The History of SCIENCE

THE BIRTH OF SCIENCE

Ancient Times to 1699

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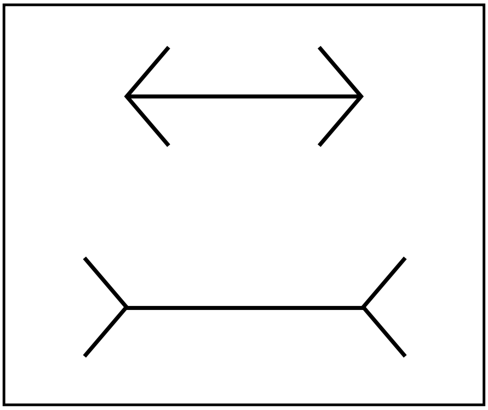
PREFACE

> *What I see in Nature is a magnificent structure that we can comprehend only very imperfectly, and that must fill a thinking person with a feeling of "humility."*
>
> —Albert Einstein

SCIENCE, OF ALL HUMAN ENDEAVORS, is one of the greatest adventures: Its job is to explore that "magnificent structure" we call nature and its awesome unknown regions. It probes the great mysteries of the universe such as black holes, star nurseries, and quasars, as well as the perplexities of miniscule subatomic particles, such as quarks and antiquarks. Science seeks to understand the secrets of the human body and the redwood tree and the retrovirus. The realms of its inquiry embrace the entire universe and everything in it, from the smallest speck of dust on a tiny asteroid to the fleck of color in a girl's eye, and from the vast structure of a far-off galaxy millions of light years away to the complex dynamics that keep the rings of Saturn suspended in space.

Some people tend to think that science is a musty, dusty set of facts and statistics to be memorized and soon forgotten. Others contend that science is the antithesis of poetry, magic, and all things human. Both groups have it wrong—nothing could be more growth-oriented or more filled with wonder or more human. Science is constantly evolving, undergoing revolutions, always producing "new words set to the old music," and constantly refocusing what has gone before into fresh, new understanding.

Asking questions and trying to understand how things work are among the most fundamental of human characteristics, and the history of science is the story of how a varied array of individuals,



Looks can be deceiving. These two lines are the same length.

teams, and groups have gone about finding answers to some of the most fundamental questions. When, for example, did people begin wondering what Earth is made of and what its shape might be? How could they find answers? What methods did they devise for coming to conclusions and how good were those methods? At what point did their inquiries become *scientific*—and what does that mean?

Science is so much more than the strange test tubes and odd apparatus we see in movies. It goes far beyond frog dissections or the names of plant species that we learn in biology classes. Science is actually a way of thinking, a vital, ever-growing way of looking at the world. It is a way of discovering how the world works—a very particular way that uses a set of rules devised by scientists to help them also discover their own mistakes because it is so easy to misconstrue what one sees or hears or perceives in other ways.

If you find that hard to believe, look at the two horizontal lines in the figure above. One looks like a two-way arrow; the other has inverted arrowheads. Which one do you think is longer (not including the "arrowheads")? Now measure them both. Right, they are exactly the same length. Because it is so easy to go wrong in making observations and drawing conclusions, people developed a system, a "scientific method," for asking "How can I be sure?" If you actually took the time to measure the two lines in our example, instead of just taking our word that both lines are the same length, then you were thinking like a scientist. You were testing your own observation. You were testing the information that both lines "are exactly the same length." And you were employing one of the strongest tools of science to perform your test: You were quantifying, or measuring, the lines.

More than 2,300 years ago, Aristotle, a Greek philosopher, told the world that when two objects of different weights were dropped from a height, the heaviest would hit the ground first. It was a commonsense argument. After all, anyone who wanted to try a test could make an "observation" and see that if you dropped a leaf and a stone together that the stone would land first. Try it yourself with a sheet of notebook paper and a paperweight in your living room. (There is something wrong with this test. Do you know what it is?) However, not many Greek thinkers tried any sort of test. Why bother when the answer was already known? And, since they were philosophers who believed in the power of the human mind to simply "reason" such things out without having to resort to "tests," they considered observation and experiments intellectually and socially beneath them.

Centuries later, though, Galileo Galilei came along, a brilliant Italian pioneer in physics and telescopic astronomy. Galileo liked to figure things out for himself, and he did run some tests, even though he had to work around some limitations. Like today's scientists, Galileo was never content just to watch. He used two balls of different weights, a time-keeping device, and an inclined plane, or ramp. Accurate clocks and watches were not yet invented, but he worked around that problem by rigging his own device. One at a time, he allowed the balls to roll down the ramp and carefully *measured* the time they took to reach the end of the ramp. He did this not once but many times, inclining planes at many different angles. His results, which still offend the common sense of many people today, indicated that, in Aristotle's example, after adjusting for differences in air resistance, all objects released at the same time from the same height would hit the ground at the same time. In a perfect vacuum (which scientists could not create in Galileo's time), all objects would fall at the same rate! You can run a rough test yourself (although it is by no means a really accurate experiment) by crumpling notebook paper into a ball and then dropping it at the same time as the paperweight.

"Wait!" you might justifiably say. Just a minute ago, you dropped a piece of paper and a paperweight and so demonstrated Aristotle's premise when the two objects hit the ground at different times. Now when we do the same thing over again, the two objects hit the ground at about the same time and we demonstrate that Galileo was right and Aristotle was wrong. What makes the difference? You have it: The second time, you crumpled the paper so that it had the same shape as the paperweight. Without crumpling the paper, you would have to make an adjustment for the increased air resistance of an 8½-by-11-inch sheet of paper as opposed to a paperweight that had less surface area.

Galileo's experiments (which he carefully recorded step by step) and his conclusions based on these experiments demonstrate an important attribute of science. Anyone who wanted to could duplicate the experiments and either verify his results or, by showing flaws or errors in the experiments, prove him partially or wholly incorrect. Since his time, many, many scientists have repeated his experiment and, even though they tried, no one ever proved Galileo wrong. There is more. Years later, when it was possible to create a vacuum (even though his experiments had been accurate enough to win everybody over long before that), his prediction proved true. Without any air resistance at all and even with much more sophisticated timing devices, his experiment came out as predicted.

Galileo had not only shown that Aristotle had been wrong. He demonstrated how, by observation, experiment, and quantification, Aristotle, if he had so wished, might have proved himself wrong—and thus changed his own opinion! Above all else the scientific way of thinking is a way to keep yourself from fooling yourself—or from letting nature (or others) fool you.

Of course, science is much more than observation, experimentation, and presentation of results. No one today can read a newspaper or a magazine without becoming quickly aware of the fact that science is always bubbling with "theories." "Astronomer Finds Evidence That Challenges Einstein's Theory of Relativity," announces a magazine cover. "State Board of Education Condemns Books That Teach Darwin's Theory of Evolution," reads a newspaper headline. What is this thing called a "theory"? The answer lies in a process known as the "scientific method."

Few scientists pretend anymore that they have the completely "detached" and objective scientific method proposed by the philosopher Francis Bacon and others at the dawn of the Scientific Revolution in the 17th century. Bacon's method, in its simplest form, proposed that an investigator trying to find out about nature's secrets had an obligation to think objectively and proceed without preformed opinions, basing conclusions on observation, experiments, and collection of data about the phenomena under inquiry. "I make no hypothesis," Isaac Newton announced after demonstrating the universal law of gravity when it was suggested that he might have an idea *what gravity was*. Historians have noted that Newton apparently did have a couple of ideas, or "hypotheses," as to the possible nature of gravity, but for the most part he kept these conjectures private. As far as Newton was concerned, there had already been enough hypothesizing and too little attention paid to the careful gathering of testable facts and figures.

Today, though, we know that scientists may not always follow along the simple and neat pathways laid out by the trail guide known as the "scientific method." Sometimes, either before or after experiments, a scientist will get an idea or a hunch (that is, a somewhat less than well thought out hypothesis) that suggests a new approach or a different way of looking at a problem. Then the researcher will run experiments and gather data to attempt to prove or disprove this hypothesis. Sometimes the word *hypothesis* is used loosely in everyday conversation, but in science it must meet an important requirement: To be valid scientifically a hypothesis must have a built-in way it can be proved wrong if, in fact, it is wrong. That is, it must be falsifiable.

Not all scientists actually run experiments themselves. Most theoreticians, for instance, map out their arguments mathematically. But hypotheses, to be taken seriously by the scientific community, must always carry with them the seeds of falsifiability by experiment and observation.

That brings us to the word *theory.* To become a theory, a hypothesis has to pass several tests. It has to hold up under repeated experiments and not done just by one scientist. Other scientists, working separately from the first, must also perform experiments and observations to test the hypothesis. Then, when thoroughly reinforced by continual testing and appraising, the hypothesis may become known to the scientific and popular world as a "theory."

It is important to remember that even a theory is also subject to falsification or correction. A good theory, for instance, will suggest "predictions"—events that its testers can look for as further tests of its validity. By the time most well-known theories, such as Einstein's theory of relativity or Darwin's theory of evolution, reach the textbook stage, they have survived the gamut of verification to the extent that they have become productive working tools for other scientists. But in science, no theory can be accepted as completely "proved"; it must remain always open to further tests and scrutiny as new facts or observations emerge. It is this insistently self-correcting nature of science that makes it both the most demanding and the most productive of humankind's attempts to understand the workings of nature. This kind of critical thinking is the key element of doing science.

The cartoon-version scientist, portrayed as a bespectacled, rigid man in a white coat and certain of his own infallibility, couldn't be further from reality. Scientists, both men and women, are as human as the rest of us—and they come in all races, sizes, and appearances, with and without eyeglasses. As a group, because their methodology focuses so specifically on fallibility and critical thinking, they are probably even more aware than the rest of us of how easy it is to be wrong. But they like being right whenever possible, and they like working toward finding the right answers to questions. That's usually why they became scientists.

The Birth of Science: Ancient Times to 1699 and the four other volumes in The History of Science look at how people have developed this system for finding out how the world works, making use of both success and failure. Throughout the series, we look at the theories scientists have put forth, sometimes right and sometimes wrong. And we look at how we have learned to test, accept, and build upon those theories—or to correct, expand, or simplify them.

We also examine how scientists have learned from others' mistakes, sometimes having to discard theories that once seemed logical but later proved to be incorrect, misleading, too limited, or unfruitful. In all these ways they have built upon the accomplishments of the men and women of science who went before them and left a long, bountiful legacy from which others could set out for new discoveries and fresh insights.

Each volume of this new edition offers expanded coverage, including more about women in science; many new photographs and illustrations; and a new section, "Science and Society," that examines the interface between science and cultural and social mores and historical events. Sidebars called "Side Roads of Science" examine weird beliefs and pseudoscientific claims of the times. Each volume concludes with a glossary, a chronology, and expanded sources for further exploration, including Web sites, CD-ROMs, and other multimedia resources, as well as recent related books and other print resources.

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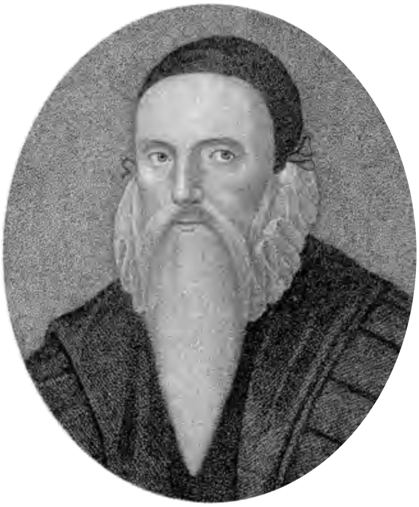
The Seventeenth Century

A Time of Transition

THE SCIENTIFIC REVOLUTION HAD brought stunning shifts in the methods and discoveries in science—establishing new and productive paradigms and perspectives, especially for physics and astronomy. Yet those not involved in science—the bakers, field workers, shopkeepers, and others—were barely touched by most of the changes that transformed scientific thinking of the day. Most people had no opportunity (or inclination) to read the books written by Copernicus, Galileo, Kepler, Newton, and others, and word of mouth spread slowly (and, as today, not always accurately). Unlike Britain's Industrial Revolution in the 18th century, while the Scientific Revolution was an exciting time for those involved, it did not yet spill over much into the lives of the general populace. Among scientists the revolutionary new ideas mixed with many old ideas that conflicted. Within the scientific community that had begun to form, a process of adjusting and readjusting, point and counterpoint, continued in attempts to reconcile differing philosophies and worldviews. The struggle to reconcile the rational with the irrational, and the process of fitting new ideas into the context of social customs and beliefs, remained a challenging effort for science—and remains so today.



John Dee. A talented scholar and mathematician victimized by his times, he was imprisoned during court intrigue, placed at the mercy of quarreling royals, duped by a magician, and was perhaps himself a believer in the occult, or a huckster. *(Edgar Fahs Smith Collection, University of Pennsylvania Library)*

John Dee: Scientist and Magician

As a result of the many swirling currents of thought prevalent in the times, many people simultaneously entertained what today may seem like conflicting philosophies. Such was the case of John Dee, a talented mathematician and scientist whose work, thoughts, and life became an entangled intersection of separate worlds.

In the 21st century devotees of magic and the occult readily recognize the name of John Dee, a name that retains heroic proportions in their eyes. However, even though he was once a highly respected scientist and mathematician, few people today would think of Dee as a scientist, and most would not even recognize his name. Yet in Renaissance England his was a name, almost literally, to be conjured with. He was a learned scholar, consultant in mathematics to English royalty. At the same time he was an early practitioner of the "dark arts" of astrology, magic, and alchemy, a man who trafficked with mediums and believed they conversed with angels. Like other scientists throughout the centuries and today, he sought to know the deepest secrets of the universe. He recognized that science opened many possibilities for expanding knowledge. Yet he thought he saw an easier way—and that is where he began to go wrong. For many science historians and modern students of Renaissance thought, Dee is a problematic figure—a tragic example of a brilliant and questioning mind diverted in its search for scientific truth, a seeker who got lost wandering down the dark dead ends of mysticism and the occult.

John Dee was born on July 13, 1527. Various sources give his birthplace as either London or the small village of Mortlake nearby.

His father, Roland Dee, and his mother, a young woman named Jane Wild, married in 1524. Roland Dee was a successful textile merchant; highly thought of in the powerful Merchants Guild, he was also a minor official in the Royal Court.

Little is known about John Dee's childhood, except that he was gifted with a quick and probing mind, attending school at Chelmsford in Essex and later at St. John's College, Cambridge, where he studied Greek, Latin, geometry, mathematics, astronomy, and philosophy. In 1546 he became a foundation fellow at Trinity College and spent the years between 1547 and 1550 traveling, studying, and lecturing. His first serious love was mathematics, and during a stay in Paris he gave a series of brilliant lectures at the Sorbonne on Euclid's *Elements* and the basics of geometry. Later he would edit the Billingsley translation of Euclid and add to it a famous preface extolling the usefulness of mathematics. Dee's lectures were so successful that he was offered a professorship at the University of Paris, which he declined as he would later decline to accept a position as lecturer in mathematics at Oxford. Valuing the freedom to pursue his own studies, Dee spent most of his life balanced precariously between the freedom that he wanted for his own pursuits and the duties that were expected of him as he sought and accepted patronage from those who were financially more secure.

During his travels, which also took him to Louvain, near Brussels, Dee met and formed a friendship in 1548 with the brilliant mapmaker Gerardus Mercator. So close was the friendship that Mercator presented Dee with two of his famous globes and a few of his newly devised astronomical instruments. Dee's growing reputation for brilliance had already been noted by the Royal Court, and shortly after his return to England, sometime around 1552 (during the reign of Edward VI, king of England and Ireland), Dee became court astrologer and unofficial court adviser on matters dealing with maps, geography, astronomy, and navigation. It was an excellent position—and the English Royal Court was certainly among the most financially, if not politically, secure of his patrons.

Dee's brilliance with mathematics served him well in these positions, and he soon began advising a varied assortment of naval officers and British explorers. In exchange for Dee's deep knowledge of maps, one explorer even promised before witnesses to grant to Dee all lands discovered north of the 50th parallel on his forthcoming voyage. (That could have included most of what is now Canada—but the voyage failed.) An able cryptographer Dee also found that his ability to encipher and decipher codes was often sought by spies and secret agents in the court's pay.

Many other scientists might have envied John Dee's position and the advantages that his scientific reputation earned for him. He could probably have carved out a secure place for himself amongst London society and the court. But since his early college days (and perhaps even before then), Dee had led something of a double life. Rumors about him had been circulating ever since his time at Cambridge when he used his mathematical knowledge and fascination with mechanics to construct an amazing device, a giant mechanical dung beetle that carried an actor flying off the stage during a theatrical presentation at the school. So amazed were people in the audience by the sudden appearance and activity of the mechanical creation that rumors started to spread that perhaps the beetle was not simply a mechanical creation at all but had been infused with some kind of spirit conjured up by its creator. John Dee, some whispered, was a sorcerer.

Dee, however, never thought of himself in that way—far from it. Sorcerers engaged in so-called black magic, evil, and the occult. Sorcerers, it was said, looked for personal power and trafficked with devils, with dark creatures. They even attempted to summon forth Satan himself to do their bidding.

John Dee did seek magical powers, but the magic he sought was "natural magic," the mathematical secrets that some believed lay buried in secret texts and arcane rituals of the past. He hoped that these might provide the key to understanding the harmonious and final truths about humanity and the universe. No magic of either kind existed, of course, but Dee became caught up in a search that he probably did not recognize was useless, a quest that had entrapped many other minds that were equal to or better than Dee's, and many otherwise reasonable seekers who became lost in labyrinths of their own making.

To make matters worse, other mazes, political and religious, would soon touch John Dee's life.

Dee found his first powerful patrons at the court of the boy king Edward VI (1537–53). But he had to scramble for continued patronage as Edward's protector, his uncle, met with execution, followed by the death of Edward, who was still a boy. A stream of contenders to the throne followed in quick succession, leaving Dee to struggle to keep his balance on the continually moving trapeze of fortune. Dur-

Royal Intrigues

The dangerous political intrigues Dee had to evade at the Royal Court of England were perhaps more extreme than at other courts and other times. Other scientists, such as Tycho Brahe, who depended upon court patronage, also encountered cycles of bounty and vicissitude, but the court of England offered especially undependable support in the early to mid-16th century due to the rapid coming and going of monarchs, executions, high treason, and dreadful intrigues.

Dee's first powerful patron, Edward VI (1537–53), was the only son of Henry VIII, king of England, and his third wife, Jane Seymour. Flagrantly flying in the face of Catholic doctrine, Henry had divorced or executed most of his six wives, broken with the pope and Rome, and brought the Protestant Reformation to England by founding the Church of England and setting himself up as its head. Edward was only nine when his father died, and he became king in early 1547. His uncle, Edward Seymour, was named Lord Protector and duke of Somerset. Under the influence of plotters, Edward ordered the dismantling of Somerset's power and his execution. Edward died the following year of tuberculosis, and the throne became a revolving door as he was succeeded in quick order first by Lady Jane Grey, who had no real claim to the throne, then by his two half-sisters in turn, Mary Tudor (1516–58) and Elizabeth (1533–1603). With Mary, who ruled as Mary I for five years (1553–58), Catholicism returned to England and executions raged in an effort to stamp out what were seen by the queen as Protestant heresies—earning the monarch the nickname "Bloody Mary." Many of those who had enjoyed the royal favor, like Roland and John Dee, found themselves stripped of their assets and imprisoned or worse.

When Mary died in 1558, her half-sister Elizabeth succeeded to the throne as Elizabeth I, queen of England and Ireland (1558–1603), bringing relative stability to the realm as she began a remarkable reign that lasted nearly 50 years at the peak of the English Renaissance.

ing the rule of Mary Tudor, he and his father were both imprisoned, and his father was stripped of his fortune though released, as was John. When Elizabeth succeeded to the throne as Elizabeth I, Dee appeared to find her easier to get along with than Mary. He was asked to use his knowledge of astrology to predict the best day for her inauguration, and he had the good luck to succeed in picking a fine day. After the splendor of this success, Dee became a favorite of Elizabeth and the court. He gave Elizabeth personal, if rudimentary, instruction in mathematics, and after the death of Dee's second wife, the queen even visited him at his home to offer her condolences. (Convention decreed, however, that she could not actually enter the house, so Dee greeted her in front of the structure.)

All of this intrigue and uncertainty must have badly interrupted Dee's research and studies. He did, however, amass an impressive library—becoming one of several scientists who collected impressive private libraries in the 16th and 17th centuries. (Many of these libraries, however, were lost in the Great Fire of London, a devastating blaze that destroyed much of the city in 1666.) During Mary's brief reign, Dee had tried, without success, to convince her to build a national library where scholars could come from all over the world to study and peruse rare books. When Mary showed no interest, he decided to establish a major library of his own. Although firmly back in the court's favor under Elizabeth, Dee's financial situation had not improved. While he was a favorite of the Royal Court, privilege did little to keep his purses full. To reduce expenses following the loss of his father's fortune he and his third wife, Jane, moved to his mother's home at Mortlake, which he inherited the following year when his mother died. There, for the next five years, he began collecting his personal library. It was an amazing achievement. By the time he was finished, he had collected more than 4,000 books and countless manuscripts dealing with matters of mathematics, science, and human knowledge. The University Library at Cambridge had fewer than 500 books at the time, far exceeded by Dee's personal library. To house all his books, manuscripts, and a laboratory for scientific pursuits, he built extensions onto his mother's home and even purchased and restructured a few neighboring houses. The library drew scholars from all over England and Europe, just as he had once hoped a national library would do.

Not every room in his impressive library was open for use by visiting scholars, though. One locked room was saved for Dee's personal use—his continuing study of alchemy, magic, and what was then called "scrying" (the use of a special object, such as a polished stone or crystal globe, which was supposed to allow one to peer into the future or past, or communicate directly with spirits).

The 21st-century scientific mind has difficulty empathizing with Dee's turn toward mysticism and the occult in his search for a true understanding of the universe. But in Dee's time the line between science and the mystical was not as clearly drawn as it is today. (Even now, faced with some of the speculations of modern cosmology, lay observers sometimes wonder if indeed the line has begun to grow fuzzy again.) However, the times were different. Even Isaac Newton, recognized worldwide as one of the greatest scientists of all time, born some 35 years after Dee's death, wasted years of his valuable time studying alchemy and searching for secrets hidden in the texts of the Bible.

Nor was Dee the first by far to look to the arcane and the occult for answers. Dee's particular tragedy was that such a brilliant and capable mind could be driven by intellectual ambition so deeply into gullible acceptance. Some historians suggest that perhaps if Dee had not fallen into bad company, he might not have fallen so badly or so far. He might have continued his legitimate and valuable mathematical and scientific work, keeping his nighttime endeavors harmless, secret, and under control.

But Dee did fall into bad company. The problem was that no matter how deft Dee was with mathematics and manipulating the esoteric knowledge he gathered from the texts of occult and religious books, he could not scrye. No matter how hard he tried, or how many hours he spent peering into his special polished stones, clear pools, or glass globes, he could see nothing. Seeing nothing, he could never hope to summon up the spirits and angels that might guide him on his journey toward solving the ultimate secrets of the universe. Instead of drawing conclusions from his own observations, Dee faulted himself. Then Dee fell into the company of Edward Kelley in March of 1582.

Not being able to scrye himself, Dee believed that if he was to make any progress at all in unlocking nature's secrets, he needed to purchase the services of someone who could. Scryers, like today's "mediums" or "channelers," were around if you could make the right connections. Before finding Kelley, Dee had already tried one scryer but distrusted him as a spy attempting to learn Dee's secrets or gather evidence that would condemn Dee as a sorcerer. Either out of

Dee's own frustration and gullibility or as a result of Kelley's charismatic persuasiveness, Dee finally took Kelley on.

Not much is known about Edward Kelley's early life, except that his real name was Edward Talbot, he was born in 1555 in the county of Lancashire, and he had a reputation as a scoundrel. At one time convicted of forgery, he always wore a skullcap to hide the mutilation of his ears, which had been cut off as punishment. Dee did not immediately trust Kelley. Soon, though, Kelley seemed to prove his ability at scrying, thereby winning Dee over completely, at which point Kelley and his wife moved into Dee's house.

Kelley soon began to make contact with discarnate intelligences. Peering deeply into Dee's special stones and globes, he was, it seems, remarkably adept at achieving conversations with spirits, angels, and even the devil once in a while. While Kelley peered into the scrying devices, Dee would carefully take down every word of the conversations as related to him by Kelley. Needless to say Dee never heard the voices but was filled with wonder by the facility with which his new ally made contact, as well as the colorful variety of conversations he brought forth.

The conversations became even more "wonderful" when Kelley summoned up a spirit who presented him with a much more powerful scrying stone. Shortly afterward, with the aid of the spirits, Kelley showed up at Dee's house with a small amount of a mysterious reddish substance. According to Kelley this red-hued material was a portion of the real thing—the "Philosophers' Stone," that long-sought treasure of alchemists that would enable the seeker to arrive at purity of soul as well as turn base metal into gold. Of course he did not have quite enough to complete the process, but Kelley was certain that with the continuing aid of the spirits and the angels they would be able to reach that magic end. In the meantime, they would continue to draw information from the spirits as well as continue their studies into the strange, new secret language, which Dee called "Enochian," presented by the angels. Needless to say the "Enochian" language, communicated through Kelley, appealed instantly to Dee's love of mathematics and secret codes, and bound Dee and Kelley even more tightly together.

Dee was still in service to Elizabeth and the Royal Court, but Dee became so involved with Kelley's supposed communication with spirits that rumors began to spread in Mortlake about his behavior. Already tainted in public opinion by his adroitness and love of mathematics (which many people thought were tools of the occult), as well as his faintly remembered exploits with giant animated beetles, Dee became more and more suspect to the locals around his home.

More favorable rumors spread abroad, rumors that held special interest to European nobility. Dee, it was said, had discovered how to make gold. Why Dee made his next move is a mystery variously interpreted and still unsolved. Was Dee blinded by his fevered search for the ultimate truths of the universe—an innocent dupe of Kelley's ambitious scheming—or had he become so frustrated by lack of progress, personal ambition, and the ever-present need for money that he acted as co-conspirator in the confidence games that would occupy both men throughout the next few years?

Whatever the answer, as the rumors about Dee and Kelley's ability to make gold spread, invitations flowed in from many noble families throughout Europe to come and work in their courts. Taking what now might be called a leave of absence from his royal duties, Dee joined up with Kelley. Thereupon they packed up their families and began a European sojourn.

One of the most lucrative offers came from a Polish noble named Laski. Dee and Kelley so assured him that messages from the angels

This illustration is thought to depict John Dee during his visit to the court of Bohemia in the 1580s. *(Edgar Fahs Smith Collection, University of Pennsylvania Library)* predicted he would soon benefit from their alchemy that he welcomed their arrival in Poland with luxurious accommodations and a well-fitted laboratory. Needless to say they were always close but never quite successful whenever Laski asked about the progress of their experiments. The angels and spirits, of course, kept coming, making promises, and offering prophesies. Meanwhile Dee continued keeping his increasingly elaborate notebooks while Kelley became bolder in his scrying. More elaborate "personages" of angels and spirits kept arriving, and Dee found himself spending ever less time with his scientific studies and more and more time keeping up with Kelley's conversations with the spirits.

Finally it became obvious to Laski, as the months passed, that despite the promises made by the spirits, he was losing a great deal of money rather than making it. Financing Dee and Kelley's experiments was obviously becoming a major burden. Soon Dee and Kelley's services were discontinued, and they and their families found themselves not only without a patron but also without any immediate prospect for funds. The prideful Dee, trusted scientific adviser and astrologer to the court of Queen Elizabeth, found himself wandering with Kelley and both their families from city to city throughout Europe working as fortune-tellers, astrologers, and alchemists (for suitable patrons), promising to turn metal into gold. Of course, they never succeeded in making the much-promised gold, despite Kelley's artful suggestions to would-be clients that they were in possession of the secret knowledge that would allow them to achieve that goal.

Inevitably, too, tension began to put a strain on Dee and Kelley's relationship. It often seemed to Dee that Kelley was taking too many liberties in promoting himself to potential clients as Dee's intellectual and professional equal. Meanwhile, to Kelley, Dee had become just another traveling huckster like himself.

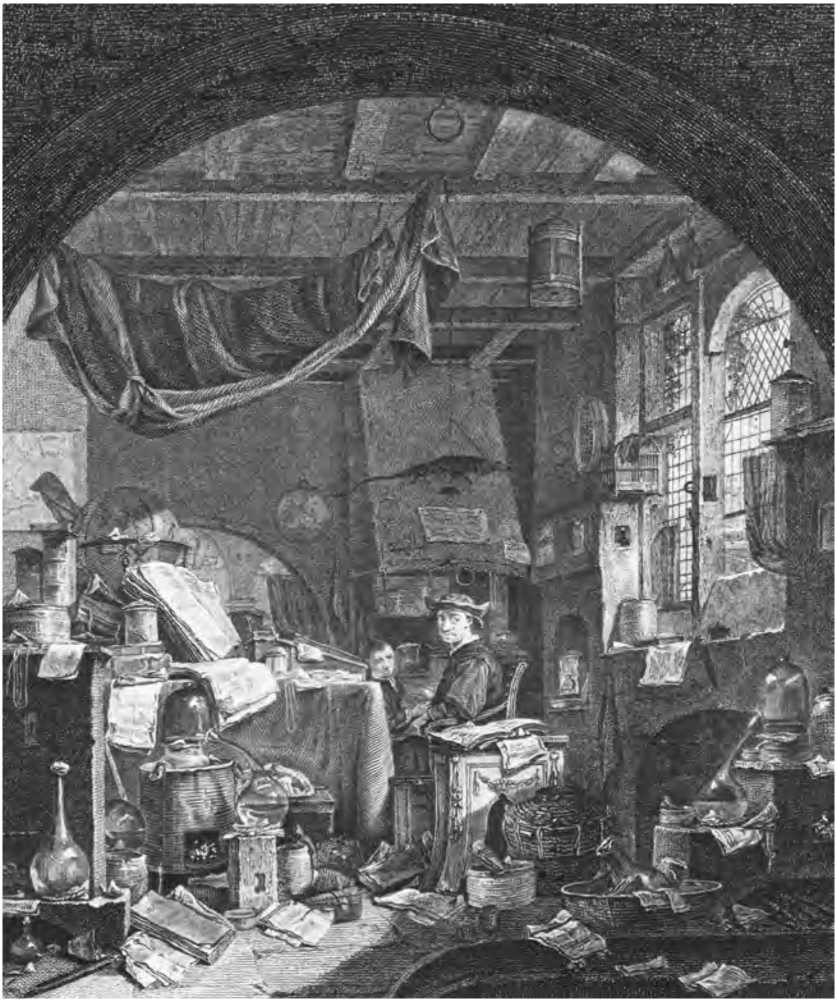
Already exhausted with travel, the constant making and breaking of promises to clients, the ongoing and increasingly complicated communications with spirits, and the growing pretensions of Kelley, Dee fell ill and decided to return home to England. He left the Kelleys behind and returned with his wife to his native shore. There his health improved briefly with the warm reception given to him in London by Elizabeth. When he returned to his home in Mortlake, though, he discovered that a mob fueled by rumors and fears about Dee's European sorceries had ransacked his home. They had destroyed or stolen many of his valuable possessions, including many of his beloved books.

It seemed, too, that despite the warm reception she gave Dee in London, the queen had found other favorites during his absence. They remained friendly, and when Elizabeth became aware of Dee's dire financial condition, she kindly arranged for him to receive various small appointments and stipends. Yet their relationship was never again the same.

Continuing with his studies alone, Dee apparently persevered throughout the last days of his life, always searching for the magic keys to the secrets of the universe he had sought so long. He died in near-poverty at Mortlake in 1608.

After the departure of Dee and his wife, Kelley continued to travel around Europe, seeking out likely patrons and claiming that he had discovered the true Philosopher's Stone that would turn metal into gold. In lean times, of which there were now many, he resorted to common fortune-telling and other simple confidence games. Kelley's end, too, was drawing near. He was arrested as a sorcerer and heretic in Prague and later freed, only to find himself arrested again in Germany. Although controversies swirl around his eventual fate, the most believed account tells that he died in a fall while attempting a prison break in southern Germany. There were no angels to catch him.

There is little doubt today of the tragedy spelled out by Dee's story—a tale of a bright and inquiring mind, derailed by ambition and lack of patience into the dark alleys of the mystical and the pretentious. It is a story of gullibility—a willingness to believe in an inviting myth of power and riches obtained through alchemy and mystical contacts with "spirits." The question, though, remains: Was he, despite possessing such a sharp and practical mind, just amazingly naïve, completely taken in by simple confidence tricks and stunts? Or was he driven by some strange twist of mind that allowed him to become a conspirator in deception, a fraudulent magus who for reasons of his own gave up the search for truth and settled instead for a life of deception? In either case, given the devotion with which he had once sought mathematical and scientific truth, his story is indeed a tragedy.



An alchemist's study *(Edgar Fahs Smith Collection, University of Pennsylvania Library)*

A Time of Intertwined Beliefs

John Dee was not alone in his entangled world of mysticism and alchemy on one side and science and mathematics on the other. His balancing act between the irrational and the rational was characteristic of efforts by most contemporary scientists to live in both worlds. Overall the 17th century stands as the beginning of a slow transition that continues even today. Out of ancient and medieval times came a legacy of superstition, mysticism, alchemy, astrology, and numerology that bore strong influences during the 16th century and remained powerful in the 17th century. These pseudoscientific echoes from the past competed with their scientific counterparts: reason, objectivity, physics, chemistry, astronomy, and mathematics. Even today we see an ever-present residue of the ancient and medieval traditions in the popular culture of the 21st century—including "New Age" beliefs in the influence of angels, crystal power, and many of the unsubstantiated practices of "alternative medicine."

In the 17th century superstition permeated the culture. When people saw a comet in the skies they believed it was a portent of some evil disaster to come. Tradition taught the axiom to be true, and experience seemed to confirm it: Something terrible always occurred (at some point) after a comet appeared. Records of this virtually universal belief date back as far as the 11th century B.C.E. (possibly around 1059 B.C.E.) in China, where astronomers recorded a comet's appearance at about the same time that war broke out between two kings. The earliest astronomers generally were also astrologers, often hired by kings to predict the future. They, as well as the public, believed a comet's appearance was a warning or sign and that dire tragedies were in store. In more recent history, in Rome, the emperor Nero executed members of his government, convinced that a passing comet warned of impending treason. In Bayeux, a small village in northern France, a tapestry hangs that commemorates the Norman conquest of England at the Battle of Hastings in 1066. The image of a comet appears in the corner of the scene, carrying its message of doom. Other examples abound. By the end of the 17th century, Edmond Halley had recognized that comets travel in orbits and obey the same laws of gravity that Newton had shown controlled other objects in the nighttime skies. But superstitions do not disappear overnight (and who can cast blame, since Halley was not proved right until the comet returned in 1758, just as he had predicted, though well after his death).

Why did the wrongheaded concepts of Galen prevail so long, preventing physicians and physiologists from understanding important facts about how the human body functions? How many patients died needlessly because their physicians did not understand the flow of blood, the pumping of the heart, and the role of the lungs? Historians surmise that Galen prevailed because his theories were comfortable. They were well known, and they fit with the dominant belief systems of the times. They made mystical allusions to governing "spirits," they appeared to be closely aligned with theological thought, and they had a comforting internal consistency. Generally the mechanistic view of physiology—of any living thing, human, plant, or animal—left the 17th-century mind uneasy. Some scientists, like Nehemiah Grew, embraced the idea of a clockwork universe, envisioning its maker as a powerful and all-knowing watchmaker. Others preferred to think in less mechanistic, more spiritual terms.

Flemish physician and chemist Johann Baptista van Helmont (ca. 1577–1644), a contemporary of John Dee's, accomplished considerable sound work in chemistry. He succeeded in isolating several gases, had a rigorous quantitative approach and a clear understand-

Secrecy and Power

By tradition and for the sake of protecting an advantage when they had it, alchemists had always clothed alchemical knowledge in a cloak of absolute secrecy. Little wonder, since the alchemist's goals centered on gaining knowledge that would lead to great wealth and enormous power. The alchemist who discovered the Philosopher's Stone, and thereby the key to success, would be able to name any price to those with the wealth to pay. Scientists of the 17th century caught the habit. Proceedings of the Royal Society were secret, and several of the most well-known scientists were obsessed with secrecy during their careers.

Newton was known for his caution and secrecy. He routinely protected his reputation by concealing his methods until he was sure of his results and ready to make a public statement. He also usually held back any assumptions he made in the early stages of experimentation until he had proof that they were valid and trustworthy. As a result he gave the impression that he did not make mistakes. According to some historians he even hid the real work and extreme focus that his wide-ranging achievements required—actively cultivating the myth that his ideas came to him by effortless inspiration. The truth only became known through a close examination of his notes and papers.

Newton's nemesis, Robert Hooke, practiced the same caution about premature announcements, but he also worried about being outdone.

ing of the indestructibility of matter, and performed considerable experimental work. Yet, familiar as he was with the gases he worked with, van Helmont thought he detected some special quality in them that he believed might indicate that they were living spirits.

Johannes Kepler, the great astronomical theorist, also earned his living partly as an astrologer and apparently saw no contradiction. Robert Boyle dabbled in alchemy, and Isaac Newton spent extensive time experimenting with alchemical recipes, which he obtained by swapping secrets with others.

Newton even embarked upon a serious quest for "philosophical mercury," having obtained a recipe from Boyle's estate. He also requested and received a quantity of reddish substance, a principle ingredient in the recipe. One historian postulates that he probably

What if, while he was testing his results for validity, someone else scooped the credit for the same discovery? Or what if a fellow scientist out and out stole his ideas from discussions held in confidence? How could he prove that he was first? (As it was, he believed that Newton had robbed him of more than one honor.) So Hooke devised a trick. At the end of his book on helioscopes, he included a cryptic message about another project, a balance-spring watch he had invented. A tool that could accurately measure time was greatly needed, especially by physicists, and he knew that anyone who could invent such a tool would become famous. The key to his invention was a concept that would also have an importance of its own, and this was the subject of his message: "the True theory of Elasticity or Springiness, and a particular Explication thereof in several Subjects in which it is to be found: And the way of computing the velocities of bodies moved by them. *ceiiinosssttuu.*" Doubtless his readers were mystified.

Two years later, when Hooke was satisfied with the timepiece and the theory behind it, he published an explanation. The anagram *ceiiinosssttuu* he had published so mysteriously stood, he explained, for *Ut tensio sic vis.* "That is," he wrote, "The Power of any Spring is in the same proportion with the Tension thereof: That is, if one power stretch or bend it one space, two will bend it two, and three will bend it three, and so forward. Now as the Theory is very short, so the way of trying it is very easie." The trick worked—no one contested his claim, and today, this principle is known as Hooke's Law of Elasticity.

Robert Boyle (pictured) and his colleague Isaac Newton traded secrets about alchemy and experienced firsthand the frustrations of trying to do the impossible—which they nonetheless persisted in believing possible. *(Edgar Fahs Smith Collection, University of Pennsylvania Library)* worked long hours with samples of mercury in the confined quarters of his laboratory, possibly overexposing himself to the mercury he was working with. The overexposure may have caused a case of acute mercury poisoning, resulting in the nervous breakdown he suffered in 1692–93—a conjecture that is somewhat reinforced by the discovery of high levels of mercury when modern microscopic analysis was done on samples of Newton's hair. If so, he risked grave personal danger, in addition to wasting precious hours looking for the proverbial pot of disappearing gold at the end of a rainbow. In fact—though difficult to imagine—Newton wrote more volumes on mysticism, alchemy, and religion than on science.

Not everyone was duped. English satirist Ben Jonson (1572–1637) wrote a play called *The Alchemist,* first performed in 1610. The title role is a conjurer who claims he can produce gold from baser metals, depicted by Jonson as a cheater, a wandering swindler, capable of gathering crowds of admirers to see his flashy presentations—as Jonson puts it:

> Selling of flies [spirits], flat bawdry, with the [Philosopher's] stone,
> Till it, and they, and all in fume [smoke], are gone.

Intolerant of swindlers, boasters, and con artists, Jonson sees the alchemist trading on people's gullibility with sleight-of-hand and trickery, taking their money, claiming to offer the priceless power of the Philosopher's Stone, then whisking himself and his accomplice away under cover of a smokescreen.

In his play *The Alchemist,* popular 17th-century dramatist and skeptic Ben Johnson portrayed the greed of those who pursued the quest for instant gold and critiqued their ethics. *(Edgar Fahs Smith Collection, University of Pennsylvania Library)*

The story of John Dee and Edward Kelley demonstrates the attraction of magic, the spirit world, and mysterious, secret incantations. Kelley's scrying was clearly a scam—if not at first, certainly he must eventually have realized that not only had no spirits ever really spoken to him, but also that they never would. The "forces" of magic and alchemy were just a quick, easy path to fame and fortune, or at least he hoped so. Ultimately Dee must have realized this when, sick and tired, he resigned from the team he had formed with Kelley.

One can hardly accuse Newton, Boyle, Hooke, and other serious 17th-century scientists of looking for easy answers, however. They pursued alchemy with the same vigor they used in their scientific experiments. These scientists lived in an age when magic still lived side by side with the new rigorous methods of science. It would take one or more generations before most scientists recognized that alchemy and other magical processes would always be fruitless. They developed more and more sophisticated testing techniques to keep from being fooled—and most of all to keep from fooling themselves.

The following century would experience a flowering of respect for rational thinking, the methods of science, and the wonders of nature—without believing in magic or superstitions. The bright beacon of reason seemed capable of solving all problems eventually, able to unlock the mysteries of the universe. It was truly an age of Enlightenment—another era of great discoveries and new insights, even greater than those of the century before.