them on an inclined plane. He accurately proposed that all objects fell down at the same rate. He ideated the concept of *free fall,* which Albert Einstein explored further, and named Galileo, *The Father of Physics*.

Galileo explained his theories in two books - *Dialogue Concerning the Two Chief World Systems* (Dialogo Sopra i Due Massimi Sistemi del Mondo) and *Discourses and Mathematical Demonstrations Relating to Two New Sciences* (*Discorsi e Dimostrazioni Matematiche, Intorno a due Nuove Scienze*). Newton had read the *Dialogue*, but not the *Discourses*.

René Descartes (1596 – 1650)

Newton studied French philosopher René Descartes (Fig. 16) and investigated deeply into his theory. When Isaac entered the university, the mechanical theory of the universe as proposed by Descartes was in vogue. According to it, the universe was filled with an invisible substance called ether. Whenever an object moved, it disturbed the medium surrounding it

Fig. 16 René Descartes.

by causing vortices. These vortices, in turn, transferred energy to objects nearby and made them move. By now, the word *gravity* was already in circulation among natural philosophers. Isaac tried to explain the motion of a cannon shot into air with the help of Descartes' theory. His method of solving cubic equations did have some influence on Newton.

Sir Francis Bacon (1561 – 1626)

Sir Francis Bacon a philosopher, statesman and a scientist studied in Trinity College and took to a political career. He sowed the seeds of the Scientific Method further developed by Newton. He advocated the method of inductive reasoning to develop laws or theories from observations. Bacon stressed that it was necessary to engage with nature in order to understand it; not merely contemplate it like the Aristotelians.

Newton Swings into Action

It was as if science and mathematics were waiting for Newton to show the way forward. After having closely studied the masters, he jumped into action. Some of the early topics he chose to work with were light and mathematics.

Scientific Method

The Scientific Method that Isaac Newton rigorously followed went on to become a universally accepted practice. We will discuss this Method in detail later.

He followed a meticulous method of study. In a notebook he called *Philosophical Note book*, Isaac listed 45 headings under natural philosophy. These include *nature of matter, place, time and motion, rarity, fluidity, softness, occult, light, colours, vision* and such.

He read and researched a topic thoroughly and made detailed notes. After researching, he subjected it to scrutiny in the light of the facts that he had observed. He asked many critical questions, which he recorded in a separate part of the notebook and called it *Questiones quaedam Philosophcae*. Then he sought to find answers through experimentation and observation. In this book he has written thus: *Amicus Plato, amicus Aristotles magis amica veritas,* translated crudely as, *Plato is my friend, Aristotle is my friend, but my greatest friend is truth.* Newton's rejection of the Aristotelian theory regarding the nature of matter, which he also used to explain gravitation, is a case in point.

Aristotle had theorized that matter was composed of the four elements of nature. He believed, for instance, that an object made of fire and air would go up while one that was made of water and earth would fall down. An apple falls because it is composed of earth and water.

Isaac dismissed the theory and concluded that all matter is made of minute particles called atoms. He wondered what would remain ultimately, when matter is progressively divided into smaller parts. Do we arrive at mathematical points of no size? Or do we arrive at actual atoms of some size? If the former were true, Isaac argued that even an infinite number of them, will still be of zero size. He also conjectured that although atoms are very small, they do not shrink to zero size. They may be indiscernible, but they are unbreakable and indivisible.

Early Experiments with Light

As pointed out earlier, Isaac was never happy with bookish or abstract knowledge. He had to *see* and *experience* to believe. Now he subjected Descartes to his investigation. The Frenchman believed that light was a form of pressure that propagated from the source, i.e., from an object to the eye of the observer. It is this pressure, he opined, that made the observer *see* the object. To put it in contemporary terms, it was a travelling pressure wave.

Isaac objected to this theory on many counts. If light was only pressure, why do we not see anything in darkness? He argued that if one accepted Descartes, then a phenomenon such as the eclipse could not occur at all. If Descartes was correct, light too should turn a windmill!

Isaac next rejected Aristotle's belief that colour was a mixture of light and darkness and that changing the proportions of the mixture would result in different colours. Isaac argued that if this were true, black ink on white paper ought to produce colours.

In 1664, to test his own assumptions about light and colour, Isaac went to a fair at Stourbridge, outside Cambridge, and bought a prism and some books. He was well aware that white light passing through a prism scattered into a spectrum of seven colours. He interpreted that the colour of an object depended upon what part of the spectrum the object absorbed and what part of the spectrum it reflected.

He looked at the sinking sun through a feather and was delighted to behold the rainbow colours. Then he ventured to use his eyes for an experiment (Fig. 17). He looked at the sun with one eye closed. Pale objects appeared red, and dark ones appeared blue. This experiment was dangerous. After several such observations, he ended up seeing pale objects as red and dark ones as blue, and when he looked, all he saw was the bright sun. He could neither read nor write. He had to shut himself in a dark room for several days.

Undeterred, Isaac embarked on another dangerous experiment a year later. In a bid to discover whether the compression of the eyeball, i.e., the change in radius of curvature, altered one's perception of colour, he stuck a bodkin (a small dagger) between his eyeball and the bone nearby. Consequently, he observed white, dark and coloured circles. This 'operation' could have blinded Isaac Newton!

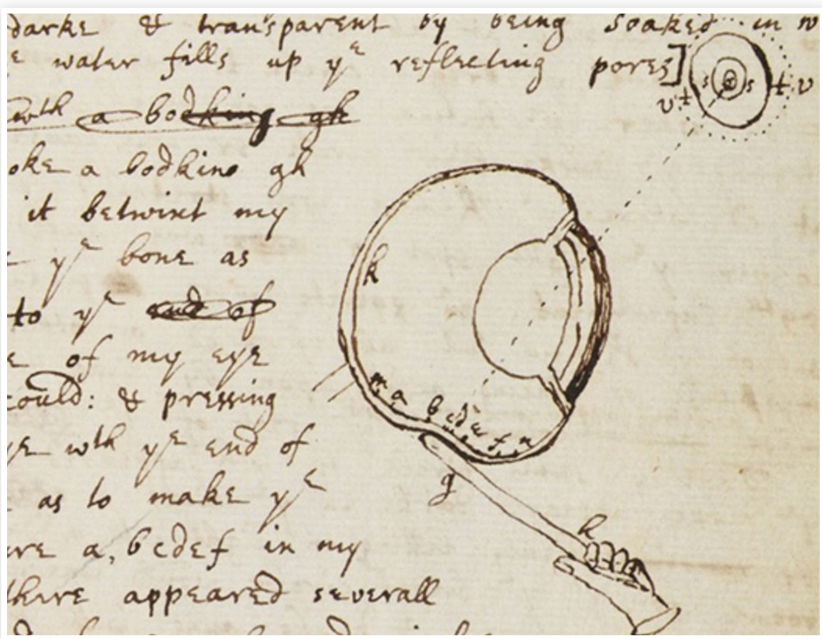


Fig. 17 Newton's dangerous experiment with his eyes.

Mathematics

While in Cambridge, Isaac learnt a great deal about mathematics on his own. How he went about it is very curious and is recorded by the French mathematician, De Moivre. First, Isaac bought a book on astrology at the Stourbridge fair. He could not make much progress as the book was replete with trigonometry. So, he bought a book on trigonometry and studied it. Since geometry was integral to trigonometry, he again made little progress. Isaac tried Euclid's book on geometry, the most famous in those times. He made some progress. Although he understood theorem statements, he did not bother going through the proofs. At this stage, Isaac bought, *La Géométrie,* by Descartes and began reading it. He inched through the book until he mastered it. Such an autodidact was he! He also studied books written by Franz van Schooten (*Miscellanies*), William Oughterd (*Clavis*), John Wallis (*Arithmetica Infinitorium*) and others.

Surprisingly Isaac did not value Euclid (often called the father of geometry) and dismissed his book as *trifling*. Albert Einstein, who revered Euclid has said, "*If Euclid failed to kindle your youthful enthusiasm, then you are not born to be a scientific thinker*."

His dislike of Euclid had consequences. In 1664, Isaac had to be elected a scholar in order to remain in Trinity to complete a bachelor's degree. He had to take an examination to qualify for the course. Since there were only a few seats, the competition was intense. Isaac failed twice in 1662 and 1663. Luck favoured him in 1664. His tutor, Pulleyn put in a word of favour to the authorities that Isaac was interested in mathematics and may, therefore, be examined by Isaac Barrow, the Lucasian Professor at Cambridge, whose expertise lay in mathematics. About ten years older than Isaac Newton, Barrow had studied a number of subjects including, Greek, theology, medicine, church history and astronomy and was appointed professor in 1664.

Though Isaac had read and mastered many well-known books and treatises, he had not studied the prescribed texts simply because they failed to sustain his interest. Yet he appeared for the oral examination. Barrow asked questions related to Euclid's geometry. We know that Newton had totally neglected Euclid. It would have been to Isaac's advantage if Barrow had quizzed him on Descartes, whom he had mastered.

Nevertheless, Isaac Newton passed this examination! It appears that his connections at the high ranks worked to his advantage. Humphrey Babington was a senior fellow in the university and was acquainted with King Charles himself. Is this how Isaac Newton passed? Or was he better than the others even in the topics he had neglected? These are some of the unanswered questions.

His aversion to Euclid did not last long. In course of time, Newton mastered Euclid, for he realized the importance of geometry to understand nature. He familiarized himself with properties of lines, triangles, circles and spheres. He had, of course, read Descartes, who had cleverly combined algebra and geometry to show that abstract algebraic equations could represent a geometric shape such as a curve. This discipline of study is today called analytical geometry. Equations had life; Newton comprehended and went further. Once he understood all the properties of curves – minima, maxima, tangent, area etc., he introduced polar coordinates to construct spirals. He developed equations for the transformation of coordinates (as, for example, from polar to Cartesian), and came up with formulae in both polar and rectangular coordinates for the curvature of a variety of curves, including conics and spirals. Some of these are given in Part 2 of the book. No wonder, that he is often called the *originator of polar coordinates*.

Isaac was not a sizar anymore. He received a stipend and a living allowance of 13 shillings and 4 farthings which is equal to a mark each year for the next four years till he received his master's degree (M.A) from the university. This was a blessing for Isaac Newton who blossomed into a mature researcher. Money was not an issue now. He could concentrate on research and study.

In 1664, a comet was predicted to pass by earth. Newton seized the opportunity to study its path in relation to fixed stars. He gazed at it all night and into daybreak. Night after night, he lay awake. He lost track of time, and of day and night.

That was Isaac Newton; he worked ceaselessly. When a problem seized him, his routine fell apart. He simply neglected food and sleep. His dinner would be prepared and laid on the table. But if on his way to the dinner table, he fancied a book or an article, gruel or milk with eggs would stand for hours and automatically become his breakfast! Or as is often said his cat grew fat on a sumptuous breakfast!

Thus, began one of the greatest explorations in science, which would change man's view of the universe and of his position in it.

Anni Mirabiles (Wonderful Year)

Summer of 1665 in England brought with it the devastating bubonic plague. A ship brought rats carrying fleas infected with bacteria to London. Death was a certainty for those who contracted the disease, as no cure was available. People began to die in hundreds and then thousands. Some 70,000 people lost their lives in London alone. Records point out that on a few occasions almost 7000 died in a day. About a sixth of London dwellers succumbed.

The plague made its way to Cambridge but fortunately, the casualties there numbered only 750. Isaac's mother Hannah on hearing the news wrote to him in her own style –

> *Isack,*
> *Received your letter and I perceive you*
> *letter from me with your cloth but*
> *none to your sisters present thai*
> *love to you with my motherly lov you and prayers to God for you I **
> *your loving mother*
>
> *– hannah, wollstrup, May 6, 1665.*

Schools and colleges in Cambridge closed and the inmates had to return home. Stourbridge Fair stood cancelled. Most students in Cambridge shifted to nearby villages along with their tutors. Isaac who needed no tutor returned to Woolsthorpe Manor, the only place he could think of. He stayed for eight months in his family house and went to Cambridge for a short spell only to return. It was not until late April, in 1667, that Isaac Newton returned to Trinity College.

Many historians refer to the period he spent at home, from 1665 to 1667 as Isaac Newton's *Anni Mirabiles* (Wonderful Years) for it was during this period that he made outstanding contributions to the field of gravity and optics and invented calculus. However, some scholars disagree with this. In fact, fantasies were built around Newton even during his lifetime. One such fantasy was that he miraculously accomplished this outstanding work in a short span of time when he was away from the university.

There is a lot of speculation among scholars regarding the exact period and duration of Newton's Anni Mirabiles. Westfall points out that the magical years for Newton started in 1664 and did not have to wait until 1666 or for him to return home. However, a statement that Newton made later in his life contradicts this argument. He says –

"*In the beginning of the year 1665 I found the Method of approximating series & the Rule for reducing any dignity of any Binomial into such a series. The same year in May I found the method of Tangents of Gregory & Slusius, & in November had the direct method of fluxions & the next year in January had the Theory of Colours & in May following I had entrance into ye inverse method of fluxions. And the same year I began to think of gravity extending to ye orb of the Moon & (having found out how to estimate the force with wch [a] globe revolving within a sphere presses the surface of the sphere) from Kepler's rule of the periodic times of the Planets being in sesquialterate proportion of their distances from the center of their Orbs, I deduced that the forces wch keep the Planets in their Orbs must [be] reciprocally as the squares of their distances from the centers about wch they revolve: & thereby compared the force requisite to keep the Moon in her Orb with the force of gravity at the surface of the earth, & found them answer pretty nearly. All this was in the two plague years of 1665-1666. For in those days I was in the prime of my age for invention & minded Mathematicks & Philosophy more then than at any time since.*"

According to him, his contributions came within those two years. Nevertheless, while evaluating his contributions, the timeframe and timeline are of little consequence.

It has been observed that the 24th year in the life of a scientist proves to be the most fruitful year. Isaac Newton and Albert Einstein are glorious examples. A recent scientific report claims that for scientists, old age sets in at 27!

Isaac enjoyed his stay at Woolsthorpe Manor. Hannah by then had forgiven her son for choosing a path other than farming. He basked in the love of a doting mother. He set up his study on the first floor. He built himself a bookshelf and organized the study comfortably; strange furniture for a farming family of those days. Servants did all the chores for him. He was left alone to science and mathematics. He opened the *Waste Book* he had inherited from his stepfather Barnabas Smith and started recording notes. He questioned, questioned and questioned! While he made notes, he also discovered the *truth* of things and realized that *truth is the offspring of silence and meditation*. Little did he know the impact his work would have on mankind.

Explorations

Although there is a hint, as noted earlier, that the results of the entrance test to the bachelor's degree was rigged, it is overshadowed by the extraordinary genius of Newton that made possible his pioneering achievements in natural philosophy.

His contribution spans all the branches of knowledge. A born intellectual, Isaac Newton lived in the world of thought. He contributed to mathematics, the occult and alchemy. Within the sphere of natural philosophy, he gave a new direction to mechanics, optics and celestial dynamics. He gave us calculus, a tool without which science and engineering would not have evolved into a discipline that shaped the modern world and influenced every aspect of it.

Year of Mathematics, 1664

Mathematics today is integral to every sphere and branch of science. Galileo had realized the importance of mathematics to explain the workings of the universe way back in the 16th century. He and other scientists believed that God had developed and hidden 'the truth' about the universe in *The Book of Nature*, in a strange language. One had to learn this language first to be able to discover the secrets of nature. For Galileo, mathematics was 'the' language, the key to understanding the universe. Mathematics for him was not just numbers and shapes, but a philosophy, a worldview. Newton's perception of science was much the same.

To understand how Newton's exploration into mathematics started and evolved, we depend upon the account given by John Conduitt (husband of Newton's niece). Isaac was required to study a number of topics for his B.A. degree. As always, he ignored the curriculum and chose his own path. He adhered to no rule or regulation. His intellect and curiosity could not be bound by a curriculum.

First, Isaac plunged into a modern analysis of mathematics after having mastered Descartes, Francois Viète, and the mathematics of infinitesimals by John Wallis. The power of his intuition was such that within six months, he thoroughly understood the mathematical analysis developed in the seventeenth century and was ready to break new ground. He had worked on 22 problems in five different categories. The *Waste Book* was now being populated with numbers and equations.

Birth of Calculus

Calculus is one of Newton's greatest achievements. As is the case with other subjects, his study of calculus too continued for a long period in his life. It is interesting that this great study began with simple questions such as, 'How to find the area under a curve? How to find the gradient of a curve?', and culminated in what we now call Integral Calculus and Differential Calculus. These are discussed in Part 2 of the book.

Students and scholars alike acknowledge differentiation and integration as the two most powerful tools of calculus. It is almost impossible to think of any scientific or engineering calculation that does not involve calculus or its by-product, differential equations. In fact, any kind of motion can be analyzed by solving a set of differential equations. We owe a lot to Isaac Newton who gave us this mathematical form. He had the power and intuition to digest any phenomenon, generalize it, and write down equations that governed it. He calculated the sine values of angles and tabulated them.

Incidentally, Gottfried Wilhelm Leibniz, a German mathematician, accomplished the same by about 1674 and published it. Who is to be credited for inventing calculus? Thus began a fierce controversy in the field of mathematics, which we will discuss later.

Gravity

If you've managed to do one good thing,
the ocean doesn't care.
But when Newton's apple
fell toward the earth, the earth,
ever so slightly, fell
toward the apple as well.

– *Ellen Bass*

Gravity and Newton are inseparable for the common man. If one mentions the name Isaac Newton, then the immediate response is – He sat under an apple tree in his garden; an apple fell on his head. Then he asked himself the question – why did the apple fall down? Why did it not go up? Then the idea of gravity flashed upon him.

This is one popular fairy tale in science. In fact, such stories emerged in Newton's time itself and lent an aura of mystery to him and his findings. However, we find that Newton had indeed told some people about his *apple tree experience*. For example, the French philosopher Voltaire has quoted it. Newton's biographers argue that Newton did not need a falling apple to explain gravity. He was mulling over it for quite some time and continued to do so long after his *Anni Mirabiles*. However, here is an account by William Stuckeley with whom Newton was associated in his later years.

We went into the garden, & drank thea under the shade of some apple trees; only he, & my self. amidst other discourse, he told me, he was just in *the same situation, as when formerly, the notion of gravitation came into his mind. "why should that apple always descend perpendicularly to the ground," thought he to himself; occasion'd by the fall of an apple, as he sat in a contemplative mood. "why should it not go sideways, or upwards? but constantly to the earths center? assuredly, the reason is, that the earth draws it. there must be a drawing power in matter. & the sum of the drawing power in the matter of the earth must be in the earths center, not in any side of the earth. therefore dos this apple fall perpendicularly, or toward the center. if matter thus draws matter; it must be in proportion of its quantity. therefore the apple draws the earth, as well as the earth draws the apple.*

Conduitt states,

In the year 1666 he retired again from Cambridge to his mother in Lincolnshire. Whilst he was pensively meandering in a garden it came into his thought that the power of gravity (which brought an apple from a tree to the ground) was not limited to a certain distance from earth, but that this power must extend much further than was usually thought. Why not as high as the Moon said he to himself & if so, that must influence her motion & perhaps retain her in her orbit, whereupon he fell a calculating what would be the effect of that supposition.

Scottish pharmacologist, Alexander Fleming, who discovered Penicillin, writes, "For the birth of something new, there has to be a happening. Newton saw an apple fall; James Watt watched a kettle boil; Rontgen fogged some photographic plates. And these people knew enough to translate ordinary happenings into something new..."

Whether the above story is true or false, the apple tree (Fig. 18) by the side of Woolsthorpe Manor has become a tourist spot. A storm in 1820 knocked down the original tree. It re-rooted thereafter and grew. Hundreds of souvenirs were made from the fallen tree, which are treasured by admirers the world over. In fact, a small chip of the tree was taken to the International Space Station in 2010 and was allowed to float in a gravity-free atmosphere while a picture of Newton watched it. Symbolically an apple tree has been planted in front of Newton's office in Trinity College, Cambridge (Fig. 19).

Fig. 18 Apple Tree at Woolsthorpe Manor today.

Fig. 19 Apple Tree in front of Newton's Office in Trinity College, Cambridge.

Although, Galileo had contemplated gravity and had attempted to measure acceleration caused by gravity, he had failed to explain its effects. Until Newton, a comprehensive conception of gravity did not exist. It is to Newton's credit that he quantified its effects and consequences, such as acceleration due to gravity, for example.

Newton's brilliance lies in his recognition of the fact that gravity, which makes an apple fall down to the earth, also holds the moon in orbit. The earth and the heavens are governed by the same law, he proved.

Newton thought about motion and started developing axioms, such as the one on motion along a curved path and area under a curve. His *Waste Book* (inherited from his stepfather) contains about one hundred axioms, which over the next twenty years consolidated into Newton's Laws of Motion, which we will discuss later and also in Part 2 of the book.

Light and Colour

Newton had before him, two theories:

a. Aristotle's theory of colours - according to which colour was essentially a mixture of white and black. As their proportion in a mixture varied, different colours were generated.

b. Descartes' theory of light - according to which, light is caused by pressure.

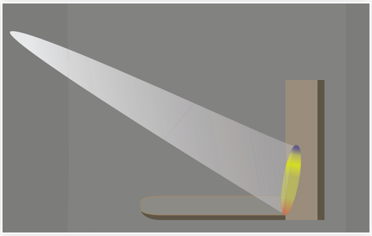


Fig. 20 Newton's colour experiment.

Newton experimented to prove or disprove these hypotheses. This time, there were no calculations. He had already bought the required equipment – a prism. In his study, he bore a small hole in the window such that the light from outside would fall on a wall 22 feet away (Fig. 20). Some have said that he led light through a hole in the curtain. He placed a prism in the path of light. He observed the rainbow colours, VIBGYOR, on the wall (Fig. 21 A). They were in the form of stripes, not in the form of concentric circles.

However, it was a known fact that when white light passed through a prism, a band of seven colours would appear. The question was why? Many theories had been put forth. One such was that the prism imparted colours to white light passing through it. Newton premised that these colours already existed in white light and separated on passing through a prism. Separation took place because colours bend (refract) differently when passed through a prism. To prove his point, he placed a second prism down in the path of light. The colours did bend further but did not change (in Fig. 21 A, only one colour is shown passing through the second prism). To prove his point further, Newton placed an inverted prism in the path of light as shown in Fig. 21 B. Now as expected the coloured rays recombined to give white light.

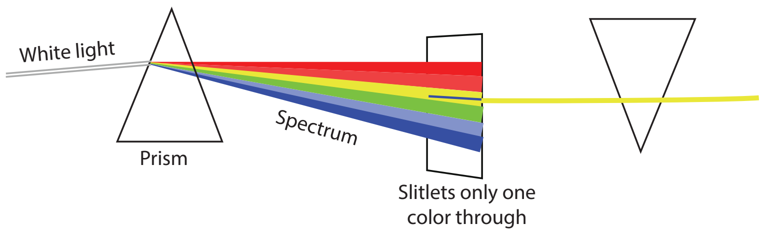


Fig. 21 A, Newton's colour experiment (continued).

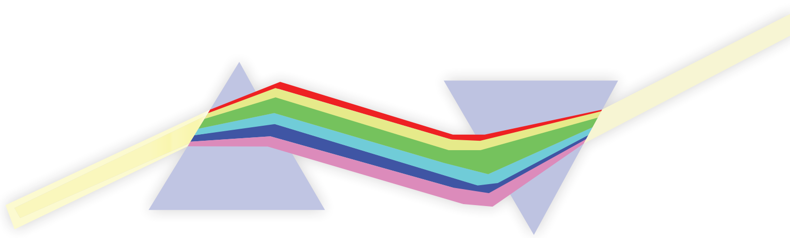


Fig. 21 B, Newton's light experiments (Continued).

Newton has stated that all these ideas did not come to him in a flash but were a result of a long thought process, which he called *Experimentum Crucis*. The phrase actually means that it is a crucial or critical experiment, which passes a judgement on an assumed hypothesis.

Mind and Body

Newton's observations during this period were not limited to mathematics, mechanics and optics. He was interested in many other areas of knowledge. He often wondered about the nature of and existence of the soul. Where is it located? In the brain? How is the soul connected with the rest of the body? What are the roles of mind and body in a given experience? This to him was a *mind-body* problem.

He was surprised by the different reactions of different people to the same stimulus. What was sweet to one was bitter to the other. The same music appeals differently to different people. How is it that some people are able to perform certain tasks, such as singing or walking home, unconsciously?

Then he pondered over imagination and creativity. You may refer to the books written by Westfall and Rob Iliffe to learn more about Newton's thoughts on this matter. Many of Newton's non-scientific pursuits may, today be dismissed as meaningless. However, we have to acknowledge the breadth of his intellect, which encompassed many disciplines.

Newton's many achievements were indeed glorious. He had moved far beyond any average B.A. student. He had learnt everything that the textbooks of his time had to offer. For him, the days of absorption were over; he had begun to make his own contributions. It is clear that he had something to offer to every branch of knowledge he ever studied. He was not just learning; he was making history.

We must acknowledge the many, many sleepless nights and his single-minded pursuit of knowledge. Newton learnt the hard way. He did make mistakes but was quick to correct them.

In the year 1666, Isaac Newton wrote three papers on motion. At the completion of each paper, it is said that the candles went out! He then gave a pause to mathematics. When he turned 24, Isaac Newton was one of the leading mathematicians of Europe; no wonder, other mathematicians grew envious of him.

Lucasian Professor

In early 1667, the fear of the plague had diminished and London was declared safe. Colleges in Cambridge reopened. Newton left his family home and returned to Trinity College. He was no more a lad. In 1666, Grantham had Herald's visitation (tours of inspection undertaken by Kings of Arms) and Newton was upgraded to a gentleman. Newton must have liked it for he began to sign his name as *Isaack Newton of Wolstropp. Gentleman aged 23*.

Having cleared the entrance exam for B.A in the year 1664, albeit through influence, Newton's immediate goal was to pass the B.A. degree examination, and obtain a fellowship at Trinity in order to pursue an academic career. If he failed, then he would have to return to cattle and dung at Woolsthorpe Manor.

Newton was at the lowest rung of the academic ladder. The first step towards ascent was to be elected a fellow of the college. There were only nine vacancies, one for the master and the rest for senior fellowships. The competition was fierce. Some of the ministers in the university, fellows and even the King of England exerted their influence. The *viva voce* was a difficult exam to clear and was held over four days in a church. Again, Newton was to be examined in subjects he had grossly ignored. Humphrey Babington was a senior fellow. Did this help again? Newton passed this examination effortlessly, it appeared.

Newton, now a minor fellow, could remain in Trinity for as long as he pleased. In fact, he lived there for twenty-eight years. One of the first things he did was to buy tools worth £1, which included a lathe. Then he spent £2 on a bachelor's gown, convertible to a master's. The gown proved a worthy investment considering that he received the degree of Master of Arts, M.A. within nine months. All fellows had to take the Holy Orders in the Anglican Church. This, Newton did on October 2, 1667 and swore – *I will embrace the true religion of Christ with all my soul …I will either set Theology as the object of my studies and take holy orders when the time prescribed by these statutes arrives, or I will resign from the college.* The position also required that chastity be observed; marriage was forbidden.

He was now eligible for a stipend from the college. A small allowance from his mother, a little fee from the students he tutored and the stipend formed his income. Newton equipped himself for research by purchasing lab equipment, a tin furnace and books on alchemy. He also bought chemicals as his book of accounts shows –

aqua fortis, sublimate, Oyle Perle [sic per se?], fine silver, Antimony, vinegar Spirit of Wine, white lead, Allome Nitre, Salt of Tartar, [mercury]	*2. 0. 0*
A Furnace	*0. 8. 0*
A tin Furnace	*0. 7. 0*
Joyner	*0. 6. 0*
Theatrum Chemicum	*1. 8. 0*

Theatrum Chemicum is a compilation of treatises on alchemy with which Newton was actively experimenting. He had several furnaces in his room. Newton's hair turned gray as early as 1670. His friend Wickins attributed it to his undivided attention to work, while Humphrey Newton (Isaac Newton's assistant and distant relative) attributed it to his experimentation with quicksilver i.e., mercury.

Some events of 1669 opened Newton's eyes to the world around. Maybe it was time to come out of hiding and tell others of his achievements. He was hesitant and wary. Several historians have observed that Newton was shy and would not talk about his findings freely with others. We also learn that he was scared of possible criticism from others. He was now forced to reckon his status as a researcher vis a vis other researchers. Although Newton by now had achieved a lot more than his contemporaries, none of his works had been published. Nicholas Mercator had published a book titled *Logarthimo Technica* in 1668. He had come up with a method to calculate logarithms of numbers based on a series expansion for log (1+x). Isaac Barrow in Cambridge received this book from John Collins, a mathematician, known for his extensive correspondence with scientists of the day in order to disseminate information. Barrow knew that Isaac Newton had done work on a similar topic and wrote to Collins that he had a friend in Cambridge who,

'hath a very excellent genius to these things, brought me the other day some papers wherein he hath sett downe methods of calculating the dimensions of magnitudes like that of Mr. Mercator concerning the hyperbola, but very generall; as also of resolving aequations.'

Barrow sent Newton's paper D*e analysi per a equationes numero terminorum infinitas (On the Analyses by Infinite Series)* to Collins without revealing the author's name. In a subsequent letter, though, Barrow mentioned the name of the author,

'*His name is Mr. Newton; a fellow of our college, & very young (being but the second year of Master of Arts) but of an extraordinary genius and proficiency in these things.'*

Barrow's words clearly establish his regard for Newton's work.

Collins and Newton both realized that Newton had achieved far more than Mercator. Collins communicated the paper to many mathematicians in Europe. He and Barrow tried to persuade Newton to publish the paper. Newton did not oblige. In 1670, he sent Collins a formula to calculate an annuity based on infinite series. As before, he permitted its publication with his name removed.

Barrow entrusted Newton with the job of revising his eighteen lectures on optics. Although the student had far exceeded the teacher's achievements, he carried out the assignment.

Newton Becomes a Professor

Barrow was the first to hold the Lucasian chair established by Henry Lucas in 1664. It was one of the eight professorial positions in the university and the only one for mathematics and natural philosophy (science). After holding that position for about five years, Barrow resigned. Two reasons have been cited for his resignation; one, he wished Isaac Newton to occupy the chair; the other and more probable is he wanted to rise to higher positions. In fact, within a year, he became Chaplain to the King and later Master of Trinity College.

On October 2, 1669, at the young age of 26, Isaac Newton was appointed Lucasian Professor with a handsome salary of £100 a year. Newton, the ill-prepared student who had been examined by Isaac Barrow just five years before, would not have dreamt of this success.

After Newton occupied the chair, the Lucasian Professorship became a very prestigious position in Cambridge. Eminent mathematicians and physicists such as Charles Babbage, Paul Dirac, Stokes and Stephen Hawking occupied the chair after him.

We do not know what Isaac Newton felt about his appointment to the chair. Was he pleased or did he take it as a matter of course?

The professorship entailed lecturing students every week for the three academic terms of a year. The professor had to deposit in the library, handwritten copies of any 10 lectures that he delivered in class every year. Failure to do so incurred a fine.

Among the topics for lecture suggested to Newton were geometry, geography, astronomy, optics, statics and mathematics. Right from the days of Barrow, professors paid little attention to lectures; a trend which continues to this day. It was to Newton's disadvantage that he was not a very impressive speaker. Another fact known now is that he stuttered.

Humphrey Newton has observed -

when he read in the Schools, as being Lucasianus Professor, where so few went to hear Him, & fewer that understood him, that oftimes he did in a manner, for want of Hearers, read to the Walls.

When he read in the Schools, he usually staid about half an hour, when he had no Auditors he Commonly return'd in a 4th part of that time or less. Mr Laughton, who was then the Library Keeper of Trinity College resorted much to his Chamber, if he commenced Doctor after that, I know not.

Occupying this important position now, Newton was undoubtedly the most famous intellectual in England. Yet not a single student has said, "I heard his lectures." Not even William Whiston, his student who succeeded him as the Lucasian professor. That Newton hated lecturing is evident from the fact that for the year 1687, he deposited only four manuscripts of his lectures in the library. Newton started his lecturing career with optics and spoke about the theory of light and colours. During his lectures, he demonstrated several concepts through experiments using lenses and prisms. He stressed that mathematical precision was important in science and advised students not to dwell on 'probable' knowledge.

He resumed his study of optics from the plague days at Woolsthorpe Manor. He performed his two-prism experiment in a more sophisticated manner. He confirmed again that the prism did not modify white light to break into a spectrum, but white light itself was composed of seven colours. Up to the year 1672, Newton had performed many experiments related to optics, none of which he had published. He chose to discuss them in his masterly treatise entitled *Opticks*, published much later.

Further Studies in Mathematics

In 1670, Newton sidelined optics and took up mathematics again. Barrow entrusted Newton with two projects: one, to revise and expand his own paper D*e analysi per aequationes numero terminorum infinitas* and the second, to annotate the Dutch book *Algebra* by Gerald Kinckhuysen. Newton completed the latter in 1670 and sent it to Collins who communicated it to a few mathematicians in Europe. They were happy to see Newton's involvement but also longed to see his own treatise on the subject. Newton, as before was reluctant to publish any of his works. Even when his discoveries were made known to others, he ensured his name was withheld. For instance, he indicated to Collins, that the author's name on the front page of his revision of Algebra by Kinckhuysen should appear as *enriched by another author*. His reluctance to own his work in the public sphere lasted all his life.

Telescope

On the sidelines of his continuous correspondence with Collins, Newton was engaged in another, very different activity, the construction of a telescope. Hans Lippershey had introduced the telescope to the scientific community as early as 1608. The year after, in 1609, Galileo also built a telescope. It is said that he used it initially to watch ships at a distant harbour. Only later, did he observe heavenly bodies, the moon, the satellites of Jupiter, etc. The telescopes built by Galileo and Lippershey, known as *Refracting Telescopes*, were built using refracting lenses, which split white colour. The resulting image was not very clear.

In addition to his path-breaking findings in Optics, let us not forget that Newton was a very good artisan. Even while he studied optics at Woolsthorpe Manor and at Cambridge, he was well aware that the telescopes of the day had a serious drawback. Refracting lenses of those days were coarse and produced Chromatic Aberration. The lens had to be ground to perfection, but there was no technology yet to achieve such perfection in the 17th century.

Newton built a *Reflecting Telescope* with parabolic mirrors to focus light. Fellow astronomers had desisted using parabolic mirrors because they could not polish the mirrors to the required accuracy. Newton's knowledge of alchemy came in handy now. He invented an alloy to polish the mirrors. Making a tube and mount for the telescope was no problem for our gifted carpenter. He succeeded in building a telescope (Fig. 22) in February 1669, measuring 15 *cm* or 6 inches in length with a magnification of 40. Comparatively, the refracting telescope was 1.8 metres or 6 feet length and Galileo's telescope was of 92.7 *cm* (36.5 inches) in length with a magnification of 20. Newton claimed to have observed Jupiter and its satellites through his telescope. He followed it up by building a second one.

Fig. 22 Replica of Newton's telescope.

Only two and a half years after building the telescope, did Newton hand it over to Barrow who presented it at a meeting of the Royal Society in London in December 1671. The members of the Society were baffled and thought that the king should have a look at it. Soon the telescope travelled to Whitehall to the king. Henry Oldenburg, the Secretary of the Society sent Newton a letter of admiration,'*it has been examined here by some of the most eminent in optical science and practice, and applauded by them.* Strangely enough, the Society took on itself the task of *securing this invention from the usurpation of foreigners*. Newton expressed surprise as to *how much care it took about securing an invention to me of which I have hitherto had so little value.* Huygens, a contemporary scientist, hailed it as *the marvellous telescope of Mr. Newton*.'

A reward followed. On January 11, 1672, Newton was voted a fellow of the Royal Society, a prestigious honour even today. In gratitude, Newton revealed the theory behind his telescope to the members of the Society through an elaborate letter- *A Theory of Light and Colours*. All the details of the telescope and the alloy used for polishing its mirrors were made known to the Society. Now Isaac Newton did not hide his authorship. He even volunteered to be present at the meeting, during which his paper would be presented and discussed. However, as can be expected, he did not bother to attend the meeting. With his telescope, Newton had established himself in the field of natural philosophy too.

Newton vs Hooke

Newton's paper on Light and Colour turned out to be explosive. It fired great debate in the realm of science. Before we describe the upheaval in detail, it is necessary to acquaint ourselves with Robert Hooke, a famous natural philosopher and his work.

Robert Hooke (1635 – 1703)

Fig. 23 Portrait of Robert Hooke.

Robert Hooke (Fig. 23) was born in Freshwater and was the last of four children. He became a staunch monarchist and developed an interest in observation, mechanical works and drawing. He studied at the Westminster School in London and mastered Euclid. He was a mathematician. He studied mechanics all through his life. He also had a natural flair for languages and mastered many. In 1653, Hooke joined Oxford University where he assisted Thomas Willis and the well-known Robert Boyle (famous for Boyle's Law). He made friends with a group of scientists at Oxford consisting of Boyle and 11 others. This group was the nucleus of the Royal Society, since its inception in 1660. His function in the Society was to curate experiments using his own methods or the ones suggested by others.

Incidentally, Hooke was also interested in almost every area that Newton was studying. He was well-versed in anatomy and geology, and engaged himself in flying machines, and watchmaking among other pursuits. However, their personalities were poles apart. Newton could shut himself away for days and study or meditate over something. Hooke, on the contrary, was social, visiting pubs, moving from one coffee house to another.

Hooke too had fabricated a telescope, or so he claimed, and apparently had watched Jupiter. He built a microscope and observed small organisms. In 1665, he published *Micrographia*, a treatise on microscopy. This book also contains his theory of light. Hooke believed that light travelled as waves in a homogeneous medium. Scholars believe that Newton had read *Micrographia*, appreciated it and learnt from it, although he would not admit it in public.

Corpuscular and Wave theory of light

Contemporary science proposes the dual nature of light i.e., light travels in the form of waves or pressure pulses and light is composed of particles or corpuscles that travel one behind the other. During Newton's time the Corpuscular and the Wave theory (Fig. 24) were considered mutually exclusive. Aristotle and Newton were proponents of the Particle Theory, which easily explained reflection of light. Huygens, Young and Hooke were the early pundits of the Wave Theory, which explained refraction and interference of light.

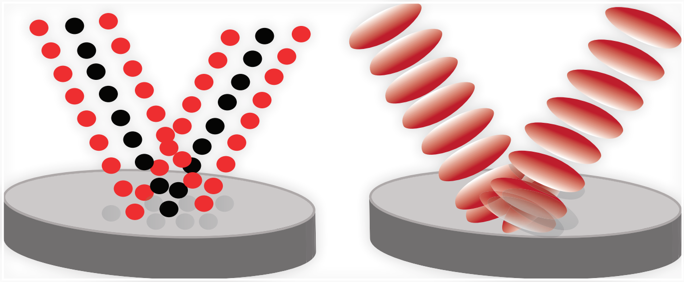


Fig. 24 Reflection of light according to Corpuscular and Wave Theories of Light.

For centuries, the debate regarding the structure of light has raged on. In 1905, Albert Einstein discovered the photoelectric effect, which supported the particle theory, and for which he won the Nobel Prize. However, his later work favoured the wave theory. Just a little later, physicists such as Niels Bohr, De Broglie, and others proposed that light exhibits a dual nature – it exists as a particle and as a wave too.

Newton's Paper Presented

A compilation of Newton's work on optics spanning many years was presented as a paper entitled *A Theory of Light and Colours* to the Royal Society in 1672 in his absence.

Newton in his paper delineated his prism experiment and his method of measuring angles of refraction. He also explained his two-prism experiment and concluded that *every coloured ray has an intrinsic predisposition to suffer a particular degree of refraction*.

Thus, he asserted that a theory of light can be formulated based on mathematical principles, and stated that white light is composed of all the primary colours. He explained that the colour of any object is the colour it reflects. Thus, a red body reflects red rays. Though he agreed that it was difficult to deduce the structure of light conclusively, he stated that it could also not be denied that light was corpuscular.

Iliffe points out that the essay was not merely the most radical challenge to accepted views about optics in modern history, but was a clear statement about what Newton took to be the proper way to investigate and justify scientific claims.

Oldenburg wrote to Newton to say that the paper was received with *singular attention and uncommon applause.* He sought permission to print it in *Philosophical Transactions*. The Society also suggested that members repeat and verify Newton's experiments. (The secretary of the Royal Society, Henry Oldenburg, a German by birth and a master of many languages, was determined to disseminate knowledge widely across Europe. He edited a journal called *Philosophical Transactions*. Scientific papers presented at the Society meetings, were considered for publication in this journal.)

Several members of the Society voiced their approval and admiration of Newton's work. One such was Christiaan Huygens, a Dutch astronomer and mathematician, although he developed reservations later.

Robert Hooke was not pleased. Within a week, he wrote to Oldenburg and attacked Newton's Corpuscular Theory. Apparently, Hooke took three to four hours to write his criticism. Scholars have opined that Hooke mistook the Corpuscular Theory to be the central theme of the paper. Hooke also rejected Newton's hypothesis that a prism merely splits the colours of light and does not add any. He argued that a prism behaves like a violin or an organ that adds its own sound to air. He argued that his numerous experiments proved that his wave theory explained the phenomena of refraction appropriately. Newton, he claimed, did not have a single convincing experiment in defense of his theory.

Newton was not one to treat criticism in good spirit. His paper was the result of eight years of hard work and many sleepless nights. He did not tolerate any negative criticism to his *Experimentum Crucis.*

To begin with, the very word *hypothesis* that Hooke had used, enraged him. According to Newton, his claim was *not a hypothesis* but it was *the final word* and had to be respected! He wrote a lengthy response to Hooke's objections, which took almost four months. Correcting him, Newton said that what Hooke was referring to (structure of light – Particle or Wave?) was not a hypothesis he had stated. He lodged an attack on Hooke's wave theory: How can it explain the fact that light travels in straight lines? Even if Hooke were half as good an experimenter, he would have found Newton to be right. Oldenburg had advised Newton to refrain from mentioning names in his rebuttal, especially that of Hooke. Newton paid no heed; he mentioned Hooke's name in the very first sentence and at twenty-five different places, almost on every page. Here is an extract –

Mr Hook thinks himself concerned to reprehend me for laying aside the thoughts of improving Optiques by Refractions. But he knows well that it is *not for one man to prescribe Rules to the studies of another, especially not without understanding the grounds on which he proceeds.*

Newton wrote and rewrote this rebuttal four times and it turned out to be longer than his original paper. He had garnered a wealth of data on optics from his studies, lectures and experiments. Newton's reply itself is a significant contribution to the study of optics. After reiterating his findings, he insisted that physical principles as well as mathematical proof were important in science. What resulted was a *star war* of words and mutual accusations. Hooke wrote to the members of the Society that he had performed all the experiments suggested by Newton and was unable to accept his theory.

Christiaan Huygens (Fig. 25), who had also supported the Wave Theory of Light, filed his objections to Newton's theory. In fact, he put forth convincing explanations for reflection and refraction of light using the Wave Theory. It was not easy to refute his argument, and his theory is still valid. He also believed in the presence of a limited number of basic colours from which all other colours emerged.

Fig. 25 Christiaan Huygens.

Newton sent Huygens a harsh reply. Oldenburg, who acted as the postmaster for all of Newton's correspondences, tried to pacify Huygens by telling him that Newton was a man of repute. Realising that Newton was adamant, Huygens decided to withdraw from the scene. Yet, he was generous enough to send Newton a copy of his book *Horologium Oscillatorium*. Newton, in turn, was kind enough to acknowledge its receipt. (Robert Boyle was another scientist who honoured Newton by sending him a copy of his book).

Among his other antagonists was Pardies, a well-known professor from Paris. Although he raised objections, he did not want to start a controversy. He simply bowed to Newton's greatness and remained silent. Liege Jesuit Francis Linus (Hall) was another critic who, although, did not refute Newton's theory, expressed his grievance that it was difficult to adhere to Newton's instructions fully in order to perform experiments to test his theory. Linus and his followers (after his death) challenged Newton to prove his theory convincingly. Newton shot back saying that Linus and his group had not followed his instructions. He stressed the importance of using quality prisms and specified the need to measure the angle of refraction correct to a minute, not to a degree.

Vexed by all this criticism and instead of engaging in objective discussion, he decided to withdraw in March 1673. He wrote to Oldenburg –

Sir I desire that you will procure that I may be put out from being any longer fellow of the Royal Society. For though I honour that body, yet since I see I shall neither profit them, nor (by reason of this distance) can partake of the advantage of their Assemblies, I desire to withdraw. If you please to do me this favour you will oblige

Sir Your humble Servant

I. Newton

I have presumed to put you once more to the trouble of receiving my quarterly duty as Fellow of the Royal Society. At next Lady day I am behind hand for half a yeare, & have therefore sent you 1^{pounds} 6^{shillings} by John Stiles. I hope you will excuse this trouble, it being the last. I shall be henceforth absent from Cambridge for about a month.

These

For Henry Oldenburg Esquire at his hous about the middle of the old Pall-Mail in Westminster

London

Oldenburg tried to placate Newton, for his withdrawal, would be a loss to the Royal Society. He wrote to him that the members of the Society had the greatest respect for him. Any criticism made was very mild and common. He also pointed out that Newton had not even met these people in person. But Newton did not relent. He wrote –

'I intend to be no further solicitous about matters of philosophy; and, therefore, I hope you will not take it ill if you never find me doing anything more in that kind; or rather that you will favour me in my determination, by preventing, so far as you can conveniently, any objections, or other philosophical letters, that may concern me.'

Newton withdrew completely from the scene. After two years, Newton himself reopened the case by writing two more papers – *A Hypothesis Explaining the Properties of Light* and *Disclosure of Experiments*. They were companion papers; the first put forth his speculations on nature of light and matter. The second described experiments, which attempted to prove the hypothesis. As much as Newton tried to remain objective, he could not refrain from making jibes at Hooke. He accused Hooke of plagiarizing Fabri, a French scientist. Hooke retaliated, accusing Newton of plagiarizing his own *Micrographia*.

Now, the two started communicating directly. There was some dignity and mutual respect for some time. In 1676, Newton tried to sum up the debate in these words, which are the most quoted words in science –

What Des-Cartes did was a good step. You have added much several ways, & especially in taking the colours of thin plates into philosophical consideration. If I have seen further it is by standing on the shoulders of Giants.

Some interpreted these words as indicative of Newton's humility. Others were certain his words were meant only to mock Hooke. It is very admirable that on April 27, 1676, Hooke performed experiments before the members of the Society to validate his antagonist's *experimentum cruces*. A theory, if factually sound, stands irrespective of who proposes it and who verifies it. Newton's hypothesis was proved right and elevated to a theory, ironically, by his rival. A strange occurrence in science, indeed!

To take orders or not

Newton had been a fellow of Trinity College for nearly four years now and had risen to the rank of a professor. To retain his Chair and fellowship, he had to become an ordained member of the Anglican clergy within seven years of becoming a fellow. Failing to ordain himself thus, the fellowship worth a handsome amount of £60 a year would be at risk.

Newton was a religious man. The Bible was another means to discover the truth in God's mind, which was also the purpose of his scientific pursuits. His religious studies had begun when he was admitted to the school in Grantham. He had read books from the church opposite his school and from the library of Barnabas Smith, his stepfather. He had also bought four books on theology when he joined Trinity.

Now, with his focus on theology, another notebook with various orthodox headings emerged. Newton never took any subject lightly. He immersed himself in serious theological study. This and his interest in alchemy (of which we will learn later) may be responsible for his slow response to the criticism leveled against his paper on light. He even indicated to Oldenburg in 1674 that he intended *to concern myself no further about promotion of philosophy.* He had also given up hopes of retaining the fellowship at Trinity College. At one point in time, he even wrote to Oldenburg asking him to waive off his dues to the Society.

During this period, Newton challenged the Christian assertion that Church, Christ and God were the same. Newton could not openly air his views against the Church; that would incur heavy penalties and the wrath of the church. His views came to light only after his death.

It was impossible for him to equate Christ with God. In the words of Joel Levy,

'he became convinced that a fraud had been perpetuated to corrupt the legacy of the early Church, and that the scripture itself had been corrupted to support trinitarianism.'

It may be noted that Trinitarianism (Fig. 26) claims that God exists in three distinct, simultaneous, co-eternal, and co-powerful forms known as the Father, the Son, and the Holy Spirit. His notes on this topic spanned nine pages in his notebook. He traced the origin of this corruption of the dogma to the fourth century. According to Newton, the conventional Catholic/Anglican doctrine, which worships Christ as God, was idolatry and a most fundamental sin. It was as if Newton had uncovered the crime of the millennium.

In the words of Westfall, it *is not hard to understand why Newton became impatient with minor diversions such as optics and mathematics. He had committed himself to a reinterpretation of the tradition central to the whole of European civilisation.*

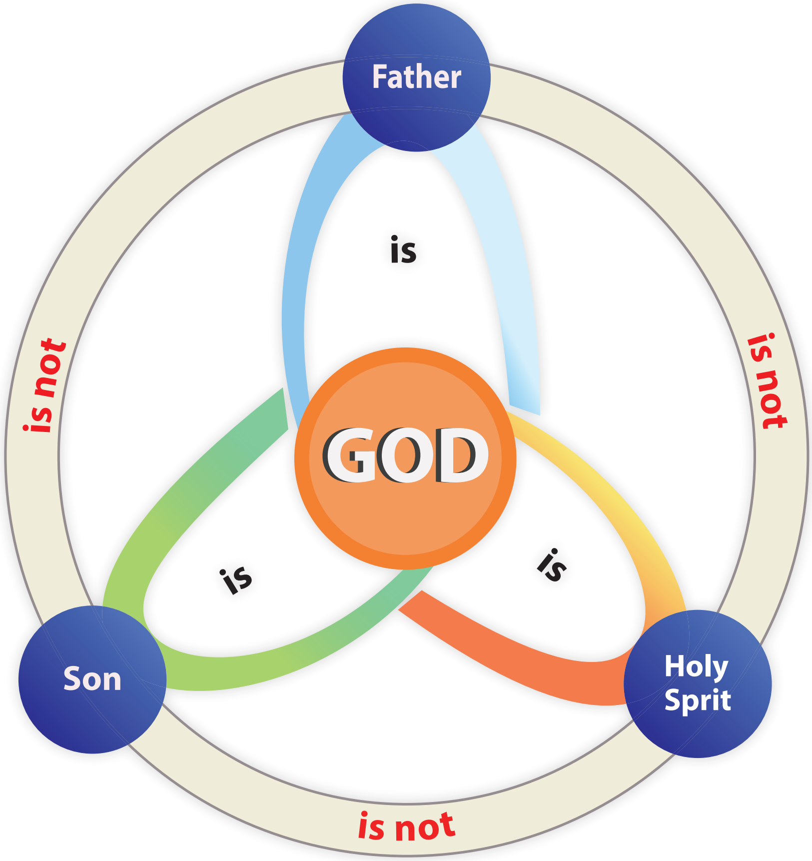


Fig. 26 A Logo of Trinitarianism.

His belief was at loggerheads with at loggerheads with at loggerheads with at loggerheads with at loggerheads with the ordination, for he was required to accept the thirty-nine articles of the Anglican Church, which included Trinitarianism. Ironically, he had 'accepted' this three or four times in the past, when he took a degree or a fellowship or the professorship. Would he repeat the drama? No. Isaac Barrow was now the Royal Chaplain. Perhaps, it was with his support that the king exempted any Lucasian professor from taking orders and Newton was allowed to continue as professor and save his fellowship.

Exemption granted, Newton did not give up theology. He remained interested in it throughout his life.

Absent Minded Professor

As Newton settled down in Trinity College, he was shocked that most other fellows were barely interested in any study at all. They seemed to be aiming for an employment in the king's palace or the Church. For example, George Modd and Patrick Cook, his contemporaries, stayed in the college for forty years without teaching or researching. This was obviously in sharp contrast to Newton who wanted to explore mathematics, mechanics, optics and a host of other topics and pursue truth. Once again, he became a solitary figure. In the words of Westfall, *This fundamental fact coloured the scene in which virtually the whole of his creative life was set.*

One has to admire his single-minded devotion to research and study. He had the focus to keep all distractions at bay. However, it also made way for absent-mindedness. There are several stories about Newton's life in Cambridge and his absent-mindedness. Here is an extract from an account by William Stuckeley, a student at Cambridge who befriended Newton later.

At Cambridge I often heard stories of his absence of mind, from common things of life. As when he has been in the hall at dinner, he has quite neglected to help himself; and the cloth has been taken away before he has eaten anything. That sometime, when on surplice days; he would go toward Saint Mary's church, instead of college chapel. Or perhaps has gone in his surplice to dinner, in the hall. That when he had friends to entertain at his chamber, if he stepped in to his study for a bottle of wine, & a thought came into his head, he would sit down to paper, & forget his friends. Thus the human *mind wholly taken up in abstract reasoning, & long concatenation of causes & consequences, was apt, as it were, to desert the body: assume it is essential & true life. & enjoy those superlative pleasures arising from contemplations of the most worthy sort, nearly approaching to angelical. tis an anticipation of part of those divine joys, in our future state of being.*

A letter written by Humphrey Newton much later is also revealing.

He always kept Close to his Studyes, very rarely went a visiting, & had as few Visitors, excepting 2 or 3 Persons, Mr. Ellis of Keys, Mr. Lougham of Trinity, & Mr. Vigani, a Chymist, in whose Company he took much Delight and Pleasure at an Evening, when he came to wait upon Him. I never knew him take any Recreation or Pastime, either in Riding out to take the Air, Walking, bowling, or any other Exercise whatever, Thinking all Hours lost, that was not spent in his Studyes, to which he kept so close.

fforeigners He received with a great deal of ffreedom; Candour, & Respect. When invited to a Treat, which was very seldom us'd to return it very handsomely, freely, & with much satisfaction to Himself. So intent, so serious upon his Studies, that he eat very sparingly, nay, oftimes he has forget to eat at all, so that going into his Chamber, I have found his Mess untouch'd, of which when I have reminded him, would reply, Have I; & then making to the Table, would eat a bit or two standing, for I cannot say, I ever saw Him sit at Table by himself, At some Entertainments the Masters of Colledges were chiefly his Guests.

At some seldom Times when he design'd to dine in the Hall, would turn to the left hand, & go out into the street, where making a stop, when he found his Mistake, would hastily turn back, & then sometimes instead of going into the Hall, would return to his Chamber again.

Newton was never known to engage in a conversation on his own accord. However, he would answer a question with great acuity. According to Humphrey, in a span of five years, Newton laughed only once. He had only three friends in Cambridge. These included John Wickins who shared a chamber with him until 1683. In fact, Newton cut off his relations with him afterwards. The other two were Humphrey Babington and Isaac Barrow. He did not mingle with anybody, even for a sport or recreation; bowling and horse riding with friends were totally out of the question.

Newton rarely left his chamber and chose to eat there by himself. Even when he went to the *Hall* to eat, he sat alone as if he knew nobody there. The Hall occupies a unique position in Trinity College and Cambridge University. It is the cafeteria where the residing scholars of the college met to have their breakfast, lunch and dinner. On certain occasions, they were expected to be dressed in their formal gowns even in the Hall. Apart from a place to dine, the Hall was where scholars engaged in lively discussion. The great Indian mathematician Srinivasa Ramanujan spent five years from 1914 to 1919 in Trinity College. During those days, Bertrand Russell, the philosopher, Prof. G H Hardy, Ramanujan's mentor and others engaged in discussions at the Hall. Being a vegetarian Ramanujan did not eat in the Hall and so missed the conversations as well. The walls of the Hall remain decorated with the portraits of Newton, Thomas Neville, Francis Bacon, John Dryden, Lord Tennyson, and Amartya Sen among others.

Newton's response to a request from Francis Aston, a fellow at Trinity, is a curious one. The latter was to travel overseas, perhaps Holland, and sought Newton's advice. Newton's reply was precise.

As Westfall puts it,

Aston should adapt his behaviour to the company he is in. He should ask questions but not dispute. He should praise what he sees rather than criticise.

Newton requested Aston to make a few inquiries about alchemy. His request exhibits a sense of worldliness on Newton's part, which most people thought did not exist.

It is interesting that Thomas Parne who collected material for the history of Trinity College made only three references to Isaac Newton while he wrote a great deal about other fellows. In a diary kept by Samuel Newton, who was the registrar of Trinity, Isaac Newton hardly gets a mention.

Newton would walk in the fellows' garden and draw diagrams in the gravel. His colleagues realised that these were important and made sure to walk around them.

Perhaps Newton's loneliness was a blessing in disguise for science. He had ample time to study, research and meditate. He could not involve himself in quotidian realities of everyday existence. He seldom left Trinity for any personal work. Records show that he stayed in the college for fifty-two weeks in 1669, forty-nine and half weeks in 1670 and forty-eight weeks in 1671. He left the college, if at all, only to visit home.

Reverend John North, the master of the college, writes, *if Sir Isaac Newton had not wrought his hands in making experiments, he had killed himself with study*.

He studied until two or three in the morning. He was not in the habit of visiting the Chapel. However, he never missed the church mass on Sundays. He had full freedom to do whatever he liked. The only three sins banned by the college were *crime, heresy and marriage*.

Mother Hanna's Death

In 1679, Benjamin Smith (Newton's stepbrother) had a fever. Newton's mother Hannah nursed him and in the process caught the same fever. Newton rushed to take care of her.

John Conduitt writes,

Sir Isaac attended her with a true filial piety, sate up whole nights with her, gave her all her Physick himself, & dressed all her blisters with his own hands made use of that manual dexterity for which he was so remarkable to lessen the pain which always attends the dressing the torturing remedyusually applied in that distemper with as much readiness as he ever had employed it in the most delightfull experiments.

He must have put to good use his experience in medicine, remedy and apothecary. None the less, Hannah died on June 4, 1679. We have no indication of the impact of Hanna's death on Newton. We only know that separation from his mother in his childhood had modified his personality in several ways. Apparently, Newton visited his family home only three times in twelve years. At 37, he was heir to a fairly large property. He stayed back for four months to set the affairs in order. There were dues to be collected from tenants, one of them being Edward Storer, the stepson of Clark with whose family Newton had lived in Grantham.

In 1683, Newton's friend and roommate, Wickins gave up his fellowship and moved from Trinity to get married and enjoy a good life. Did this hurt Newton in any way? Historians have attempted to find out. Only five letters between Newton and Wickins exist. The information or feelings exchanged in these letters throw no light on the matter. To date, the exact nature of their relationship remains a mystery.

It was at this stage that Humphrey Newton came into Newton's life and lived in his chamber, helping him in many ways. One of the great services that Humphrey undertook was to transcribe *Principia*. He also copied many of Newton's works on mathematics, theology and alchemy. He writes that Newton loved walking in his garden. He could not tolerate weeds and so hired a gardener to deweed and maintain his garden. He is known to have been utterly careless with money. He would keep about a thousand guineas by his window. Some wonder if it was a ploy to test Humphrey for his honesty. He also loved apples. He worked endless hours, again forgetting to sleep and eat.

An Alchemist in Search of Truth

When viewed from the high pedestal upon which we have placed Isaac Newton, it is puzzling that he was involved in many pursuits, which are now considered unscientific. After the publication of his paper on light and colour, we have seen that a volcano of discussion erupted. Voices of praise, as well as dissent, were heard from scientists all over Europe. The scientific community waited for some response from Newton; needless to say, the community was met only with silence. His replies, if at all, came very late. In his replies to Oldenburg, Secretary of Royal Society, he often said that he was busy with other things, *business of my own which at present almost take up my time & thoughts*.

It was Newton's engagement with this *business* that delayed his response to Hooke and dragged the dialogue for years. As a result, at one point of time, he was even ready to sever contact with the Society, one of the highest bodies for Natural Philosophy. The 'business of his own' that he mentions was not mechanics or mathematics, or even optics. It was alchemy. Records indicate that Newton may have started this venture in 1669. It was not just a pastime or a preoccupation; he was engrossed in it.

Alchemy, the Predecessor of Chemistry

Alchemy was a speculative discipline with a long history.

It was the predecessor of the stream of science we call *Chemistry* today, although it encompassed many other faculties such as religion, occultism and spirituality. It involved all the methods of chemistry, such as mixing of powders and potions, heating, dissolving, distilling and such processes. Hundreds of chemicals including mercury, iron and various acids were distilled in crucibles, furnaces and alembics.

The art of alchemy emerged in Egypt between the 2nd and 4th centuries BCE where, the Hermetic Tradition took birth. Then, the Islamic countries took to alchemy and it reached Europe during the Middle Ages and the Renaissance. Some masters of alchemy claimed they could converse with spirits and exercise control over the weather. Alchemical activities, discoveries and studies were often shrouded in secrecy. Alchemists developed their own vocabulary and codes as shown in Fig. 27.

Fig. 27 Alchemy Symbols.

Alchemy was practiced in most of the early civilisations of India, China and Egypt. The Vedas from India describe a connection between eternal life and gold. The use of mercury, very sacred to practitioners of this art, was documented as early as the 3rd and 4th centuries. In India, it was called *Rasāyana*, meaning a manipulation of nectar, mercury and juice to be used as drugs, compounds and medicine, which was supposed to restore youth and health. Apparently, a Buddhist monk had developed a method of converting mercury into gold.

During the seventeenth century (the time of Newton) Europe witnessed the rise of a network of alchemists exchanging ideas, books and knowledge. A number of Newton's contemporaries were involved in alchemy. A large section of the society compared it to sorcery and condemned it as an illegal practice meant to cheat people with tall claims of transmuting any metal into gold. Many practitioners of alchemy lost money, their homes and even their powers of discrimination.

The main objectives of alchemy were to, (1) create the philosopher's stone (Fig. 28), which purportedly had magical powers (2) transmute ordinary metals into noble metals (gold or silver) using the philosopher's stone, and (3) develop *elixir vitae*, which supposedly prolonged youth and bestowed longevity.

Fig. 28 Diagram of Philosopher's stone.

Newton, an Alchemist

It is baffling that a man of Newton's caliber believed that an ordinary metal could be converted to gold. Scholars have searched for answers. For Newton, his alchemical inquisition was part of his pursuit of truth. In the contemporary world, advancement in knowledge and technology is an index of wisdom and civilization; in the 17th century, ancient civilisations were believed to be 'closer to God' than the civilized ones, for they had gained perfect wisdom, or *prisca sapientia*. This concept is analogous to the existence of a perfect crystal or substance of zero entropy in Thermodynamics. From that point onwards, humankind corrupted perfect wisdom. Alchemy was a tool to rediscover that wisdom and re-establish humanity's proximity to God. It was an instrument to decode what God had hidden in the universe. Boyle, for instance, believed that it could explain many important functions of nature.

True, alchemy was entirely different from the mechanical philosophy that Newton upheld at the Royal Society. Mechanical philosophy was concerned with body or matter and attempted to explain everything in terms of mechanics. Alchemy, on the other hand, searched for the spirit hidden in all matter. There was life everywhere, in the firing of a cannon, the falling of a stone and the moon circling the earth. In all actions of the universe, there was a male element, a female element and a spirit.

It is clear that gold or money was the last thing that interested Newton. He was a philosopher in search of the Christian truth. What mattered to him was truth and truth alone. Being born on Christmas Day, he thought it was his mission to search for it and that he was well equipped to do so. He also used a pseudonym to write his alchemical writings, *Jeova Sanctus Unus* meaning *One Holy God*, which reiterates the spiritual nature of his pursuit.

Newton was not alone in his alchemistic endeavours. Lifetimes were spent in its pursuit and many of his contemporaries were deeply engaged in it. He did not need a formal induction into alchemy. He had started his internship in his school days. He learnt about dyes and remedies for a few diseases from the book by Bate - *The Mysteries of Nature and Art*. He had copied them into his notebook. Working with Clark in his apothecary was the next step. In his college days at Trinity, Humphrey Babington introduced him to chemistry, while Henry More an alumnus from King School in Grantham was an alchemist himself. Newton was deeply involved in alchemy for a long time: while he worked for Isaac Barrow, developed his theories of light and during the critical debate that followed the publication of his papers.

Though his early studies provided him with the foundation, the real alchemical inspiration came from Robert Boyle (Fig. 29) who was one of those responsible for the formation of the Royal Society. He wrote a book, *Sceptical Chymist* that attempted to mold chemistry on a scientific basis. Newton and Boyle met in 1675 and became good friends. Consequently, Newton filled his notebook with 47 headings related to alchemy including Amalgam, Crucible, Extraction and *Menstruum Peracutum* (the recipe for a substance that dissolved gold).

For about two years from 1668, Newton made many trips to London. He met 'friends' here and there. Information about alchemy flowed from mysterious sources including the Hartlib circle of which Newton was a member. Hartlib, an alchemist from Prussia, lived in London and had a big following. In the period 1630 – 1660, Hartlib and his associates exerted their influence over intellectuals in Europe and America on many matters – alchemy, agriculture, medicine and religion.

Fig. 29 Robert Boyle.

Newton and Boyle were conscious of two distinct practices in natural philosophy – one was the *magical* way of the alchemists and the second was the *scientific* method of the modernists such as Descartes. They tried to combine the two approaches. *The Origine of Formes and Qualities* by Boyle was a product of this dual interest. Newton seems to have learnt a great deal in his company and utilized his learning substantially when he formulated his own theories of gravity and light.

Newton travelled to London for the first time in 1669 and bought quite a few pieces of equipment including a furnace and *Theatrum Chemicum*. He also bought some books on Alchemy. When Newton died, his personal library contained 169 works on alchemy and chemistry. Michael White, who authored a biography of Newton has said that *he possessed the finest* *and most extensive collection of alchemical texts*. He read voraciously for nearly twenty-five years and made extensive notes (Fig. 30). His reading was not limited to printed texts; it included handwritten manuscripts as well. Prof. Dobbs confirms, Newton probed *the whole vast literature of the older (i.e., pre - seventeenth century) alchemy as it has never been probed before or since.* In Westfall's estimate, Newton's alchemical notes total over a million words.

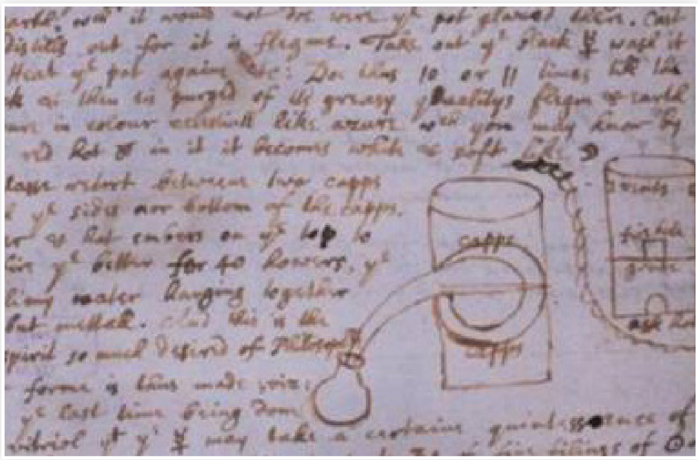


Fig. 30 Newton's notes on alchemy.

For some time Newton shared a chamber with Wickins. His alchemical adventures took place in a shed attached to this chamber. Humphrey Newton became his assistant in 1683 when Wickins left. He writes about the way Newton worked in his laboratory,

He very rarely went to Bed, till 2 or 3 of the clock, sometimes not till 5 or 6, lying about 4 or 5 hours, especially at spring & ffall of the Leaf, at which Times he us'd to imploy about 6 weeks in his Elaboratory, the ffire scarcely going out either Night or Day, he siting up one Night, as I did another till he had finished his Chymical Experiments, in the Performances of which he was the most accurate, strict, exact: What his Aim might be, I was not able to penetrate into but his Paine, his Diligence at those sett times, made me think, he aim'd at somthing beyond the Reach of humane Art & Industry. I cannot say, I ever saw him drink, either wine Ale or Bear, excepting Meals.

While modern science stresses reproducibility of results, alchemy did not. It was indeed not possible to repeat experiments and get the same result, since the results obtained from alchemical experiments were dependent upon the performer and his mental and spiritual attitude and status. Spontaneous instinct played an important role in these studies. No wonder, mainstream science looked down upon alchemy. That is the reason why most alchemical works were carried out in secrecy, and was hence coded and encrypted.

Surprisingly, Newton invested in alchemy the same dedication and passion as he did for his study of gravity and optics. He wrote down headings in his notebook, studied related literature and asked questions. Sometimes, he jotted down more than 50 different descriptions under the same heading. He used the jargon of his fellow alchemists. To quote from Joel Levy – *in some passage Newton writes 'a wondrous bright water in which the sun doth set'*, decoded as *'mercury (wondrous water) has been used to dissolve gold (the sun).*

In 1677, a fire broke out in his laboratory destroying quite a number of his papers, and speculation has been rife that these could have included many of his alchemical observations and his early work on optics. Unfortunately, we lost things that Newton wanted to tell us.

In search of Regulus

Newton believed in the transmutation of substances. Mercury or quick silver was considered an ideal transmuting agent for two reasons: it is the only metal that exists in liquid form at ordinary temperatures, and it dissolves most metals including gold to form amalgams. For Newton, *mercury* was *prima materia* meaning the *first matter*. However, *prima material* was not the same as quicksilver or ordinary mercury. The alchemist's aim was to isolate *prima materia* or the soul of all matter from the rubbish. It was the primordial form of all metals. Once *prima materia* is isolated, they believed they could convert it *into* philosopher's mercury and then into philosopher's stone. This process was called *putrefaction*. The *prima materia* could be transmuted to any other metal including gold through another process called vivification. The former undertook the cleansing of the substance while the latter instilled life into it. These were considered as the male and female aspects respectively. The belief was that metals could also be vegetated as plants and animals.

Attempting putrefaction, in one of his experiments, Newton dissolved ordinary mercury in nitric acid and then added lead and copper. When allowed to precipitate, only ordinary mercury remained at the bottom of the container. A disappointing result. He could not separate the dross and obtain *prima materia*!

His next venture was to manufacture *Regulus* or *little king,* a crystalline compound of antimony and iron with shards radiating outwards. Newton thought he had succeeded only to realise later that Regulus was not philosopher's stone.

Universal Spirit

Alchemists including Newton believed in the existence of a spirit or a force that acted upon the universe, which was responsible for all activity in the universe, be it the germination of a seed, birth of an animal, a chemical reaction, or transmutation of a metal. Newton called it *vegetative spirit* because its influence was plant-like. Proving the existence of that spirit and understanding it was more important than the philosopher's stone or the elixir. It is no surprise that poet William Blake called this spirit, a *Divine Geometer* (Fig. 31).

Around 1672, Newton may have had a spark of inspiration.

He wrote,

The vegetation is the sole effect of a latent spirit & that this spirit is the same in all things.

Newton envisaged a spirit or a force that acted throughout a mass. Thus, an idea had been

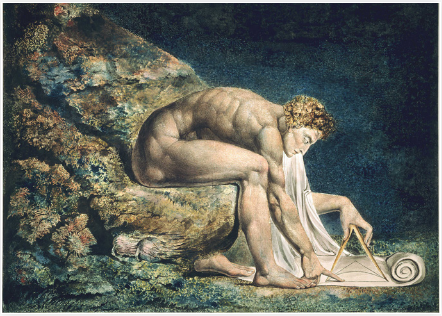


Fig. 31 The Divine Geometer.

sown in his mind that would germinate into the concept of gravity, a force that acts within a body and between two bodies even though there is nothing material between them, sometimes referred to as *Action at a Distance*. The implied meaning is that a body such as the earth can influence the motion of the moon even though there is no physical contact between the two.

There is therefore .. in the textures of the grosser matter a more subtle secret & noble way of working in all vegetation .. & the immediate seat of these operations is not the whole bulk of matter, but rather an exceeding subtle & unimaginably small portion of matter diffused through the mass which if it separated there would remain but a dead and inactive earth.

Compare the above statement with what he says in 1686, at the end of his masterly treatise *Principia Mathematica*.

And now we might add something concerning a certain most subtle Spirit which pervades and lies hid in all gross bodies; by the force and action of which Spirit the particles of bodies mutually attract one another at near distances, and cohere, if contiguous; and electric bodies operate to greater distances, as well repelling as attracting the neighbouring corpuscles; and light is emitted, reflected, refracted, inflected, and heats bodies; and all sensation is excited, and the members of animal bodies move at the command of the will, namely, by the vibrations of this Spirit, mutually propagated along the solid filaments of the nerves, from the outward organs of sense to the brain, and from the brain into the muscles. But these are things that cannot be explained in few words, nor are we furnished with that sufficiency of experiments which is required to an accurate determination and demonstration of the laws by which this electric and elastic Spirit operates.

Thus, alchemy too was a blessing in disguise for he could conceptualise gravity. His experiments in alchemy continued until his death. Of course, he had no luck as far as the fundamental quests of alchemy were concerned.

Westfall observes, there is no reason to expect that he should have remained satisfied for ever with his first love. Mechanical Philosophy had surrendered to *his desire, perhaps too readily. Unfulfilled, he continued the quest and found in alchemy and in allied philosophies a new mistress of infinite variety who never seemed fully to yield… Newton wooed her in the earnest for thirty years.*

Newton was not just a theoretician; he was a hard-core experimentalist. He tested, built apparatus such as furnaces and crucibles. He wrote down his observations in a language only his alchemy friends could understand. For example, he wrote,

May 10 1681 I understand that the morning star is Venus and that she is the daughter of Saturn and one of the doves….

Philosophiæ Naturalis Principia Mathematica

God showed himself to be Newton's equal in Mechanics when He built His cosmos upon them, says Westfall in *Never at Rest, A Biography of Isaac Newton.*

Principia Mathematica undoubtedly is one of the most influential books ever written. Newton gave us a model of the physical world and the tools to calculate the motion of objects both solid and fluid. The book changed the course of science altogether and the laws stated therein are used even today in science and engineering.

Hooke Throws a Challenge

The events that led Newton to write this treatise are quite interesting. It is not wrong to say that irritation and not inspiration may have been the cause. Newton had made quite a few advances in both mechanics and optics since his Anni Mirabiles days. After the several controversies with fellow scientists, especially the one with Robert Hooke, Newton withdrew from the public sphere. He severed all contact with the Royal Society and with Oldenburg, its Secretary. But he never gave up contemplation and study.

His isolation did not last long. Several developments around him goaded him into action. The first of such was the death of Oldenberg, the Secretary of the Royal Society in November 1679 and the subsequent appointment of Robert Hooke as Secretary.

Hooke invited Newton to participate in the deliberations of the Society and offered his own paper, published five years before, for discussion. We are not certain that Newton was aware of its publication at that time. Perhaps, Hooke's intention was to bring Newton back to the Society. Hooke, in his paper, had put forth a hypothesis that *planetary motions are compounded of a tangential motion and an attractive motion towards the centrall body.*

We know that if the sun does not pull the planets towards its centre, the planets will assume straight line paths and shoot off in tangential directions (Fig. 32). A similar phenomenon occurs with respect to moon's revolution around the earth. While Hooke only proposed this theory, Newton proved it mathematically in the years to come. Hooke's proposition thus foretells Newton's own discoveries, to be revealed later in his *Principia*.

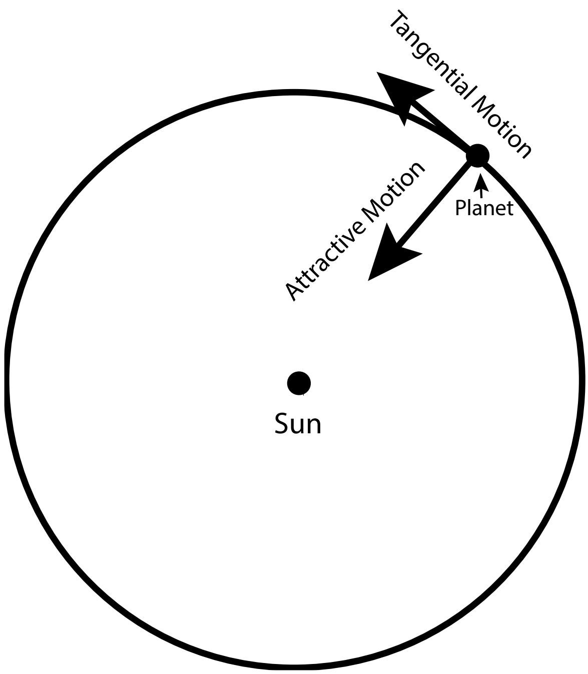


Fig. 32 Two motions for a planet according to Hooke Diagram.

Newton was not interested in any controversy or dialogue with Hooke and brushed him aside, saying he had no time for such discussions. He compared himself to a tradesman who was not concerned with the activities of another tradesman. Newton however offered a reply delineating his own theory about a falling body. He argued that a falling body does not hit a stationary earth, but an earth rotating about its axis. Therefore, it does not land at point B but reaches point D as shown in Fig. 33. Without the resistance of earth, (or in the absence of it) the object would trace a spiral, DEC, as shown.

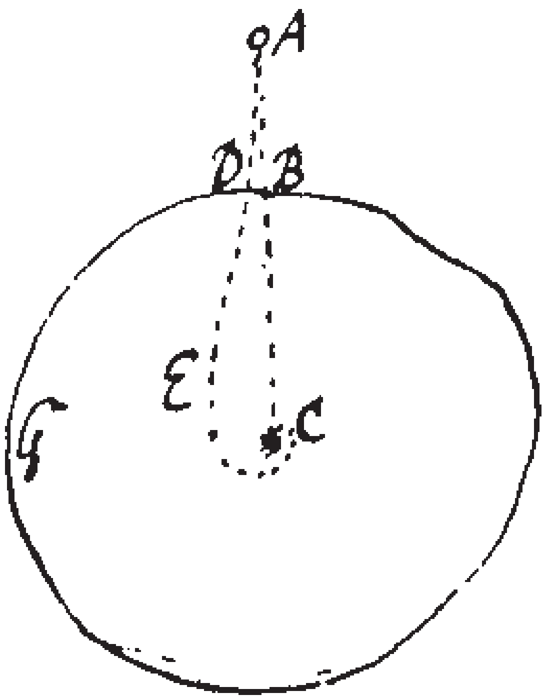


Fig. 33 Newton's Response.

Hooke was quick to point out that the path of the falling object would be an ellipse and not a spiral as shown in Fig. 34. ABDE is the surface of the earth; AFGH is the path of the object when there is no resistance and AIKLMNOPC is the path with resistance. Obviously, there was a mistake in Newton's understanding. He had mixed up theories for a falling body and for Orbital Mechanics. This correspondence led the two scholars to conceive the inverse square law. Newton confessed to Dr. Edmond Halley (1656 – 1742), English astronomer and mathematician, eponymous with the Halley's Comet, on a later occasion that this indirect communication with Hooke prompted him to review Orbital Mechanics.

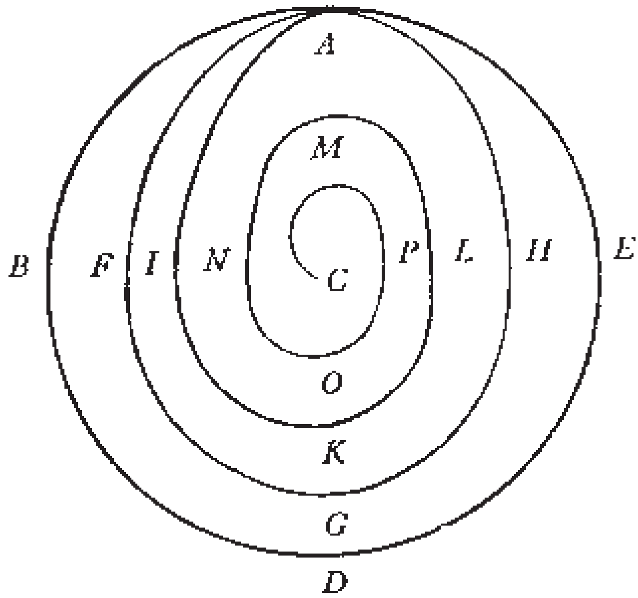


Fig. 34 Hooke's Answer.

Hooke by this time had exhausted his intellectual resources and abilities. He left it to the greater master Newton to complete the theory. Hooke has said,

That by your excellent method (Calculus) you will easily find out what that curve must be and its properties and suggest a physical reason of this proportion.

The challenge, therefore, was to arrive at a mathematical expression to show that if the force between a planet and the sun should obey an inverse square law, then the planet must follow an elliptical orbit. Newton did not respond to Hooke but was preparing for his masterstroke.

Call of the Comet

The second invitation that prompted Newton to write the *Principia* came from a comet. In the winter of 1680–81, a comet called *The Great Comet*, appeared in Europe, a brilliant and frightening phenomenon. Most astronomers assumed that there were two comets, not one. The first appeared early one morning in November while the second appeared early evening in mid-December. The latter was four times the size of the moon and was seventy degrees long, meaning that the angle subtended by the extremities of the comet at the centre of the earth was 70^0.

John Flamsteed, the Royal Astronomer of the day was intrigued by its sheer size. However, he believed that there was only one comet, which was sighted twice. He opined that the comet had changed its direction near the sun and given the impression of two comets. He wanted someone to corroborate his belief and looked up to Newton. Since he was not well acquainted with Newton, Flamsteed approached him through a friend. Newton had closely observed the comet with powerful telescopes. He had also gathered data from fellow observers and existing literature. He wrote two long letters to Flamsteed rejecting and criticising his one-comet theory.

In 1682, another comet, now called *Halley's Comet* made its appearance. (Fig. 35) Again, Newton made careful observations and collected data. He developed a clear understanding of comets. Most astronomers and scientists then believed that comets were bodies foreign to our solar system and consequently, laws true to planetary motion were not applicable to them. In fact, they thought comets followed rectilinear paths. After a careful study, based on his own observations and those of others, Newton revised his opinion asserting that comets too, like our planets, obeyed the inverse square law and followed curved paths. He eventually also conceded that Flamsteed was indeed right! There was only one comet. Although, by now, he had made considerable progress in his Universal Law of Gravitation, he kept it to himself.

The third motivation to write *Principia* was a meeting of the Royal Society. Halley and Christopher Wren (a noted English architect, well-versed in astronomy and mathematics) were also engaged with Hooke's challenge to Newton. They were all interested in Celestial Mechanics, Inverse Square Law and Kepler's Laws. However, none of them could translate the ideas into mathematical formulations.

Fig. 35 Halley's Comet as seen in 1910.

At the January 1684 meeting of the Royal Society, Hooke boasted that he had already solved the challenge. Wren was skeptical and demanded that Hooke present proof within two months. Seven months went by and there was no sign of any proof. Halley realised the futility of expecting a solution from his friends, and in August, rushed to Cambridge to meet the only man who he was certain would find it.

What happened in Cambridge is best explained by Newton himself in his recollections made to the famous French mathematician, DeMoivre. Here is an extract from the latter's writing.

In 1684 Dr Halley came to visit him at Cambridge. After they had been some time together, the Dr asked him what he thought the curve would be that would be described by the planets supposing the force of attraction towards the *sun to be reciprocal to the square of their distance from it. Sir Isaac replied immediately that it would be an ellipse. The Doctor, struck with joy and amazement, asked him how he knew it. Why, saith he, I have calculated it. Whereupon Dr Halley asked him for his calculation without any farther delay. Sir Isaac looked among his papers but could not find it, but he promised him to renew it and then to send it him…*

Scholars opine that Newton probably played safe. The paper could not have been lost, for, in fact, it exists even today. Maybe, he did not want another episode such as the one with Hooke. Or perhaps he wanted to redo and cross-check his calculations and verify his results before making public the paper; which he did, only to reconfirm the veracity of his results.

De Motu Corporum in Gyrum

In November, Newton sent a nine-page paper to Halley through one of his friends. It was, infact, a treatise titled ***De Motu Corporum in Gyrum*** *(On the Motion of Bodies in an Orbit)*. He had mathematically shown that an elliptical orbit entails inverse square law. Through his calculations, he also demonstrated that his theory was in accordance with Kepler's Second and Third Laws. Halley realised that Newton had achieved something unprecedented in Celestial Mechanics. He once again rushed to Cambridge to meet Newton and requested his permission to present the paper to the Society. Newton promised that he would send the paper to be duly registered. Flamsteed informed the Society of this great progress. The paper synthesised all the knowledge that Newton had gathered about motion, and contained four theorems and five problems concerning motion in the absence of resistance.

Halley's role in getting the best out of the master cannot be undermined. The master did not stop there. He delved deeper into the subject. He actively corresponded with Flamsteed requesting more data concerning the orbital periods of Jupiter's satellites and the magnitudes of their orbits, about comets that made appearances, velocities of Jupiter and Saturn and even about tides in the estuary of Thames.

Newton was restless and knew very well that he had undertaken a task of great importance. There was a vast amount of information to synthesise. His daily activities including the essential ones such as eating took a big hit. Humphrey Newton, who has recorded all of his eccentricities during this time, writes,

When he has sometimes taken a Turn or two, has made a sudden stand, turn'd himself about, run up the stairs, like another Archimedes, with an Εὕρηκα,(Eureka) fall to write on his Desk standing, without giving himself the Leasure to draw a Chair to sit down in.

At some seldom Times when he design'd to dine in the Hall, would turn to the left hand, & go out into the street, where making a stop, when he found his Mistake, would hastily turn back, & then sometimes instead of going into the Hall, would return to his Chamber again.

Newton was involved in an epoch-making study and these minor aberrations of behaviour are of little consequence.

Emergence of *Principia*

Although the Society assumed that Newton would polish the paper and send it, in reality, he worked to enhance the scope of his paper *De Motu*, from mere motion of objects in orbit to motion of all objects. He had a grand plan and was aiming very high. He went to the heart of the matter and attempted to formulate the basic dynamics involving motion of bodies. He consolidated the concept of *inertiae or inertia,* introduced by Galileo and captured the basics of Dynamics. All this study combined with his ingenuity culminated in the Three Laws of Motion, which we will discuss later. Over two years, the nine-page paper De Motu, after several revisions, transformed into a treatise of two volumes or *Books* as he called them. It was almost ten times the length of the parent paper. A third volume (or *Book*) was also in the making. Principia is thus a combination of these three volumes.

In the words of Westfall,

The investigation that seized Newton's imagination late in 1684 and dominated for the following two-and-a-half years transformed his life as much it transformed the course of Western science.

Newton writes in the preface to his masterpiece,

But after I had begun to consider the inequalities of the lunar motions, and had entered upon some other things relating to the laws and measures of gravity, and other forces; and the figures that would be described by bodies attracted according to given laws; and the motion of several bodies moving among themselves; the motion of bodies in resisting mediums; the forces, densities, and motions, of mediums; the orbits of the comets, and such like; deferred that publication till I had made a search into those matters, and could put forth the whole together.

In April 1686, Isaac Newton placed in Halley's hands the first part of the resulting manuscript *Philosophiae Naturalis Principia Mathematica (Mathematical Principles of Natural Philosophy).* Halley, now the clerk of the Society, immediately informed the members of its receipt and declared it ready for print. It was approved for publication. However, Halley had overstepped his authority, for Newton had still not officially permitted its publication. To complicate matters, the Society had no funding for publication and decided that Halley should bear the cost. He was to be the publisher of the great book. This was a great responsibility, which would elevate his status in academic circles. Halley, however, was not rich. Besides, he was just married.

Halley had a tough time with Newton who would not consent to any revisions or changes suggested. On the other hand, he made revisions endlessly. Speculation was rife in academic circles about whether Newton would acknowledge Hooke for suggesting the inverse square law. Newton expressed to Halley that Hooke had said nothing that he was unaware of himself; and that Hooke had only imagined the Inverse Square Law by reading Newton's previous correspondence with him. He proclaimed that he had pestered him for years. He accused Hooke of being a great pretender. He even threatened to withhold Volume (Book) 3 of *Principia* at one point of time.

Even as Newton was busy with parts Two and Three of the treatise, Halley used all his diplomatic skills to persuade him to permit the printing process. By July 1687, the book was ready. Halley sent Newton twenty copies to be distributed among the philosophers of Cambridge. Their immediate reaction was as expected.

In the words of Humphrey Newton,

After the Printing Sir Isaac was pleas'd to send me with several of Them, as Presents, to some of the Heads of Colledges, & others of his Acquaintance, some of which (particularly Dr. Babington of Trinity) said That They might study seven years, before They understood anything of it.

A student who saw Newton on a street remarked,

There goes the man that writt a book that neither he nor anybody else understands.

These exclamations may be compared with the ones made when Albert Einstein presented to the world his theory of relativity. Someone remarked that *only three people in the world understood relativity.*

Inside *Principia*

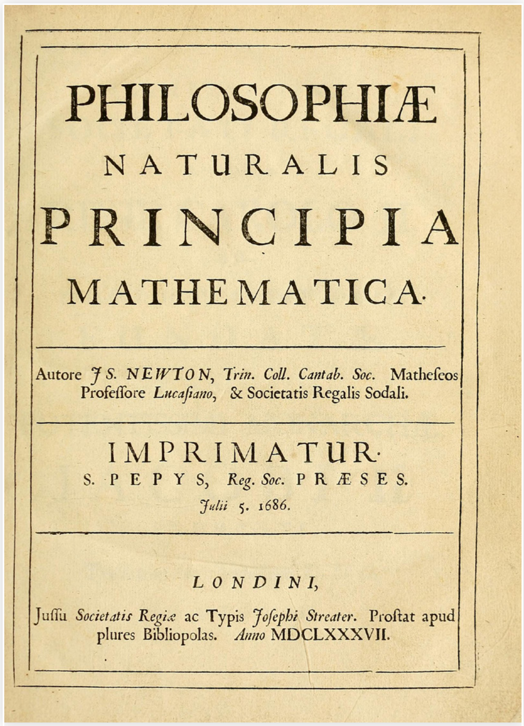
Written in Latin, *Principia (Fig. 36)* comprises of three books. It begins with a section called *Definitions* that discusses the concepts of absolute time, absolute space and motion. Then he introduces terms such as *mass, inertia* and *centripetal force*. For example, mass is defined as:

Quantity *of matter [or mass] is a measure of matter that arises from its density and volume jointly.*

Newton defined every term along with a formula to measure it. Although we use terms such as mass, velocity and inertia in our daily conversations and technical discussions, we are not aware that it was Newton who introduced them and defined them. In fact, they have become a part and parcel of physics. Refer to Part 2 for details.

Before elaborating his Laws of Motion, Newton defines time and space thus:

Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is *called duration: relative, apparent and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time ...*



PHILOSOPHIÆ

NATURALIS

PRINCIPIA

MATHEMATICA.

Autore J S. NEWTON, *Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.

S. PEPYS, *Reg. Soc.* PRÆSES.

Julii 5. 1686.

LONDINI,

Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Fig. 36 *Principia* in original.

Time, according to Newton, is a dauntless river which flows unaware of its shores.

So was space, which he defined as,

Absolute space, in its own nature, without regard to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies: and which is vulgarly taken for immovable space.

Consequently, one hundred meters for me will be a hundred meters for everybody. These ideas appeal to common sense. We are all accustomed to this belief.

Ordinary men and scientists remained complacent in this belief for more than two hundred years. Albert Einstein (1879–1955) overturned this hypothesis in 1905 and showed that both space and time depend upon how they are measured. A stationary observer and a moving observer measure different values for space and time. However, these relativistic effects are pronounced only at speeds nearer to that of light.

Then, Newton explains the concept of relative motion in comparison to absolute motion.

The treatise continues with *Newton's Laws of Motion,* as known today. Refer to Part 2 for an elaborate discussion.

The treatise then continues as Book 1, Book 2 and Book 3 in which Newton discusses the consequences of his laws.

Book 1, *De Motu Corporum* *(On the Motion of Bodies),* discusses motion of bodies in the absence of resistance, for instance, friction. The book presents theorems concerning centripetal force and Kepler's law. One important outcome of this book is the formalisation of the concept of gravity, which had haunted him all his life.

He stated:

Of this sort is gravity, by which bodies tend to the centre of the earth .. and that force, whatever it is, by which the planets are perpetually drawn aside from the rectilinear motions, which otherwise they would pursue, and made to revolve in curvilinear orbits. (Taken from Joel Levy).

Book 2, (untitled) talks about resistance to motion, hydrostatics and flow of compressible fluids. Here Newton dismisses Descartes' Mechanical Theory, which states that motion is a result of the interaction of vortices. At the same time, Newton considers fluid motion with resistance.

Book 3, *De Mundi Systemate* *(On the System of the World)*, deals with gravity and some of its consequences on astronomy. Newton showed many interesting facts, which were a consequence of the application of his theories from Books 1 and 2. Some of these are an explanation for the perturbations in the orbit of Saturn, density of air at different heights, weights of the same mass on Earth and on the Sun's surface. He showed that the earth is not a perfect sphere but an oblate spheroid. The book also contains a detailed discussion on comets, their orbits and functions.

The unification of Galileo's theories based on his experiments on force and motion and that of Kepler's Laws is a great achievement in this book.

Newton's Laws along with the Law of Universal Gravitation have many interesting consequences. These include the effect of earth's gravity on the surface of the moon, the weight of an object on the moon, 'the magnitude of the earth's gravity, weight of the earth, the fact that earth is not a perfect sphere and the effect of gravity on tides. Some of these are discussed in Part 2 of the book.

At the beginning of Book 3, Newton presented what he called *Rules of Reasoning in Philosophy,* which formulated the Scientific Method as is in use today. These are:

Rule 1: *We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.*

Rule 2: *Therefore, to the same natural effects we must, as far as possible, assign the same causes.*

Rule 3: *The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.*

Rule 4: *In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypothesis that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.*

Such a prescription was perhaps necessary because many philosophers then were still Aristotelian, and dismissed experimentation altogether. According to them, those who performed experiments were just technicians. Real philosophers, on the other hand, contemplated, reasoned and evolved knowledge. If an experiment did not correspond to a theory they had proposed, it was because the technician was ill-equipped or the experiment was not performed properly. For instance, if a commonly held 'fact' such as **heavy body falls faster than a light body or that the earth is the centre of the universe** could not be verified through experimentation, then it was not because the fact was indeed false, but because the technician was incorrect or the experiment itself was faulty. Newton cautioned against such unscientific attitude.

He insisted that verification with experimentation was indispensable in scientific study. The journey of a scientific investigator he opined begins with an observation of the world around. The investigator must then strike at the root of his observation and formulate a possible explanation for the phenomenon observed or, in scientific terminology arrive at a *Hypothesis*. He must, thereafter, devise experiments and perform them. Based on the results obtained through experimentation he must either accept or reject the hypothesis. This is how a scientific theory should be established. Thus, *Theory guides, experiment decides*.

Newton cautions that it is not possible to understand everything for an individual or even a whole generation,

To explain all nature is too difficult a task for any one man or even for any one age. 'Tis much better to do a little with certainty, and leave the rest for others that come after you, than to explain all things.

The fact that scientific research continues ceaselessly stands testimony to this fact. Every scientific discovery reveals that there is more to be understood. The reality of the four fundamental forces in nature remains a mystery.

In this spirit, Newton would not speculate beyond what he could prove. He had observed the consequences of gravity and was able to enunciate the Law of Universal Gravitation. However, he had no means to find out the cause of gravitation. Therefore, he did not attempt an explanation. However, he believed that a spirit or 'some active principle' governed the Law of Universal Gravitation, which allowed the transmission of force from one body to another.

He writes in *Principia* (taken from Iliffe),

And therefore those Ancients who rightly understood the mystical philosophy taught that a certain infinite spirit pervades all space & contains & vivifies the universal world; and this spirit was their numen, according to the Poet cited by Apostle: In him we live and move and have our being.

The Fame of *Principia*

Principia's greatness lies in the fact that it stands as a pioneering work of what can today be called modern scientific methodology. This monumental work took him only twenty years. Even teams of scientists would have taken much longer to accomplish it.

Principia has had a great impact on our understanding of the physical world. It marked the cornerstone that separated philosophers and scientists. Earlier, philosophers had a say in every occurrence of the universe. The term natural philosophy was also in vogue. With the advent of the book, scientists were different and had a clear method of work. The method to establish a scientific fact was defined – observe, hypothesize, experiment, collect data and infer, and then formulate a theory.

The definitions, propositions and proofs therein gave us a system to understand the physical phenomena around us such as falling of a stone, tides, motion of planets and their moons and comets. Particularly unprecedented was the exactness in description; every feature such as velocity, acceleration and force had a specific number. His theory was extended to include fluid motion. He formulated equations to calculate fluid motion, which are in use even today in the design and understanding of flying objects including airplanes and spacecrafts. Extensions to calculate vibrations of bodies, flow of heat etc. followed. John Dalton's atomic theory was another consequence.

Thus, the master had created what may be called the Newtonian Model, which can be used as a key to understand almost everything. People used it to understand human nature and the sciences as well.

The book made history. Philosophers (scientists) of the day were waiting for such a treatise. Halley, the first admirer was astonished by its contents. He wrote a review in the *Philosophical Transactions.*

The review begins this way,

This incomparable Author having at length been prevailed upon to appear in publick, has in this Treatise given a most notable instance of the extent of the powers of the Mind; and has at once shewn what are the Principles of Natural Philosophy, and so far derived from them their consequences, that he seems to have exhausted his Argument, and left little to be done by those that shall succeed him. His great skill in the old and new Geometry, helped by his own improvements of the latter, (I mean his method of infinite Series) has enabled him to master those Problems, which for their difficulty would have still lain unresolved, had one less qualified than himself attempted them.

David Gregory, the Scottish mathematician, and astronomer, John Locke, the British philosopher, Oxford academic and medical researcher, Abraham De Moivre, the French mathematician and others learnt of the book and rushed to read it. Locke called Newton *one of the intellectual giants of the age*. Very soon, three leading journals published reviews of the book. It was hailed as *the most perfect mechanics that one can imagine*.

In Europe, two leading mathematicians, Christiaan Huygens and Gottfried Wilhelm Leibniz read the book with care. Huygens found the theory of attraction rather absurd, while Leibniz objected that Newton had not given the cause of gravity. However, both confessed that they were certainly influenced by Newton's work. Huygens praised the book for the *beautiful discoveries* he found in it and made it a point to meet Newton when he was in England. He was in continuous correspondence with Newton until his death in 1695. Marquis de l'Hôpital reacted by saying *Good God what a fund of knowledge there is in that book?*

The greatest discoveries stand the test of time. *Principia* is a perfect example. British astronaut Tim Peake named his 2015 mission into space after *Principia.* About 4000 people were consulted to suggest a name for the mission. *Principia* was suggested 20 times. He says, *Not only does it have the link with space and gravity but also it's a celebration of science and that is what the space station is about now.*

Revision of *Principia*

Newton undertook a revision of *Principia* in 1711. A young academic and a fellow of Trinity, Roger Cotes assisted him in this venture. Newton cooperated but expressed annoyance when Cotes pointed out an error. Newton advised him thus,

… you need not give yourself the trouble of examining all the calculations of the Scholium. Such errors as do not depend upon wrong reasoning & can be of no consequence & may be corrected by the reader.

Swiss mathematician Johann Bernoulli found an error in the procedure of a particular problem that Newton had solved and informed him through his nephew (Nicholas Bernoulli).

Upon examination, Newton located the error. This correction turned out to be very time consuming, a good two and a half years. The issue with Leibniz, which we shall discuss later, was another distraction that delayed the revision process. At times, revision progressed slowly and at others, it came to a standstill. Newton in his customary manner did not bother to thank Cotes, in print or word, for his help in revision.

He concluded the treatise almost poetically,

This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent being. And if the fixed Stars are the centers of other like systems, these, being formed by the like wise counsel, must all be subject to the dominion of One. [...] This Being Governs all things, not as the soul of the world, but as Lord over all: And on account of his dominion he is wont to be called Lord God παντοκρατωρ, *(pantokrator), or Universal Ruler.*

Newton Becomes a Member of Parliament

The solitary pursuit of Newton into gravity and motion had fructified in the form of *Principia*. His fame travelled far and wide. A copy of *Principia* was sent to the king of England, James II with an indication that Newton's calculations regarding tides might interest him. There is no information as to whether the king was interested or impressed.

The king in a bid to appoint Catholics to key positions in major institutions sent a mandate to the vice-chancellor of Cambridge (mostly a Protestant university) to accept a Benedictine monk, Father Alban Francis and award him a master's degree, overlooking eligibility and procedure. He was not to be administered any oath. Conferring degrees to men at the behest of the powerful was not unprecedented. However, the difference in the case of Alban Francis was that he would remain in the university and participate in its proceedings. Newton was a branded anti-Catholic and was obviously against the appointment. The university senate chose him as one of the eight advisors to the vice chancellor to protest against this appointment. Newton readily accepted. Consequently, the king dismissed the vice chancellor and threatened disciplinary action against Newton and the other advisors. Newton did not concede; the Benedictine monk did not get his degree. Soon, James II was dethroned and the kingdom fell into Protestant hands. William of Orange became the new king.

The king called for a new Parliament. By now, Newton's fame as the author of Principia and as one who took a bold stand against the former king had reached its peak. The university elected him as one of the two Members of Parliament from Cambridge. He moved to London where he lived for the most part of the year. No more a solitary philosopher, he now had the honour of dining with the king.

Parliament records do not mention any active participation of Newton in its deliberations. An often-quoted incident is as follows. He stood; the entire house fell silent. They thought he would make a speech. All he said was, "Would somebody mind closing down the window? There is a bit of draft, my wig may fall off." Then he sat down!

London was not as confined a place as Cambridge. Newton met many important people who visited the city. These included Christiaan Huygens who had raised objections to his Theory of Light. The two had a couple of meetings and attended the sessions of the Royal Society together. He acquainted himself with the philosopher John Locke. They talked of religion and discussed the Bible. Locke praised him as *the incomparable Mr Newton* in his 1690 masterpiece, *An Essay Concerning Human Understanding.* During this period, Newton, Locke and Boyle had corresponded several times in matters of alchemy. Charles Mordaunt, the Earl of Monmouth and Charles Montague, an English politician were among the others who became acquainted with him. Newton's personality during this phase underwent a sea change. He was no more the sullen, withdrawn individual with whom conversation was impossible. He turned out quite friendly. Now that *Principia* had been published and accepted by the community, he probably felt less threatened. He no longer had to fear criticism. Newton, now very influential, developed friendships with youngsters. One of them was Edward Paget, a master at a school run by Christ's Hospital. David Gregory was another who sought Newton's help and became the Savilian Professor of Astronomy at Oxford. William Whiston was once an undergraduate student of Newton and had attended his lectures. Following Newton's work, he submitted a thesis, *New Theory of the Earth*. He not only became Newton's deputy but also succeeded

Newton when he relinquished the Lucasian Chair in 1701. Edmond Halley, another disciple of Newton was appointed to another Savilian Chair at Oxford.

Nicolas Fatio de Duillier

One acquaintance that Newton made during this period and who had considerable influence on him and his life was Nicolas Fatio de Duillier (Fig. 37), a young man, twenty-five years of age. He was a brilliant Swiss mathematician and visited London in June 1689. He carried a letter of recommendation from a person well-known to the Royal Society and was thus admitted as a member. He met Newton in a meeting of the Society where Huygens presented his work on gravity and light.

Newton immediately took to the handsome, intelligent Fatio. He could not live by science alone, it suddenly seemed. Emotions and desires, which probably he had suppressed for too long in pursuit of science, began to take wings. Newton longed to be with Fatio. When Newton returned to London for his second term in the parliament, he wrote to Fatio - *I intend to be in London the next week & should be very glad to be in the same lodging with you. I will bring my books and your letters with me.*

Fig. 37 Nicholas Fatio de Duillier.

Newton later spent a month with Fatio in London when the latter transcribed a part of Book II of *Principia*. The two read together *Treatise of Light* by Huygens. On many an occasion, Newton was absent from Cambridge, spending time in London. Fatio is known to have informed

Newton of some potion developed by one of his alchemical friends, supposedly a marvellous cure for many ailments. He had coaxed Newton to invest in its development and eventually market it.

Newton shared all his knowledge, be it mechanics, theology, alchemy or mathematics with Fatio. It is interesting that Fatio became a liaison of sorts through whom Huygens and Leibniz learnt about Newton's views on gravity, light and mathematics. He had become an informant!

Then there was a surprise. Soon after Fatio left London in 1692, he wrote a letter to Newton.

I have Sir almost no hopes of ever seeing you again. With coming from Cambridge I got a grevious cold, which is fallen upon my lungs… I thank God my soul has been extremely quiet, in which you have had the chief hand… Were I in a lesser feaver I should tell you Sir many things. If I am to depart this life I could wish my eldest brother, a man of extraordinary integrity, could succeed me in your friendship…

To which Newton replied,

I last night received your letter, with which how much I was affected I cannot express. Pray procure ye advice and assistance of Physicians before it be too late, and if you want any money I will supply you. I rely upon the character ye give of your elder brother, and if I find that my acquaintance may be to his advantage I intend he shall have it… Sir, with my prayers for your recovery, I rest,

Your most affectionate and faithful friend, to serve you, Is Newton

Obviously, Fatio feared his cold excessively. He lived another sixty-one years! Newton clung to Fatio, writing to him offering him money and accommodation to keep him close to him. However, Fatio decided to distance himself. He stated:

I could wish sir to live all my life, or the greatest part of it, with you.

Then he told somebody, *the reasons I should not marry will probably last as long as my life.*

Breakdown

By the end of 1692, after Fatio's exit from his life, Newton withdrew once again from society. He barely communicated. Then he suddenly wrote a letter to Samuel Pepys, one of his friends, a product of Cambridge University, Member of Parliament and well-known diarist.

September 13, 1693.

Sir,

Some time after Mr Millington had delivered your message, he pressed me to seeyou the next time I went to London. I was averse; but upon his pressingconsented, before I considered what I did, for I am extremely troubled at theembroilment I am in, and have neither ate nor slept well this twelve month, norhave my former consistency of mind. I never designed to get anything by yourinterest, nor by King James's favour, but am now sensible that I must withdrawfrom your acquaintance, and see neither you nor the rest of my friends any more, if I may but leave them quietlv. I beg your pardon for saying I would see youagain, and rest your most humble and most obedient servant,

Is. NEWTON.

This letter was followed by one to John Locke.

SIR,

Being of opinion that you endeavoured to embroil me with women, and by other means, I was so much affected with it, as that when one told me you were sickly and would not live, I answered, 'twere better if you were dead. I desire you to forgive me this uncharitableness; for I am now satisfied that what you have done is just, and I beg your pardon for my having hard thoughts of you for it, and for representing that you struck at the root of morality, in a principle you laid in your book of ideas, and designed to pursue in another book, and that I took you for a Hobbist(a 17th century philosopher).*I beg your pardon also for saying or thinking that there was a design to sell me an office, or to embroil me. — I am your most humble and unfortunate servant,*

Is. NEWTON.

The manic euphoria that Newton experienced during the success of his *Principia* did not last long. In 1693, known as his black year, Newton suffered a bout of depression that lasted nearly eighteen months. The news first reached Huygens. Friends confined him until he regained his composure. Leibniz, John Wallis and many other natural philosophers of Europe heard the news and were rather distressed.

However, it is true that Newton was not in sound mind as the above letters clearly indicate. Both Pepys and Locke made inquiries about Newton's mental health with people they knew in Cambridge. Newton eventually replied to Locke and stated the truth.

The last, winter, by sleeping too often by my fire, I got an ill habit of sleeping; and a distemper, which this summer has been epidemical, put me farther out of order, so that when I wrote to you, I had not slept an hour a night for a fortnight together, and for five days together not a wink. I remember I wrote to you, but what I said of your book I remember not. If you please to send me a transcript of that passage, I will give you an account of it if I can.

We should not forget that he had a similar breakdown, although of a lesser degree, in 1677. Westfall has speculated at length the possible reasons for this breakdown. In his opinion, the writing of *Principia* stretched Newton's mental stamina beyond limits. He had undertaken a monumental work of assembling different strands of mechanics into a single unifying theory. His failure to secure, in 1689, the position of a provost at King's College in the university and the subsequent soliciting of employment in London in 1690, added to the pressure. By 1693, he had stopped his theological endeavours and was concentrating on revising *Principia* and had also begun writing on optics. This was an onerous task. He was disillusioned with alchemy. There may have been a fire as well. Above all perhaps, the abrupt end, after four years, of his friendship with Fatio, contributed to this breakdown.

Newton did come out of his depression, but Westfall points out that after his revival, he did not start anything new in natural philosophy, alchemy or theology. On hindsight, his creative activity had come to an end. He spent the remaining thirty-four years of his life reworking the results of his earlier studies.

One such was the study of manifold perturbations of the lunar orbit. These perturbations are a result of the moon's orbit, which is not a regular mathematical curve as the earth is not a perfect sphere; it is flattened at the poles. The study of lunar perturbations leads to what scientists call the Three Body Problem, frequently encountered in the realms of Classical and Quantum Mechanics. The motion of a planet and its satellite around a star is an example from Classical Mechanics. For Newton, the three-body problem consisted of the motion of the moon and the earth around the sun.

The Controller of the Royal Mint

The *Principia* fame brought a few professional invitations to Newton. In May 1690, he learnt through a friend (a solicitor) that the government was looking for a suitable candidate for the position of Controller for the Royal Mint in London. Newton was disappointed with the fact that the fame of *Principia* had not fetched him bigger positions in the University and society. In fact, his peers had risen higher than him. Besides, the college was steeped in financial doldrums and Newton was considering moving out of Cambridge to pursue his academic interests. However, London was a better place to make a living and have a good time.

It was against this background that Newton was willing to accept the position of warden of the Royal Mint in 1696. His well-wisher Charles Montague, who became Baron Halifax in 1700, signed his letter of appointment. He was a Member of the Treasury and President of the Royal Society. Newton prepared to leave Trinity in Cambridge after thirty-five years of stay. Although he retained the fellowship and the chair, he visited Cambridge only for half a week during his tenure of five years at the Mint. As can be expected, he corresponded with none of his associates back in Cambridge.

The Mint was not a bed of roses; neither was Trinity College. The Mint was crisis-stricken. It was a small department within the Treasury, which was engaged in meeting the financial needs incurred by the on-going war with France. The Treasury itself belonged to the government.

As Westfall observes,

The Mint was an institution within an institution within an institution, all three of which faced crises.

Besides, the silver coin, which was the currency in vogue, had become excessively debased. Counterfeit silver coins adulterated with copper had gained widespread circulation. The government was considering recoinage as a remedy. It was at this crucial juncture that Newton assumed responsibility as warden.

When consulted for his opinion, Newton wrote an essay, *Concerning the Amendm^t^ of English Coyns*. His thoughts were well-received and prompted the Treasury to implement recoinage. Newton took it upon himself to see the project through. Predecessor wardens of the Mint had treated the position as only a sinecure, a position which paid but demanded no action or responsibility. In fact, Montague who had elevated Newton to the position had also considered it as a sinecure, earning him about five to six hundred pounds. Yet, Newton who never flinched from duty, supervised the recoinage process very efficiently. After the task had been carried out, Montague would exclaim that it would have been impossible without Newton. Thereafter, the government made the temporary position of the warden, a permanent one.

Upon taking charge, Newton first gained a thorough understanding of the Mint's accounting system. His extraordinary skill in ordering and categorising data came to his aid and soon, he proved he was a born administrator.

To enhance the efficacy and accountability of the five country mints located at Norwich, Chester, York, Exeter and Bristol, Newton appointed deputy officers who would report to the officer at the Tower Mint in London. With Newton's intervention, the Tower Mint operated from four in the morning until midnight. Three hundred workers worked with a team of fifty horses that turned ten mills. Each of the nine presses struck between 50 and 55 times a minute. The Mint produced up to £100,000 per week initially, which increased to £2,500,000. Newton noted that in a period of two years (1696 – 98) the Mint recoined 6.8 million pounds, which was about twice the amount it had coined during the previous thirty years.

During Newton's tenure as controller, Thomas Neale was the master of the Mint. Needless to say, Newton did not get along with him. He complained to the Parliament about Neale's way of working. In reality, Newton had already started behaving like the master of the Mint. He carried out a thorough investigation of the working and the expenses incurred in running the Mint. He had even considered the cost of a melting pot and the number of times it could be used. He had determined the amount coined by weight, both in gold and silver during 1659–61. This study was as detailed and accurate as his study of the orbits of planets! He had copied existing documents pertinent to this study two or three times over. He was very meticulous in his work; even a minor letter would go through two drafts and two fair copies! He even wrote the report that Neale should have submitted to the government.

Besides, due to bad decisions on the part of the government most of the silver coins went to goldsmiths for melting! This obviously meant that the face value of the metal was more than the material value.

Besides the task of recoinage, Newton had to root out counterfeiters. He identified and prosecuted forgers. He made as many as fifty-eight depositions in a span of two months from the Newgate suburb and London prisons. He had a capable assistant, Humphrey Hall, who was provided with a suitable disguise, which enabled him to mingle with the counterfeiters.

The chief among the counterfeiters was William Chaloner. Newton conducted exhaustive research on him and reported to the Parliament.

A japanner in clothes threadbare, ragged and daubed with colours... turned coiner and in a short time put on the habit of a gentleman.

Chaloner was very clever and had invented his own method of counterfeiting. He had been successful in cheating the king and the government in many ways. He went to the extent of submitting papers to the Privy Council on the subject of abuses in the Mint and counterfeiting. He offered to improve the coinage and wanted to be appointed as the supervisor of the Mint. Newton played his cards very well and got a warrant issued for Chaloner's arrest and hired spies to report his movements. He had prepared the case in such a manner that there was no escape for Chaloner. He was convicted for treason. He appealed to the King for clemency. The King himself heard the petition and decided against it. Chaloner and six others were hanged. A triumph of Newton's investigation.

Newton was still officially the warden and Neale the Master of the Mint. Newton received a salary of £400 a year and Neale, £500 a year and a share in the profits. During recoinage itself, Neale had earned more than £22000. These facts must have enraged Newton because Neale did nothing himself. He had made Newton and another assistant to do all the work.

Newton became the official Master of the Mint immediately after Neale's death on December 23, 1699. He still held his chair at Cambridge. In the first year as Master, he earned an income of £3500 that made his Cambridge income seem petty. A year later, he resigned from his professorship in Cambridge to become a full-fledged civil servant. Newton's student William Whiston succeeded him and occupied the Lucasian Chair at Trinity College.

Newton's income from the Mint varied from year to year. Over the twenty-seven years that he was the Master, his average income was estimated at £1650 a year. There were years when he received no income at all, for instance, between 1703 and 1707, the period of the Spanish succession. His average income though was quite splendid and allowed him a lavish lifestyle in London. However, his mind was never at rest. If work at the Mint did not sufficiently occupy him, he had several other things to ponder over such as perturbations in lunar orbits as mentioned earlier.

The position as the Master of the Mint earned him a membership in the House of Commons of the British Parliament. In fact, he even contested for a seat in the Parliament in 1701 and was elected. But the

Parliament itself was dissolved in 1702; Newton decided not to contest thereafter.

Newton Knighted

Montague was keen that Newton should contest for a seat in Parliament in the forthcoming election. In 1705, he arranged the Queen's visit to Cambridge. It was a grand visit with people lining the streets everywhere the Queen went. During this visit, Newton was knighted, not just for his contribution to science but also for the role he played at the Mint. Newton's social status increased. He was on stage with the queen, and dined with her at Trinity College. Newton made a few visits to Cambridge to solicit votes but he lost the election. He won 115 votes while his opponents won 162 and 182. Newton's political career was over.

Life of the Mint Master in London

An account by John Conduitt, husband of Newton's niece Catherine Barton gives an insight into Newton's life in London. There was style, there was dignity. The house was well-furnished. There were four landscapes decorating the walls along with twelve Delft plates.

Westfall gives an inventory – *three dishes, three salvers, a coffee pot, two candlesticks (all of silver), forty plates, a full set of silver flatware, about ten dozen glasses and six and a half dozen napkins.*

There were also two chamber pots made of silver. His clothes were valued at only £8 3s. However, this inventory was taken much later when he suffered from many old age problems.

His bed, draperies, curtains, hangings were all crimson, his favourite colour. He owned a coach and a large number of servants, six at the time of his death. He perhaps wanted to avenge for his days as a sizar at Cambridge. He could now afford luxury and he went for it. However, it is said that he abstained from eating meat and lived on vegetables. He once hosted French visitors who complained that he served cheap wine.

His accounts show that during a week he ordered goose, turkey and chicken for his kitchen. In fact, at his death, he owed £10 26s 4d to a butcher, while it was only 19s to a fruiter. He owed £7 10s for fifteen barrels of beer suggesting that he was anything but a moderate drinker.

It is surprising that Newton who belonged to high society in London showed no interest whatsoever in literature or theatre. He told William Stuckeley that he ran out halfway through the only opera he ever attended.

Though Newton served as the master of the Mint, he was more famous as the professor from Cambridge who had written *Principia*. By virtue of this fame, many people visited him from all over England and overseas. In 1698, Jacques Cassini visited him and offered him a pension from Louis XIV, which came with an appointment to the Academy of Sciences in France. Newton declined the offer.

Intellectual Work Continues

Although he was at the peak of his fame, Newton did not give up his studies. In 1690, he was busy tying up loose ends in *Principia*. He returned to optics in late 1680 after a lapse of nearly twenty years. He wrote a treatise and decided not to publish it.

Alchemy and theology received little attention when he was busy with *Principia*. He returned to alchemy in 1690 and Westfall points that he devoted more time to alchemy than to all other interests put together. Newton wrote a paper *De Natura Acidorum (On the Nature of Acids),* based on his alchemical research and attempted to explain alchemical phenomena in terms of forces in mechanics. It was around 1693 that Newton gave up his passionate study of Alchemy, on which he had built tremendous hope. Among other occurrences, his disappointment with Alchemy could also have contributed to his emotional ailment the same year.

In 1694, Newton focused his attention on the moon again. He had observed perturbations in the lunar orbit and he sought to explain this phenomenon through his theory of gravitation. Only one person, John

Flamsteed (Fig. 38), could provide him the required data. Newton tried to collaborate with him but did not succeed, as they were incompatible in nature and person. Then, Newton tried to team up with Halley for a study of comets. Both these attempts bore no fruit. The Lunar problem surfaced again in 1697. Now, Newton visited Greenwich, where Flamsteed was the Astronomer Royal and the 'co-operation' continued. Newton managed to extract some useful data from him.

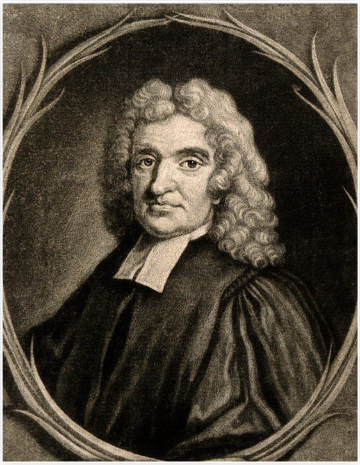


Fig. 38 John Flamsteed.

Flamsteed had written a paper cataloguing fixed stars and solar tables, slated for publication in 1699 in a journal called Opera, edited by John Wallis. He had inserted in his paper a paragraph regarding Newton's rectified lunar theory, based on Halley's observations. Newton pressurised him not to disclose anything about his theory. Flamsteed and Wallis wrote several letters seeking permission in this regard. Newton remained silent for a long time and finally wrote very strongly to Flamsteed,

SIR,

Upon hearing occasionally that you had sent a letter to Dr. Wallis about the parallax of the fixed stars to be printed, and what you had mentioned therein with respect to the theory of the moon, I was concerned to be publicly brought upon the stage about what, perhaps, will never be fitted for the public, and thereby the world put into an expectation of what, perhaps, they are never like to have. I do not love to be printed on every occasion, much less to be dunned and teased by foreigners about mathematical things, or to be thought by our own people to be trifling away my time about them, when I should be about the King's business. And, therefore, I desired Dr. Gregory to write to Dr. Wallis, against printing that clause which related to that theory, and mentioned me about it. You may let the world know, if you please, *how well you are stored with observations of all sorts, and what calculations you have made towards rectifying the theories of the heavenly motions. But there may be cases wherein your friends should not be published without their leave. And, therefore, I hope you will so order the matter, that I may not on this occasion be brought upon the stage. — I am, your humble servant,*

IS. NEWTON."

Flamsteed removed the paragraph.

However, the row between Newton and Flamsteed did not end here.

Newton was elected president of the Royal Society in 1703 and the next year he paid a visit to the Greenwich observatory as if to exercise his authority. Another motive that prompted the visit was to collect some more data from Flamsteed to support his Lunar Theory, which he knew was in Flamsteed's possession.

Newton forced him to publish his observations (Fig. 39). Flamsteed however was not ready to publish a half-baked paper. He wanted his work

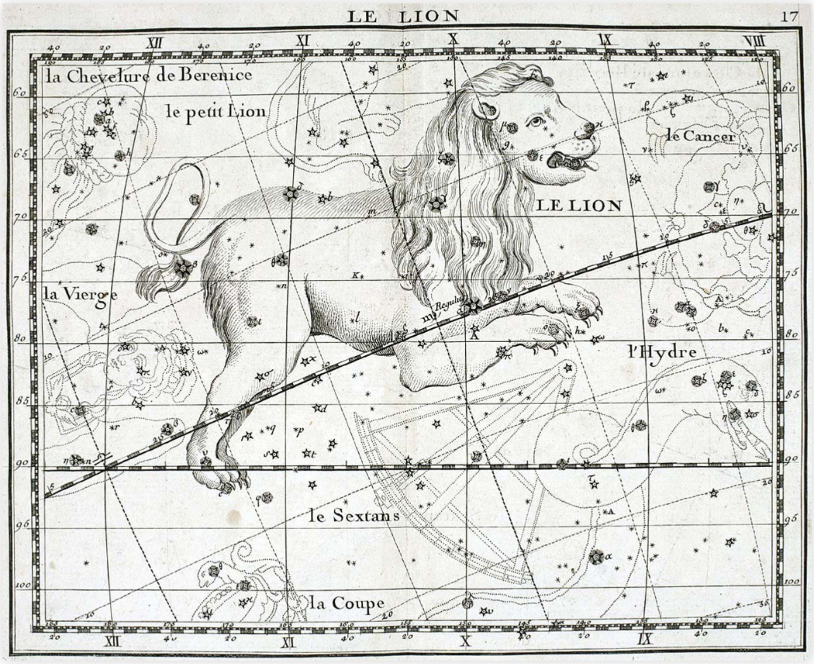


Fig.39 One of the plates from Flamsteed's Atlas.

to be accurate and precise. But Newton would not relent. He compelled and succeeded in making him write a draft called *Historia Britannica Coelestis (British History of the Heavens)*. Newton presided over the presentation of the manuscript to the Royal Society and even sought and succeeded in getting the Society's approval for printing the book. The Society sought funding from Prince George. It elected the prince as a member; the prince approved the funding.

A committee headed by Newton was formed to referee Flamsteed's work for publication. Newton ensured that the committee rejected the author's plan of the book and directed him to obtain and present data the way Newton wanted. The Society even granted £180 for the calculators who assisted Flamsteed. The pages went to press. The prince died in 1708 and the work came to a halt. In a fit of rage, Newton ensured that Flamsteed's name was struck off the register of the Royal Society.

The two men did not communicate thereafter. Each nursed a grudge. Newton was unhappy that despite all the arm-twisting he failed to lay hands on the data he required; Flamsteed felt that Newton had prevented him from publishing his book according to his own will. Newton engineered the situation with great cunning.

In 1710, he used his power to urge the Queen to proclaim that the president of the Royal Society and other council members were visitors to the Royal Observatory in Greenwich. In 1711, Flamsteed was commanded by the Queen to send the remainder of the material for printing. He replied saying that he required more time to complete his observations. Then, he received a communication not from the Queen but from Newton, which ended thus,

if instead thereof you propose anything else, or make any excuses or unnecessary delays it will be taken for an indirect refusal to comply with her Majesty's order. Your speedy & direct answer & compliance is expected.

Flamsteed was sure that Newton would not publish his book without manipulating the contents. His work, a result of thirty-five years of toil was now at the mercy of Newton. He could mutilate and twist the contents and presentation. Flamsteed mustered courage and replied.

I have now spent 35 years in composing and work of my catalogue, which may in time be published for the use of her Majesty's subjects and ingenious men the world over. I have endured long and painful tempers by my night watches and day labours. I have spent a large sum of money above my appointment, out of my own estate, to complete my catalogue and complete my work under my own hands. Do not tease me with banter by telling me yet these alterations are made to please me when you are sensible nothing can be more displeasing nor injurious than to be told so.

Make my case your own, and tell me ingenuously and sincerely, were you in my circumstances, and had been at all my labor, charge, and trouble, would you like to have your labors surreptitiously forced out of your hands, conveyed into the hands of your declared, profligate enemies, printed without your consent, and spoiled, as mine are, in the impression? Would you suffer your enemies to make themselves judges of what they really understand not? Would you not withdraw your copy out of their hands, trust no more in theirs, and publish your own works rather at your own expense, than see them spoiled, and yourself laughed at, for suffering it?

I will proceed to print the remaining part of the catalogue as fast as my health, and the small help I have, will suffer me. But if you like not this, I shall print it alone, at my own charge, on better paper, and with fairer types than those your present printer uses; for I cannot bear to see my own labors thus spoiled, to the dishonor of the nation. Queen, and people.

Newton was adamant and with Halley's help completed printing the book in 1712. Now, he undertook to revise his *Principia* and removed all reference to Flamsteed and even struck out his name on the plates wherever he could. Flamsteed says in his autobiography '*God forgive him. I do*.'

History took a turn in 1714 when Queen Anne died. Her proclamation regarding the Greenwich observatory was no longer valid. Montague too died. Newton no longer had any royal connections. Somebody in the scheme of things helped Flamsteed procure all the 300 copies of his book that Newton had printed. He burnt them to make way for his own version of the book. When Princess Caroline visited the observatory in 1716, Flamsteed told her that *Newton was a rascal who had stolen two stars from him*.

Two of Flamsteed's assistants published his book as he had wanted it, posthumously. It has been hailed as one of the greatest landmarks in astronomy.

Newton's altercation with Flamsteed dented Newton's image to such an extent that when he or his disciples such as Halley recommended candidates for the chairs at Oxford, none would be selected.

Newton's intellectual work continued even as late as 1697, when he was involved with the Mint. The famous French mathematician, Johann Bernoulli, in the journal Acta Eruditorum, challenged the intelligentsia to find the path along which a heavy body will descend more quickly from one point to another that is not directly below it. Stated in scientific terms it becomes - 'To find the curve connecting two points, at different heights and not on the same vertical line, along which, a body acted upon only by gravity, will fall in the shortest time'.

He gave a period of six months for an answer. When Bernoulli received no satisfactory reply even after twelve months, he decided to give it a wider circulation. He added a second problem and published it in *Philosophical Transactions*. Newton was also informed of the problem. Both Bernoulli and Leibniz thought that the problem would baffle Newton and they could establish their supremacy over him.

Newton took it as a personal challenge. He was busy with the work at the Mint, but was bent on solving the problem.

Conduitt has written,

When the problem in 1697 was sent by Bernoulli — Sir I.N. was in the midst of the hurry of the great recoinage and did not come home till four from the Tower very much tired, but did not sleep till he had solved it.

Newton sent the answer to Charles Montague, the President of the Royal Society. Bernoulli recognised the author at once *as the lion is recognised by his paw*.

Royal Society

Although Newton presented *Principia* at the Royal Society and had it published, he took little interest in the institution itself. The most significant reason for his distance from the Society was his animosity with Robert Hooke. Each time Newton presented a paper or proclaimed a discovery, Hooke would declare that he knew it already or had discovered it earlier. Newton, there, chose to remain away from Hooke and from the Society.

After Hooke's death in March, 1703 it was assumed that Newton would return to the Society and be elected president. Hooke's death did bring Newton back to the Royal Society. He was elected president, although not unanimously, and without enthusiasm.

About the time he became president, the Society's popularity had soured. Membership had trickled down to half from a good two hundred. Members hardly discussed science during meetings. They were happy to chitchat and make merry.

The first task at hand for the great natural philosopher was to clean up the Society in the same manner he had cleaned up the Mint. The Society had for a long time been spearheaded by people with political power rather than intellectual brilliance. Many of them were absentee presidents. Montague, a past president had attended one meeting of the council in three years while the preceding president, John Lord Somers, had attended none during his five-year tenure. Newton involved himself actively and attended all the council meetings of the Society (Fig. 40). He missed only three meetings during the next twenty years. The Society that had seen its president three times during the past eight years, now saw him almost on every occasion.

Fig. 40 Newton presiding over the meeting of Royal Society.

Newton took the law into his own hands with a commitment to systematise the activities of the Society. He put to good use his administrative powers and skill and the Society revived. He declared that Natural Philosophy,

consists in discovering the frame and operations of Nature, and reducing them, as far as may be, to general rules or laws—establishing these rules by observations and experiments, and thence deducing the causes and effects of things.

Further, he identified five major branches of natural philosophy – mathematics and mechanics, astronomy and optics, zoology, anatomy and physiology, and botany and chemistry. He proposed to appoint, with salaries, four reputed experts in major branches of philosophy (science) to attend the meetings. Their responsibilities included conducting meaningful discussions and keeping members abreast of scientific developments. It may be recalled that Robert Hooke was indeed one such expert and had very effectively done the same job. Newton indirectly acknowledged his enemy, but replaced him with a team. One such member was Francis Hauksbee, who served the Society for nearly ten years, and became a great scientist in his own right. He worked on air pumps, electricity, capillary action, among others. Another member was Dr. James Douglas, who dissected animals for experimentation. Newton also entertained members by telling them about insignificant events such as that of a man who died of drinking brandy and a dog that was killed by Macassar poison!

With Newton's proactive participation, the membership of the Society more than doubled and became financially sound. Newton passed new orders for the conduct of the council meetings. Only the president was allowed to sit at the head of the table. The two secretaries sat at the lower end. Members had to address the president first before talking among themselves. The mace, a symbol of authority, was to be placed on the table only during the presence of the president. Else, it was to be placed on its stand. The meetings now discussed serious science. Newton was successful in finding a new building for the Society in Crane Court. During the shifting, a portrait of Robert Hooke went missing. How and why is not hard to guess. Newton schemed its disappearance. Some have even said that Newton personally oversaw the destruction of the only available portrait of his enemy.

Fight with Leibniz

Fig. 41 Gottfried Wilhelm Leibniz.

A HUGE CONTROVERSY ABOUT WHO invented calculus erupted between Newton and Gottfried Wilhelm Leibniz (born 1646). Although a lawyer, diplomat and philosopher, Leibniz's first love was mathematics (Fig. 41). A member of the Royal Society, he is credited with building a calculating machine.

Leibniz claimed that he had invented calculus independent of Newton in 1674. He published his findings in 1684. Though Newton had invented Calculus in 1665–1666, much before Leibniz, he had kept all his work to himself.

Leibniz's claim that he had no access to Newton's work would not stand considering the fact that Leibniz had visited London in 1677 and had met Collins who had showed him the unpublished papers of Newton on calculus. There had been some correspondence between them in 1676, although Newton did not write to Leibniz directly. He communicated through Henry Oldenburg, the then Secretary of the Royal Society.

In 1691, mathematician David Gregory requested Newton to write about his binomial expansion. Newton responded with a full exposition of his calculus, which he called *De Quadrature Curvarum (On the Quadrature of Curves).* He did not forget to mention the correspondence he had had with Leibniz. Newton had developed his own notations. For example, Leibniz indicated a Summation as the integral ∫ while for Newton it was a Quadrature denoted by Q (Fig. 42). Again, Newton preferred not to publish the paper fearing criticism.

Though Newton preferred silence, his self-acclaimed disciple Fatio wanted to speak out. He wrote letters to Huygens and claimed that Newton had developed calculus before Leibniz had even thought about it. Yielding to pressure, Newton published a condensed version of his paper in the magazine *Opera* (edited by John Wallis). When Leibniz heard of it, he wrote a polite and nervous letter to Newton,

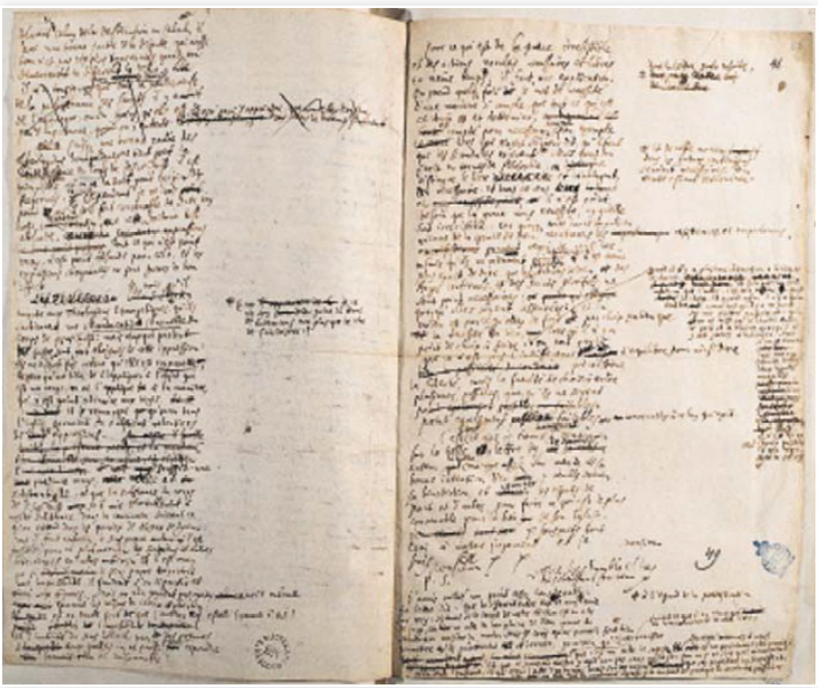


Fig. 42 Notes of Leibniz.

How great I think the debt owed to you, by our knowledge of Mathematics and of all nature, I have acknowledged you even in public when occasion offered. You had given an astonishing development to geometry by your series;

but when you published your work, the Principia, you showed that even what is not subject to the received analysis is an open book to you.

Nevertheless, Leibniz did not stop proclaiming his precedence in inventing calculus. Newton ignored at first. Months later, he wrote a polite reply,

I hope indeed that I have written nothing to displease you, and if there is anything that you think deserves censure, please let me know it by letter, since I value friends more highly than mathematical discoveries.

Newton then published a full-length paper in *Opera*. European mathematicians including Leibniz, Huygens and Johann Bernoulli interpreted this act as a bid on Newton's part to suppress Leibniz with this publication. Johann Bernoulli opined that Newton had concocted it out of Leibniz's work. In England, Gregory and others supported Newton. Gregory wrote that it had been fully demonstrated that Leibniz's calculus reduces to that of Newton's. Wallis wanted to keep the controversy alive. He requested Newton to send all the correspondence on his paper for publication. Months later Newton obliged and included an earlier correspondence of 1673 from Collins to indicate that he already knew the methods in calculus.

In 1711, when Newton was busy with the revision of *Principia* with the assistance of Roger Cotes, Hans Slone, the Secretary of the Royal Society, received a letter from Leibniz, asserting his priority over the invention of calculus. Newton was greatly disturbed and distracted.

It seemed that Newton's contribution to calculus was known only in England, and of course to Leibniz. Leibniz's past correspondence with Newton was now made public. Discussions erupted. Fatio stepped in to say,

But I now recognize, based upon the factual evidence that Newton is the first inventor of this calculus, and the earliest by many years; whether Leibniz, the second inventor, may have borrowed anything from him, I should rather leave to the judgment of those who have seen the letters of Newton and his other manuscripts. Neither the silence of the more modest Newton, nor the remitting exertions of Leibniz to claim on every occasion *the invention of the calculus for himself, will deceive anyone what examines these records as I have.*

Leibniz fought back saying that when he published his work, Newton only had the method of tangents in hand.

It was against this background that Newton finally published as an appendix, two chapters on calculus in his *Opticks* in 1704. He claimed that he had invented the method in 1666 itself.

The facts were that Newton had invented calculus in 1666, but had not published it for quite some time. However, Leibniz had invented the same calculus ten years later but had published it. Who should be given the credit?

As Westfall observes,

Varignon remarked that the glory of invention was sufficient for both men. If the glory of invention was enough for both, so was the blame for contest.

Having hidden calculus from his friends and colleagues and the world at large, Newton built a mafia of mathematicians who would support him, come what may. Leibniz perhaps should have acknowledged his communication of 1676 with Newton in the publication. Despite all this, Leibniz never failed to accept that Newton was indeed a great philosopher.

He said,

that taking mathematicians from the beginning of the world to the time when Sir Isaac lived, what he had done was much the better half; and added that he had consulted all the learned in Europe upon some difficult points without having any satisfaction, and that when he applied to Sir Isaac, he wrote him in answer by the first post, to do so and so, and then he would find it.

It was never difficult for Newton to find people to speak on his behalf. Many *flatterers and cryers always* flocked around, doing his bidding. This time Newton chose to speak through John Keill. Keill readily wrote the following as an appendix to one of his papers, *Philosophical Transactions*, in 1708,

All of these laws follow from the now highly celebrated arithmetic of fluxions which Mr. Newton, without any doubt, first invented, as anyone *who reads his letters published by Wallis can readily determine. ... yet the same arithmetic, under a different name and method of notation, was afterwards, published by Mr. Leibniz in the Acta Eruditorum.*

Leibniz did not expect this behaviour from the author of *Principia* and *Opticks*. He complained to the Society and wanted Keill to withdraw his accusation and render an apology.

The society organised a meeting to discuss the letter. The meeting was a farce indeed, with Newton presiding over and the Society directing Keill to write a letter that would establish Newton's claims!

Keill took a month and a half to write his letter. During this time, Newton paid little attention to his revision of *Principia*. The letter was mailed to Leibniz. Though Leibniz knew that Newton was speaking through Keill, he appealed to the Royal Society for justice in 1712. The Society thus appointed a committee. The committee consisted of Newton's *Yes Masters* and he called it *numerous, skilful and composed of gentlemen of several nations* (A minister of the King of Prussia who was in London and was part of the committee, made the committee international!). Three members were included during the last week!

Newton had done all the groundwork by collecting appropriate papers and correspondence. The committee met and did not bother to call Newton or Leibniz to give any evidence or statement. In reality, Newton carried out all the investigation and even wrote the report, which was made public within six weeks after the committee was appointed.

Newton passed judgement upon himself that he was the one who invented calculus. Leibniz's case was dismissed!

Keill wrote a report, which concluded,

For which reasons we reckon Mr. Newton the first inventor and are of the opinion that Mr. Keill in asserting the same has been in no way injurious to Mr. Leibniz ...

Newton and his disciples, now jubilant, aired their views on Leibniz in a book called *Commercium Epistolicum*. Newton went to the extent of ridiculing Leibniz over the communication of 1677, with the following words, *Thus the method which he earlier wanted, asked for, received, and understood with difficulty, he discovered forsooth either first or at least by his own effort.*

Newton gives the impression that he had helped Leibniz develop his method.

Angered by *Commercium Epistolicum,* Leibniz replied anonymously in the form of a pamphlet and distributed it across the Continent. In it, he stressed that he had published his calculus much before Newton and he was certain that Newton had stolen his calculus and claimed it as his own. Discussion followed and Bernoulli and others joined in supporting Leibniz, again anonymously. Bernoulli specifically requested Leibniz not to reveal his name. He wanted to be faithful to Newton from whom he had received favours. The issue was picked up by a journal in the Netherlands where Keill submitted his version of the controversy. While Bernoulli and Wolf argued on Leibniz's behalf, Keill and De Moivre stood up for Newton. The master too wrote anonymous letters in *Philosophical Transactions*.

Now Leibniz began to challenge Newton on philosophical grounds.

He wrote,

Natural religion itself seems to decay [there] very much ... Sir Isaac Newton and his followers also have a very odd opinion concerning the work of God. According to them, God Almighty needs to wind up his watch from time to time, otherwise it would cease to move. He had not, it seems, sufficient foresight to make it a perpetual motion. ... I hold that when God works miracles, he does not do it in order to supply the wants of nature, but those of grace. Whoever thinks otherwise must needs have a very mean notion of the wisdom and power of God.

Leibniz died on November 4, 1716. Newton received word of it from his friend in Italy,

Mr. *Leibniz is dead; and the dispute is finished.*

Truly, it took another six years before the dispute fizzled out. Cartoons spoofing the great controversy in science history are created even today.

Catherine Conduitt

Catherine, born in 1679, was Newton's niece and came to live with him twenty years before her marriage in 1717 and continued to live with him even after. She was the daughter of Newton's half-sister Hannah Smith. Her father died in 1693. Newton purchased an annuity for Hannah's three children in 1695. He stayed in Jermyn Street along with Catherine who was known for her beauty and wit.

Among the rich and the famous who were attracted to her was Voltaire. He stated,

I thought in my youth that Newton made his fortune by his merit. I supposed that the Court and the City of London named him Master of the Mint by acclamation. No such thing. Isaac Newton has a very charming niece, Madame Conduitt, who made a conquest of the minister Halifax (Montague). Fluxions and gravitation would have been of no use without a pretty niece.

Charles Montague the Earl of Halifax was another admirer and lover of Catherine. In his will, he gave away all his jewels and £3000 to Catherine and also purchased an annuity for her. He later bequeathed her another £6500. He also gave her land and buildings. It is estimated that the Earl left her a total estate of about £150,000. Apparently, Catherine was his mistress and they were also secretly married.

It is curious that Newton allowed this relationship to continue under his nose, in his household. Should he have exercised his intellectual superiority over his niece? Well, his own life had taught him lessons, the chief of them being, to live and let live. Newton could also have let this affair pass since he had received many favours from Montague, including his position at the Mint.

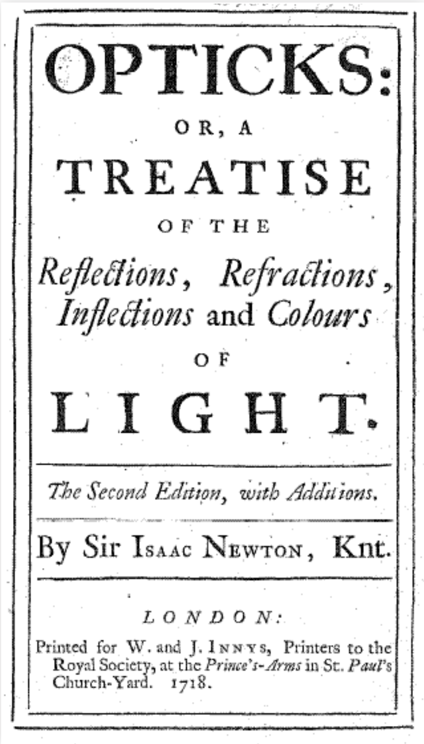
However, in 1717 Catherine married John Conduitt, a wealthy man who had served as a commissary to the British army in Gibraltar. Newton and Conduitt met at the Society. Conduitt had apparently identified the site of the Roman city Cartiea, built by the Tyrians in the first millennium BC. Newton's interest in the subject was triggered as he was working on evolving the Chronology of ancient kingdoms (to be discussed later).

Conduitt and Catherine were wed in a traditional manner. Conduitt's joy knew no bounds. He was proud and excited to be related to and in the company of such a great man as Newton. He adored and worshipped him. When Conduitt died twenty years later, his plaque mentioned Newton's name and his greatness.

Conduitt recorded all his conversations with Newton and many anecdotes from his life.

Opticks

February 16, 1704 was a very special day for Newton. He presented his second great work, *Opticks* (Fig. 43) to the Royal Society.



OPTICKS:
OR, A
TREATISE
OF THE
Reflections, Refractions, Inflections and *Colours*
OF
LIGHT.

The Second Edition, with Additions.

By Sir Isaac Newton, Knt.

LONDON:
Printed for W. and J. Innys, Printers to the Royal Society, at the *Prince's-Arms* in St. *Paul's* Church-Yard. 1718.

Fig. 43 *Treatise Opticks.*

Although this treatise had been in the making for quite some time, almost from 1666, true to his style, he hadn't published it. In 1702, he promised his associates that he would publish his work on light and quadrature soon. Newton's admirers, John Wallis and David Gregory also encouraged him in this pursuit.

He explains the reasons for the delay in publication and, why he finally chose this as the opportune moment for its publication.

To avoid being engaged in Disputes about these Matters, I have hitherto delayed the printing, and should still have delayed it, had not the importunity *of Friends prevailed upon me. If any other Papers writ on this Subject are got out of my Hands they are imperfect, and were perhaps written before I had tried all the Expertments here set down, and fully satisfied myself about the Laws of Refractions and Composition of Colours. I have here published what I think proper to come abroad, wishing that it may not be translated into another Language without my Consent.*

Needless to say, being engaged in disputes is a reference to his dispute with Hooke. Hooke's death had of course cleared his way and led to the publication of Opticks.

Opticks describes Newton's discoveries related to light. It includes his theory about light and its heterogeneity. Newton believed that here too there is action at a distance, similar to gravity in mechanics.

Opticks differs from Principia on two counts. First, Principia was written in Latin and Opticks in English, with an intent to target a wider audience. (The Latin edition of the book was published in 1706). Second, while Principia, relies on theory and mathematics for its substance, Opticks relies on experimentation and observation. Besides, Opticks has more philosophy than Principia. This too was epoch making and influenced natural philosophy (science) in the eighteenth century.

Newton spells this out clearly,

My Design in this Book is not to explain the Properties of Light by Hypotheses, but to propose and prove them by Reason and Experiments.

The two masterpieces together establish Newton as an authority of both theory and experimentation, the two aspects of science.

Westfall points out that there is nothing new in Opticks. Calculus had been invented thirty years before its publication. Now he was only making a public declaration of it. All that he has written about optics too had been taking shape since 1670. In fact, he had even communicated some parts of it to the Royal Society. So, Opticks is basically a compilation of all his studies and discoveries related to light.

Opticks is divided into three books.

Part 1 of Book I includes eight different definitions of rays of light, refrangibility, angle of incidence, among other concepts. This is followed by eight axioms, which are illustrated and explained. For example, Axiom I says, "The Angles of Reflexion and Refraction, lie in one and the same Plane with the Angle of Incidence." This is followed by PROPOSITIONS with proofs. PART II of Book I includes more propositions.

Book II has four Parts and dwells on the reflection of light, wherein he argues for the particle theory of light.

And this Problem is scarce otherwise to be solved, than by saying, that the Reflexion of a Ray is effected, not by a single point of the reflecting Body, but by some power of the Body which is evenly diffused all over its Surface, and by which it acts upon the Ray without immediate Contact. For that the parts of Bodies do act upon Light at a distance shall be shewn hereafter.

Newton concludes that both reflection and refraction of light are caused by sulphurous parts contained in the surface of the reflector.

Book III discusses diffraction of light. He states that diffraction occurs when light passes through a slit or a small opening or encounters an obstacle in its path. Again, he stresses the concept of action at a distance and suggests the presence of *ether* to facilitate it. The book concludes with what are called *Queries*, sixteen in the first English edition and thirty-one in the Latin edition of 1706.

There was to be a **Book IV**, explaining Newton's beliefs about the ultimate nature of things. But, even at this stage of his life he feared criticism. When pressurised, he only wrote a page and a half. By the time he published his Latin edition he had shed his fear of criticism and wrote elaborately. The result was the new *Queries,* thirty-one of them. The Queries are a free expression of his views, which he had desisted from disclosing all this while.

In the words of Westfall,

on nature of light, nature of bodies, relation of God to the physical universe, presence in nature of the range of forces which furnish activity necessary for the operation of the world and its performance.

In 1703 another episode like that with Leibniz occurred. A scholar named Dr. George Cheyne had written a book on calculus entitled, *The Inverse Method of Fluxions and was looking for a publisher.* Through common friends, Cheyne met Newton and showed him his manuscript and requested help. Newton commented that it was not intolerable. Instead of helping him publish it, Newton offered him a bag of money to cancel its publication! Cheyne did not yield. Newton insisted. Disgusted Cheyne withdrew from the Royal Society, gave up natural philosophy altogether and took to medicine. Later, Newton accused Cheyne of stealing content from his manuscript that he had lent to one of his friends.

It was around the same time that the issue with Leibniz over the priority of invention of calculus was blooming. Newton was quick to react. He hastily appended two chapters on calculus in *Opticks,* titled *Tractus de quadrarura curvarum (A Treatise on the Quadrature of Curves) and Enumeratio linearum terii ordinis (Enumeration of Lines of the Third Order).* It may be recollected that Newton had worked on calculus way back in 1660 and 1670 and had included some of its elements in *Principia.*

In *Opticks,* Newton also foretells the publishing of an account of the 'crowns of colours' that sometimes appears around the sun and the moon. A book called *Dioptrica by Huygens published* posthumously in 1703 covered the same topic. Newton perhaps wanted to establish that he had done the study independently.

Newton drew from his extensive studies of many years and pondered over the forces acting in the universe. He concluded that there were two important forces in nature that caused motion. The first was gravity, which was behind large motions. The second force was the one that propelled small motions between particles. He described inertia as a force that enables bodies to persevere in their motion. However, he cautiously stated that although gravity was present, he did not know *how* it was caused.

He had stated in the early edition of *Opticks* that *infinite space is the sensorium of God*. But later he thought of revising the phrase. So he collected all the unsold copies of the book and cut out the page and inserted the following sentence. *Is not Infinite Space the Sensorium of* *a Being incorporeal, living and intelligent, who sees the things themselves intimately and thoroughly perceives them, and comprehends them wholly by their immediate presence to himself?*

Leibniz happened to lay hands on a copy of *Opticks* in which this correction had not been made. He used the notion that infinite space is the sensorium of God and picked on Newton.

In 1717, thirteen years later, Newton published the second edition of *Opticks* in English with some revisions, and the second edition in Latin was published in 1719. A year later, Pierre Coste's translation of *Opticks* in French was published. In 1721 Newton himself brought out the third edition in English.

Principia was closer to his heart than *Opticks*. He believed that in *Principia* he had expressed his ideas in a perfect idiom. He undertook its revision with a young member of the Royal Society, Henry Pemberton. The project lasted another two and a half years. Now Newton was past eighty years and incapable of extended concentration or discussion. Unlike the revision of the second edition of *Principia* with the assistance of Henry Cotes, the revision for the third edition progressed smoothly. It was presented to the Royal Society on March 31, 1726 by Martin Folkes on behalf of Newton, richly bound in Morocco leather. It is said that 1250 copies were printed, 50 among them on fine paper.

Newton and Theology

In his old age, Newton concentrated on prophecy, the history of church and chronology. One should note that all through his life, he was more concerned with theology than science; indeed, he wrote about 1.3 million words (some say it is more than 2 million words) on Biblical subjects. These and his other non-scientific writings lay hidden for a long time until they were discovered in 1936 and auctioned off for a meagre sum of £9000. The great economist John Maynard Keynes acquired these in 1942. After reading them, his perspective of Newton changed.

He writes,

Newton was not the first of the age of reason. He was the last of the magicians, the last of the Babylonians and Sumerians, the last great mind which looked out on the visible and intellectual world with the same eyes as those who began to build our intellectual inheritance rather less than 10,000 years ago. Isaac Newton, a posthumous child born with no father on Christmas Day, 1642, was the last wonder child to whom the Magi could do sincere and appropriate homage.

Why did Newton, the consummate scientist, concern himself with theology?

He says,

I have a fundamental belief in the Bible as the Word of God, written by men who were inspired. I study the Bible daily.

Yet, this vast legacy was hidden from public view for two centuries until the auction. We must not forget that Newton was very religious from a young age and had listed the sins he had committed as a mark of confession. We have already seen that he was primarily interested in *Prisca Sapienta* or the Primary Wisdom.

Newton and his contemporaries believed in the existence of a God; the universe was His making. They believed that *In the beginning was the Word, and the Word was with God, and the Word was God.* God had created the universe with a language, which was the code of creation; the language of nature, which humans had to strive to understand. Therefore, it was the duty of natural philosophers to break the code and share the revealed information with the world. Humans had corrupted the perfect order that had existed when the universe began. It was the task of the natural philosophers to trace back and reconstitute that order. Newton also believed that there was a perfect religion, which had to be reconstructed.

Newton's first claim was that Catholics and Trinitarians had deliberately corrupted the text of the New Testament. He conducted extensive research and studied the various versions that existed before the text was corrupted. He found that some passages, not found in the Greek manuscripts, had been added. Besides, he believed, the Catholic tradition had given some sort of a guarantee to its authenticity. He was able to pinpoint that Father Jerome (420 to 340 BC) a Latin priest who had translated the Bible into Latin (which came to be known as the *Vulgate*), was responsible for corrupting the text.

Newton focussed on the prophecy as explained in the Book of Revelation and the Book of Daniel. He searched for the original prophecy, determined to filter out the corruptions that had been made over centuries. Perhaps, the history of scripture and theology held a clue. It was from this point of view that Newton undertook a study of chronologies of the ancient kingdoms.

The Revelation of St. John in the New Testament became sacred to Newton. He thought that it held the key to the prophecy and wrote about it in 1670 and continued to write about it until his death. He states that his motto was,

Having searched (and by the grace of God obtained) after knowledge in the prophetic scriptures, I have thought myself bound to communicate it for the benefit of others. ... If they [the prophetic Scriptures] are never to be understood, to what end did God reveal them?

One of the projects he undertook was to predict the date of the Second Coming of Christ. He thus studied all prophecies and verified their fulfilment. Newton was using the scientific method he adopted in natural philosophy. It is interesting that he predicted 2060 for the Second Coming of Christ. His book, *Observations upon the Prophecies* was published posthumously.

Newton studied the Bible in as many as six languages and took interest in the religions of Egypt, Greece, Rome and the Middle East. He was determined to find out how each of these cultures had corrupted true religion. He believed that a reconstruction of the primary religion could save the universe.

Newton firmly believed that all nations had only one religion at first and that it was well appreciated by Pythagoras, Confucius, Socrates and others.

All nations were originally of the Religion comprehended in the Precepts of the sons of Noah, the chief of which were to have one God, & not to alienate his worship, nor prophane his name; to abstein from murder, theft, fornication, & all injuries; not to feed on the flesh or drink the blood of a living animal, but to be mercifull even to bruit beasts; & to set up Courts of justice in all cities & societies for putting these laws in execution.

As a part of this project, Newton studied the practice of Judaism in ancient times. He took an interest in Solomon, the Jewish king. His temple was believed to have been built on a divine plan and that in it was encoded the laws of nature. It represented the universe itself. Newton learnt Hebrew so as to be able to read the Book of Ezekiel. With this knowledge, he produced a floor plan of the temple (Fig. 44). To Newton, the inner sanctum of the temple represented the cosmos itself and the temple was the *pure* model. All other temples built later were corrupt and degraded. Restoration of this order was therefore of utmost importance.

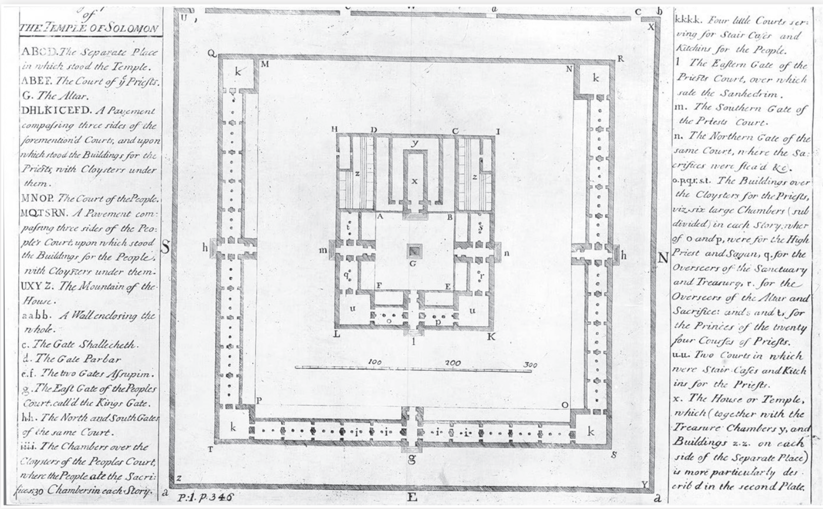


Fig. 44 Plan of the temple of Solomon.

Newton was highly interested in dating events of antiquity and spent many years in his old age evolving a chronology. To deduce the dates of Biblical events, he investigated natural phenomena such as eclipses and the occurrence of comets. The Princess of Wales, Caroline, who heard about the chronology that Newton had developed wished to see it. But Newton was not very keen. However, yielding to pressure he prepared a shorter version of his studies for her. A longer version came to light in 1728, after his death. He dated the voyage of the Argonauts to 936 BC and was able to connect Egyptian history with the events mentioned in the Old Testament. He also traced the birth of civilisation and the evolution of the different forms of worship of various cultures.

Scholars have questioned whether Newton should have bothered about all of this. Today, his theological findings may not be of any consequence. The scientific discoveries for which he is known have subdued his theological endeavours. Arguing from today's stand point, all of his theological studies can be rated as glorious tales and fascinating suppositions. However, we should view Newton in the context of his time. People believed in God and scriptures. For him science was similar to alchemy, which in turn was similar to theology.

He aimed for a holistic view of the universe in which various disciplines merged seamlessly. All study was worth his effort. Perhaps he was right. Perhaps we are wrong to separate theology from science. Perhaps, a holistic view, of the subjective and the objective is the right one.

Newton has said,

He who thinks half-heartedly will not believe in God; but he who really thinks has to believe in God.

Decline and Death

By the time Newton turned eighty years of age, all the turmoil he had lived through had ended – the issues with Flamsteed, the fight with Leibniz, smaller fights in the Mint and so on. He now undertook to revise the two masterpieces he had written. He had the satisfaction and pride of knowing that his Natural Philosophy had spread all over Europe, and many European universities were teaching his theories. Voltaire, Algarotti (Venetian philosopher and expert on Newtonianism) and Madame du Châtelet (French mathematician) had done an admirable job of promoting his work. He was, no doubt, the greatest natural philosopher that ever lived. He was determined to lead the life of a true Christian.

About eight years before his death, he befriended William Stuckeley, a doctor and member of the Royal Society. He also had his roots in Lincolnshire. Like Conduitt, he was engaged in collecting and recording information about Newton. Conduitt and Stuckeley remain the primary sources of information about Newton's last days.

Stuckeley reports,

A life W^{ch} was one continued series of labour, patience humility temperance meekness humanity beneficence & piety without any tincture of vice, exhibits an example wch is more universally beneficial & imitable beneficial than theatchievements of a Cesar or the triumphs of an Alexander.

From his writings, we learn that Newton was of middle stature and plump with piercing eyes and gracious aspect. His hair was as white as snow. A lock of his hair has been preserved in the Wren Library of Trinity College along with his walking stick.

Stuckeley observes,

According to my own observation, tho'. Sr. Isaac was of a very serious, & compos'd frame of mind yet I have often seen him laugh, & that upon moderate occasions. he had in his disposition, a natural pleasantness of temper, & much good nature, very distant from moroseness, attended neither with gayety nor levity. he usd a good many [shrewd] sayings, bordering on joke, & wit. in company he behavd very agreably; courteous, affable, he was easily made to smile, if not to laugh.

Both Conduitt and Stuckeley have noticed that even in his old age Newton was hardly seen idling his time. He was always found with a book and a pen, near his death as well.

Augustus De Morgan says in his *Essays on the Life and Work of Newton*,

Isaac Newton was born at Woolsthorpe, near Grantham, in Lincolnshire, 1642: a weakly and diminutive infant, of whom it is related that, at his birth, he might have found room in a quart mug. He died on March the 20th, 1727, after more than eighty-four years of more than average bodily health and vigour; it is a proper pendant to the story of the quart mug to state that he never lost more than one of his second teeth."

Prince George II and Princess Catherine became Newton's special friends and would entertain him for hours. During this period, he developed another fancy he was happy to pose for portraits.

Very few in his family recognised Newton's merit as a scientist and thinker. They understood him the least. For them he was only a rich man living in London. Most of them were poor and needed help to carry on with their lives. They depended on Newton who was happy to financially support them. He paid one person money at regular intervals, he bought an annuity for someone else; he stood surety for another person. There is a long list of his beneficiaries. He distributed copies of the Bible. Historians have found a large number of letters requesting Newton's support. Westfall observes that his fights with Flamsteed and Leibniz were somewhat compensated by his generosity in later years.

It was at this stage that Newton revealed to at least three people about his *apple story*. He was engaged in conversations with Conduitt about the cosmos. His very popular quotation could have come into one such conversation.

I don't know what I may seem to the world, but as to myself, I seem to have been only like a boy playing on the sea-shore and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

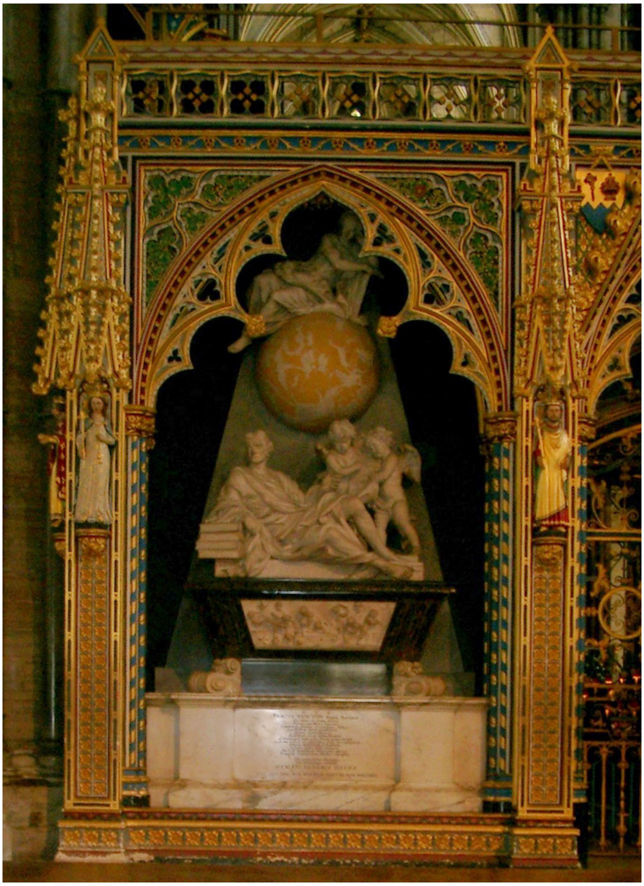


Fig. 45 Newton's tomb in Westminster Abbey in London.

His health began to deteriorate in 1723. His sphincters had grown weak and he had developed urine incontinence. Consequently, his life and eating habits changed. Meat was taboo; vegetables, broth and soup crept into his menu. In 1725, he suffered from a cough and inflammation of the lungs. He could no longer attend meetings of the Royal Society as regularly as he had previously. He moved away to live in Kensington, a suburb of London.

March 2, 1727. Newton presided over the meeting of the Royal Society for the last time. His cough continued when he went back home. Doctors found a stone in his bladder. Death became imminent. Sweat ran from his face.

Stuckeley describes,

The pain rose to such a height that the bed under him, and the very room shook with his agonys, to the wonder of those that were present. Such a struggle had his great soul to quit its earthly tabernacle!

Newton died in the early hours of the morning of March 20, 1727. Physician Richard Mead attended him during the last hours. It is said that Newton then confessed to Mead that he was a virgin. Three days later, the Royal Society announced -

March 23rd 1726.

(It may be pointed out that two calendars were in use during his time. According to the old calendar, it was 1726.)

The Chair being vacant by the Death of Sir Isaac Newton there was no meeting this day.

Tributes poured in from every corner. Gazettes announced his death. He was described as the *greatest of philosophers, and the glory of the British nation*. The Poem, *Sacred to the Memory of Sir Isaac Newton* by James Thomson reached its fifth edition within a year. Conduitt organised Newton's funeral. Newton's body was laid to rest at Westminster Abbey. Some of the officials of the Abbey attended the funeral while the Lord Chancellor, two

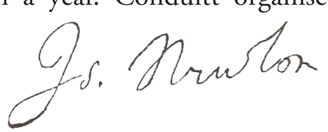


Fig. 46 Newton's signature

dukes and three earls bore the pall. Many of the members of the Royal Society followed. A monument was erected in 1731.

Voltaire observed,

He was buried like a king who had done well by his subjects. No scientist before or since has been so revered and interred with such high honour.

The inscription speaks of it all,

H. S. E. ISAACUS NEWTON Eques Auratus, / Qui, animi vi prope divinâ, / Planetarum Motus, Figuras, / Cometarum semitas, Oceanique Aestus. Suâ Mathesi facem praeferente / Primus demonstravit: / Radiorum Lucis dissimilitudines, / Colorumque inde nascentium proprietates, / Quas nemo antea vel suspicatus erat, pervestigavit. / Naturae, Antiquitatis, S. Scripturae, / Sedulus, sagax, fidus Interpres / Dei O. M. Majestatem Philosophiâ asseruit, / Evangelij Simplicitatem Moribus expressit. / Sibi gratulentur Mortales, / Tale tantumque exstitisse / HUMANI GENERIS DECUS. / NAT. XXV DEC. A.D. MDCXLII. OBIIT. XX. MAR. MDCCXXVI

Translated as:

Here is buried Isaac Newton, Knight, who by a strength of mind almost divine, and mathematical principles peculiarly his own, explored the course and figures of the planets, the paths of comets, the tides of the sea, the dissimilarities in rays of light, and, what no other scholar has previously imagined, the properties of the colours thus produced. Diligent, sagacious and faithful, in his expositions of nature, antiquity and the holy Scriptures, he vindicated by his philosophy the majesty of God mighty and good, and expressed the simplicity of the

Fig. 47 A statue of Newton.

Gospel in his manners. Mortals rejoice that there has existed such and so great an ornament of the human race! He was born on 25th December 1642, and died on 20th March 1726.

Alexander Pope, the poet, wrote three years later,

Nature, and Nature's Laws, lay hid in Night. God said, Let Newton be! and All was Light.

Thus ended a great life; one dedicated to the perennial quest for knowledge, one, which was restless throughout, one which would not admit contemporaries' superiority, one which went any length to establish its supremacy, which, yet gave a new direction to the understanding of the working of the physical world. Einstein may have corrected Newton, but no one has overturned him. There is no reason to.

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Note: *Principia* and *Opticks* can be downloaded freely from the internet.

APPENDIX

A: Newton - Chronology

1642: December 25**,** Isaac Newton born in Woolsthorpe, England. His father had died three months before.

1646: January, Mother Hannah marries Barnabas Smith and moves to live with him. Newton is brought up by Hannah's mother.

1653: Barnabas Smith dies; Hannah returns to live with Isaac, bringing three children with her from her second marriage.

1655: Newton enrolls in the Grantham Grammar School.

1659: Newton is recalled by his mother from Grantham to Woolsthorpe.

1660: Autumn, Newton returns to Grantham School and boards with the Headmaster, John Stokes.

1661: Newton joins Trinity College, Cambridge.

1664: April 28, Newton is elected scholar.

1665: Newton receives his B. A. from Trinity College, Outbreak of plague in London and Cambridge. Newton retires to his mother's home in Woolsthorpe.

1665 to 1667: *Anni Mirabiles* (Wonderful Years). He conducts the famous prism experiments, works out his system of fluxions, leading to modern calculus; begins to consider the idea of gravity.

1668: Newton is granted Master's Degree, Cambridge.

1669: February, fabricated the telescope using reflecting mirrors, October: Newton appointed to the Lucasian Chair of Mathematics at Trinity, a position he held for the next thirty-four years.

1671: Barrow exhibits Newton's telescope at the Royal Society.

1672: January 11**,** Newton elected to the Royal Society.

1672: February**,** Newton's paper on optics and his prism experiments sent to the Society. Rivalry with Hooke begins.

1679: June 4**,** Death of mother, Hannah, November 24, first of a series of letters exchanged with Robert Hooke, concerning the problem of planetary motion.

1681: Newton observes the Comet until March and corresponds with John Flamsteed.

1682: December, Newton observes Halley's Comet.

1684: January**,** Hooke, Christopher Wren and Halley discuss principle of inverse squares, August, Halley goes to visit Newton in Cambridge, and learns that Newton has already proved the law of inverse squares, November, Newton completes his calculations on gravity and shares them with Halley, who begs him to publish his results.

1685: February, Newton sends a brief paper, *Propositiones de Motu,* to the Royal Society, outlining his findings to be registered at the Royal society.

1686: April 28, Newton presents the book, *Principia* to the Royal Society.

1687: September, *Principia* published.

1689: Newton elected as Cambridge's representative to Parliament, Newton meets Nicolas Fatio de Duillier. Their relationship breaks abruptly in 1693.

1693: Newton is plagued by depression and insomnia, and apparently suffers a nervous breakdown in September. Sends letters to John Locke and Samuel Pepys.

1694: Newton visits John Flamsteed at Greenwich.

1695: Newton appointed warden of the Mint and leaves Cambridge, moves to London.

1700: Newton becomes Master of the Mint.

1701: Newton elected to Parliament by Cambridge Senate, resigns his position as Lucasian chair of mathematics.

1703: Hooke dies; Newton elected President of the Royal Society.

1704: Publication of *Opticks*; Feud with Leibniz begins. **1705:** Newton knighted by Queen Anne.

1712: Royal Society commission, under Newton's direction, investigates the claims of Leibniz to having developed calculus, and decides in favour of Newton.

1713: Second edition of the *Principia* published.

1716: November 14**,** Death of Leibniz.

1726: Third edition of the *Principia* published; all reference to Leibniz has been removed.

1727: March 2, Newton attends Royal Society for last time, March 18, his health fails, he collapses, March 20, Isaac Newton dies at Kensington between 1.00 and 2.00am, March 28, his body lays in state in Westminster Abbey, April 4, his body is buried at Westminster Abbey.

B - List of Sins Committed by Isaac Newton

Before Whitsunday, 1662

1. Using the word (God) openly.
2. Eating an apple at Thy house.
3. Making a feather while on Thy day.
4. Denying that I made it.
5. Making a mousetrap on Thy day.
6. Contriving of the chimes on Thy day.
7. Squirting water on Thy day.
8. Making pies on Sunday night.
9. Swimming in a kimnel on Thy day.
10. Putting a pin in Iohn Keys hat on Thy day to pick him.
11. Carelessly hearing and committing many sermons.
12. Refusing to go to the close at my mother's command.
13. Threatening my father and mother Smith to burne them and the house over them.
14. Wishing death and hoping it to some.
15. Striking many.
16. Having uncleane thoughts words and actions and dreamese.
17. Stealing cherry cobs from Eduard Storer.
18. Denying that I did so.
19. Denying a crossbow to my mother and grandmother though I knew of it.
20. Setting my heart on money learning pleasure more than Thee.
21. A relapse.
22. A relapse.
23. A breaking again of my covenant renued in the Lords Supper.

24. Punching my sister.
25. Robbing my mother's box of plums and sugar.
26. Calling Dorothy Rose a jade.
27. Glutiny in my sickness.
28. Peevishness with my mother.
29. With my sister.
30. Falling out with the servants.
31. Divers commissions of alle my duties.
32. Idle discourse on Thy day and at other times.
33. Not turning nearer to Thee for my affections.
34. Not living according to my belief.
35. Not loving Thee for Thy self.
36. Not loving Thee for Thy goodness to us.
37. Not desiring Thy ordinances.
38. Not long {longing} for Thee in {illeg}.
39. Fearing man above Thee.
40. Using unlawful means to bring us out of distresses.
41. Caring for worldly things more than God.
42. Not craving a blessing from God on our honest endeavours.
43. Missing chapel.
44. Beating Arthur Storer.
45. Peevishness at Master Clark's for a piece of bread and butter.
46. Striving to cheat with a brass halfe crowne.
47. Twisting a cord on Sunday morning.
48. Reading the history of the Christian champions on Sunday.

Since Whitsunday, 1662

1. Glutony
2. Glutony
3. Using Wilfords towel to spare my own.
4. Negligence at the chapel.
5. Sermons at Saint Marys (4)
6. Lying about a louse.
7. Denying my chamber fellow of the knowledge of him that took him for a sot.
8. Neglecting to pray 3
9. Helping Pettit to make his water watch at 12 of the clock on Saturday night

C: List of Lucasian Professors

Year Appointed	Name	Expertise	Tenure Years
1664	Isaac Barrow (1630 – 1677)	Classics and Mathematics	6
1669	Isaac Newton(1642 – 1726)	Mathematics and Physics	33
1702	William Whiston (1667 – 1752)	Mathematics	9
1711	Nicholas Saunderson (1682 – 1739)	Mathematics	28
1739	John Colson(1680 – 1760)	Mathematics	21
1760	Edward Waring(1736 – 1798)	Mathematics	38
1798	Isaac Milner(1750 – 1820)	Mathematics and Chemistry	22
1820	Robert Woodhouse(1773 – 1827)	Mathematics	2
1822	Thomas Turton(1780 – 1864)	Mathematics	4
1826	George Biddell Airy(1801 – 1892)	Astronomy	2
1828	Charles Babbage(1791 – 1871)	Mathematics and Computing	11
1839	Joshua King(1798 – 1857)	Mathematics	10
1849	George Gabriel Stokes (1819 – 1903)	Physics and Fluid Mechanics	54
1903	Joseph Larmor(1857 – 1942)	Physics	29
1932	Paul Dirac(1902 – 1984)	Physics	37
1969	James Lighthill(1924 – 1998)	Fluid Mechanics	10
1979	Stephen Hawking(born 1942)	Theoretical Physics and Cosmology	30
2009	Michael Green(born 1946)	Theoretical Physics	

PART 2

Scientific Contributions of Isaac Newton

Isaac Newton's contributions in the fields of Mechanics, Optics and Mathematics are fundamental with far reaching consequences. However, it is not possible to explain all these in a book of this size. We merely outline his major achievements. It is hoped that the reader will be encouraged to read advanced books in science to fully appreciate his work. Newton's work in optics has already been discussed in detail in Part 1 of the book. In this section, we will discuss his major findings in Mechanics and Mathematics.

1. Mechanics

Definitions of Terms

Newton defined for the first time some of the concepts we use in science and everyday conversation. *Principia* begins with eight such definitions quoted below.

a. Mass is defined as,

Quantity of matter [or mass] is a measure of matter that arises from its density and volume jointly.

And thus the formula,

$$mass = density \times volume$$

b. Momentum

> *The quantity of motion (*which is called Momentum today*) is the measure of the same arising from the velocity and quantity of matter conjunctly.*

And thus the formula,

$$momentum = mass \times velocity$$

c. Inertia

> *The vis insita, or innate force of matter, is a power of resisting, by which everybody, as much as in it lies, endeavours to persevere in its present state, whether it be of rest, or of moving uniformly forward in a right line (straight Line).*

This definition of Inertia is also Newton's first law of motion and *vis insita* or *innate force* of matter is *inertia*. Since the first law has important consequences, we will discuss it separately.

d. Force

> *An impressed force is an action exerted upon a body, in order to change its state, either of rest, or of moving uniformly forward in a right line.*

The following four definitions are specific to centripetal force, a force which makes a body follow a curved path. This force is perpendicular to the direction of motion and is directed towards the centre of the curved path.

e. *A Centripetal Force is that by which bodies are drawn or impelled, or in any way tend, towards a point as to a centre.*

f. *The absolute quantity of a centripetal force is the measure of the same, proportional to the efficacy of the cause that propagates it from the centre, through the spaces round about.*

g. *The accelerative quantity of a centripetal force is the measure of the same, proportional to the velocity which it generates in a given time.*

h. *The motive quantity of a centripetal force is the measure of the same proportional to the motion, which it generates in a given time.*

Space and Time

Newton writes regarding space and time as follows,

Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time ...

Absolute space, in its own nature, without regard to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies: and which is vulgarly taken for immovable space ... Absolute motion is the translation of a body from one absolute place into another: and relative motion, the translation from one relative place into another

Until the arrival of Albert Einstein, two hundred years after, the above statements regarding space and time by Newton remained unchallenged. For Newton, time and space were both absolute. Five minutes for one person are five minutes for anybody else. What is 100 metres for one person is 100 metres for everybody.

With Albert Einstein's *Special Theory of Relativity* (1905) and *General Theory of Relativity* (1915) this belief in absolute time and space was overturned. He showed that both space and time are relative and depend upon the speed of the observer. However, relativistic effects become important only at high speeds comparable to that of light. At ordinary speeds, Newton's Laws still govern all motion.

Newton's Laws of Motion

First Law: Every body continues to be in a state of rest or of uniform motion along a straight line unless it is compelled to change that state by an external force.

This law easily appeals to common sense. An object, say a stone, placed somewhere continues to stay there forever. If it has to move, someone has to 'move' it or apply a force. Now consider an object, which is moving along a straight line. If there is no obstruction to its motion, it continues to move in a straight line. If it has to come to rest, a force need be applied. Then arises the question, why then does an object such as a marble moving horizontally on a surface comes to rest by itself? Do not forget that there is resistance to motion or friction due to the surface. This is more pronounced for a grainy surface. In the absence of resistance, a marble rolling on a surface goes on forever.

You may have already recognised that this is the phenomenon called inertia. Newton did not quite discover this concept. Galileo was well aware of it.

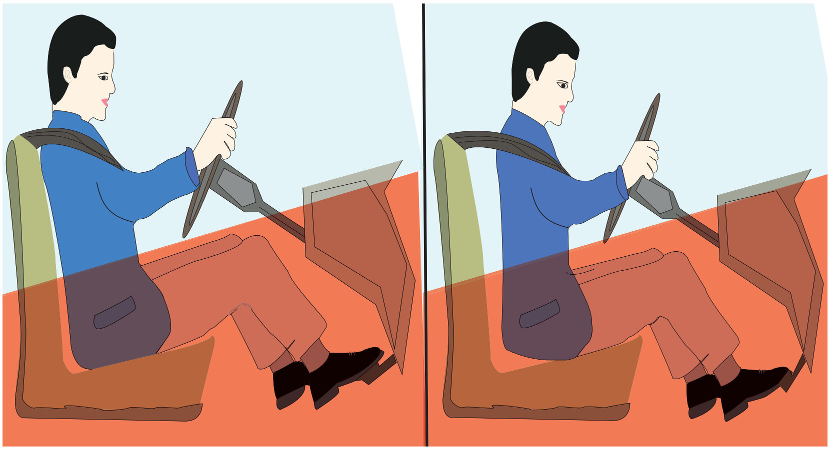


Fig. 48 Why should one wear seatbelt?

We come across inertia in everyday life and experience it. Assume that you are travelling in a bus and you are standing. What happens when the driver applies brakes suddenly? You have a tendency to fall forward. Why? You were moving as the floor of the bus moved. When the brakes were applied, the bus comes to a stop. However, your body, which was moving, continues to move. Hence you tend to fall. You may now realise that this is the reason why passengers and drivers in a car or bus are advised to fasten seat belts (Fig. 48) so as to prevent injury if the bus or car comes to a halt due to an accident or the driver applies brakes suddenly. Your body tends to move forward even though the vehicle has come to rest. Hence the injury.

Have you ever had coffee while in a moving car? When the car is at rest or moving at a uniform speed, coffee stays in the cup and is unperturbed. What happens when the car is accelerated? Due to acceleration, a force is felt by all parts of the car and the seat in which you are seated. The car and you too accelerate. But coffee does not sense this force. It moves slowly at its original speed and meets your lap! Hence the spill. Similarly when the car is brought to rest by braking, the car and you come to rest. Coffee still moves. It may splash on the windscreen.

One may perform this well-known experiment to demonstrate inertia. Take a cup or tumbler and put a thin cardboard on top of it as shown in Fig. 49. Then keep a coin on top of the cardboard. Now with your fingers push the cardboard. The cardboard flies off but the coin falls into the tumbler. Why?

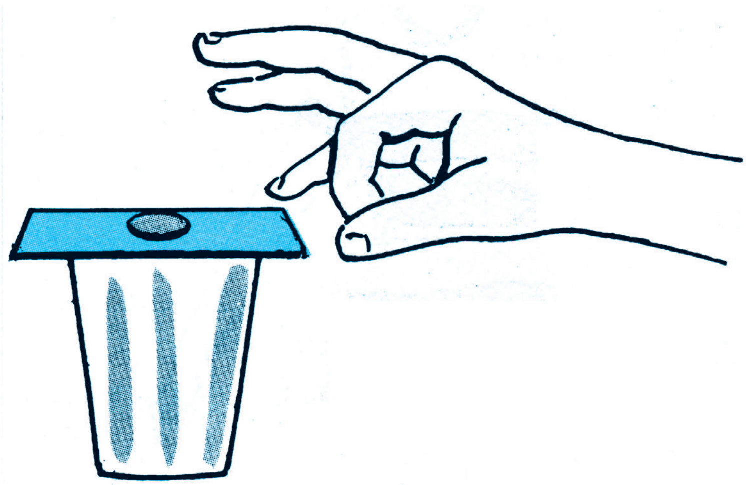


Fig. 49 Experiment to demonstrate inertia.

Second Law: The second law can be stated in many ways. It concerns the net force acting upon an object and the acceleration the object undergoes as a consequence.

And thus the formula,

$$F = ma,$$

where $\boldsymbol{F}$ is the net force acting upon the object, $\boldsymbol{m}$ is its mass and $\boldsymbol{a}$ is the acceleration. This formula can be used to calculate the motion of solids, liquids and gases.

In other words, the acceleration produced on an object is directly proportional to the net force. More the force, more the acceleration, less the force less the acceleration. It may be noted that acceleration is inversely proportional to the mass of the object. For the same force if the mass is doubled, acceleration gets halved. On the other hand, if the mass is halved, acceleration is doubled. The above equation, which must have been formulated after Newton, however does not appear in *Principia*.

Suppose you have a small marble and a big stone. If you want to accelerate them to the same level (say 30 cm/s^2) then the marble needs a smaller amount of force and the stone needs a larger force. These forces can be quantified. If the marble has a mass of 5 gms and stone 5 kgs then as per the second law ($F = ma$) the force required will be 5×30 and 5000×30 dynes or 0.00015 and 0.15 Newtons. On the other hand, when a force of 1 N is applied, the marble and the stone accelerate to 200 m/s^2 and 200 mm/s^2 respectively.

While applying the formula $F=ma$ to calculate motion it is necessary to note that $\boldsymbol{F}$ is the net force required. In any motion friction is necessarily present. Then you will need a force, which can overcome the friction and then accelerate the body. In case of the motion of a motor car, bus or train, the road friction or resistance, has to be overcome. In case of an aeroplane, air resistance or drag has to be overcome.

Scientists and engineers have been widely using this formula to calculate velocities, drag, efficiencies and a host of other useful information. This formula assists in determining the most ideal shape and size of an aircraft wing, the ideal temperature of gases in an aircraft engine, the quantity of petrol a car might consume to be driven from point A to point B, whether a certain blockage of the artery will be fatal to a patient and many such instances.

Third Law: For every action there is an equal and opposite reaction.

How is it that you are able to stand on the ground without being sucked into it? The answer is simple. You are pushing the ground with a force, which is equal to your weight. That is action. The ground on the other hand pushes you back with the same force. This is reaction. Action and reaction are equal (in magnitude) and opposite (in direction). This is why you are able to stand at one place. Otherwise, you would have gone into the ground. On the other hand, we cannot stand or float in air because air does not exert enough force to counteract our weight.

When you hit a wall with your hand, you are exerting a force upon the wall and it produces a reaction equal to the force. Hence the injury. One of the best illustrations of the Third Law is an aircraft engine (Fig. 50).

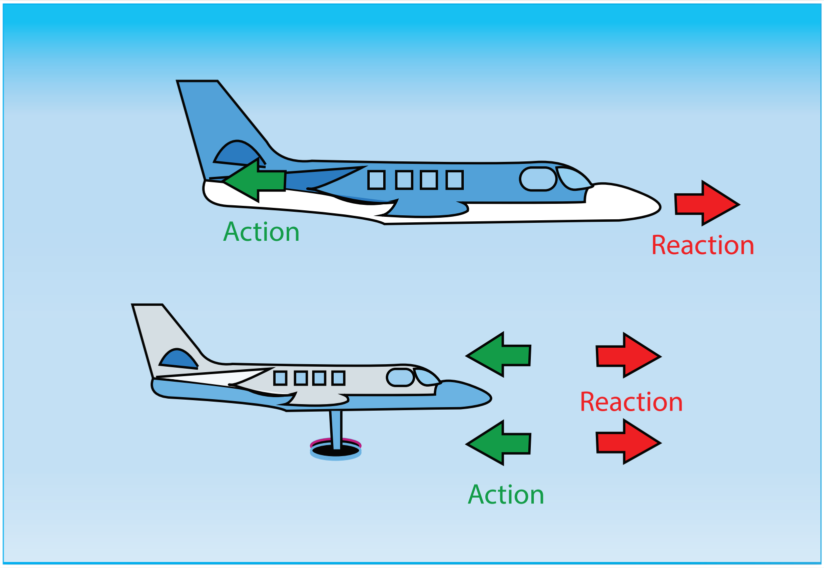


Fig. 50 Third Law in action.

The engine is ignited by a mixture of fuel and oxygen. The hot gases thus produced are issued out through a nozzle. This forms the action. As a reaction, a force is produced in the opposite direction, which propels the aircraft forward. A similar action and reaction take place in case of a propeller driven aircraft and rocket propulsion (Fig. 51).

Fig.51 Rocket Propulsion.

The third law is in action again when one dives in a swimming pool (Fig. 52). Look at the picture. It is easy to locate the action and the reaction.

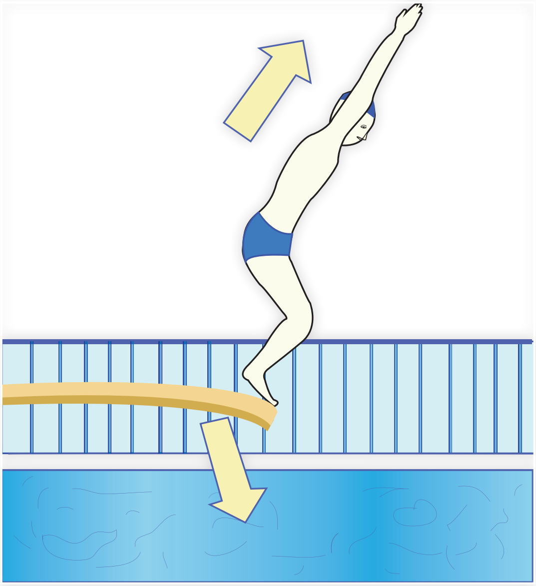


Fig. 52 Person diving in a pool.

Newton's Law of Gravitation

Isaac Newton faced a challenge in relating the Inverse Square Law with a planetary orbit. Here is a short account of Kepler's Laws of Planetary Motion which are central to Newton's theories.

Kepler's Laws

1. *The orbit of a planet about the Sun is an ellipse with the Sun at one focus (Fig. 53).*

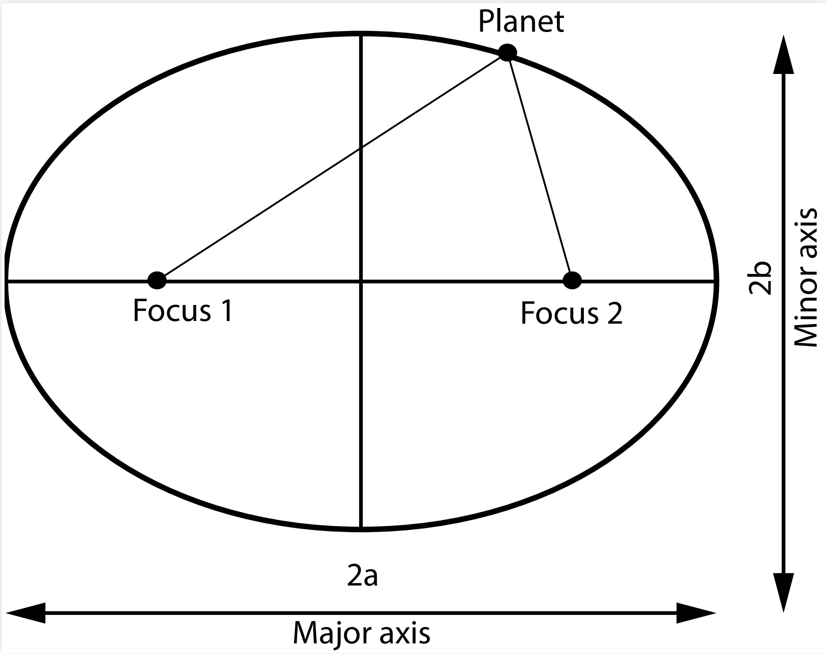


Fig. 53 Kepler's first law.

2. *A line joining a planet and the Sun sweeps out equal areas in equal intervals of time.*

   In Fig. 54, the areas swept out by the planet moving in its orbit around the sun in equal intervals of time are shaded.

$$Area\ OAB = Area\ OCD$$

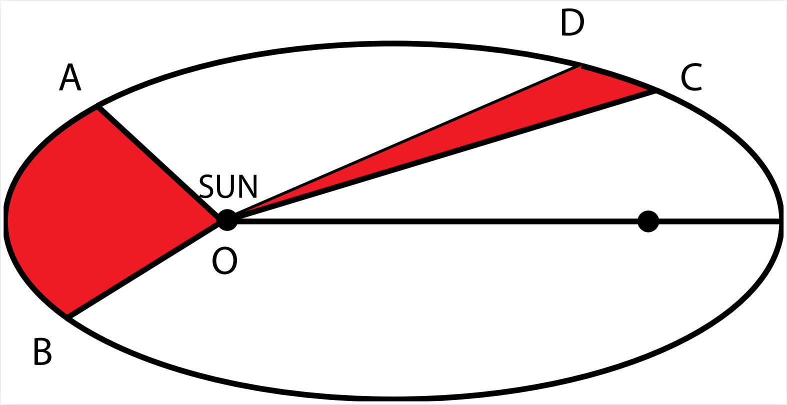


Fig. 54 Kepler's second law, a planet sweeps out equal areas in equal intervals of time.

3. *The squares of the sidereal periods of the planets are proportional to the cubes of their semi-major axes.*

If a is the semi-major axis (half of the length of major axis) measured in astronomical units and P is the period of the planet measured in years, then for all planets

$$\frac{P^2}{a^3} = \text{constant.}$$

Newton's Law of Universal Gravitation

Newton devised the following law or formula to calculate the force of attraction between any two bodies,

$$F = G\frac{m_1 m_2}{r^2}$$

Where m_1 and m_2 are the masses of the two bodies and r is the distance between them. G is called the Gravitational Constant = 6.673×10^{-11} N·(m/kg)$^{2(\text{m/kg})}$. From this formula Kepler's Laws can be deduced. An important result of combining Newton's and Kepler's Laws is the formula,

$$P^2 = \frac{a^3}{m_1 + m_2}$$

Masses expressed in units of solar masses; period, P, in years, a in AU (astronomical units). This formula helps determine the masses of cosmic objects. Currently, this is the only available method for it.

Consequences of Newton's Law of Gravitation

Earth's gravity on Moon's surface

Newton's Laws helped us to calculate the force of gravity exerted by the earth or the moon. The distance from the Moon to the centre of the earth is approximately 60 times the radius of the earth. Therefore, the earth's gravity on the moon should be 60^2 times less than that on the earth. We know that on earth's surface, acceleration due to gravity has a value of 9.8 m/s^2. Hence on the moon its value should be $9.8/60^2$ = 0.0027 m/s^2. Consequently, the moon comes closer to earth by 1.4 mm in each second of its orbit.

Weight of an object on Moon

How much does an astronaut weigh on the moon? The acceleration due to gravity of the moon on its own surface is smaller and less massive compared to earth, i.e, 1.6 m/s^{2s} (not to be confused with 0.0027m/s^{2s}, which is the value of earth's gravity on the surface of the moon). Therefore a man who weighs 75 *kgs* on earth will weigh (75/9.8) × 1.6 = 12.25 kgs on the moon. Note that his mass remains the same.

How large is earth's gravity?

According to Newton's Law, a force of attraction exists between any two objects.

Let us calculate the magnitude of this force in different situations.

To begin with, the mass of earth is 6 × 1024 kg; earth causes an acceleration of 9.8 meters/sec^{2sec}

Now consider two mighty objects of mass 10,000 tons (107 kg) separated by 100 meters. The force between them would be $(6.67 \times 10^{-11} \times 10^7 \times 10^7) / (100)^2 = 0.67$ Newtons.

Applying Newton's second law of motion, acceleration = force/mass, and thus the acceleration on each would be 6.7×10^{-8} meters/sec^2, too tiny to measure.

Compare this with acceleration due to gravity which is 9.8 m/s^2.

Consider a mass m, which is placed on the surface of the earth. What is the force of attraction between it and the earth?

We have,

$$F_{earth} = G\frac{m_{earth}m}{R^2_{earth}}$$

Then, what is the force exerted by the sun on the same mass? Let the distance between the surface of the earth and the sun as dsun.

The force is represented as,

$$F_{sun} = G\frac{m_{sun}m}{d^2_{sun}}$$

The ratio is represented as,

$$\frac{F_{sun}}{F_{earth}} = \left(\frac{m_{sun}}{m_{earth}}\right)\left(\frac{R_{earth}}{d_{sun}}\right)^2$$

We have m_{sun} = 2 × 1030 kg and m_{earth} = 6 × 1024 kg, while d_{sun} = 1.5 × 108 *km* and R_{earth} = 6400 *km*, thus,

$$\frac{F_{sun}}{F_{earth}} = \left(\frac{2\times10^{30}}{6\times10^{24}}\right)\left(\frac{6400}{1.5\times10^{8}}\right)^2 = 6\times10^{-4}$$

Gravitational force on us on earth due to the sun is less than a tenth of a percent of the earth's gravitational force on us. Now consider two lovers in a room each weighing 60 kgs and 1 m apart. The force between them compared to earth's gravity is,

$$\frac{F_1}{F_2} = \left(\frac{60}{6\times10^{24}}\right)\left(\frac{6400}{0.001}\right)^2 = 2.4\times10^{-9}$$

So, the earth loves them far more than they do themselves!

Weight of the earth

Using the same equation the weight of the earth can be calculated. The weight due to any mass m is the force with which the earth attracts that mass.

Hence,

$$W_m = mg = G\frac{m\,m_e}{R_e^2}$$

Therefore,

$$m_e = \frac{gR_e^2}{G} = \frac{9.8\times(6.37\times10^6)^2}{6.67\times10^{-11}} = 6\times10^{24}\ \text{kg}$$

This calculation was first performed by Henry Cavendish (a British scientist famous for his discovery of Hydrogen) in 1798.

The earth is not a perfect sphere

The world was well aware that the earth was round and not flat. Newton went further and predicted that the earth is not a perfect spheroid but is an oblate spheroid; it is flat at the poles (Fig. 55). Today we know that the earth's diameter at the equator is about 12,700 *kms*. But the distance from pole to pole is about 40 *kms* lesser than this.

Newton proved that this difference is a consequence of earth's rotation. The centrifugal force acting at the equator causes a bulge in the shape of the earth. At the poles there is no centrifugal force. If the earth were a solid mass this oblation would not have occurred. But there are viscous fluids within the earth contributing to the flattening at the poles.

Considering the shape of the earth to be an ellipsoid one can define flattening f as

$$f = \frac{a-b}{a}$$

Where a is the semi major axis (in this case the equatorial radius of the earth) and b is the semi minor axis (in this case the polar radius of the earth). Some of the representative values of f are 1/300 (earth),

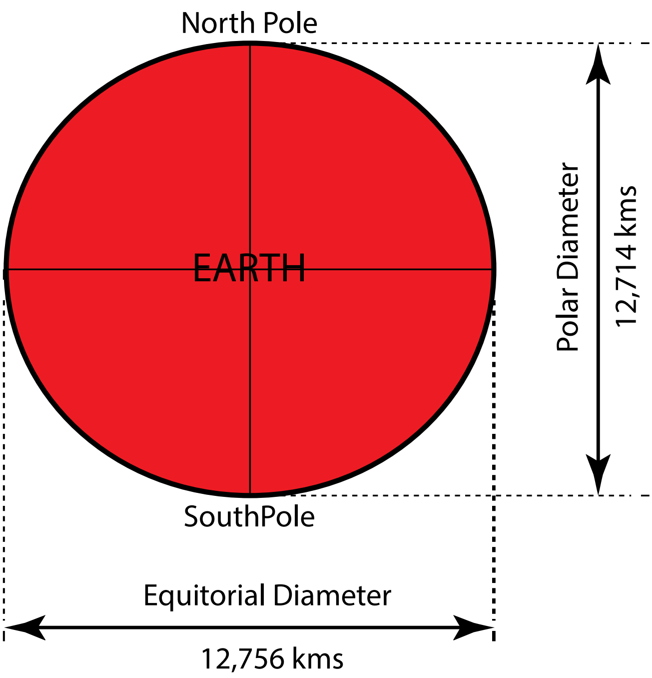


Fig. 55 Earth an oblate spheroid.

1/825(earth's moon), 1/15 (Jupiter), 1/3 to ½ (one of Saturn's moons Telesto). Lower the denominator more elliptical the object.

A team of French and Spanish scientists in 1735 sailed to Peru and Lapland and verified Newton's calculations regarding earth's flattening at the poles. The outcome was that Newton's prediction was correct.

Tides

Application of the Theory of Gravitation to the formation of tides (Fig. 56) brings out another interesting fact. The gravitational forces of the sun and the moon acting on the oceans, cause tides. However, it is now known that the tide generating force between any object and the ocean is inversely proportional to the cube of the distance between the two. The sun's mass is 27 million times larger than that of our moon. The distance between the sun and earth is 149785000 *km*, while the distance between the moon and the earth is 382835 *km*.

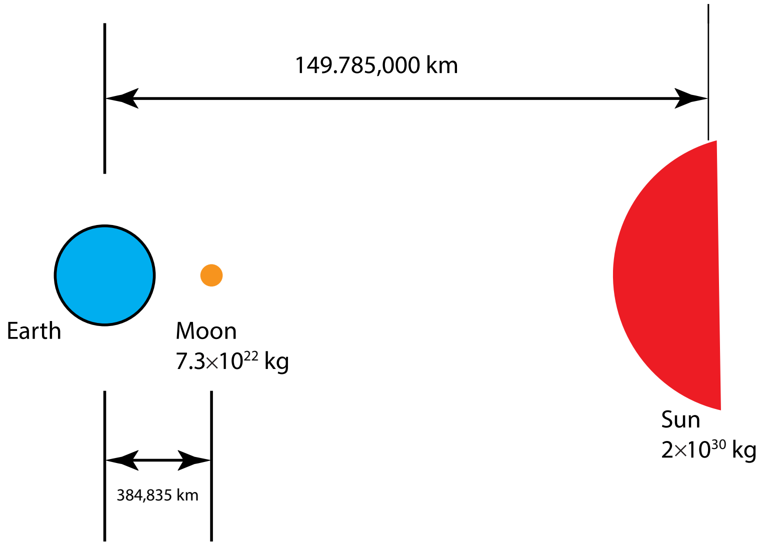


Fig. 56 Tides.

The attractive force between the earth and moon is represented by,

$$Fg_m = G\frac{m_{moon}\, m_{earth}}{d_{moon}^2},$$

That between the sun and earth is represented by,

$$Fg_s = G\frac{m_{sun}\, m_{earth}}{d_{sun}^2}.$$

Their ratio is represented by,

$$\frac{Fg_s}{Fg_m} = \left(\frac{m_{sun}}{m_{moon}}\right)\left(\frac{d_{moon}}{d_{sun}}\right)^2 = \left(\frac{2\times10^{30}}{7.3\times10^{22}}\right)\left(\frac{382835}{149785000}\right)^2 \approx 177$$

Consequently, the sun's gravitational force is 177 times as powerful as that of the moon upon the earth.

Now consider the tide producing forces.

For Fts, Tide generating force exerted by the sun we have,

$$Ft_s \propto \left(\frac{m_{sun}}{d_{sun}^3}\right) = \left(\frac{2\times10^{30}}{149785000^3}\right)$$

For Ft_m, Tide generating force exerted the moon, it is,

$$Ft_m \propto \left(\frac{m_{moon}}{d_{moon}^3}\right) = \left(\frac{7.3\times10^{22}}{382835^3}\right)$$

Thus, $\frac{Ft_s}{Ft_m} = \left(\frac{2\times10^{30}}{7.3\times10^{22}}\right)\left(\frac{384835}{149785000}\right)^3$ = 0.46, say 50%.

Though the attractive force due to the sun is 177 times than that due to the moon, the tide generating force due to the sun is only 46% of that due to the moon. This difference can of course be explained by the large distance between the sun and the earth.

Orbits of satellites

How is it that the moon keeps its orbit around the earth and doesn't fall off into the earth's surface or take off in another direction? For that matter, how do the artificial satellites that we send regularly to space keep their orbits? Newton's famous thought experiment of firing a cannon (Fig. 57) explains the phenomena. Consider a cannon, which is fired from the surface of the earth as shown. For a small speed of firing, such as A, the cannon will fall to the ground after travelling a parabolic path. As the speed of firing increases, say C, the cannon goes further, does not fall back into the earth's surface, but somewhat follows the curvature of the earth. The canon simply encircles the earth. So, we see that with varying speeds, the cannon follows different trajectories as shown. Newton showed mathematically that if the cannon is fired with a certain speed, it will orbit around the earth and will be within its gravitational field.

The velocity with which a satellite must revolve in order to orbit at a given height from the earth can also be calculated. While orbiting, the gravitational force due to earth's attraction, F_g, is balanced by the centripetal force, F_c, due to the motion of the satellite as shown in (Fig. 58). Assume that the satellite is at a height h above the earth's surface. This phenomenon can be expressed thus,

$$F_g = G\frac{m_e m_s}{(R_e + h)^2} = \frac{m_s v_s^2}{R_e + h} = F_c$$

Leading to

$$v_s = \sqrt{\frac{Gm_e}{R_e + h}}$$

If the velocity of the satellite is less than *vs* the satellite will fall to the ground. Otherwise, it will keep its orbit. Substituting for *G*, *me* and *Re* as before we obtain, *h=0*,

Vs = 7.92 km/s

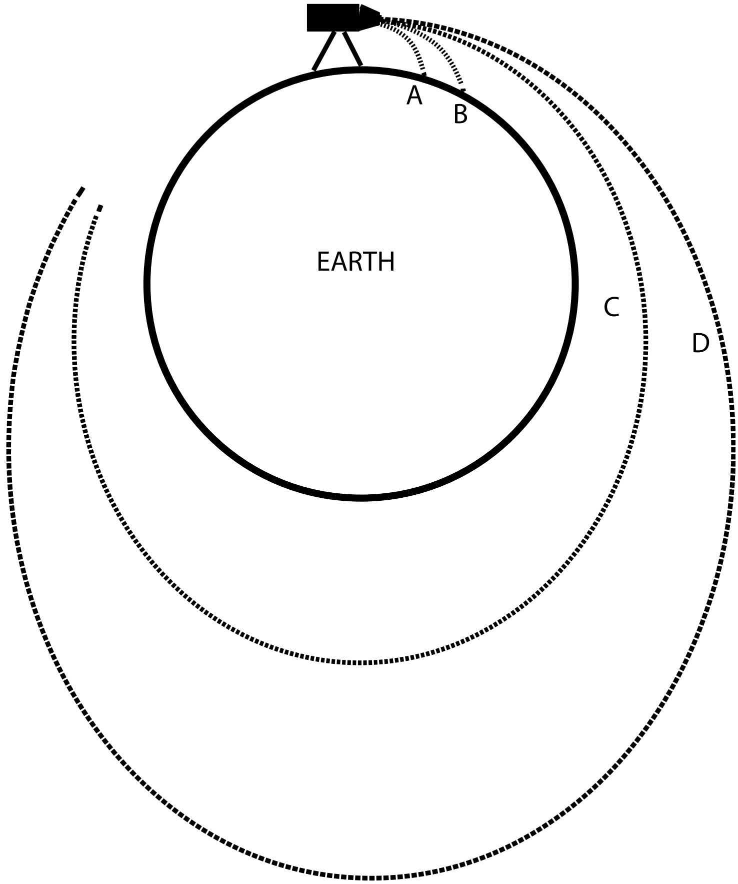


Fig. 57 Cannon experiment.

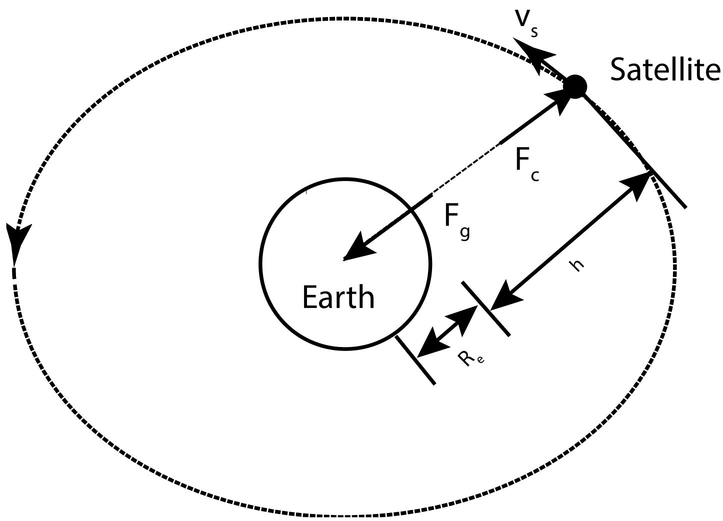


Fig. 58 Velocity of a satellite.

Einstein gives a different view

Albert Einstein (1879–1955) two hundred years later proposed a different interpretation of gravity. For Newton gravity was a force of attraction between two objects. However, Einstein argued that gravity is the curvature of this space-time continuum. He redefined our conception of space and time. He viewed the world around us as four dimensional (x, y, z, t). While it is easy to imagine in our minds a three dimensional world, to imagine a four-dimensional space is a little tricky. In fact, any number of dimensions can be illustrated mathematically. Such a conception is known as the space-time continuum.

Let's imagine the space-time continuum as a mattress. When objects such as planets are placed on it, the mattress becomes curved. The extent and form of curvature depends on the mass and shape of the object. This distortion in the mattress or of the space-time continuum, according to Einstein is gravity.

Many of Einstein's predictions have been experimentally verified. One such is that a ray of light bends in a gravitational field.

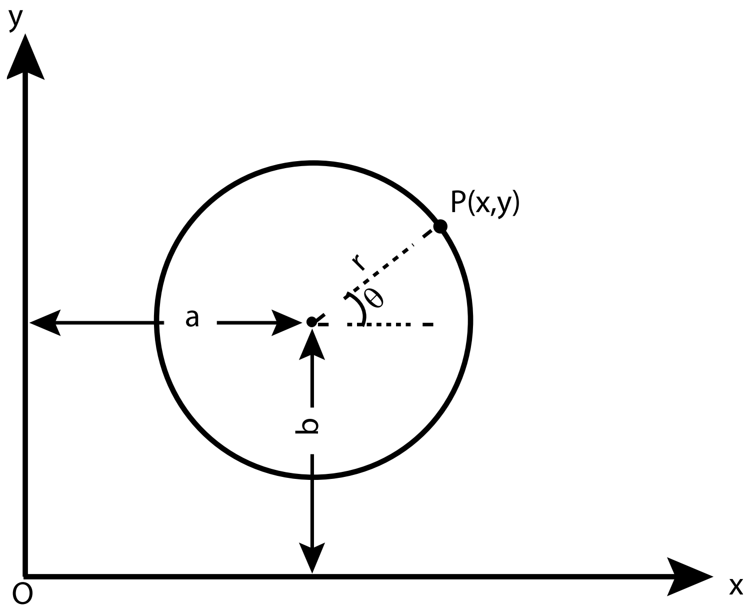


Fig. 59 Transformation of equations.

Transformation of Equations.

The most widely used method of representing curves is with (x, y) coordinates called the Cartesian Coordinates, after Descartes. However, in certain situations, this may not be the most convenient system. For example, a circle is represented in Cartesian coordinates as,

$$(x-a)^2 + (y-b)^2 = r^2.$$

The method of Polar coordinates (r, θ) is also used to represent a circle as shown in Fig. 59. Here *r* is the radius of the circle and θ is the angle that a point subtends at the centre.

Isaac Newton invented a formula to convert any information in one set of coordinates to that in the other set of coordinates. In the above example the relationship is represented as,

$$r = \sqrt{(x-a)^2 + (y-b)^2}; \quad \theta = tan^{-1}\left(\frac{y-b}{x-a}\right)$$

Calculus

Today most students at university would have studied some calculus. It is not an exaggeration to say that most of the calculations in science and engineering are not possible without calculus. Differential and integral calculus are the two main divisions in it.

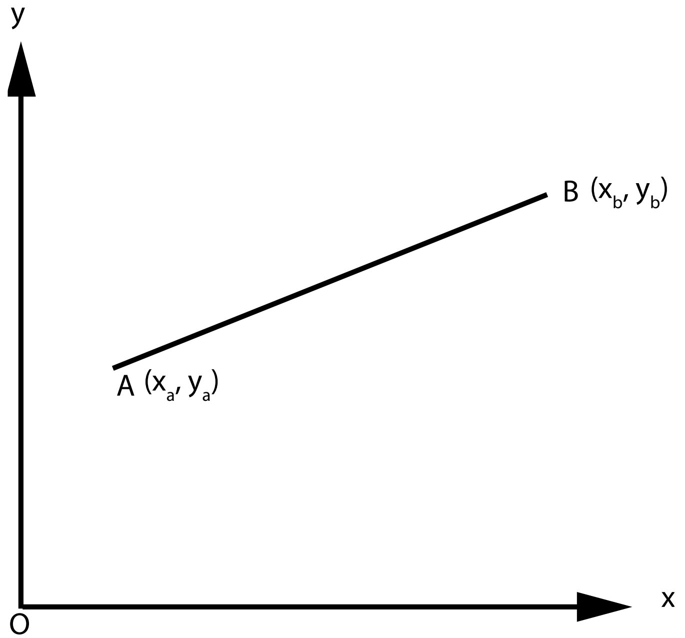


Fig. 60 Finding the slope of a curve 1.

Differential Calculus

How do we calculate the slope of a curve? The slope of a straight line, a particular case of a curve, as the one in Fig. 60 can be calculated accurately with the formula,

$$Slope = \frac{y_b - y_a}{x_b - x_a}$$

Can we apply the same rule to calculate the slope of a general curve instead? Consider the curve shown in Fig. 61. How do we find the slope of this curve at any point, for instance, *C*? Imagine that this curve traces the path of a particle in time. In other words, x-axis is the time taken and y-axis is the distance travelled. How do we find the speed of a particle at any given point in time?

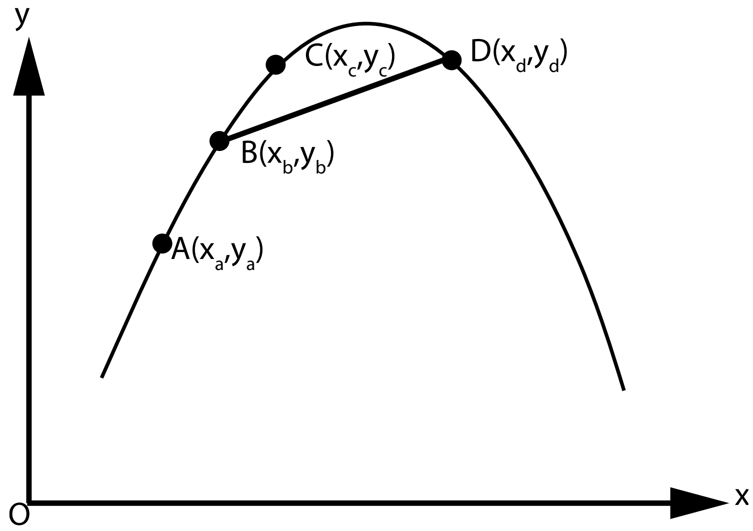


Fig. 61 Finding the slope of a curve 2.

One intuitive idea is to consider distance travelled in a specified time and to divide one by the other. Accordingly, to calculate the slope at point *C* the formula would be,

$$Slope_C = \frac{y_d - y_b}{x_d - x_b}$$

However, we soon realize that this formula helps calculate the slope of line BD and not of the curve.

Newton solved the problem by taking a large number of points on the curve so that the distance between the points on the curve becomes vanishingly small as shown in Fig. 62. Now that above equation determines the slope of the curve at *C* more accurately as the points B and D are very close to it. To be exact, mathematicians, easily realise there should be infinite number of divisions. Newton gave an expression to find the slope.

If the curve is defined by a function,

$y = f(x)$,

then, the gradient $f' = \frac{dy}{dx}$, and this is called the *Differential Coefficient* and is the slope of the curve at any given point (x, y). The process of obtaining it is called *Differentiation*.

If $f = x^2$ then $f' = 2x$, if $f = x^3$ then $f' = 3x^2$, if $f = x^n$, then $f' = nx^{n-1}$

For complicated expressions such as $f = x^3 + 3sinx$, $f' = 3x^2 + 3cosx$

Thus one can find f' for any function.

We can also have $f'' = \frac{d^2y}{dx^2}$, and $f''' = \frac{d^3y}{dx^3}$ and other subsequent derivatives depending upon the function, f.

Applying the theory to mechanics, if f is an expression for the distance travelled by a particle for different times, then f' is its velocity and f'' is its acceleration.

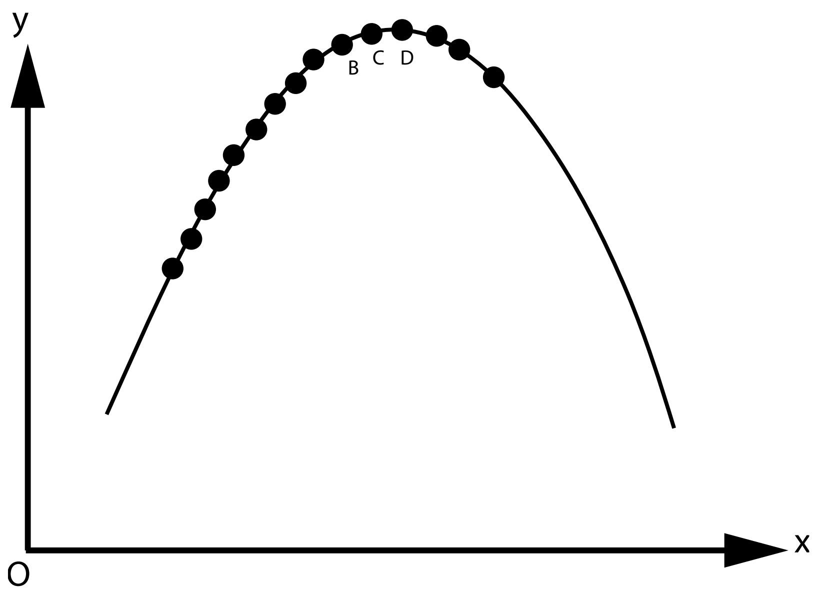


Fig. 62 Finding slope of a curve 3.

This is a very simple explanation of Differential Calculus. Complexities occur in practical applications. We also have ordinary differential equations and partial differential equations.

Integral Calculus

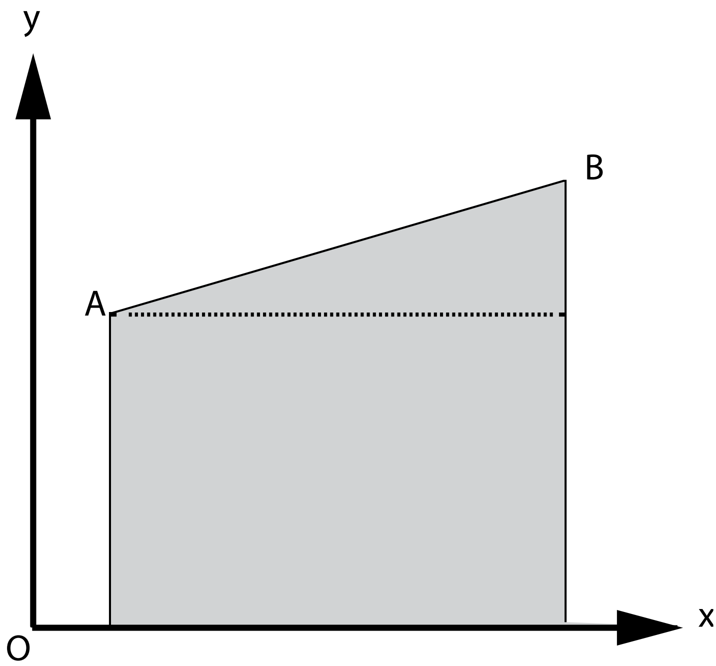


Fig. 63 Finding the area under a straight line.

Integral Calculus denotes the reverse of differentiation and helps find the area under a curve. Again, consider a straight line AB as shown in Fig. 63. The area under the curve, which is shaded in the picture, is calculated as the sum of the areas of a rectangle and a triangle.

How do we find the area if we had a curve instead of a straight line (Fig. 64)? Newton's method was to divide the area to be calculated into a number of rectangles. The sum of the areas of these rectangles will give an approximate value of the area under the curve. Note that the width of each of the rectangles is Dx. Obviously, if this is kept small, we calculate a better value for the answer. The difference between the correct area and the area we calculate is the sum of unshaded areas in Fig 64. As Dx becomes smaller and smaller the unshaded areas also become smaller and smaller.

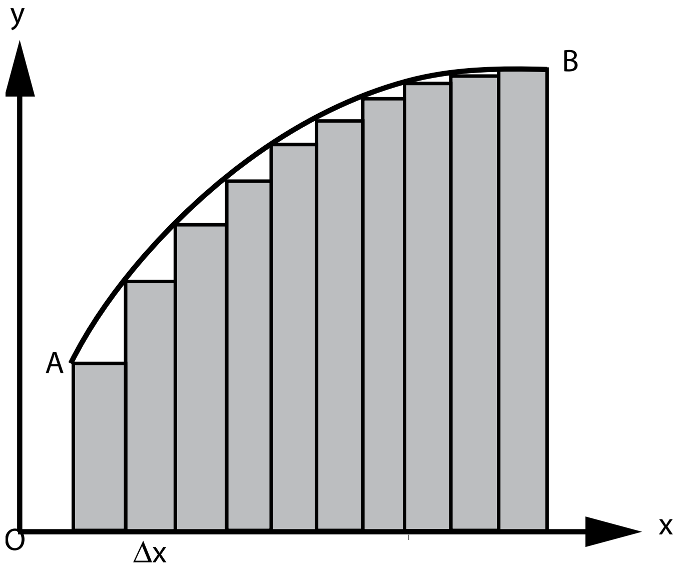


Fig. 64 Area under a curve.

In fact, such a procedure can be carried out even when we do not have an equation for the curve AB. There are many approximations to calculate the area under the curve. Numerous functions are available to perform this operation using a computer.

If we have an expression for the curve AB, the procedure simplifies and we do not need a computer. We perform an operation, which is the opposite of differentiation, well known as *integration*.

Suppose the equation to the curve AB is given by

$$f = x^2$$

Integrating this expression, we have $\int f(x)\,dx = \int x^2\,dx = x^3/3 + C$, where C is the constant of integration.

Area under the curve AB will be $\int_A^b x^2 = \left.\frac{x^3}{3}\right]_A^B = \frac{(x_B^3 - x_A^3)}{3}$

For a general $f = x^n$, $\int x^n\,dx = x^{n+1}/(n+1) + C$

If the curve represents the velocity of a particle at different times, it may be verified that the area under the curve is the distance travelled by the particle from time at A to time at B.

What we have considered are the simplest examples of differentiation and integration. These become very complex in real life problems encountered in science and engineering. Closed form solutions as the ones we have indicated may not be viable in many situations. Resorting to numerical techniques becomes essential. Computers become handy. Example can be given of calculating the air pressures and speeds around a flying aircraft, forces on a sailing ship, temperatures and pressures in automobile and aircraft engines, flow of air within a large building, blood flow in human arteries and veins and many others. These involve solving what are called Partial Differential Equations and will require enormous computing resources and money.

Finding roots of an equation

Newton devised a method to find the roots of an equation. Known as Newton's method it is prevalent even today and has many variations. It is essentially an iterative method and can be illustrated as follows. Consider AB, which is given by a certain equation as shown in Fig. 65. The curve intersects the X–axis at *C*. Hence, C represents the root of the equation. When the equation is simple, there are methods to solve them and obtain the root. But if the equation is complex there may not be a straight forward procedure. Newton's method comes to our rescue.

The method starts with an initial guess. In our case it is $x = P_1$. Obviously, this is not a good solution. Draw a tangent to the curve at P_1. This intersects the x-axis at Q_1. Draw a vertical here, which hits the curve at P_2. Again, draw a tangent, which hits the x-axis at Q_2. We observe that we are already close to the solution. Repeat the process. We will land very close to *C*.

This is a simple description of Newton's procedure to find the roots. In an algorithmic format, it can be represented as,

$$x_{n+1} = x_n - \frac{f(n)}{f'(n)}$$

Where *n* is the present approximation to the root, *f(n)* is the present value of the function and *f'(n)* is the value of the gradient at the present approximation, *n+1* is the improved value of the root or a better approximation. The procedure has to be continued till $(x_{n+1} - x_n)$ is below a prescribed tolerance.

There are many algorithms in literature to carry on Newton's iteration to find the roots. The method is used even while solving partial differential equations in Fluid Mechanics as well as Solid Mechanics.

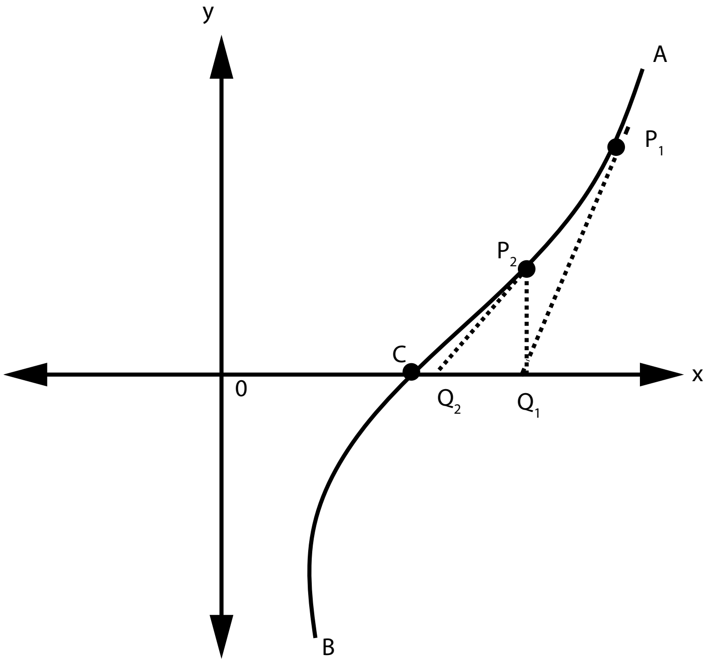


Fig. 65 Finding the roots of an equation

Binomial Theorem

Binomial expansion was known to scientists and mathematicians for a long time. There are references to it in Chinese, Islamic and Hindu scriptures. Even the poet Omar Khayyam is credited with knowing about it. What Newton gave was an expansion of $(a+b)^n$ where n can be positive, negative or a fraction. It reads,

$$(a+b)^n = a^n + na^{n-1}b + \frac{n(n-1)a^{n-2}b^2}{2!} + \frac{n(n-1)(n-2)a^{n-3}b^3}{3!} + \cdots + b^n$$

This is called the Generalised Binomial Theorem. Its applications are many.

3. Other Contributions

Newton's Law of Cooling

This is a very important aspect of Heat Transfer and has relevance to cooling and heating. Newton showed that the rate of change of temperature of an object is proportional to the difference of temperatures between the object and the ambient. If T is the temperature of the object and Ta, the ambient temperature then,

$$\frac{dT}{dt} = -k(T - T_a),$$

where k is a constant.

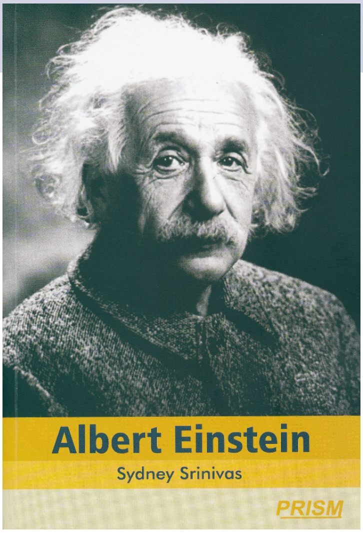
Speed of Sound

In *Principia*, Newton gave a formula for the speed of sound as,

$$c = \sqrt{\frac{E}{\rho}}$$

where E is the Modulus of Elasticity and ρ is the density of the medium.

By suitable substitution for the terms the above formula reduces to $c = \sqrt{\frac{p}{\rho}}$ where p is the pressure of the medium. This is the form that is used in most applications. In aerodynamic and gas dynamic applications one can see that it takes the familiar form, $c = \sqrt{\gamma RT}$ where γ is the ratio of specific heats (=1.4 for air), R is the gas constant; T is the temperature in ^{0}K.



Albert Einstein

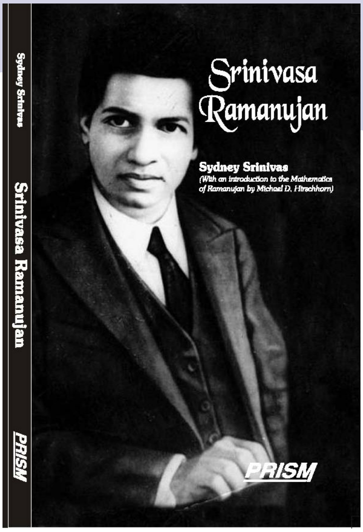
Albert Einstein by Sydney Srinivas is a comprehensive account of the life and times of Einstein, perhaps the greatest intellectual of all times. The book traces the various influences through childhood and adulthood that shaped his scientific temper and culminated in his Theories of Relativity.

Rather than being just a chronological compilation of the highlights of Einstein's life, the biography lucidly interweaves the socio-cultural and political ethos of the times. Evoking such a context becomes important in assessing the greatness of Einstein as a path finding physicist and more importantly as a human being with a strong moral fibre who stood for justice at all times. Nevertheless, the author doesn't resile from touching upon the frailties and weaknesses of Einstein.

The book delineates Einstein's all consuming passion for physics, which did take a toll on his family life. The transition from scientist to social and political activist comes alive in the book.

The inclusion of several interesting anecdotes from his life add colour to the narrative.

The various theories proposed by Einstein are included in Part 2 of the book. The complex theories are explained in simple style, devoid of complex jargon, making the book an ideal read for students and laymen alike.



Srinivasa Ramanujan

By Sydney Srinivas, (with an introduction to the Mathematics of Ramanujan by Michael D Hirschhorn), published by Prism Books Private Limited, 2012, 13, 15.

Srinivasa Ramanujan was a world-class mathematician from India. Born in 1887, in the state of Tamilnadu, India, Ramanujan proved to be a prodigy when still at high school. His extraordinary mathematical powers came to light during his college days. His undivided attention to mathematical study took its toll; he failed his exams and had to give up formal studies. However, he continued to tackle complex mathematical problems in the humble environs of his home. Endowed with extraordinary mathematical insight, he was able to propose, without proof, more than 3000 theorems; highly qualified mathematicians are still trying to prove them.

Encouraged by his mentors, Ramanujan sent some of his findings to Prof. Hardy of Cambridge University, who at once invited him to be his colleague. They worked together for five years and contributed significantly to *Partitions, Continued Fractions* and other branches of mathematics. Ramanujan was elected a Fellow of the Royal Society and Fellow of Trinity College. However, he was forced to return to India due to ill health. He died when he was only 32.

In this book, Sydney Srinivas gives an impressive and lucid account of Ramanujan's life. Apart from many visuals and photographs, it contains numerous anecdotes from a life that oscillated between agony and ecstasy. The author traces Ramanujan's childhood, through his student days and as a clerk at the Madras port and his struggles in England. The great influence of his mother Komalathammal in his life is clearly evoked.

A special feature of the book is the short introduction by Dr Hrischhorn, an eminent Ramanujan scholar, to Taxicab Numbers, Partition Numbers and Continued Fraction, some of the complex mathematical problems that Ramanujan tackled.

SELECTED COMMENTS ON THE BOOK

I saw the movie THE MAN WHO KNEW INFINITY. Then I re-read your book. The English film-makers sugar-coated it somewhat. I learnt a lot more about Ramanujan from your short biography of him. What a sad story and what an amazing genius. Thanks for writing it. Tom Cowan, Cinema Director and Producer and the photographer for the Kannada movie-*Samskara*.

Thanks for your lovely slim volume on the great mathematician, Ramanujan. I have dipped into it, and it looks wonderful. Karl S. Kruszelnicki, Science presenter and writer.

I found your book very interesting indeed – I enjoyed it and I learned a lot. I learned much about Ramanujan, and his times. It made the film about Ramanujan much more real. I also enjoyed reading Michael Hirschhorn's appendix which made the possible derivation of some of Ramanujan's formulae come alive. Thank you for sharing your work with me. I very much appreciate it. Cheryl Praeger, Professor of Mathematics, University of Western Australia.

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6	13	"Wind Mill near Grantham" by Anonymous - Wikipedia.
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