The Warden of Time and Space

Sir Isaac Newton: genius, heretic, and SOB.

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Nature and Nature's laws lay hid in night.
God said "Let Newton Be" and all was light. —*Alexander Pope*

In 1685 James II was proclaimed King of England. An aggressive Catholic, he immediately began to consolidate his power and "catholicize" some of England's thoroughly Protestant institutions, including the universities. In 1688 his second wife—who, unlike his first, was also Catholic— gave birth to a son. Chafing under Catholic rule and horrified at the thought of a succession of Catholic kings, the historically antagonistic Whigs and Tories briefly set aside their differences and conspired to get this untoward papist off their throne. A "bipartisan" committee invited King James' son-in-law, a Dutch prince who spoke no English, to "invade" and depose his uncle. His qualifications to occupy the throne of England? He was Protestant.

The manufactured "invasion" turned out to be both bloodless and "glorious." England was now free to return her full attention to the ongoing war with France—a costly project that began to drain the Royal Treasury. England's coffers gradually became depleted, and by 1696 the strain had begun to show. But there was another financial crisis looming, potentially even more dangerous. England's financial foundations were being nibbled away from within by economic termites, destabilizing the currency through counterfeiting and coin clipping.

Counterfeiting was relatively easy in those days. The techniques for producing coins in England had hardly changed since the Middle Ages, and quality control was so bad that coins could vary in weight substantially. The simple images that were stamped on the coins were crude and easy to copy onto counterfeit coins made of different or diluted raw materials, while the lack of rolled edges—standard for modern coins—facilitated the age-old crime of clipping: the practice of cutting slivers off the edges of the coins to be melted down and sold, leaving the central part of the coin sufficiently intact to serve, albeit suspiciously, as currency.

Hence, at a time when the economic demands of the war demanded a robust economy, the deteriorating quality of its coins was destroying England's faith in its currency. Workers, whose weekly pay was a bag of coins largely counterfeit or clipped beyond recognition, were rioting; shopkeepers were inflating their prices to compensate for the counterfeit coins they anticipated receiving for their goods. Bartering, basically gone since the Middle Ages, had returned. A financial collapse would undo the accomplishments of the Glorious Revolution and, God forbid, the Stuarts might recover the throne. Something had to be done.

The solution proposed by England's chancellor, Charles Montagu, was recoinage: the process of reminting existing coins, most of which dated from Elizabethan times and some from 150 years earlier, during the time of Edward VI. The crown would recall the coins currently in circulation and exchange them—the legitimate ones—for a new currency. It was a bold solution to a massive problem.

To administer the recoinage project, Montagu appointed a personal friend as warden of the royal mint, a position recently vacated by the promotion of the previous occupant. Montagu promised that the job would pay "five or six hundred pounds per annum" and would not "require more attendance than you can spare." The position was offered as a political plum—good salary, little work. Recoinage, once initiated, should proceed more or less automatically, or so Montagu imagined.

The new warden, however, was not in search of a sinecure. He liked challenging problems and immediately attacked his new job with an extraordinary vigor. He streamlined the physical production of the coins, saving large quantities of both time and money. He calculated that suppliers had been overcharging for unprocessed ore and brought those expenses into line. He fired lazy workers and made the others work hard. He worked 16 hours a day himself as he transformed the London mint into a model of productivity. The presses, powered by scores of horses and three hundred men, ran in two shifts, from 4 a.m. to midnight, six days a week. In June of 1697 alone, for example, the mint turned out over 360,000 pounds. The shiny new coins flowed like a blood transfusion into the dying economy, and England began to recover.

By 1698 the recoinage efforts began to relax, freeing the warden to go after the source of the problem—the counterfeiters and coin clippers. Not content to let conventional authorities use conventional techniques to bring these unconventional criminals to justice, he traded his genteel robes for underworld garb and moved into the shadowy back streets of London. He hung out in taverns and brothels like some seventeenth-century Sherlock Holmes, becoming part of the squalid scenery until he could sit across the table from a drunken counterfeiter and hear his confession.

Nor was the warden content simply to ferret out the criminals: he had himself appointed justice of the peace in 19 counties so he could also prosecute those he gathered evidence against. In the two-year period leading up to 1700, he conducted some 200 "cross-examinations" of suspects, informers, and witnesses. In a single week in February of 1699, he conducted seven such investigations and had ten prisoners lined up for hanging. How horrified they must have been when they discovered that the justice of the peace was also the disheveled comrade who had staggered with them into the back alleys to see the counterfeiting machinery!

The warden's most challenging case was a certain charismatic rogue named Chaloner, whose sophisticated manner had enabled him to defraud a great many people and institutions, often through the betrayal of accomplices who trusted him. The warden pursued this infamous counterfeiter for three years, repeatedly capturing him and then watching him slither away as witnesses "disappeared," were strangled, or changed their stories. But Chaloner, despite his cleverness, was no match for the tenacious warden, who eventually collected depositions sufficient to have him convicted of high treason. On March 22, 1699, the now-broken Chaloner, who had begged the warden for mercy, was dragged on a sledge to the gallows, where he was hanged until almost unconscious, at which time, still breathing, he was disemboweled and hacked into quarters before a jeering mob. Counterfeiting was treason, and, perhaps more significant, it upset the warden. The warden always won, despite death threats, despite incompetence in those above him, despite the novelty of the challenges he faced.

But no challenge he faced as a civil servant was as curious as one that arrived on January 29, 1697, when the recoinage was running full steam. A famous Continental mathematician, Johann Bernoulli, had posed an interesting puzzle and sent it to Charles Montagu, the president of Britain's Royal Society, to test the mettle of British mathematicians. Montagu, who had appointed the warden of the mint and knew he liked mathematical puzzles, passed this particular one on to him. The problem was the "brachistochrone" or "least time" problem, and it had proved to be beyond the leading mathematicians on the Continent. The warden took up the challenge.

The brachistochrone is one of those classic mathematical puzzles that become fixtures in the standard curriculum of mathematical physics. Students learn the techniques of what is now called the "calculus of variations" and then apply those techniques to a number of rather interesting problems, such as the shape of the curve of a rope hanging from both ends (like the cable on a suspension bridge), or the brachistochrone. The brachistochrone problem is this: imagine that an unconstrained object, under the influence of gravity, is going to move between two points, not in the same horizontal plane, and not along the same vertical line. Such a trajectory, for example, would connect your nose to a point two feet in front of your waist, assuming you are not lying down. What is the shape of the path that will allow the object to move between those two points in the shortest possible time? (If you guessed a straight line, you are way off!)

The brachistochrone challenge was posed to me and my physics classmates at Eastern Nazarene College in 1977. By then it was a standard homework problem in classical mechanics, a way to verify that we had mastered the material in the chapter on the calculus of variations. In the seventeenth century, however, the brachistochrone was a far more challenging problem because the calculus of variations was virtually unknown.

On that day in January, the warden returned from the mint at 4 p.m., physically exhausted. His niece handed him the problem that Montagu had sent. Despite his fatigue, he set to work immediately on the brachistochrone, and by the time the next day's shift at the Mint began at 4 in the morning he had solved it. He submitted it anonymously to his Continental challengers, who nevertheless identified its origin, tipped off by the elegance of the work. "The lion is known by his paw," said Bernoulli. That lion with the famous paw, the warden of the mint who rescued England's economy, who sent a horde of counterfeiters to the gallows, who bested the colorful Chaloner, who met the brachistochrone challenge, was none other than Isaac Newton.

The Sober, Silent, Thinking Lad

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. —*Isaac Newton*

It is difficult, in our age of manufactured hype, to appreciate Newton's impact on his contemporaries and the scope of his influence over the centuries. In the estimation of many scholars, Newton is nothing less than the greatest scientist known to history.

The circumstances of his birth were not auspicious, though it was on Christmas Day in 1642, the year of Galileo's death, that Isaac Newton was born, prematurely, a sickly baby not expected to live. His father had died three months earlier, and, by the time little Isaac was 3, his mother Hannah had married the Reverend Barnabas Smith, 30 years her senior, a rather uninspired cleric. When Hannah moved in with Barnabas, she effectively orphaned the already fatherless Isaac, who was left in the care of his grandmother and a grandfather who appears to have resented him or at least cared so little that he left the 10-year-old Isaac nothing when he died.

Recent biographers have speculated that some of Newton's bizarre behavior as an adult can be traced to the joint traumas of never having known his father and the early rejection by his mother. He hated his stepfather and resented his mother for abandoning him for this tedious vicar. Isaac later confessed, at least to his notebook, that he had entertained thoughts about burning the house down around his stepfather's (and absentee mother's) ears. Nine years later the stepfather died, and Isaac was reunited, at least physically, with his mother, who returned to the family farm with three of Barnabas's children in tow. Hannah planned for Isaac to take over the family farm, a task for which he seemed hopelessly unqualified.

Anecdotes from this period have Isaac leading an empty bridle into the barn, not noticing that the horse had escaped; or building a kite contraption that lofted candles into the air in the middle of the night and scared the people of the town. Files in the local courthouse indicate multiple fines for Isaac's carelessness in "suffering his sheep to break the stubbs," "suffering his swine to trespass in the corn fields," and "suffering his fence belonging to his yards to be out of repair." Hannah tried to address the situation by assigning a servant to supervise Isaac, but that just gave him a chance to run off and read while the servant did all the work. (Although extremely interested in books—he used to spend the day in a friend's library while a servant assigned to "help" him marketed the farm goods on his own in town—Isaac had little or no early training in mathematics.)

When it finally became clear that he was completely useless on the farm, he was sent back to school in nearby Grantham, and then, with the help of a family connection, on to university. He had by then become so unpopular among the farmhands that they all rejoiced at the departure of the lazy, difficult, and troubled lad, proclaiming that he was suited for nothing "except the 'Versity.'"

Isaac arrived at Cambridge in 1661, a little older than most of the other new undergraduates because of his interrupted schooling. For some reason Hannah Newton would not provide her son with the necessary funds to attend Cambridge as a regular student, although she certainly could have afforded to do so. Perhaps she was irritated that he had failed so miserably at learning how to farm. His mother's stinginess forced Isaac into the role of a "subsizer"—a student who earned his keep by working as a servant for wealthier students, running errands for them and emptying their chamberpots. Isaac thus stood on the bottom rung of the highly stratified world of Cambridge University. But the bottom rung of the ladder at Cambridge was for him a far more congenial place than the top rung at the farm he had left behind.

He began to flourish academically even while he continued to squirm socially. The curriculum at Cambridge in the 1660s was still dominated by traditional Aristotelian teachings, but Isaac kept himself abreast of new ideas, including the revolutionary views of Galileo and Descartes. He made few friends but began to display some mathematical prowess. He graduated without fanfare in 1665, the same year that plague broke out in London and the university was closed.

The 23-year-old Isaac went home, where he stayed for the best part of two remarkable years. In that time he completed work that can modestly be described as changing the world, or at least providing the blueprints for such a change. During those two years he derived the inverse square law of gravity, a task that required mathematical techniques beyond all but a handful of Europe's leading mathematicians. This was but a minor delay for Isaac, as he quickly mastered the mathematical status quo and began extending it into new territories. In his spare time he investigated the nature of light, discovering and naming the spectrum, the rainbow pattern of colors produced when white light passes through a prism. None of this, of course, made any impact on the scientific world at the time, because Isaac didn't tell anybody what he was up to. Papers with solutions to the hardest scientific problems anyone had yet addressed successfully lay in disarray in his boyhood bedroom at Woolsthorpe.

Newton's extraordinary powers of concentration and fanatical devotion to his search for knowledge became apparent during this period. What had seemed to the illiterate farmhands merely a peculiar form of laziness was shown during those two plague years to have been the chrysalis of genius. Staying up for days at a time concentrating on a problem, he would have to ask an astonished servant what day it was, or how long since he had eaten. His passion for experiment grew so strong that it threatened to engulf him.

Once, as part of an optics experiment, he stared directly at the sun for so long that he went temporarily blind and had to shut himself up in a dark room for three days until his sight returned. He stuck a metal rod behind his eyeball and pressed to see what would happen to his vision when he changed the shape of his eyeball. He mixed all manner of toxic chemicals and then tested them in a variety of ways that included drinking them. Such was the genius of the young Isaac Newton, as he bided his time at the family farm, oblivious to the fact that it was a farm, waiting for the plague to abate so he could resume his studies at Cambridge.

Professor, Inventor, Heretic

There goes the man that writt a book that neither he nor any body else understands. *—A Cambridge student, pointing at Newton strolling across the campus*

Cambridge University reopened in 1667, and Newton was elected to a fellowship at Trinity College. By 1669 he had begun to impress some of the leading mathematicians at Cambridge, most notably Isaac Barrow, who held the Lucasian Chair of Mathematics (which, incidentally, is now held by Stephen Hawking). Barrow resigned in 1669 and recommended Newton as his successor. And so it was that at age 26 Isaac Newton became Lucasian Professor of Mathematics at Cambridge University, where, just a few years earlier, he had been emptying the stinking chamberpots of rich students who had paraded their fancy accents and sneered at him.

The chair gave him a secure position for life (if he so chose) with no responsibilities beyond a single course of lectures each year. Fortunately, it was required only that Newton deliver these lectures, not that anyone attend them. His lecture style was so opaque that he often spoke to an empty hall! Nevertheless, the poorly attended lecture series provided him with the framework to organize his thoughts on a variety of subjects, from optics to mechanics to alchemy.

By 1672, largely through work done for his imaginary lecture audience, Newton had finished the first part of what was to become his epic treatise *Opticks*, which he did not publish until 1704, because of a ridiculous dispute with Robert Hooke (1635-1703). In fact, Newton cared so little for publishing—he despised the inevitable subsequent controversies—that he often left important work on his desk for years, the results known only to him.

Hooke was the president of the Royal Society. Widely regarded as one of England's greatest experts on optics, particularly by himself, he had dared to criticize Newton's work when it was first presented to the Royal society. Unable to tolerate even mild criticism from knowledgeable colleagues, Newton went sulking back to Cambridge and hid his work away. Newton's famous remark, "If I have seen further than other men, it is because I have stood upon the shoulders of giants," comes from an ambiguous and possibly sarcastic letter that he wrote to Hooke during this dispute.

References to the "giants" of the past were common in Newton's day, and many people have magnanimously assumed that Newton was referring to Galileo, Kepler, Descartes, and other close predecessors, since his work in mechanics clearly built upon theirs. But in common usage the "giants" were generally the ancients, especially the Greeks, who were thought by many, including Newton, to have figured it all out 2,000 years earlier.

In any event, in a 1675 letter to Hooke, who is known to have been very short, even dwarfish, Newton says that he has been standing on the "shoulders of giants." It is entirely possible that Hooke would have interpreted this as an insult, and not at all as an affirmation of the importance of his, and others', work to Newton. That Newton would pay the despised Hooke such a compliment strikes me as highly unlikely, although Newton scholars are divided on this point.

Hooke's reckless and promiscuous life ended in 1703; he died blind, destitute, and alone. Newton published the *Opticks* the following year. Alongside the *Opticks*, which was lying around waiting for Hooke to die, was Newton's magnum opus, the *Principia Mathematica*, arguably the most important science book ever published (with the possible exception of Darwin's *Origin of*

Species) and a work that continues to command attention. (We'll return to it in the next installment in this series.) And the Principia might have lain dormant on Newton's desk for who knows how long if it were not for the insistence of Newton's friend Edmund Halley, of comet fame, that it be published. As it was, the *Principia* appeared in 1687, two decades after much of it had been written.

The Cambridge phase of Newton's life saw his ascendancy to the pinnacle of European science and mathematics. The production of the *Principia*, the *Optiks*, or the invention of the calculus—any one of these three achievements would have been more than adequate to place his star securely in the firmament of greatness. The ideas expounded for the first time in all three of these areas—ideas original with Newton and not based heavily on prior work—are still a part of the standard undergraduate curriculum in physics. Each fall I teach Newton's Laws to a new generation of physics students.

But Newton did much more. By the time he began his research into optics, the basic two-lens telescope that had been developed by Galileo and others had matured considerably. No longer a simple "optical tube" that could be carried to parties as a conversation piece, telescopes had become serious technology and were reaching up to 200 feet in length. While this great enlargement multiplied their magnifying powers, telescopes continued to be plagued by various optical defects such as spurious rainbow rings that limited their effectiveness.

Newton tried to limit such defects by grinding some nonspherical lenses, but he eventually realized that any telescope based on lenses would have this problem, an inevitable byproduct of refraction known as chromatic aberration. So he invented a novel new telescope based on mirrors. This design, known today as the Newtonian reflector, allowed a squat six-inch telescope to magnify more than a traditional telescope six feet long. Isaac Barrow delivered Newton's new telescope to the Royal Society for examination at the end of 1671. It created a great stir. (Newton's telescope is on display in the bedroom of his childhood home in Woolsthorpe, which I visited in the summer of 1999.)

It is surprising in some ways that it was the telescope that did the most to introduce Newton to seventeenth-century Europe. The secrecy with which he worked on his more theoretical studies was strangely missing from his work on the telescope, which he was only too happy to circulate, and he clearly relished the recognition that came to him as its inventor. No doubt the concrete reality of the telescope made it a less ambiguous achievement than his more theoretical studies, which tended to draw him into controversies with lesser thinkers who did not always understand his work.

Shortly after Newton's ascendancy as the inventor of both a remarkable telescope to collect light, and an even more remarkable theory to explain light, he embarked upon a most curious voyage of theological inquiry. The motivation for this new course of study remains hidden. Richard Westfall, Newton's preeminent biographer, speculates that his theological trajectory may have been motivated by his impending need to be ordained in the Church of England if he were to continue as the holder of the Lucasian Chair of Mathematics. On three separate occasions he had earlier sworn an allegiance to the doctrines of the church, apparently without difficulty, but perhaps also without due consideration. The impending ordination was no doubt something that should be given a bit more thought. But Newton never gave anything, excepting his food and sleep, an amount of thought that could be described as a "bit." And so it was that he found himself, sails unfurled, on yet another voyage of discovery.

Newton wrote over a million words on theology and biblical studies, more than he wrote on any other subject. This oft-quoted statistic is sometimes used to argue that Newton was more interested in theology than in science and mathematics. Framed in this way, however, the comparison is simply misleading, as anyone familiar with both the mathematical sciences and theology can attest. Theology texts are often rather ponderous affairs, and not infrequently come in multiple volumes. Mathematical texts, by contrast, are generally brief despite the often herculean effort that it takes to make one's way from the preface to somewhere near the end.

Still, Newton's theological investigations were indeed extensive, and they clearly indicate the seriousness with which he took the subject. He was particularly interested in the controversy over Arianism, which had precipitated an intense and even bloody confrontation in the fourth century. The conflict—between Arianism, which denied the full divinity of Christ, and the orthodox Trinitarian understanding—was resolved at the first Council of Nicea.

In the course of his investigations into the controversy, Newton appears to have mastered the writings of the church fathers. His notes contain extensive analyses of the writings of Athanasius (the principal defender of orthodoxy against the Arians), Gregory Nazianzen, Jerome, and Augustine, whom he saw as the principal architects of Trinitarianism. He also studied Irenaeus, Tertullian, Cyprian, Eusebius, Eutychius, Sulpitius Severes, Clement, Origen, Basil, John Chrystostom, Alexander of Alexandria, Epiphanius, Hilary, Theodoret, and a host of others. He became convinced that a massive fraud had perverted the legacy of the early church. The Scriptures had been altered and early Christian writers had been misquoted to make it appear that Trinitarianism had been the original faith. Newton noted, for example, that one of the classic verses to which Athanasius appealed—"For there are three that bear record in heaven. … and these three are one" (1 John 5:7)—was "not read thus in the Syrian Bible."

Newton thus conceived his own version of a heresy that has appeared in many forms in the history of the church—as Socinianism, for example, beginning in Italy early in the sixteenth century, and Unitarianism, which became influential in England (and North America) only after Newton's time, though Unitarian writings were published in England during his lifetime. Convinced that Christ was but a mediator between God and man, Newton came to regard the Roman Catholic Church, which had perpetrated the "fraud" of Trinitarianism, as the great whore of Babylon. And to accept ordination into the Anglican Church, he believed, would be to "worship the Beast and his image and receive his mark in his forehead or in his hand."

Accordingly, he began to make plans to be unemployed, and in January 1675 he wrote to the Royal Society asking for his dues to be suspended, since he anticipated that he would soon be unable to pay them. Trinity College, Cambridge, was no place for a Unitarian. However, Cambridge was nothing if not a place where patronage and friends in high places could pull strings and divert the largest of ecclesiastical streams. Barrow, who had resigned the seat a few years earlier, making room for Newton, managed to get the holder of the Lucasian Chair, whomever it might be, exempted from the requirement of ordination. Newton's heresy, like so much of his tortured genius, remained hidden from the world in which he lived. There is no evidence that anyone had any idea that Trinity College's most famous professor was utterly convinced that the college was named after a heretical perversion of true Christianity. This was a secret that Newton took to his grave, only hints of which he allowed select and like-minded dissidents, such as John Locke, to glimpse.

Indeed, unlike a great many other scientists of this period—Kepler comes immediately to mind—Newton was blessed to see his accomplishments widely recognized and his genius, if not his personality, applauded by leading thinkers both in Britain and on the Continent. The rural boy who was the joke of the family farm in 1660, straining at the ties that bound him to Woolsthorpe, succeeded in breaking those ties so fully that by 1666, despite having to learn almost everything on his own, he had transformed himself into the foremost mathematician in the world and the equal of any natural philosopher. Despite the rather inefficient and haphazard way in which Newton's early accomplishments were disseminated to the literate world, they were of a quality that left no doubt as to their significance. His star and his prospects rose steadily.

Cantankerous Master

Talk of war with a Briton, he'll boldly advance,
That one English soldier will beat ten of France;
Would we alter the boast, from the sword to the pen,
Our odds are still greater, still greater our men;
In the deep mines of science though Frenchman may toil,
Can their strength be compared to Locke, Newton, and Boyle?
—James Boswell

In 1687, Newton addressed Parliament on behalf of Cambridge University, in which capacity he successfully blocked a royal initiative aimed at undermining official university prejudice against Catholics. This role, of course, was extremely ironic. If Newton's private religious beliefs had been known at the time, his colleagues would have been appointing delegates to have him removed! Nevertheless, as a result of his success, Newton was elected as Cambridge's member of Parliament in 1689, holding the seat until Parliament was dissolved in 1690 and returning to hold it again in 1701. He discovered that he enjoyed politics and the circles in which politicians moved. In the meantime he was promoted from warden to master of the mint, a position he retained until his death.

Despite Newton's success in public life, on top of the acclaim he received for his scientific and mathematical work, there is ample evidence, as recent biographers have pointed out, that the painful wounds inflicted on him in childhood never healed. This third phase of Newton's career, which should have been a time of great satisfaction, was instead marked by continual conflict. Newton's childhood insecurities had not been extinguished, or even mitigated, by his ascent to the intellectual and political stratosphere.

In 1703 Newton became president of the Royal Society, the position formerly occupied by his enemy Robert Hooke, who died in that same year. The departure of Hooke, as we have seen, motivated Newton to publish his Opticks, which created an even bigger splash than had the publication of the *Principia* in 1687. But this triumph was soon clouded by one of the most bitter of the many disputes in which Newton became embroiled.

The *Opticks* was reviewed (anonymously) by the great German philosopher and mathematician, Gottfried Wilhelm von Leibniz, one year after its publication. The review claimed that the calculus had originally been invented by Leibniz and that Newton's version of the calculus, which he called "fluxions," was derivative. This claim, which subsequent historical scholarship has completely dismantled, enraged Newton, who responded in kind, charging Leibniz with plagiarism. A priority dispute erupted, which lasted until after Leibniz died in 1716. The Royal Society conducted an official investigation under Newton's direction, concluding—big surprise!—that Newton had been the original inventor of the calculus. (Historians now agree that Newton and

Leibniz discovered the calculus independently, which is not surprising, since some of the classic mathematical challenges of their age were pointing in that direction.)

The calculus dispute soured British mathematicians on Leibniz's contributions to such a degree that a century would pass before they realized that Leibniz's version of calculus was superior to Newton's. In the meantime continental mathematicians were racing ahead, refining and extending Newton's original work. Modern advanced textbooks on Classical Dynamics, the field that Newton founded with the publication of the *Principia*, are filled with names like Laplace, Lagrange, Bernoulli, Maupertuis, l'Hopital, Euler—all mathematicians who learned calculus from Leibniz rather than Newton, and none of them Brits.

Newton was knighted by Queen Anne in 1705, but in the same year he was drawn into another contentious dispute with John Flamsteed, the Royal Astronomer, with whom he had tangled ten years earlier. Flamsteed was England's leading observational astronomer and had been, for decades, an important source of the precise observations that Newton and others had been using to check their theories of celestial mechanics. As early as 1681 they had been corresponding about the comet, an important exploration that contributed to Newton's central idea that motions in the solar system took place about the sun.

Despite the importance of Flamsteed's observations, Newton made scant mention of them in the *Principia*. When Newton was refining his idea that the moon was held in its orbit by the same Earth-originated force that pulled apples from trees, he checked his predictions against Flamsteed's precise, state-of-the-art measurements of the position of the moon. As the centerpiece of the second edition of the Principia, published near the end of the century, Newton was attempting to solve a subtle problem in the orbit of the moon caused by the fact that the moon is subject to both the gravitational attraction of the sun and the Earth. This is the critically important three-body problem, which is now known to be insoluble. In any event, Newton needed some exceptionally accurate measurements of the motion of the moon and he began what Flamsteed thought was to be a collaboration—the kind of observationalist/theorist relationship that has synergized a great many scientific investigations from Brahe/Kepler to Rutherford/Bohr. But Newton could no more collaborate that he could tend sheep.

The dispute between Newton and Flamsteed became mired in extraordinary pettiness, especially on Newton's part. Arrogant, hypersensitive to imagined slights, willing to suppress or distort evidence when it suited him, he seemed incapable of rising above conflict. Things came to such a pass that Newton and Flamsteed had a showdown at the Royal Society, where they yelled and called each other names.

At one point Flamsteed launched legal proceedings against Newton to secure the return of some of his books that Newton had borrowed six years earlier. When Flamsteed failed to pay his membership dues at the Royal Society, Newton immediately had his name erased from the list of fellows. (Recall that some years earlier, when Newton's heresy seemed vulnerable to exposure and he anticipated losing his job he had requested that his dues be waived. As president of the Royal Society, Newton had no such grace to extend to Flamsteed, despite his preeminence in the society.)

Against Flamsteed's wishes, an unauthorized version of his observational work had appeared under Halley's guidance in 1712. The data in this book reappeared the following year in the second edition of the *Principia*, where they were used to demonstrate successfully Newton's lunar theory. References to the astronomer who had taken the data were conspicuously missing.

Flamsteed's political stock rose a bit after Newton's primary political contact died, when Flamsteed became friends with the lord chamberlain, the Duke of Bolton. The chamberlain gave Flamsteed permission to collect the extant copies of the unauthorized tables. He rounded up all 300 copies, which he took to the Royal Observatory and "sacrificed." Flamsteed's work did finally appear in the form that he intended, but a preface he had written, highly critical of Newton, was, at the insistence of Newton—who still presided over the Royal Society—suppressed.

Newton did not enjoy a serene old age. Apart from the vexations of endless disputes, he had suffered for some time from kidney stones, urinary incontinence, and gout. Death came sometime between 1 and 2 A.M. on March 20, 1727. Less that three weeks earlier he had attended his last meeting of the Royal Society. A week later he was laid to rest in Westminster Abbey, where his remains reside today.