CHRISTIAN HISTORY

Issue 134

How the church fostered Science and Technology

"Great are the works of the Lord, studied by all who delight in them."
Psalm 111:2, NRSV

The first issue in our Faith and Flourishing series

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134
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STUDY THIS In this 1268 papal bull, Clement IV enlarged the charter of the new University of Paris (see pp. 6–12).

Did you know?

CHRISTIAN THINKERS HAVE ALWAYS STUDIED GOD'S CREATION THROUGH SCIENCE—AND USED THE RESULTS TO BENEFIT OTHERS

LET THERE BE LIGHT—AND NATURAL LAW

Theologian Basil the Great (c. 329–379) authored the first scientific writing by a Christian, a commentary on the creation chapters of Genesis. He titled it *Hexameron*, from Greek words meaning "six days." Others soon did the same (see p. 18). Basil was one of the first to use *nomos physeos*, or "natural law," to refer to nature rather than to the natural moral law of humans.

GOOD HEAVENS Robert Grosseteste, bishop of Lincoln (*right*), wrote well-known scientific treatises in the 13th c. (see p. 21). This illustration of the planets (*above*) comes from a manuscript by one of his disciples.

TAKE TWO HERBS AND CALL ME LATER

Are therapy animals, aromatherapy, the mind-body connection, and healthy gut bacteria all inventions of modern science and psychology? No! We can find references to each of them in the writings of Hildegard of Bingen (1098–1179), a medieval abbess, botanist, medical writer, and composer. (Read more on pp. 14–17.)

DID THE BOOKSTORE BUY IT BACK?

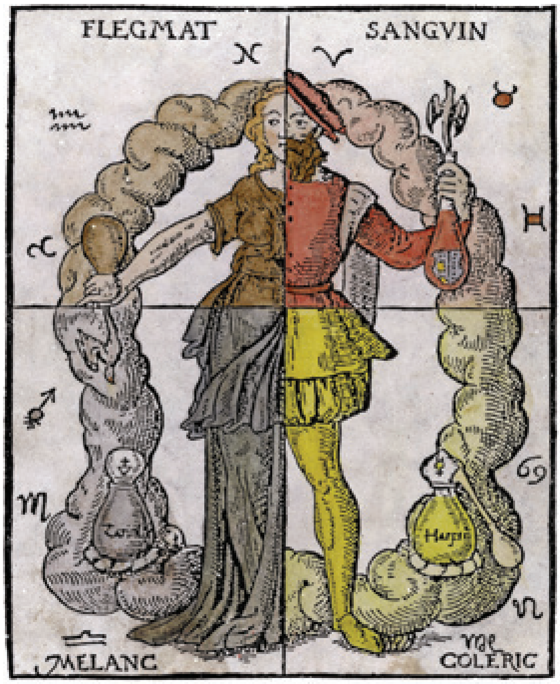
How soon did *your* college science textbook go out of print? John of Sacrobosco (1195–1256) wrote *On the Sphere of the World* around 1230. It was used until about 1650. That's over 400 years!

MUSIC OF THE SPHERES

In 1619 astronomer Johannes Kepler developed musical notation to represent the variations in the speed of each planet when nearest to and furthest from the sun. The harmonies produced by the planets' notes, he felt, proclaimed the glory of God. Kepler was not the only early modern scientist to influence music. One of Robert Boyle's books, *The Martyrdom of Theodora, and of Didymus*, became the basis for Handel's opera *Theodora*. Isaac Watts also based a hymn stanza (later set to music by William Billings) on a section of Boyle's *Occasional Reflections*

SCIENCE VS. RELIGION? *Right:* A cartoonist imagines the Society for the Suppression of Blasphemous Literature trying to muzzle agnostic Herbert Spencer (see p. 33).

IN BALANCE *Below:* Scientists from the ancient Greeks through the 18th c. conceived humans as being composed of four "humours."



Upon Several Subjects: "Our life contains a thousand springs, / And dies if one be gone. / Strange that a harp of thousand strings / Should keep in tune so long."

"WILL IT FLY? AND WHERE?"

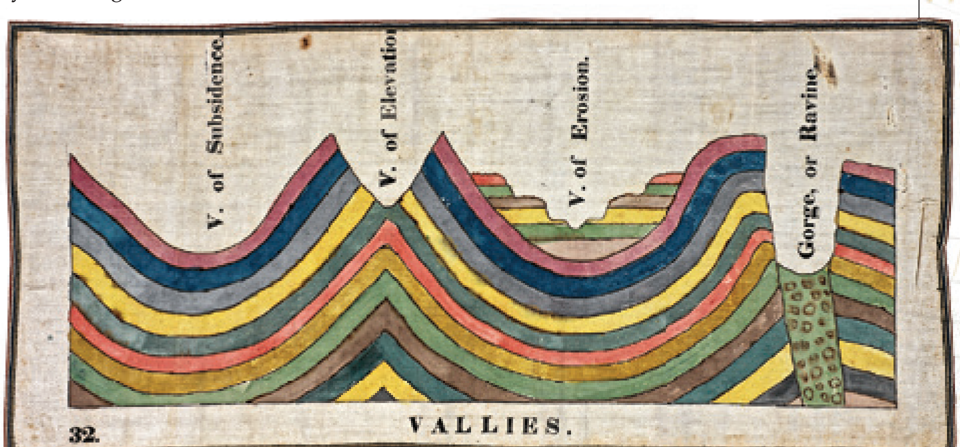
Christian physicist James Clerk Maxwell (1831–1879) laid the foundation for modern inventions, including color photography, through his experiments. He was known for using his terrier Toby as a sounding board to discuss his theories! Maxwell liked Scottish poetry and wrote this parody of Robert Burns's "Comin' Through the Rye": "Gin [If] a body meet a body / Flyin' through the air. / Gin a body hit a body, / Will it fly? And where? / Ilka [Each] impact has its measure, / Ne'er a ane hae I, / Yet a' the lads they measure me, / Or, at least, they try." (See p. 42.)

HUMAN COMPUTERS

The "Harvard Computers" were skilled women employed to calculate astronomical data, partly because they could be paid less than men. One, Henrietta Swan Leavitt (1868–1921), was a devout Christian, the daughter of a Congregational minister. Her study of Cepheid variables, a kind of pulsing star, remains foundational to cosmic distance measurements and undergirded Edwin Hubble's (1889–1953) determination of the expanding nature of the universe. Hubble's experiments confirmed theories advanced by Jesuit priest Georges Lemaître (1894–1966). CH

Thanks to Edward B. Davis for several items in this DYK.

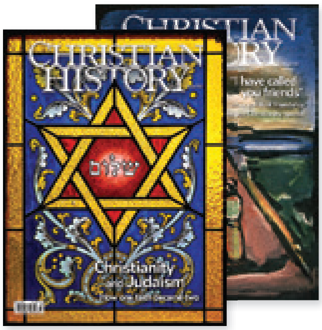
LITTLE DINO ON THE PRAIRIE Artist Orra White Hitchcock (see p. 38) illustrated her geologist husband Edward's lectures (*right*) and books, including this sketch of dinosaur tracks (*above right*).



FOUR TEMPERAMENTS—*CHRONICLE* / ALAMY STOCK PHOTO
THE SOCIETY FOR THE SUPPRESSION OF BLASPHEMOUS LITERATURE AGAINST HERBERT SPENCER. FROM *PUCK*, V. 13, NO. 314, (1883 MARCH 14), COVER. LIBRARY OF CONGRESS / PUBLIC DOMAIN
ORRA WHITE, *DINOSAUR TRACKS*, LITHOGRAPH, PERSONAL PHOTOGRAPH—EDWARD B. DAVIS
VALLIES, BY ORRA WHITE HITCHCOCK, 1828–1840; ARCHIVES & SPECIAL COLLECTIONS AT AMHERST COLLEGE / PUBLIC DOMAIN

Letters to the editor

Readers respond to *Christian History*



OUR SPIRITUAL FRIENDS

Truly enjoyed *CH* issue #132, p. 9, "Don't call it a list." Now I want to read the book, *When the Roll Is Called Down Here* by Fred Craddock. Your magazine is magnificent and I am very grateful for the beautiful copy.—*Pam Malcolmson, Canyon Lake, CA*

I look forward with great anticipation to receiving *CH* magazine and once again, issue #132 was a delight to read and study. Many of the stories are familiar and some new ones were insightful. It is a gift having them all bound in one volume. I especially appreciated your emphasis on friendship that knows no boundaries such as age, class, race, etc. I even chuckled when I read of some who even placed their friendship above theological conviction. We need that example today. —*Tom Edmunds, Washington, NJ*

SPREADING THE WORD

Got #133 today. I want to order more to give to my history teacher colleagues at the high school where I teach. Excellent issue! Thank you. . . . Whenever you have a good issue that has significant implications for world history, as this issue does, I like to hand it out to my peers. — *Greg Yankey, Owasso, OK*

Thank you for sharing our work with your colleagues! We've received a number of comments about issue #133—asking about our treatment of biblical exegesis, supersessionism, anti-Semitism, and Christians during the Holocaust—and we'll be devoting the letters page of #135 to addressing them.

PRAISE FOR MORE PAST ISSUES

Just wanted to say a big THANK YOU for the great work you all do and especially for the Grand Miracle devotional. It was such a blessing and I was sad to see it end.—*Scott Dove, Rockingham, VA*

We've heard from many people that this was a meaningful Advent journey for our readers.

I don't know when I've been more inspired than during and after reading "Our First Woman Reformer" [Argula von Grumbach] from issue #131. The issues stack up, unread much of the time, I'm sorry to admit; but I'm encouraged to diligently find the time to read each issue as there's no telling how many other articles I would have enjoyed, much less benefited from. If you have contact with the author, Peter Matheson, please thank him from a reader for sharing this courageous lady with your reading public.—*Sharon Bridges, Kingwood, TX*

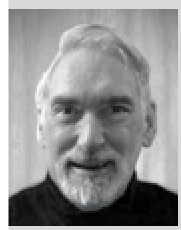
We let Dr. Matheson know, and he was very pleased to hear it!

YOUNG PLINY, PLEASE STAND UP

On p. 8 of issue #133, we referred to Pliny the Elder as governor of Turkey in the early second century and author of a famous letter to Trajan about Christians. It was his nephew, Pliny the Younger, who was intended.

MEET THE STAFF: DAN GRAVES

How long have you been at CHI and what is your role?
The details of my hiring in 1996 are miraculous. Troubled by the material I handled as a prison librarian, I had given notice; on my last day I had no idea what I was going to do next. Months earlier I had bought a Vision Video product that included a set of CHI's *Glimpses* bulletin inserts about scientists. I had long wanted to issue similar resources; angry that someone had preempted my dream, I crushed the *Glimpses*. The Holy Spirit rebuked me: "You should be glad someone is doing what you don't have the resources to do." So I contacted founding director Ken Curtis, but he lost my info. The day my job ended, he found it and called me. Talk about providential timing! I began as a part-time writer and later found myself doing website development and magazine layout.



What is your favorite part of the job?
I enjoy the variety of responsibilities that come with researching and writing about Christians.

What do you most wish readers knew?
I wish readers understood we don't agree with every person or movement *CH* covers. We are telling history, not endorsing points of view.

What do you do in your spare time?
I enjoy family, friends, and church—and I write. Lately I've produced science fiction: *A Severe Paradise* and *His Last Recursion and Other Stories*. For refreshment I read, solve sudokus, and listen to Christian music (from Schütz to Delirious). While on vacation I search thrift stores for used books and CDs, and I play spider solitaire. CH

CHRISTIAN HISTORY #133
CHRISTIAN HISTORY #132
DAN GRAVES, PERSONALPHOTO

Editor's note

FOR THIS EDITOR'S LETTER, you're going to hear from two editorial voices, because we have differing backgrounds on this issue.

I (Jennifer) grew up in a household with a chemist-turned-United-Methodist-pastor for father. As far as I knew, science and faith went hand-in-hand. But as I grew older, I learned that many scientists and Christians have assumed an aggressive posture toward each other. Highly popular media portrayals of scientific topics have reinforced the conflict. I (Chris) recall this unsettling discord in my youth between scientific exploration and faith. In fact when editing issue #76 on *The Christian Face of the Scientific Revolution*, I wrote:

> Before I started working on this issue, I had always harbored (though fancying I knew better) a vague, unsettling notion that the things of science and the things of God are somehow incompatible . . . [and] an equally disturbing sense that, throughout its history, the church had seen science as a potential threat to the faith. . . . [This idea is] a pretty disruptive poltergeist in the mental house of any modern Christian who suffers with it.

CREATION IS A GIFT

Yet if we actually look at church history, we find a very different story. From the very earliest years of the Christian church, creation was taken to be a gift, made and given to us humans by a good God. And human reason was seen as an important part—even *the* most important part—of the image of God implanted in us at creation. The world is a place of beautiful order and regularity, shaped by God and everywhere reflecting his glory and his supreme intelligence (we told that story at length in issue #119, *The Wonder of Creation*), and God in Genesis mandates that we use reason to work with the raw materials of creation for human flourishing.

Furthermore, the Scientific Revolution was led by people of faith who pursued scientific and technological innovation out of Christian motives and understandings; and the Christian preparation for that Scientific Revolution turns out to have been particularly intense and effective during the medieval period in the West—when Christians founded the university and laid the groundwork for modern science.

The thinkers we discuss in this issue—ranging from the late ancient period through the twenty-first century—knew that mathematical and naturalistic explanations do not preclude theological ones and that scientific understanding does not rule out awe and wonder. In fact it may aid them. They saw their study of science as reflecting their deeply rooted faith and their faith as being enriched by their increasing understanding of the scientific world. They weren't scientists in spite of being Christians; they were scientists because they were Christians first. Issue #76 has some more good words for us to remember:

> We live this science. Even the confirmed Luddites among us find our lives entangled, improved, and burdened a hundred ways each day by modern science. And we live, or try to live, this faith. That is, we know we have our being in God—and should have our minds conformed to Christ—while at our computers, in our cars, at the doctor's office, and everywhere else science meets us.

Let the stories of these faithful innovators guide and inspire you as you seek to have your mind conformed to Christ in your own work and life. CH

Chris Armstrong,
senior editor

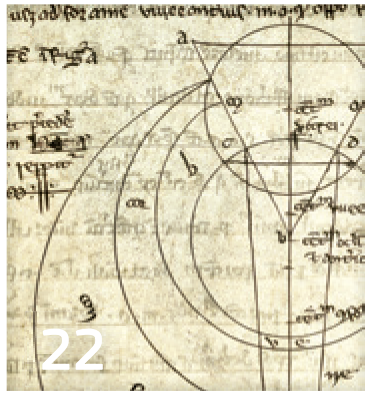
Jennifer Woodruff Tait,
managing editor

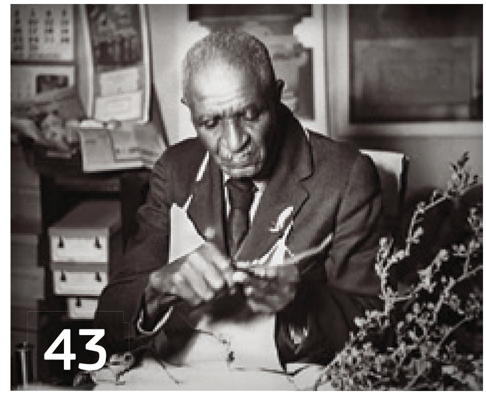
P.S. We thank Robert Bishop for his assistance in brainstorming for this issue.

This issue was about to print when our lives entered a new reality: COVID-19. (In fact, it was delayed in printing as we waited for museums in Europe to reopen and provide our first choice of images to enhance the material.) As the world reels from this crisis, many of us are wrestling with questions of life and death as never before. We tune in daily or even hourly to news sources for updates from the scientific community looking for answers in the lab, and from politicians setting public policy. And through it all, we look to our faith for comfort, guidance, and hope. Providentially, we were already prepared in the following pages to look at the intersection of science and faith—but we were also reminded specifically of plagues and epidemics throughout church history and the ways Christians have responded to them. With that in mind, we've been hard at work on a bonus issue to cover that topic; this bonus issue will print in midsummer, closely followed by our already-scheduled fall issue on Methodist missionary E. Stanley Jones.

VISION VIDEO/CHI HEADQUARTERS—LINE DRAWING BY ROBIN HELLER
JENNIFER WOODRUFF TAIT—CATHERINE TAIT
CHRIS ARMSTRONG - GREG HALVORSEN SCHRECK

CHRISTIAN HISTORY





Christians, science, & technology

Also:

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PHILOSOPHY WITH THE SEVEN LIBERAL ARTS—NICOLAS XAVIER WILLEMIN (1763–1833) / PUBLIC DOMAIN—WIKIMEDIA COMMONS
BACON, *PERSPECTIVA*, (1614). PUBLIC DOMAIN—IMAGE COURTESY HISTORY OF SCIENCE COLLECTIONS, UNIVERSITY OF OKLAHOMA LIBRARIES
CARVER AT WORK AT TUSKEGEE INSTITUTE IN SEPTEMBER 1938—ALPHA HISTORICA / ALAMY STOCK PHOTO

Divine power, wisdom, and goodness

THE MEDIEVAL FLOURISHING OF NATURAL PHILOSOPHY IN CHRISTIANITY

James Hannam

PAY ATTENTION 14th-c. students at the University of Paris (*left*) and Bologna (*above*) seem to have occasionally let their minds wander during lectures too.

THE CARICATURE of the Middle Ages and scientific progress is of a world of bitter rivals; Christian theology and natural philosophy (as scientific study was called) fighting until the former emerged as the victor. But for most medieval theologians and scientists alike, the relationship looked far different. Instead of a battle, it was a royal court. Theology, the "queen of the sciences," reigned, and natural philosophy was her handmaiden. And in that court, natural philosophers did not just walk hand-in-hand with the church—they were, more often than not, senior members of the clergy.

THE MATHEMATICIAN POPE

On Palm Sunday of AD 999, Christendom's foremost mathematician became Pope Sylvester II. Gerbert of Aurillac (c. 946–1003), as the new pontiff had been known before his elevation, reached these heights in spite of humble family origins. Gerbert's first calling was as an educator. He taught his students arithmetic, astronomy, and harmonics; in turn they spread an interest in mathematics across France and Germany. He even introduced Arabic numerals 0 through 9—the very ones we use today—into Europe.

Holy Roman Emperor Otto II took notice of Gerbert's talent and holiness and appointed him as tutor to his son. Gerbert must have had quite an influence on the lad, for when the boy received the imperial mantle himself as Otto III, he made his old teacher pope.

To be fair Gerbert's scientific knowledge was modest by the standards of classical Greece and Islamic Spain. Following the collapse of the western Roman Empire, knowledge of the Greek language had been lost in western Europe and, with it, access to the works of ancient geniuses like Euclid, Ptolemy, and Aristotle. However, Gerbert's career showed that in the so-called dark ages, a passion for natural philosophy was no impediment to a highly successful career in the church.

For medieval Christians science always consisted of the study of creation; that there *was* a creator behind the material world was a foregone conclusion. This had some important consequences for how they approached the subject. First, they expected to see God's character reflected in the material world. Nature should be law-abiding rather than capricious, benevolent rather than amoral. As the twelfth-century philosopher William of Conches put it, "in the creation of all things, one can behold divine power, wisdom and goodness." That meant Christians found it worthwhile to study nature and to figure out the rules that God had ordained for nature to follow.

Second, if God invented natural laws, they had to be consistent with the Bible, God's other great work. Hugh of St. Victor, another twelfth-century scholar, saw a clear analogy between Scripture and nature when he wrote, "The whole of the sensible world is like a book written by the finger of God." The study of creation was just as appropriate for Christians as the study of the Bible.

Not everyone accepted this congruence between the book of nature and the book of Scripture. One notorious

2 + 2 = 4 Before Pope Sylvester II (*left*) became the first French pope, he was a mathematician, penning treatises on geometry (*far left*), arithmetic, astronomy, and music.

sect, the Cathars, rejected both. As dualists who believed that the material world was the product of a malicious deity, they also rejected traditional orthodox interpretations of the Bible. The church has deservedly been criticized for the severity with which it dealt with this heresy by starting a war in southern France to stamp it out. But in addition to wielding the sword, it also launched campaigns to convert heretics. To succeed, the church had to convince the Cathars that dualism was objectively wrong. The one God, not his evil twin, had created the world.

NEW SCIENCE, NEW BEAUTY

Luckily the tools for this struggle had recently become available. In 1085, Toledo, the capital of Islamic Spain, fell to the Christian King Alfonso VI; the city's magnificent libraries were now in Christian hands. At around the same time, the Crusades opened up the Byzantine Empire and the Near East to western scholars. Catholics finally had access to the science and mathematics of the ancient Greeks, as well as to the achievements of Arabic science and mathematics.

These works—in particular the philosophy of Aristotle—further revealed the beauty and intricacy of the natural world, proving to many readers that a good and rational God created it, not a malignant spirit as the Cathars insisted. The newly established Order of Preachers, better known as the Dominicans after their founder Dominic of Caleruega (1170–1221), led the charge in these efforts to harness natural philosophy for the faith.

The Dominicans learned to use Aristotle to refute the arguments of heretics without having to rely on the Bible. Their most famous member, Thomas Aquinas (1225–1274), made his name by synthesizing Christianity and Aristotelianism. His teaching came close to becoming Catholicism's official philosophy for generations.

Yet from a Christian perspective, Aristotle's doctrines were not without their problems; after all he was a pagan born four centuries before Jesus. For example Aristotle had taught that the universe is eternal and uncreated, that "god" has no interest in humanity, and that people do not possess individual immortal souls.

Unsurprisingly in 1210 authorities discovered a group of heretics inspired by Aristotelian thought active around Paris. Known as Amalricians, they were pantheists who believed that the universe itself is a divine being. The local bishop, overreacting in bureaucratic mode, promptly banned books by Aristotle.

The pope took a more measured view and lifted the ban, but made clear that Aristotle's books had to be read with care to ensure they didn't encourage heresy. He expected Christians to distinguish useful elements of Aristotle's philosophy while rejecting damaging teachings. Before long the University of Paris drew up a syllabus stipulating that students who wanted to study theology must first master Aristotle: not just his science, but also his works of reason, logic, and ethics.

The University of Paris was in fact the preeminent example of a new kind of educational establishment springing up all over Europe. Traditionally schools had centered around an individual teacher or a monarch's sponsorship. When the teacher retired or the monarch died, the school went with them. Universities were different. Structured as corporate bodies, they could set their own internal rules and face off against the world as a collective. Masters and students might come and go, but the university endured. Indeed most of these medieval foundations are still operating today.

Universities provided a home for scholarship, including natural philosophy and mathematics. To obtain a bachelor's degree, every student had to learn arithmetic, geometry, and astronomy. These students

HE'S FAMOUS A 13th-c. Islamic manuscript (*above*) shows Aristotle teaching a student, and a 15th-c. Christian manuscript (*above left*) gives us an allegorical representation of logic at the top and Aristotle as an example of logic at the bottom.

needed lecturers, so scholars who wanted to devote their careers to science found employment—and also intellectual freedom of at least a limited sort.

STICK TO PHILOSOPHY

The universities disciplined their members; only rarely did church hierarchy get involved in more serious cases. History proves the common caricature of scientists being burned at the stake for meddling in forbidden knowledge almost wholly unwarranted. As far as we know, no executions for beliefs we today understand as "scientific" ever took place. The closest example was Cecco D'Ascoli, an astrologer executed in Florence in 1327 for teaching that Jesus's poverty and death resulted from his birth under the wrong stars. Even Cecco had to commit a second offense before he paid this ultimate penalty.

That's not to say that Aristotelian science became uncontroversial after the Amalrician debacle. Debates continued to rage at the University of Paris through the thirteenth century. Eventually the university insisted that philosophers stick to philosophy and leave theological speculation to doctors of divinity, who had studied Aristotle themselves before spending at least seven more years on the Scriptures and the opinions of the church fathers.

Ultimately the church supported the study of natural science because it buttressed faith. Despite this subservient status, science enjoyed sufficient resources and prestige and made significant theoretical advances. Some of the most important developments took place at the University of Oxford in the first half of the fourteenth century. A group of Merton College scholars known as "the Calculators" started to use math to place Aristotle's kinematics, the science of moving objects, on a more rigorous footing.

Thomas Bradwardine (c. 1300–1349) was one of the Calculators' earliest representatives. "Whoever has the effrontery to pursue physics while neglecting mathematics," he declared, "should know from the start that he will never make his entry through the portals of wisdom." Following his own advice, Bradwardine derived a numerical formula that describes how Aristotle said objects moved when a force is applied to them. His formula is wrong because Aristotle's kinematics was wrong, but it showed how effectively the world could be described in mathematical terms.

Bradwardine eventually left Oxford, pursued a successful clerical career, and became archbishop of Canterbury. However, his Calculator colleagues extended his work, discovering another formula that describes how far a uniformly accelerating object moves

TAKING ARISTOTLE TOO FAR The burning of Amalrician heretics, while dramatic, was not typical of the medieval church's attitude toward science.

Natural adversaries?

Has Christianity always warred with science? Or, conversely, did Christianity create it? In issue #76, CH *asked these questions of David Lindberg (1935–2015), Hilldale Professor Emeritus of the History of Science at the University of Wisconsin. Here is an excerpt.*

***Christian History*: Many people today have a sense that the church has always tried to quash science. Is this, indeed, the case?**

DL: This view, known as the "warfare thesis," originated in the seventeenth century, but came into its own with certain radical thinkers of the French Enlightenment. These people were eager to condemn the Catholic Church and went on the attack against it.

***CH*: What other myths about science and Christianity are commonly accepted today?**

DL: One obvious one is that before Columbus, Europeans believed nearly unanimously in a flat earth. . . . The truth is that it's almost impossible to find an educated person after Aristotle (d. 322 BC) who doubts that the earth is a sphere. In the Middle Ages, you couldn't emerge from any kind of education, cathedral school or university, without being perfectly clear about the earth's sphericity and even its approximate circumference.

***CH*: Was there medieval conflict between them?**

DL: Christianity and science had a complex relationship. Before Christ's birth, Aristotle and Plato had written treatises on scientific questions; centuries later, Ptolemy and Galen would do so. These books entered medieval Christendom during the twelfth century in Latin translation from Greek and Arabic versions. Christian scholars immediately realized that these books were impressive and valuable, teaching them how to think about a wide range of scientific questions. But it was also clear that [they] contained theological landmines. . . . Medieval scholars had a terrible dilemma. They were not prepared to compromise the central doctrines of Christian theology. But they also recognized that the classical sciences had great explanatory power. . . . They corrected the ancient sources where that seemed necessary, and on occasion they reinterpreted theological doctrines. And they argued vigorously for the usefulness of the classical sciences.

There were certainly skirmishes, including several cases in which a university scholar was condemned for teaching doctrines judged dangerous, but most were local and temporary. And there was never anything approaching intellectual warfare. . . . In the end Christendom made its peace with the classical tradition. Aristotle's writings became the centerpiece of medieval university education, and the church became their greatest patron.

***CH*: What guided medieval scholars as they worked out this accommodation?**

DL: Augustine (354–430) gave them their principal tool. He had cautioned centuries earlier that Christians should not make fools of themselves by reading their astronomy from the Bible:

> Usually, even a non-Christian knows something about the earth, the heavens, and the other elements of this world, about the motion and orbit of the stars and even their size and relative positions, about the predictable eclipses of the sun and moon, the cycles of the years and the seasons, about the kinds of animals, shrubs, stones, and so forth, and this knowledge he holds as certain from reason and experience.
>
> Now it is a disgraceful and dangerous thing for an infidel to hear a Christian, presumably giving the meaning of Holy Scripture, talking nonsense on these topics; and we should take all means to prevent such an embarrassing situation, in which people reveal vast ignorance in a Christian and laugh that ignorance to scorn. CH

BURNING ALMARICIANS—*CHRONICLES OF SAINT-DENIS*. 15C. ATTRIBUTED TO JEAN FOUCQUET. NATIONAL LIBRARY OF FRANCE

AQUINAS RULES *Above:* Medieval Christian artists often imagined Aquinas triumphing over Averroës, famed Islamic philosopher of a previous generation.

ON THE SAME TEAM *Left:* A German manuscript shows Plato talking with Philosophy at the top and philosopher William of Conches talking to his king at the bottom.

in a given time. Known as the mean speed theorem, it formed a key part of Galileo's work on mechanics in the seventeenth century and is still taught in schools. However, Galileo didn't give any credit to his predecessors, so the contribution of the Oxford Calculators was forgotten until rediscovered by modern historians.

I SHOT AN ARROW IN THE AIR

Equally important scientific developments took place in fourteenth-century Paris. The rector of the university, John Buridan (1301–1359), wanted to understand why objects keep moving after the withdrawal of the force that set them off. Aristotle said things could only move if something else is acting on them. Buridan realized this couldn't be right: after all, when an arrow is shot from a bow, it continues to fly through the air even though nothing is pushing it. He formulated the concept of *impetus*, a force that keeps the arrow racing toward its target until air resistance slows it down.

Impetus raised an interesting question: what would happen without air resistance or another kind of friction? Obviously this could never happen on the earth, but what about the heavens? Aristotle had said that the continuous action of God rotates the celestial spheres that carry the planets around the earth. Buridan thought this might not be necessary. Once God set the planets on their courses at the beginning of time, there would be nothing to slow them down and they would keep moving forever. This conclusion was an important precursor to Sir Isaac Newton's (1642–1727) first law of motion, on inertia, 300 years later.

Buridan also wrestled with God's freedom to perform miracles if he saw fit. In general he believed the material world follows regular laws that God had ordained and philosophers could investigate: "It is evident to us that every fire is hot and that the heavens are moved, even though the contrary is possible by God's power. And it is evidence of this sort that suffices for the principles and conclusions of natural philosophy."

Everyone agreed that miracles are possible, but also that they are rare enough not to interfere with studying the ordinary course of nature. God's freedom also meant he could have organized the world in any way he pleased; he wasn't bound by how Aristotle thought he should have done it. Buridan decided to examine whether God had arranged the world to follow one of Aristotle's most important propositions—that the earth is stationary at the center of the universe.

"I, GODLIKE PHILOSOPHY" This illumination from a 12th-c. encyclopedia for nuns shows Philosophy as the center of the liberal arts, which included scientific topics.

PHILOSOPHY WITH THE SEVEN LIBERAL ARTS, NICOLAS XAVIER WILLEMIN (1763–1833) / PUBLIC DOMAIN—WIKIMEDIA COMMONS

On an everyday basis, it seems to us that the earth isn't moving; the sun, moon, and stars appear to rotate around us every 24 hours, while we can't feel anything to suggest the earth is in motion. The ancients believed that if the earth were actually turning, a rushing wind would accompany it. Not so, said Buridan: if the atmosphere rotates *with* the earth, things would appear the same whether the earth or the heavens rotates. God could have arranged things either way. Indeed it seemed more elegant for him to make the tiny earth spin around its axis each day rather than move the vast sphere of the heavens.

Buridan explained this concept with the example of a boat floating down a river passing another vessel moored to the bank. Without reference to the surrounding landscape, someone on the moving boat observing the stationary one would not be able to tell which was in motion: motion is relative to our frame of reference. Copernicus (1473–1543) adopted exactly this argument, again without attribution, when he wanted to show why we can't tell that the earth is orbiting the sun.

Technological as well as theoretical progress occurred frequently in the Middle Ages. During the thirteenth century, the mechanical clock was invented, probably in England, to ring the bells so that monks would wake up in time to perform the divine office. Clocks rapidly spread into the towns, where they regulated the lives of workers as well as clergy. Hours became constant units of time rather than varying as the length of days and nights changed with the seasons.

Eyeglasses were another medieval invention, first appearing in late thirteenth-century Italy. They substantially increased the working life of scribes by providing a remedy for far-sightedness. Medieval Christians eagerly adopted inventions from the Far East as well—including the compass, gunpowder, and printing. Once they had grasped the basic concepts, they improved on them and developed technologies that allowed Europe to dominate the early-modern world. The compass enabled voyages out of sight of land across the Atlantic and Indian Oceans, while gunpowder provided a huge advantage in warfare.

Printing may have been the most significant new industry of the Middle Ages and required amalgamating several different technologies. Johann Gutenberg (c. 1398–1468), a metallurgist from Mainz in Germany, combined movable metal type, a wine press, and a sticky black ink from turpentine and soot to produce the first printed books in the 1450s. Paper made out of rags was much cheaper than parchment from animal skins and brought the cost of books down further.

DISMISSED AS SUPERSTITION

The rise of printing coincided with another area of renewed interest in the ancient world: the literature of Greece and Rome. Enthusiasts for the works of Plato and Cicero actively denigrated medieval scholarship as superstitious and (much worse) written in a degraded form of Latin. Luckily the new printed books preserved the natural philosophy of the Merton Calculators and John Buridan, ready for it to be picked up by Copernicus and Galileo.

Many people still imagine the Middle Ages as a period of stagnation dominated by an overbearing church. But it was in fact a period of dynamic change, of technological and scientific advances, and of the birth of institutions like universities, now so central to the modern world. Without the foundations laid during the Middle Ages, modern science as we know it might never have occurred. CH

James Hannam is the author of The Genesis of Science: How the Christian Middle Ages Launched the Scientific Revolution.

The condemnations of 1277

Debates over Aristotle's role in scientific exploration

NOW IN HARMONY? Both Aquinas (*fifth from left*) and Siger (*far right*) appear on this 19th-c. fresco illustrating scenes from Dante's *Paradiso*.

CASA MASSIMO FRESCOS: *STANZA DI DANTE*—CEILING BY PHILIPP VEIT. SAILKO / [CC BY SA 3.0] WIKIMEDIA

By 1277 Stephen Tempier (1210–1279), the bishop of Paris, had come to the end of his tether. Fierce arguments had been bubbling away for years at the University of Paris—and now even Pope John XXI, an alumnus of the university, was taking an interest. At the heart of the debate was one crucial question: what are the limits of God's power?

On one side were the students of Siger of Brabant (c. 1240–1284), a brilliant master in the Faculty of the Arts, who followed the deterministic philosophy of Averroes (1126–1198), a Muslim commentator on Aristotle. On the other side stood Paris theologians who defended the freedom of God to do whatever he wishes, subject only to not bringing about a logical contradiction.

The Paris theologians accepted that both Aristotle and Averroes could be useful, but Siger always seemed to adopt the most radical interpretation of their words. For example while Averroes appeared to cast doubt on personal immortality, Siger taught that after death we rejoin a hive mind responsible for the rationality of humanity as a whole. Averroes showed that the universe *could* be eternal and uncreated. Siger claimed it *must* be eternal and that God absolutely could not have created it.

Siger couldn't say that his ideas were actually true: that would be heresy and land him in hot water. Instead he walked a theological tightrope—explaining that while logic meant his teaching should be true, faith actually contradicts reason, and as a good Christian, he believed what faith taught. His students went further, however, and suggested that two truths could coexist: one according to reason and another according to faith. The church found this suggestion unacceptable, instead defending rationality as a gift from God that could never conflict with Christian doctrine.

MULTIVERSE, YES OR NO?

Siger's great intellectual opponent had originally been Thomas Aquinas, who had tried to reconcile the philosophy of Aristotle and Averroes with Catholic theology. By 1277, though, Siger had left Paris and Aquinas was dead. But still the debate simmered.

As a result Bishop Tempier took stringent action. In March of that year, he published a list of 219 opinions that derived from the teaching of Siger and his disciples and forbade Christians to hold any of the ideas on the list. The condemnations of 1277 prohibited the denial of personal immortality and human free will. It became illegal to say God could not have created more than one universe or a vacuum.

The condemnations did not aim to lay down doctrine: the bishop was careful to avoid making positive statements about the actual number of universes, or whether a vacuum actually could exist. After all, scientific orthodoxy at the time followed Aristotle by saying that a vacuum is impossible. Tempier *did* insist that God could create a vacuum through his absolute power—and furthermore, that he could have ordained the laws of nature to permit vacuums. We now know this is true and that most of space is empty.

Despite their strictness, the condemnations did not shut down scientific debate. On the contrary they permitted natural philosophers to consider whether Aristotle might be wrong and work through the physical consequences of that. Above all they preserved God's freedom to arrange the universe as he saw fit and the freedom of human beings to make moral choices.—*James Hannam*

LISTENING TO THE SPIRIT In this 13th-c. illumination, Hildegard receives a vision in the presence of her secretary, Volmar, and her confidante, Richardis.

HILDEGARD RECEIVES A VISION IN THE PRESENCE OF HER SECRETARY VOLMAR AND HER CONFIDANTE RICHARDIS—© FINE ART IMAGES/HERITAGE IMAGES / ALAMY STOCK PHOTO

To make whole

HILDEGARD OF BINGEN, NATURALIST AND APOTHECARY

Glenn Myers

> Oats (*avena*) are hot, with a sharp taste and strong vapor. Oats are a happy and healthy food for people who are well, furnishing them with a cheerful mind and a pure, clear intellect. . . . One who has a rash should . . . take the stem and leaves of lilies and pound them [and] knead this juice together with some flour, and keep anointing the part of the body which suffers from rash. . . . The odor of the first buds of lilies, and indeed the odor of the flowers, makes a person's heart joyful and furnishes him with virtuous ideas.

THUS HILDEGARD OF BINGEN (1098–1179) described the medicinal value of oats and lilies, just two out of the nearly 300 herbs, plants, and trees detailed in her work *Physica*. She offered hundreds of natural cures, ranging from compresses for the eyes to potions for drinking. While many of these home remedies seem antiquated to the modern reader, others are remarkably relevant: they describe the value of aromatherapy and the connections between gut, mind, and mood that are at the cutting edge of research today. Over 800 years after her death, Hildegard was named a doctor (teacher) of the Catholic Church in 2012, only the fourth woman to receive this honor.

"THE VAULT OF HEAVEN"

Born to a noble family, Hildegard was abbess of two Benedictine monasteries that she founded along the Rhine River in Germany. She was originally sent to the monastery of Disibodenberg as a child—perhaps as young as eight—and remained a nun for the rest of her life, eventually being elected by the other nuns to lead the community when she was in her late thirties. Through perseverance she won an independent location for her nuns about a decade later. Even as a child, her interests were broad and deep:

> From my early childhood . . . I have always seen this vision in my soul, even to the present time when I am more than seventy years old. In this vision my soul, as God would have it, rises up high into the vault of heaven and into the changing sky

and spreads itself out among different peoples, although they are far away from me in distant lands and places. . . . I am constantly fettered by sickness, and often in the grip of pain so intense that it threatens to kill me, but God has sustained me until now. The light which I see . . . is far, far brighter than a cloud which carries the sun. I can measure neither height, nor length, nor breadth in it; and I call it "the reflection of the living Light." And as the sun, the moon, and the stars appear in water, so writings, sermons, virtues, and certain human actions take form for me and gleam.

Hildegard has been appreciated over the centuries for her morality play *Ordo Virtutum* (*Order of the Virtues*, c. 1151)—the first known morality play in history—as well as her writings on theology and spirituality. Beyond these specifically spiritual contributions, however, she was also a polymath—dabbling in everything. She painted beautiful illustrations for her books, composed music still played today, and became especially known for her work as a naturalist.

Fascinated with the world in which we live, she contributed to the study of the therapeutic value of animals, birds, fish, and minerals; served as an apothecary; and provided medical care to many who came to see her. Far from being a heavenly minded saint who was no earthly good, Hildegard ministered to the physical and spiritual health of untold numbers of people.

DESCENDING FOR US This image of Christ redeeming creation, possibly by Hildegard, illustrates an edition of her *Liber Scivias*.

THE REDEEMER. MINIATURE FROM *LIBER SCIVIAS* BY HILDEGARD OF BINGEN. MUSEUM: EIBINGEN ABBEY—ALBUM / ALAMY STOCK PHOTO

THE WHOLE PERSON

Hildegard researched and prescribed herbal cures out of care for the whole person and concern for the well-being of others: body, soul, and spirit. As well as wanting people to draw close to God, Hildegard also desired them to be in good health: healthy *and* holy. Indeed, in both German and English, the words "health" and "holiness" come from the same root, meaning "to make whole."

Hildegard looked at many aspects and ailments of the human person in her cures—from digestion to balding, from dreams to eyesight. She explored psychology and physiology, and even prescribed the appropriate age for marriage and procreation. Surprisingly for a nun, she discussed specific sexual issues (in discreet terminology): the pleasures of sexual activity, the dangers of sex outside of marriage, and nocturnal emissions. She offered remedies for menstrual difficulties in women and for diluted semen in men, so families would be able to have children.

In her *Causes and Cures*, Hildegard recognized the body-soul interrelatedness of human beings, addressing issues such as madness—proposing what she saw to be the physical dynamics of uncontrollable "rage" as well as the spiritual forces at work. She likely composed music at least in part because it helped to dispel "melancholia," a generic term including various types of depression.

The unique and valuable observations in Hildegard's writings on cures stemmed from her appreciation of balance in the human organism. Following medical thought prominent since antiquity, Hildegard saw the human body as containing four "humors"—blood, phlegm, yellow bile, and black bile. But it was Hildegard who originally asserted that for us to be healthy, these humors need to remain in balance, just as medieval people thought the four elements of the universe should be. She stressed the need for bringing them back to

GOOD FOR YOU This 11th-c. herbarium shows that Hildegard was not alone in her interests.

equilibrium, much as modern medicine recognizes the need for hormonal and chemical balance in the body.

Likewise Hildegard sought equilibrium between the ancient Hippocratic "hot" and "cold," as well as the "moist" and "dry" qualities of things. To treat body and spirit, one needed to know what combination of these attributes each herb contains: "Every plant is either hot or cold, and grows thus, since the heat of the herbs signifies the spirit, and the cold, the body. . . . If all herbs were hot and none cold, they would cause difficulty to the user. If all were cold, and none hot, they would provide an imbalance in people."

GRAND SCHEME OF CREATION

Hildegard's interests in the healing and sustaining powers latent in creation went far beyond herbs. Her *Physica* also catalogs scores of plants, elements, trees, stones, fish, birds, animals, reptiles, and metals—describing each and stating how it can be used for various ailments. Along with her descriptions of how nearly 230 plants should be cooked or boiled, she detailed 36 species of fish and other aquatic animals; 72 birds and insects; 45 land animals, informing her readers which are beneficial as food and which are not; and no less than 63 varieties of trees from around the globe, as well as various precious stones, presenting the putative healing value of each.

Causes and Cures, Hildegard's larger work in medicine, offers a more comprehensive discussion of the natural world and human bodies. Hildegard explored the sources of various illnesses and addressed human sexuality, sleep, nutrition, bathing, and skin complexion; even including instruction on phlebotomy—bloodletting—a common medical practice that sought to detoxify the body, as well as more cures for the illnesses she had identified. She even addressed how the various phases of the moon affect us.

Not the first to make such a compendium of ailments and their cures, Hildegard clearly followed her predecessors. Because professional physicians were few and expensive, apothecaries performed much medical care up to the twelfth century; many were monks and nuns. (*Read more about this in* CH 101—*Editors*). Rather than being isolated from the world, medieval monasteries provided medical care to ailing and aging monks and nuns and also to local townspeople who regularly came for help.

Monastic houses cultivated herb gardens for medicines and maintained libraries with medical books. In fact most works on home cures were produced and copied in monastic scriptoria. Hildegard was well read, and her works summarize much of the thinking of the day. But she took the bold step of inserting her own insight and application throughout.

Hildegard placed her study of the natural world and herbal medicines in the grand scheme of God's creation and plan of salvation. She believed that God created a good universe filled with heavenly harmony and teeming with the fiery power of God's Spirit. She wrote of "the fiery life of divine essence . . . [which] awaken[s] everything to life." All of creation is orderly and benevolent, she said, maintaining a balance of the classic four elements of the universe: fire, air, water, and earth. Such balance, she posited, would remain until Judgment Day.

Following the opening chapters of Genesis, she saw man and woman as the apex of creation: "With earth was the human being created. All elements served mankind and, sensing that man was alive, they busied themselves in aiding his life in every way. And man in turn occupied himself with them."

That pristine state of creation did not last, however. At the serpent's temptation, Adam and Eve rebelled against God. The Fall brought corruption not only into human souls but also into the physical world: "Driven into a wretched exile, they became corruptible along with the other fruits of the earth. At their fall and banishment all creatures of the earth were darkened."

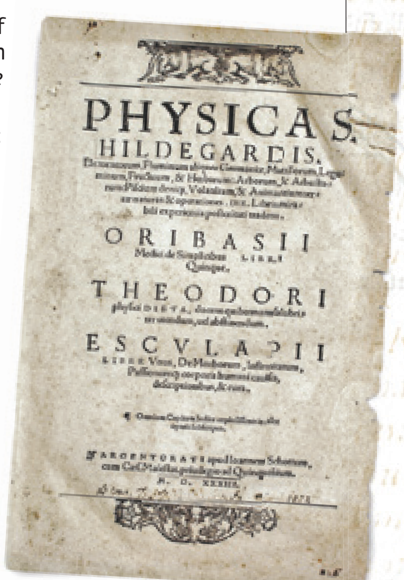
Even after the Fall, however, some of the goodness of nature remained; so she felt it was humanity's task to learn which plants and animals are now healthy for us and which are not. Just as God provided a way for the human soul to be redeemed, God had offered much goodness in plants, food, and even minerals for the healing of our ailments. Hildegard's concern came from her understanding of a Creator who heals and saves. Humankind is both part of creation and given the task to explore nature and use it.

LIKE THE SUN AND MOON

Hildegard saw humans as a microcosm corresponding to the macrocosm of the universe. Just as we need sleep to regain our strength, so in nature growing plants are restored during the fallow winter months. "As the soul holds the entire body of a human being, so the [four winds of the earth] hold together the entire firmament." She added, "[our] eyes are made according to the likeness of the firmament. The pupil of the eye has a likeness to the sun, the black or grey color around the pupil has a likeness to the moon."

Though she spoke to her own times, this cloistered noblewoman has lessons for ours: to embrace God's good creation; to pursue knowledge and read broadly in the sciences; to care for the whole person, the physical body as well as the human spirit; to be attentive to balance and moderation; and to take a fresh look at alternative approaches to wellness. Perhaps above all Hildegard provides a model for viewing science, our lives, and all of nature in the grand scheme of God's economy of creation and salvation: with each detail of the cosmos—from the furthest-flung galaxy to the smallest subatomic particle—part of a divine metanarrative being told by the God of love.

The more we grasp the grandeur of the Creator revealed in the beauty, awe, and detail of the universe, the more we see how science and faith belong hand in hand. Hildegard's very heavenly mindedness enabled her to be of utmost earthly good, bringing healing to people all around her through wise understanding and careful use of God's creation. CH



UNDER ATTACK A 16th-c. edition of *Physica* (*right*) shows threats to human health and wholeness from inside (*above left*) and outside (*above right*).

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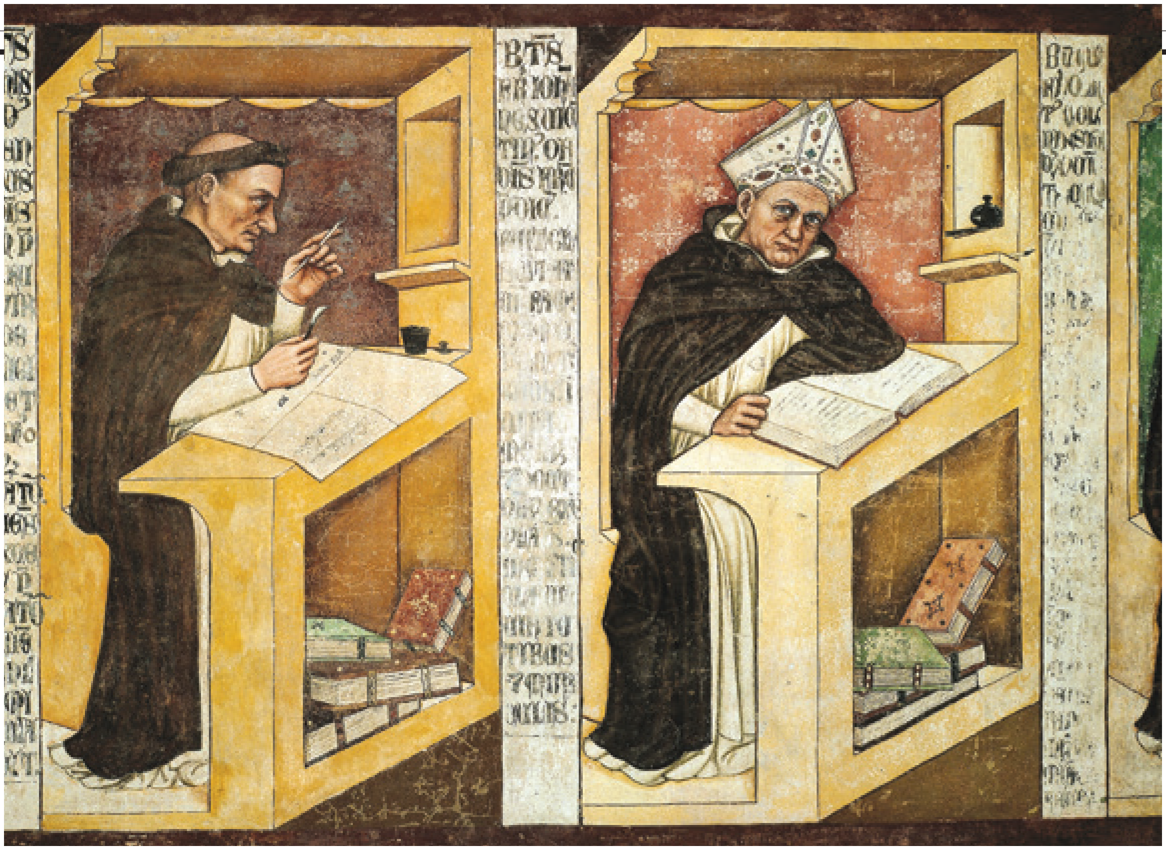
PLATES AND FRONTISPIECE FROM HILDEGARD OF BINGEN, *PHYSICAS* (ARGENTORATI, 1533), PUBLIC DOMAIN—IMAGES COURTESY HISTORY OF SCIENCE COLLECTIONS, UNIVERSITY OF OKLAHOMA LIBRARIES



ST. GIOVANNI DA SCHIO AND ST. ALBERT THE GREAT (FRESCO), TOMMASO DA MODENA, 14THC—DE AGOSTINI PICTURE LIBRARY / BRIDGEMAN IMAGES

What is so great about Albert?

THE PRESERVER OF SCIENTIFIC RICHES

Michael W. Tkacz

HISTORIAN ETIENNE GILSON once remarked that Albert the Great (1200–1280) is far less known than he is celebrated. Indeed, if Albert is known at all today, it is most likely as the teacher of Thomas Aquinas (1225–1274). Yet in his own day, Albert's fame far exceeded that of his student and fellow Dominican. While Thomas was still young and relatively unknown, Albert already bore the title *Magnus*, "the Great," in honor of his vast learning.

The thirteenth century's "gossip columnist," Roger Bacon, with clear outrage and perhaps a bit of envy, complained that most students, and even some very learned men, considered Albert as much of an authority on philosophy as the renowned Aristotle—even though Albert was still alive! Bacon clearly believed this an unprecedented indecency. Yet Bacon would have had to admit Albert's substantial contributions to the intellectual life of his time.

THE MEDIEVAL SCIENTIFIC REVOLUTION

To truly understand Albert's contribution, it is necessary to see it in the historical context in which it was conceived and carried out. Albert was born in

EVERYBODY STUDY Albert (*at right*) appears in this fresco in a 14th-c. Dominican chapterhouse along with another Dominican saint, Giovanni da Schio.

the Danube town of Lauingen; instead of pursuing his father's military profession, he left home for the university town of Padua to study the liberal arts. There he met a Dominican friar, Jordan of Saxony, who inspired him to join the newly founded Order of Preachers. By 1228 Albert had completed his novitiate and four years of theological study. His scientific and theological talents became obvious, resulting in subsequent advanced studies at the University of Paris.

All this occurred against the background of a profound event in intellectual history: the recovery of Aristotle's books in Latin-speaking western Europe during the decades preceding Albert's birth. The significance of this lay in the contents of these books primarily devoted to the natural sciences. Some 1,500 years earlier, Aristotle had worked out the basic structure of an empirical research program and had himself conducted research in biology and other sciences.

By the time Albert was a student at Paris, Aristotle's natural science was just beginning to make an impact on the intellectual life of the Latin Christian West.

A HANDBOOK This 13th-c. manuscript, *On the Nature of Things*, once attributed to Albert, is now believed to be by his Dominican colleague Thomas of Cantimpré.

A LONG-REQUESTED GUIDE

The story of Albert's *own* impact essentially began in the year 1249 when Albert, who had been a Dominican for about two decades, finally yielded to the pleas of his Dominican colleagues to compose a work explaining Aristotle's natural science. Albert had come to the University of Paris six years before as a professor of theology while teaching under the direction of the Dominican theologian Guéric of St. Quentin. In 1245 he succeeded Guéric as a lecturer and held this chair until 1248.

But Albert's learning was not confined to theology alone. His colleagues soon recognized his skills in the natural sciences and began asking him to compose an introduction to Aristotle's books on nature. Albert put the brothers off for three years until the Dominican master general ordered him to resign his professorship at Paris and establish a school of theology at Cologne.

Thus in the hot dusty summer of 1248, Albert and a small band of Dominican friars (including the young Aquinas) made their way on foot along the old Roman road flanking the Rhine River to the Priory of the Holy Cross in Cologne. The following year Albert finally began work on the long-requested guide to Aristotle's books on the empirical sciences, including cosmology, meteorology, biology, and many others.

It didn't take long for the reluctant writer to find his footing. Albert first finished an ambitious commentary explaining Aristotle's *Physics* (a treatise on the general principles of nature). Yet his ultimate goal was far greater. Albert had been trained in theology and mandated by his religious superiors to establish a seminary, but now additionally devoted himself to long-term research in the natural sciences.

From the very beginning of his commentary, Albert declared that he was setting out to make the newly discovered learning of Aristotle intelligible to Latin readers. Indeed Albert wrote what some called the world's first encyclopedia, covering far more than his Dominican brethren could have imagined. He did this while continuing to teach, rising in the Dominican Order, becoming a bishop, and finally being relieved of that job by the pope so he could preach the Crusades. (As a bishop he refused to travel through his diocese on a horse and was nicknamed Boots the Bishop by his flock!)

Albert followed up his elementary guide to Aristotle's *Physics* with a systematic and learned treatment of the whole of human knowledge—in one modern edition, it encompasses 38 volumes. He treated, in orderly fashion, all the natural sciences—both celestial and terrestrial. In addition he wrote on mathematics, logic, rhetoric, ethics, economics, politics, and metaphysics. Albert intended all this from the start and carried out his plan in a deliberate and systematic way following the order of Aristotle's books.

Albert's procedure was to report on Aristotle's original research, describing his methods and conclusions. However, he did not stop there, for he extended and updated Aristotle at nearly every turn. To Aristotle's extensive zoological studies, for example, Albert added equally extensive descriptions of species Aristotle had not known, including his own original research. He also added books on sciences not treated by Aristotle, but clearly needed to complete the Aristotelian program of empirical studies, such as mineralogy and geomorphology. In addition he provided careful studies of Aristotle's scientific method, showing how

Aristotle had established the essential elements of a scientific research program. Indeed Albert's treatment of Aristotle's scientific writings was comprehensively planned, carried out deliberately, and operated in accordance with a carefully defined understanding of the place of scientific learning in Christian culture.

But Albert's voluminous writing was just the beginning. He established a groundbreaking curriculum at Cologne by stressing empirical study as a key element in robust Christian formation. Though the sacred Scriptures and the works of the church fathers remained the primary sources for theological studies, Albert added Aristotle's books to the typical curriculum, including books on the empirical sciences.

During the academic year 1257–1258, for example, Albert supplemented his lectures on the Gospels with lectures on Aristotle's zoological treatises, guiding his students in replicating some of Aristotle's original experiments and even involving them in original zoological field studies. Clearly Albert considered that those preparing for the priesthood would not only require knowledge of the Scriptures but also an appreciation for the order and intelligibility of nature.

Before the reception of Aristotelian science in the then newly established universities, higher education had been mostly confined to theology. The seven liberal arts—grammar, logic, rhetoric, arithmetic, geometry, proportions, and mathematical astronomy—were studied in early medieval monastic schools, but mostly as a preparation for advanced theological studies. This now radically changed. For the first time, European scholars had access to an extensive body of empirical studies as well as a detailed account of a method for conducting science with promise of future scientific progress. This resulted in a medieval scientific revolution, initiating the common use of experimental methods upon which modern science was eventually based. By the time of his death in 1280, Albert was accepted as the primary medieval authority on these methods, and his work influenced Galileo and other early modern scientists.

STILL GREAT, LATER Cologne, where Albert established his seminary, would still have looked familiar to him in the 15th c.—when the lecture notes (*left*) of Swedish student Olaus Johannis Gutho depict Albert arguing with Aristotle.

HARMONIOUS FLOURISHING

Albert's dissemination and extension of Aristotle were not unique, though. Equally fascinated by the research potentials of the new science, others also commented on Aristotle's books and pursued empirical studies modeled on Aristotle. Rather, Albert's special merit lies in the fact that he was the first scholar to clearly define the rightful place of scientific learning in Christianity. Albert passed this on to his most talented student, Aquinas, who would go on to demonstrate that scientific knowledge of nature is both compatible with and supportive of Christian doctrine.

This meaning has not been lost on the church, then or now. In 1941, in the dark days of World War II, Pope Pius XII declared Albert patron saint of those who devote themselves to research in the natural sciences. When some wielded scientific learning only to bring about suffering and destruction, the pope proposed a different place for science in human affairs, pointing to Albert as a model of how "science and faith can flourish harmoniously" in human culture. CH

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Understanding God through light and tides

And God said, 'let there be light.' And there was light." In chapter 1 of Genesis, this verse signals the first day of the creation of the world. Aptly enough this sentence also begins the natural philosopher Robert Grosseteste's (1175–1253) treatment of the first day of creation in his theological masterwork from the 1230s, the *Hexameron*. Taken from the Greek, *Hexameron* means "six days," and the term refers to a genre of commentary writing that dates back to the fourth century. Basil of Caesarea, Augustine, and—much later—the Venerable Bede all wrote such commentaries, and Ambrose produced one in Latin that was an adaptation of Basil's Greek work.

Grosseteste followed the conventions of this ancient tradition, but he also brought to bear the fruits of his lifelong study of nature. This included detailed descriptions of such phenomena as planetary motion, the tidal periods of the sea, and, of course, light and vision. After all, as he reminded his readers, the light described in Genesis "is understood . . . to be physical light."

Grosseteste was able to fortify his interpretation of the Scriptures with a deep knowledge of nature thanks to the many years he had spent as a student, and then a master, at the nascent universities of western Europe. Born to a family of modest means in Suffolk, England, he received an early education in the arts, law, and medicine before beginning his career as a master at Oxford sometime around 1200.

He interrupted his teaching at Oxford to study theology at the University of Paris from 1209 to 1214. Upon his return, he became the chancellor of Oxford University (1214–1230), and five years later was elected bishop of Lincoln; he served in that position until his death. A prolific author on many subjects, he penned a treatise on Christian law and translated (with commentary) Aristotle's *Nicomachean Ethics*.

PREACHER AND PHILOSOPHER A 15th-c. rendition of Grosseteste adorns the initial letter of one of his sermons in an edition of his works.

EXPERIMENT AND CAUSE

All the while Grosseteste pursued with interest recent translations of Greek and Arabic works on the natural sciences; soon he began to write treatises on these subjects himself. In 1221 he explored the causes of sound. Five years later he finished a study on the effects of the moon's motion on the periodic movements of the tides. And from 1232 to 1235, before starting the *Hexameron*, he busied himself with a treatise on mathematics and three treatises on light: on color, the sun, and the rainbow. In the third he employed the law of refraction to explain a rainbow's shape and its position in relation to the observer.

Grosseteste's conclusions were not always right according to the findings of modern science (for instance, though his account of the rainbow employs the law of refraction, it is incorrect). Nevertheless his work was highly influential and continues to interest historians, in part because he applied a systematic method in his studies. Building on but going beyond ancient Greek mathematics and logic, he called his method "analysis and synthesis." Through it he sought to resolve or analyze the effects of nature back to their initial conditions.

Grosseteste instructed his readers to begin with an experience (*experientia*) and to work backward from it to find its causes. Scholars continue to debate the extent to which Grosseteste's method anticipated the later scientific standard of hypothesis-driven experimentation. What remains clear is his own commitment to using this method to better understand the order of the cosmos—the relationship between God the final cause and his creation.—*Nicholas Jacobson, postdoctoral fellow in the history of science, medicine, and technology, Observatoire de Paris*

WISE THOUGHTS 20th-c. artist Howard Pyle imagines Bacon at work in his study.

Faithful friar or scientific sorcerer?

ROGER BACON ON EXPERIMENTAL SCIENCE

Richard Oosterhoff

IN JULY OF 1266, Roger Bacon (c. 1219–c. 1292) found himself in an awkward position. He and the current pope, Clement IV, had known each other for years, going back to the late 1250s when Clement had been a papal legate and Bacon himself had recently joined the Franciscan Order. In those earlier days, the two had shared conversations about the state of the world.

Both were of an ascetic bent. Both believed that Christendom's internal conflict and Middle Eastern threats signaled the end times. Drawing on those conversations, Bacon now promised the pope a diagnosis of the age's problems—and solutions to combat them. Clement IV swiftly wrote back, requesting Bacon's insights and freeing him from any conflicting obligations to his Franciscan superiors. The response sent Bacon into a brief panic: he had not yet developed the proposed work!

Moreover, although he had spent years writing and teaching as a master of philosophy at Oxford and Paris, he had written little since joining the Franciscans in 1256. His position was further complicated by financial considerations; his family could not support him, having lost its wealth in Henry III's expensive civil war with England's barons. Yet this unpromising start led to a prophetic work of natural science: the *Opus maius*, a "greater work" in seven parts that sketched out his plan of reform. (Later installments, an *Opus minor* and an *Opus tertium*, filled in the details.)

COMPLETE WISDOM

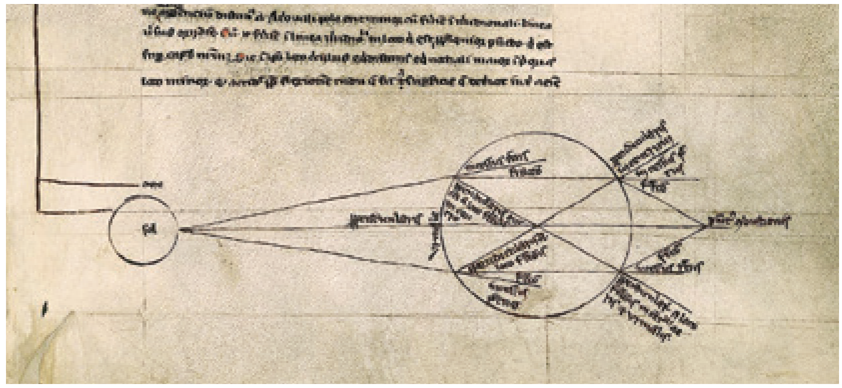
Bacon began with the causes of error in society—people were ready to believe too much without good evidence—and then offered a way forward to what he called "complete wisdom." Philosophy would have to be reformed. Universities should begin by teaching Greek and Hebrew and then the branches of mathematics before presenting a study of nature—or as Bacon called it, "experimental science" (*scientia experimentalis*). Teaching philosophy this way would supply theologians a moral foundation for healing Christendom.

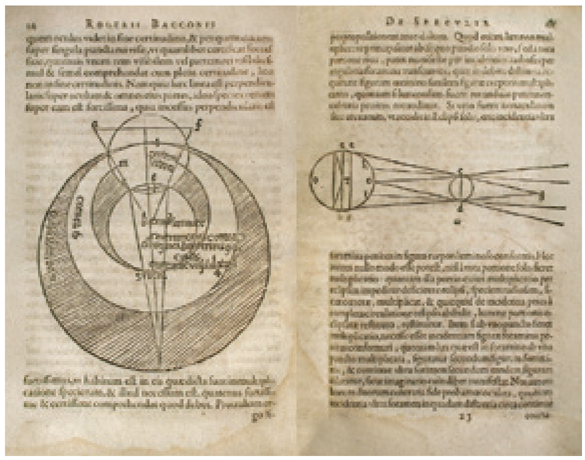
Early fans of Bacon obscured his actual achievement. Medieval alchemists attached his name to their writings, ascribing a body of treatises to him. Renaissance thinkers described him as a *magus* or sorcerer using alchemy and astrology to uncover and manipulate the secrets of nature. Playwright Robert Greene (1558–1592) popularized legends of Bacon as a renegade monk using demonic magic to animate a talking brass head.

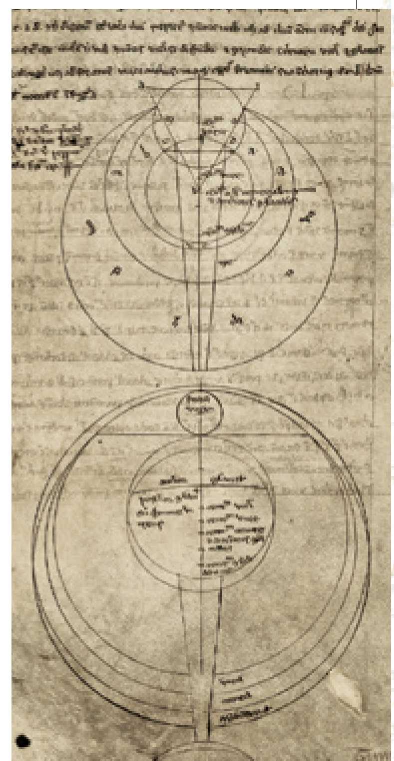
In early modern Protestant England, many downplayed Bacon's Franciscan vocation and focused instead on his technological prowess. This was so in the Royal Society of London, the group of "new philosophers," including Robert Boyle and Isaac Newton, who helped forge experimental techniques into new, coherent philosophies of nature. It became even more true in Victorian England, where proscience, anti-Catholic Protestants assumed Bacon could not have been both a devoted Catholic and an influential scientist. They were wrong: Bacon had seen his experimental science as a force for good capable of helping humanity out of its ignorance and toward a better future. But he did so because of his Franciscan commitments, not despite them.

"FRIAR" BACON IN HIS STUDY (ROGER BACON), 1903 (OIL ON CANVAS)—GIFT OF MR. AND MRS. HOWARD P. BROKAW, 2007 / BRIDGEMAN IMAGES

Bacon's vision of science looks modern in startling ways. He was committed to innovation, preferred experience over authority, and above all saw science's value for society as lying in its technological utility. Even Bacon's temper and style appears modern; he readily lambasted his opponents or those he thought intellectually dim. While commending the accomplishments of Aristotle and the lost knowledge of the ancients, he urged his contemporaries to improve on them. He repeatedly criticized translations and argued that Hebrew, Greek, Arabic, and even Latin should be subjects of sustained study—so scholars could amend bad manuscripts and clear up conflicting interpretations of the Bible and of ancient philosophers.







STILL USEFUL These diagrams from Bacon's work in optics and perspective may look familiar if you've ever been fitted for glasses or studied drawing!

CALCULATING EASTER

More than any other medieval intellectual, Bacon also recommended mathematics and disciplines using mathematical reasoning—optics and perspective, cartography, astronomy—as the sharpest tools for thought. He dedicated his longest section of the *Opus maius* to mathematics, calling it the "gate and key" to all knowledge, and expanded on its use in medieval theology: the computation of church calendar dates like Easter, the use of astronomy to understand eclipses (such as the one supposed to have occurred during Christ's Passion), and geometrical and arithmetical pictures of the Trinity.

Bacon fastened upon light and sight as an example of how mathematical entities infused all of nature—the "science of rays," or perspective. This idea was so important to Bacon that he sent Clement IV an additional treatise expanding on it. *On the Multiplication of Species* argues that all change in the natural world happens through "species," a force or power by which one object acts on another. Bacon used this to explain light bending when it hits glass or water or a mirror, and vision when the image of something moves through the eye's pupil to the optic nerve.

Bacon partly owed this "light metaphysics," as some historians have called it, to Robert Grosseteste (see p. 18), whom Bacon had admired and probably read at Oxford. Grosseteste had written widely on optical subjects and reflected carefully on how to use experience in specific cases to understand more than mere intuition can—untangling complex truths that mingle mathematical and physical phenomena. Bacon added one ingredient more, thanks to his reading of scholars such as Arabic perspectivist Hasan Ibn al-Haytham (Alhacen): using experiments not merely to uncover new truths, but to *test* knowledge systematically.

Bacon encouraged a hands-on approach to nature and claimed to have spent a small fortune of over £2,000 on language study, books, instruments, and materials. His writings on perspective describe many experiments with pinholes, lenses, or materials such as "crystals" for separating a rainbow's rays. But to isolate all these marks of a *scientia experimentalis* from the purposes Bacon intended for his method misrepresents him.

Bacon's larger concern was for the future of Christendom. Grosseteste shared this concern; in 1250 he had gained an audience with Pope Innocent IV and used the occasion to warn the papal court that its neglect of pastoral care was at the root of current wars throughout Europe, the threats of Mongols and Turks, the loss of Jerusalem, and especially the discontent and self-serving ambition of Christians. Depravity flowed from the "head" out to the body of the church in its dioceses. The only answer could be reform of the clergy. But how?

MAGIC TRICKS Queen Elizabeth I's personal *magus*, John Dee (1527–1608/9), pictured above performing an experiment for the queen, collected Bacon's manuscripts.

Universities, new institutions in the early 1200s, had supplied growing cities and courts with secretaries and bureaucrats, specialist lawyers, physicians, and theologians. The new mendicant orders, Dominicans and Franciscans, had set up study centers within universities so that their fast-growing memberships straddled ecclesiastical and secular lines of learning.

Only students with the stomach for completing the philosophy degree could study law, medicine, or theology. Previous papal restrictions on new translations of Aristotle relaxed, and new translations of Arabic commentators also circulated. Philosophical study became more sophisticated and standardized around new handbooks on Aristotle's logic. Masters measured student progress in verbal examinations, called disputations; these public events drew crowds to witness logical swordplay.

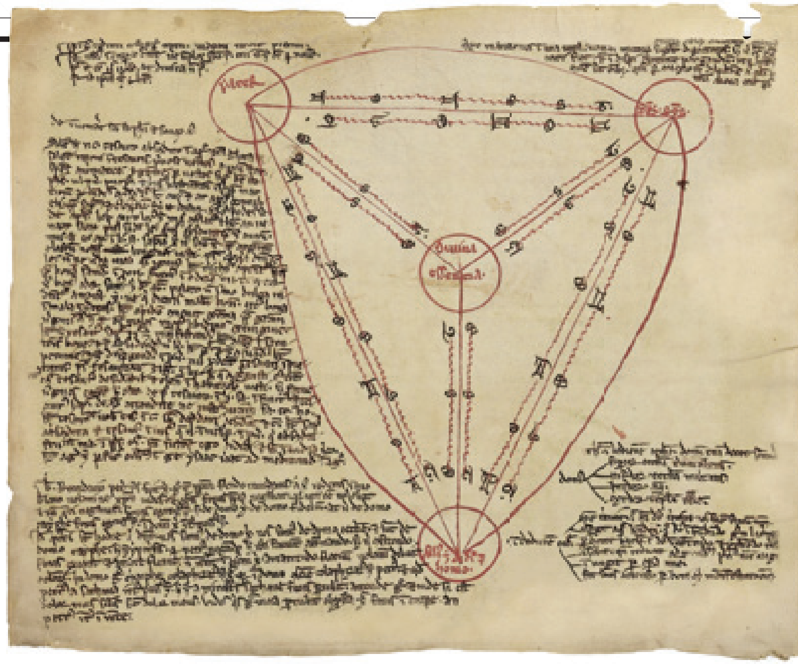
Frustration with flaws developing in this system ran through Bacon's advice. Bacon took a conservative view of the system, drawing on the ideal of the universities of his youth, when they seemed more clearly motivated by the Augustinian search for wisdom. The first book of the *Opus maius* argues that wisdom had become blocked by widespread error and ignorance, rooted in the pride of so-called scholars who accepted any authority simply because it was ancient or fashionable. The second book urges a return to the main goal of philosophy: to know the Creator from the created things.

FALL, APOCALYPSE, TECHNOLOGY

Another of Bacon's driving assumptions was similarly widespread: that God had given Adam an original knowledge, much of which had been lost in the Fall, only glimpsed by ancients from Solomon to Aristotle, and corrupted through human institutions and history. The loss could be balanced and restored, however, by Christ's first and second comings.

Bacon's views of knowledge took on special intensity in the context of thirteenth-century debates over reform. Medieval religious orders had generally been founded to seek the state of grace of the primitive church, and the Franciscans were no exception. The followers of Francis of Assisi emphasized the spiritual value of ordinary and unlearned people; they stressed their founder's simplicity, setting him alongside the ancient church's hermits and apostles, fishermen and carpenters—like Christ. Franciscan debates over how to interpret Francis's example reached fever pitch in the 1250s, during Bacon's first years in the order. These debates focused on poverty: teaching, study, and travel required money, even for mendicants.

For Bacon, though, the idea of "original knowledge" showed that *learning* could revive this early perfection, and it could do so through experiment. Rather than webs of corrupting hearsay, designed to tickle ears but hide the truth, he proclaimed that *touching*, *tasting*, and *seeing* were the ways to understand the manner in which God had set the world's foundations in place.



RIGHT KNOWLEDGE Bacon was influenced by both Ibn al-Haytham (whose diagram of the eye is *below*) and Robert Grosseteste (whose diagram of the Trinity is at *right*).

Apostolic simplicity cut two ways. It countered selfish, greedy clergy and monks who used logic and authority only to compound ignorance. And for Bacon it suggested that lowly handcraft and experience could improve knowledge. The last shall be first.

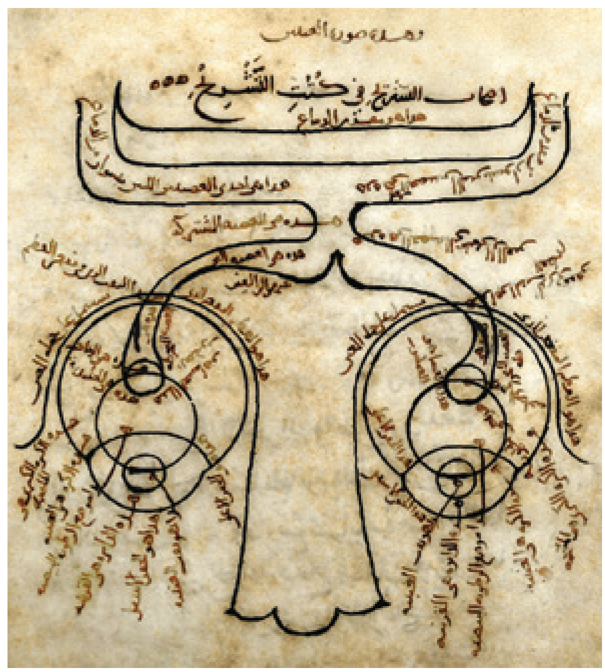
DEEPEST ILLS

Such concerns grew even more acute due to a widespread sense that Christendom had come to a turning point in history. European Christians were killing one another, proving that the last days had come. The more rigorous wing of Franciscans turned to Daniel and Revelation to calculate various chronologies culminating in the appearance of the Antichrist—who was variously identified with the Mongols, Muslims, or a particular king or pope. Emperor Frederick II joined in the calculations, as did several popes.

Thus Bacon's science was bound up with an evangelism designed to bring in the final number of the saved. Bacon believed right knowledge helps to diagnose sources of error, identifying what stops people from believing the truth. Unbelief could be countered with better proofs for faith. Moreover, better knowledge of geography and world affairs would equip the Latin West to anticipate and defend against the onslaught of the Antichrist's armies.

The *Opus maius* suggests that alchemical wisdom would supply gold to fund armies and could devise large-scale weapons: diseases that spread through contact and might destroy an enemy without an army, or explosions of fire that burned even in water, or mirrors that could confound an enemy at a distance, or even incantations that might bring down heavenly power on an enemy's head. Many came from the *Secret of Secrets*, an advice manual for princes translated from the Arabic tradition, and these earned Bacon much of his later reputation as a conjuror.

Like most ancient and medieval thinkers, Bacon also believed that environment—such as food and weather—affects health, body, and mind, and that the sun and other planets differently influence people in different places around the world. Heavenly powers therefore might shape human dispositions—including belief in particular truths. Within this framework Bacon advised the use of astrology to identify the distinctive natures of different peoples. Through it Christians would best learn how to persuade the nations of Christian truth.



In this distant setting it is easy to miss Bacon's ideas that remain foundational assumptions in our own world, such as the promise of technology to help us address humanity's deepest ills. Apocalyptic times allowed Bacon to give a vision of technology not merely as a conservative return to primordial wisdom, but a story of improvement, a progressive history. This assumption has underwritten some of the most ambitious projects of modernity—from eugenics to space exploration. Bacon might have been shocked to find himself sharing such ground. CH

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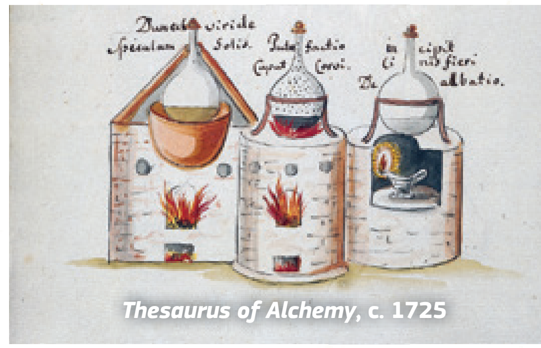
Faith and Science

Hildegard of Bingen, *Liber divinorum operum*, 13th-c. edition

- ***c. 370*** Basil the Great writes the earliest known *Hexameron*, a commentary on the Genesis account of creation.
- ***c. 397*** Augustine writes *Confessions*, which includes theological and scientific commentary on Genesis.
- ***416*** Augustine publishes *The Literal Meaning of Genesis*.
- ***c. 530–34*** John Philoponus, perhaps the first Christian scientist in history, writes *On the Eternity of the World against Aristotle*.
- ***c. 703*** The Venerable Bede begins his *Hexameron*.
- ***999*** Mathematician Gerbert of Aurillac becomes pope as Sylvester II.
- ***1088*** University of Bologna, considered the oldest European university, is founded.
- ***1096*** We have the earliest evidence of formal teaching at what became the University of Oxford.
- ***c. 1150*** Hildegard of Bingen writes *Physica* and *Causes and Cures*.
- ***1200*** University of Paris is officially chartered.
- ***1216*** Dominican Order is founded; many Dominicans will become leaders in science and universities.
- ***1230*** John of Sacrobosco publishes *De sphaera mundi*.
- ***c. 1235*** Robert Grosseteste writes his *Hexameron*.
- ***1249*** Albert the Great begins writing his influential commentaries on Aristotle.
- ***1267*** Roger Bacon sends his *Opus Majus* to the pope.
- ***1277*** Bishop of Paris, Étienne Tempier, issues a condemnation of interpretations of Aristotle that fall outside of Christian orthodoxy.

Albertus Magnus, *Liber aggregationis*, 15th-c. edition



Thesaurus of Alchemy, c. 1725

- ***c. 1290*** Thomas Bradwardine, foremost of the mathematicians and philosophers called the "Oxford Calculators," is born.
- ***c. 1350*** John Buridan develops the concept of impetus.
- ***1413*** University of St Andrews is founded.
- ***c. 1450*** Metallurgist Johannes Gutenberg develops movable type, enabling mass printing.
- ***1543*** Nicolaus Copernicus publishes *De Revolutionibus*, laying out his heliocentric theory.
- ***1596*** Johannes Kepler writes the first public defense of the Copernican system.
- ***1609*** Kepler publishes his first two laws of planetary motion.
- ***1616*** The Roman Inquisition issues its first judgment against Galileo.
- ***1617*** Kepler begins publishing the *Epitome of Copernican Astronomy* and sends a copy to Galileo.
- ***1619*** Kepler develops a musical notation for planetary movement.

A few of the highlights of

CHRISTIAN EXPLORATION OF SCIENCE

THAT WE TOUCH ON IN THIS ISSUE

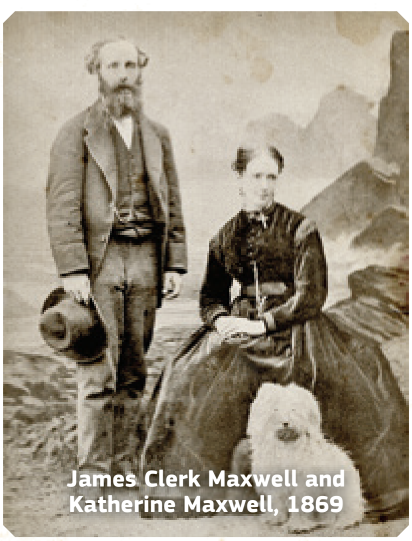
1630 Galileo finishes his *Dialogue* and obtains permission for its printing from the Vatican.

1633 The Inquisition convicts Galileo of heresy; his sentence is commuted to house arrest, and he continues experimenting.

1660 Robert Boyle and others found the Royal Society of London for Improving Natural Knowledge.

1665 Boyle publishes the popular *Occasional Reflections Upon Several Subjects*.

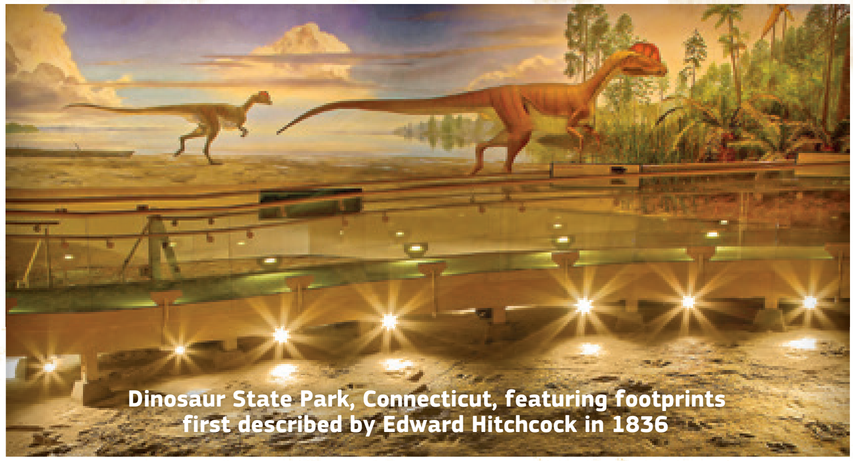
1668 Newton builds his first reflecting telescope.


James Clerk Maxwell and Katherine Maxwell, 1869

1687 Isaac Newton publishes his three laws of motion and the law of universal gravitation.

1686 Boyle publishes *A Free Enquiry Into the Vulgarly Receiv'd Notion of Nature*.

1704 Newton combines mathematics and experiments in his particle theory of light.


Dinosaur State Park, Connecticut, featuring footprints first described by Edward Hitchcock in 1836

1821 Michael Faraday makes his confession of faith as a Sandemanian; the same year he discovers electromagnetic rotation.

1825 Faraday begins his Christmas lectures, which explain science to children.

1839 Faraday begins publishing *Experimental Researches in Electricity*.

1851 Edward Hitchcock publishes *The Religion of Geology and Its Connected Sciences*.

1856 James Clerk Maxwell becomes a professor at the University of Aberdeen.

1873 Maxwell publishes *A Treatise on Electricity and Magnetism*.

1874 John William Draper publishes *History of the Conflict between Religion and Science*.

1881 Maxwell publishes *An Elementary Treatise on Electricity*.

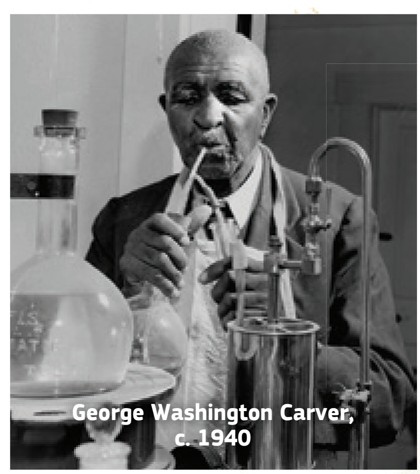
1896 Andrew Dickson White publishes *A History of the Warfare of Science with Theology in Christendom*; Booker T. Washington invites George Washington Carver to head the agriculture department at Tuskegee Institute.

1906 Carver begins a popular Bible class at Tuskegee.

1908 Henrietta Swan Leavitt begins publishing in the field of astronomy.

1921 Carver testifies before Congress in support of a peanut tariff; the incident makes him famous.

1927 Priest Georges Lemaître proposes what becomes known as the "Big Bang" theory.


George Washington Carver, c. 1940

FOSSILIZED DINOSAUR TRACKS, DINOSAUR STATE PARK, CONNECTICUT—GEORGE OSTERTAG / ALAMY STOCK PHOTO
JAMES CLERK MAXWELL WITH HIS WIFE KATHERINE, 1869—WIKIMEDIA
UNKNOWN. "GEORGE WASHINGTON CARVER." SPECIAL COLLECTIONS, USDA NATIONAL AGRICULTURAL LIBRARY. ACCESSED MARCH 24, 2020, HTTP://WWW.NAL.USDA.GOV/EXHIBITS/SPECCOLL/ITEMS/SHOW/1070

AN EXPERIMENT ON A BIRD IN THE AIR PUMP, 1768 (OIL ON CANVAS)—BRIDGEMAN IMAGES

The clergy behind science as we know it

ENLIGHTENMENT-ERA PASTORS DIDN'T OPPOSE MODERN SCIENCE. THEY HELPED ADVANCE IT.

Jennifer Powell McNutt

THE SCIENTIFIC REVOLUTION hit western Christendom hard. Right? When Nicolaus Copernicus (1473–1543) hypothesized that Earth was not at the center of the universe and published *De Revolutionibus Orbium Coelestium* (1543), a bitter struggle ensued between Christianity and science to shape the reigning worldview. Science came to dominate from the Enlightenment forward. Or so we've been told.

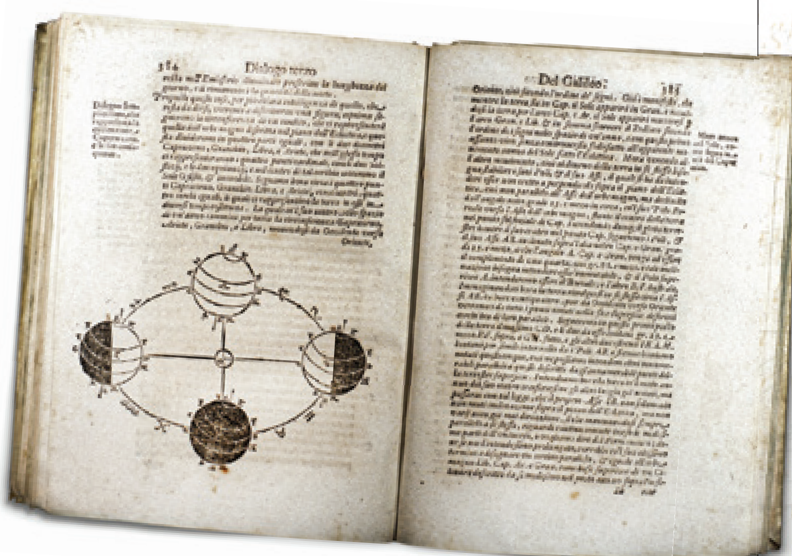
PASTORS PROMOTING SCIENCE

But in fact a Lutheran minister and theologian named Andreas Osiander (1498–1552) was the one who published Copernicus's seminal piece. That should be our first clue that the story of enmity between Christianity and science has often been distorted and overstated, leading us to forget some of history's most influential science advocates and fueling a false dichotomy.

FOR THE BIRDS Joseph Wright gave us this famous 18th-c. image, based on descriptions by Robert Boyle, of a scientist demonstrating a bird in an air pump.

The prevailing narrative that Christianity is inherently antiscience gained acceptance in 1896 with Andrew Dickson White's *A History of the Warfare of Science with Theology and Christendom* (see p. 33). White singled out prominent Protestant pastors such as John Wesley and Increase Mather for promoting an attack on the new science. "From the first to last," White wrote, "a long line of eminent divines, Anglican and Calvinistic, strove to resist new thought."

Wesley had *already* been singled out by other nineteenth-century writers for opposing scientific reasoning in support of the orthodox Christian faith. Yet Wesley's own publications engaged the science of the times by advocating for the usefulness of electricity,



PLAYING DEFENSE? This 19th-c. painting of Galileo before the Inquisition (*right*) defending his *Dialogo* (*below*) captures the sense of conflict we imagine.

exploring natural philosophy, and promoting natural solutions for curing diseases (rather than merely spiritual solutions). White conveniently ignored these writings in his hypothesis.

White is correct in at least one regard: if a war had been waged between theology and science, some prominent Enlightenment-era pastors would have led the charge. Yet when we delve into the history of eighteenth-century clergy, we discover a different story: pastors who engaged the latest scientific discoveries and experiments in a variety of ways and with a predominantly receptive attitude. The very idea that science and Christianity inherently conflicted would have defied their theological mindset.

Pastors after the Scientific Revolution viewed engagement with new science as an opportunity to understand God as Creator with greater depth to bring him greater glory. Clergy were frequent promoters rather than detractors, enthusiasts and participants rather than fear mongers. Their observations and contributions through publishing, preaching, and their own scientific pursuits helped enable the advancement of modern science in western communities.

NEW SCIENCE AND "HOT" PROTESTANTS

If any group of clergy opposed the new science, surely it was Puritans? Nathaniel Hawthorn often stereotyped Puritans as cold, rigid, and judgmental. But the Puritans' contemporaries did not consider them cold. Rather they maligned Puritans as "hot" for wanting to loosen what they considered the rigidity of the Church of England's liturgy out of the desire to lead worship extemporaneously, determined to be sensitive to the free movement of the Holy Spirit.

Though not without their blind spots, Puritans defy common stereotypes and expectations when it comes to the new science. Historian George Marsden has shown in his biography of Jonathan Edwards (1703–1758) that New England clergy embraced the Newtonian worldview (that God can work through secondary causes) as well as many other important scientific advancements—and they frequently made their positions public. Marsden wrote, "New England clergy, being the best educated persons in their communities, were often the chief interpreters of the new science."

Consider the story of Increase Mather (1639–1723), a contemporary of Isaac Newton (1642-1727), a minister, and the sixth president of Harvard. His name is often linked to the Salem witch trials, during which Mather made efforts (not without criticism) to curb the hysteria by discounting the use of spectral evidence in the courtroom. He promoted new science by helping to found the Boston Philosophical Society and stringently advocated for pioneering preventative approaches to disease along with his son, Cotton (1663–1678).

In 1721 for example, 60 percent of Boston's residents contracted smallpox. The medical community did not support smallpox inoculation, or the variolation method. This practice involved inserting scabs or fluids of smallpox disease (or variola) underneath the skin through small cuts to immunize.

Although inoculation did reduce the risk of dying from smallpox, some would die from the vaccine, including Edwards himself in 1758. When public debate over the risks versus benefits of the procedure

STUDYING GOD'S THOUGHTS *Left:* Devout Anglican philosopher Francis Bacon helped advance our ideas of experimental science.

PERSISTENT VISION *Below left:* Copernicus (in a 19th-c. painting) and his theory (in a 1617 edition) were accepted by clergy of his era far more readily than we realize.

came to the forefront in the city's newspapers, it was the clergy who advocated on its behalf. One historian has called this exchange "the most heated newspaper debate in colonial America."

Mather published two pieces on the subject that year, including the elaborately titled *Several Reasons Proving That Inoculation or Transplanting the Small Pox, Is a Lawful Practice, and That It Has Been Blessed by God for the Saving of Many a Life* (1721). When his son wrote the first pro-inoculation piece for the *Boston Gazette*, Mather and four other Boston clergy signed it.

Expressing a pro-inoculation position in such a public manner was fairly courageous, especially given the unsuccessful attempt made on Increase's life when a bomb was planted in his home. But in the end, many lives were saved and much suffering prevented because of this pastoral involvement.

The Mathers promoted the new science in the colonies in other ways too. As one of the leading Puritan clergymen of his generation, Cotton gained widespread acclaim for his observations in botany and writings on nature, and was elected Fellow of the Royal Society of London for his 1721 work, *The Christian Philosopher: A Collection of the Best Discoveries in Nature, with Religious Improvements*. There the function, use, beauty, and order of vegetables captured his attention. Even matters as seemingly monotonous as experiments with wheat led Cotton to enthusiastically declare God's goodness and admirable design:

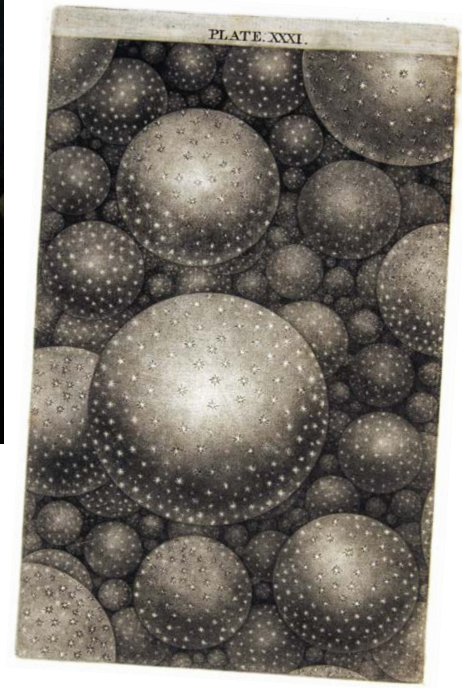
> All this Curiosity many times lying in a Body much smaller than the smallest Grain of Sand. . . . Dr Harris affirms that not only in black Pepper-water but also in Water wherein Barley and Oats, but especially Wheat, hath been steeped for about four or five Days he hath seen prodigious Numbers of [insects]. Great GOD we are amazed!

Jonathan Edwards later modeled this passion for new science as the clerical leader of the Great Awakening and president of the College of New Jersey (now Princeton University). As a young man, Edwards spent considerable time studying arachnids. In his words "Of all insects, no one is more wonderful than the spider, especially with respect to their sagacity and admirable way of working." As his personal notebooks attest, Edwards nurtured a lifelong interest in natural science, reflecting on Newton's theories, including those regarding rainbows and motion.

CITY OF CALVIN

Meanwhile the new science was also making headway across the pond in the Calvinist city of Geneva. Imagine sitting in your pew Sunday morning and listening to your pastor expound on the intricacies of quantum

BACON, (1640) PUBLIC DOMAIN—IMAGE COURTESY HISTORY OF SCIENCE COLLECTIONS, UNIVERSITY OF OKLAHOMA LIBRARIES
COPERNICUS (1617), PUBLIC DOMAIN—IMAGE COURTESY HISTORY OF SCIENCE COLLECTIONS, UNIVERSITY OF OKLAHOMA LIBRARIES
HELIOCENTRISM



mechanics while exegeting the biblical text. Hearing science in the pulpit was not an uncommon experience for the eighteenth-century Genevan congregant. In a city where roughly 3,000 worship services were held each year, the sermon was a pivotal means of public communication in shaping theological and biblical understanding, and it provides important insight into cultural mentality.

In his sermon on the importance of Christ's Resurrection, pastor Pierre Mouchon (1733–1797) stressed the human inability to escape from sin by comparing sin to corrupted blood that circulates throughout the body. His explanation reflected the perspective of the time that diseases resulted from fluids like blood (hence the practice of "bloodletting") rather than viruses. Granting this, Mouchon took the orthodox theological understanding of inherited sin and grounded it in physiological explanation.

Another Genevan pastor, Ezekiel Gallatin (1685–1733), also incorporated scientific examples into his preaching. Gallatin turned to the telescope, microscope, and gravity to illustrate 1 Corinthians 13:9–12 ("For now we see through a glass, darkly"). Without the telescope the naked eye would never have discovered the vast expansiveness of the universe. Similarly the microscope allowed the discovery of microorganisms 20,000 times smaller than could be seen by the human eye.

Yet even with this, he argued, human understanding grasps only a small part of what God has achieved. Even with the telescope and the microscope, we literally look through a glass darkly. For Gallatin this was not an opportunity to wallow but to revel in God's revelation through his Son and the promise that our human curiosity and knowledge will be fully satisfied at the end of the age.

STUDYING CREATION A philosopher demonstrates an orrery (solar system model) in another Joseph Wright painting (*above left*). Thomas Wright (no relation) hypothesized a multiverse (*above*).

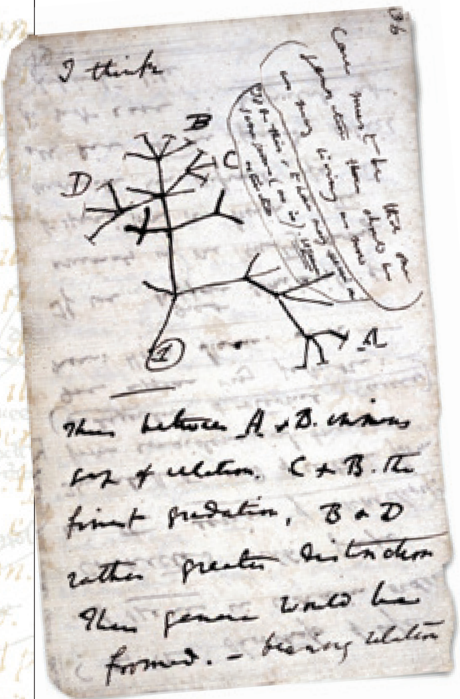
NEW INSIGHT *Left:* An archangel shows the physical creation to philosophers and scientists from the ancient Greeks through Isaac Newton in this engraving.

FINDING FRANKENSTEIN

Just as science was welcome in the sermons of Geneva, so clergy were welcome in the academy's scientific posts. The vast majority of professors holding posts in the new sciences at Geneva's Academy (today the University of Geneva) were ordained pastors. Pastor François-Etienne Jallabert (1658–1724) held Geneva's first chair of mathematics, established in 1704; his son, Jean Jallabert (1712–1768), also an ordained Genevan pastor until 1744, served as professor of experimental physics, mathematics, and philosophy.

Founded by John Calvin as a seminary and law school, Geneva's Academy grew in prestige over the century as it embraced experimental philosophy and mechanistic physics. Supported by Geneva's Company of Pastors, Jean Jallabert worked at the forefront of experimenting with electricity to treat illness. In fact his electrotherapy is the reason that Mary Shelley set *Frankenstein* in eighteenth-century Geneva.

The clergy also supported the study of astronomy in the city by raising funds for an observatory and a professor of astronomy. Their support opened the



door for the construction of a meteorological building followed by the establishment of a chemistry laboratory. Finally, although White made a blanket claim about clerical resistance to the addition of lightning conductors within eighteenth-century cities, Geneva's clergy caused no such opposition when professor Horace-Bénédict de Saussure planted a lightning rod in their city.

The clergy of Geneva did not regard the emergence of the new science as revolutionary, and by 1791 Thomas Jefferson had declared, "On the continent of Europe, no place is comparable to Geneva. The sciences are there more modernized than anywhere else." Without a doubt the advancement of new science owed much to Geneva's clergy.

"ALL TRUTH IS GOD'S TRUTH"

The notion that Christianity worked tirelessly to block the progress of science from its inception is a difficult perception to dispel, but time and again it runs counter to the historical record. Eighteenth-century clergy consistently helped their communities understand and interpret the new science transforming their world. They modeled and advocated engagement with science as they integrated it into their ministries.

Even in the post-Darwinian era, theologian-pastors Charles Hodge (1797–1878) and B. B. Warfield (1851–1921) embraced some scientific evidence in favor of evolutionary theory, though they also reframed those results theologically. Hodge rejected a process that functioned blindly according to natural laws. Instead he defended the agency of God as Creator of the world and as the governor of all physical causation

TOPSY-TURVY? Eventually some came to associate science only with the unbelief of Darwin (whose sketch of his theory is at *left*) and Thomas Paine (caricatured *above*).

without denying the efficiency of secondary causes in cooperation with God's will.

The twenty-first century is a rapidly changing scientific age when boundaries are being crossed that were once never imagined: from genetically engineering pigs to growing organs for human transplant to permanently changing the DNA germline of human embryos. The seventeenth and eighteenth centuries show us Christians in the field of science who were able to engage actively and effectively in scientific advancement. These pro-science thinkers provided theological and ethical perspectives that reframed, redirected, and advanced discoveries and understandings adeptly in light of Scripture and the claims of the Christian faith.

Acknowledging that "all truth is God's truth" encouraged a needed posture and practice of listening, embracing, cautioning, and contributing to the new science. It could do so for our own century as well. CH

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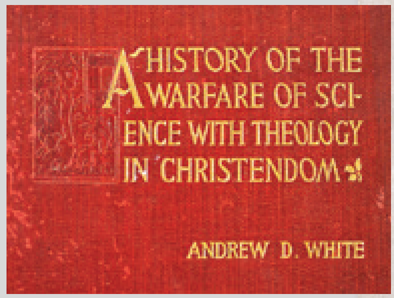
CHARLES DARWIN'S 1837 SKETCH, HIS FIRST DIAGRAM OF AN EVOLUTIONARY TREE FROM HIS FIRST NOTEBOOK ON TRANSMUTATION OF SPECIES; CHARLES DARWIN / PUBLIC DOMAIN—WIKIMEDIA
THE AGE OF REASON, 1819, GEORGE CRUIKSHANK (1792–1878)—© THE TRUSTEES OF THE BRITISH MUSEUM

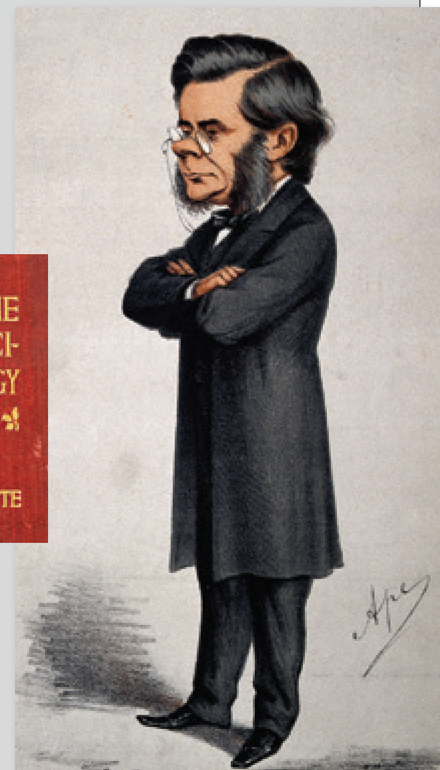
Science vs. religion:

What is really at war here?

In *Faith vs. Fact* (2015), biologist, professor, and antitheist Jerry A. Coyne confidently stated: "Science and religion are incompatible, and you must choose between them." Known as the "conflict" or "warfare thesis," this philosophy of history holds that science and religion are fundamentally and irrevocably at odds and scientific progress has eliminated the need for religious belief. Advocates of the conflict usually point to certain historical episodes to support their contention: they cite as evidence Christian suppression of learning during the Middle Ages, or the trial of Galileo in 1632 (see *CH #76, The Christian Face of the Scientific Revolution*), or religious opposition to Darwin's ideas about evolution in the second half of the nineteenth century (see *CH #107, Debating Darwin*).

Closer examination of these key episodes casts doubt on accepted caricatures. Medieval monasteries, for example, were the center of literary culture, and from monastic schools the first universities emerged in Christian Europe. Galileo was neither tortured nor imprisoned, and the affair itself was complicated by the scientific consensus of the time as well as broken friendships and political intrigue. Finally, numerous religious leaders supported Darwin or found other ways of reconciling evolutionary theory with orthodox Christian faith.





SECULAR SCIENCE? The "warfare thesis" owes much to the 19th-c. advocacy of historians such as Andrew D. White (his famous book is *above*) and scientists such as Thomas Henry Huxley (*right*).

NEW THEOLOGY

In actuality this "warfare thesis" is a fairly recent development; it was popularized in the nineteenth century. Biologist Thomas Henry Huxley (1828–1895), physicist John Tyndall (1820–1893), and evolutionary philosopher Herbert Spencer (1820–1903), among others, made up a Victorian coterie of "scientific naturalists" trying to professionalize and secularize the sciences. John William Draper's (1811–1882) *History of the Conflict between Religion and Science* (1874) and Andrew Dickson White's (1832–1918) *A History of the Warfare of Science with Theology in Christendom* (1896) both promulgated the belief that science and religion have been and always will be at war.

But many Victorians did not, in fact, envision a conflict between science and the Christian faith. Instead what they wanted to protest was *dogma*. Debates about the character of religion raged both inside and outside the church during the nineteenth century, and out of these debates emerged new—and to some, heretical—ways of thinking about God, the nature of Christianity, and the historical Jesus. This "new theology" was deeply contested, but many men and women of the period believed that the reconciliation of science and religion depended on accepting it. Significantly those who promoted this version of Christianity contrasted the idea of a free, progressive scientific inquiry against what they saw as authoritative, reactionary methods of theology as it had traditionally been practiced. The conflict was not simply between scientific truth and religious truth, but between contesting theological traditions, new and old.

The scientific naturalists agreed. Their argument was nothing new; as far back as the sixteenth century, Protestant reformers had used history, reason, and natural philosophy in their attack on the Catholic Church. Now more liberal Protestants used the same polemic of history, reason, and science against their orthodox opponents. Toward the end of the nineteenth century and the beginning of the twentieth, however, religious skeptics, freethinkers, and atheists appropriated the polemic and began to use it against all religion—and they still do.

—James Ungureanu, author of Science, Religion, and the Protestant Tradition: Retracing the Origins of Conflict *and Honorary Research Fellow at the Institute for Advanced Studies in the Humanities at the University of Queensland and the Department of History at the University of Wisconsin–Madison.*

HOW THE HEAVENS GO Boyle once described creation as "like a rare clock," specifically an earlier version of this astronomical clock in Strasbourg.

STRASBOURG CATHEDRAL'S ASTRONOMICAL CLOCK—PHOTO BY DAVID ILIFF / [CC BY-SA 3.0] WIKIMEDIA

A world of love and light

CHRISTIAN THEOLOGY SHAPED MODERN SCIENCE THROUGH THE WORK OF JOHANNES KEPLER AND ROBERT BOYLE

Edward B. Davis

ON OCCASION Albert Einstein (1879–1955) invoked the divine despite rejecting traditional Judaism. Writing to fellow physicist Max Born, one of the founders of quantum mechanics, Einstein dismissed the interpretation that things happen purely randomly at the atomic level: "Quantum theory yields much, but it hardly brings us close to the Old One's secrets. I, in any case, am convinced He does not play dice with the universe."

Questions about science that science itself cannot answer have been central to the field since the ancient Greeks, especially at times when science takes a fundamentally new direction. This was true of the revolutions in physics of the early twentieth century that Einstein participated in. But the establishment of modern science in Europe during the sixteenth and seventeenth centuries was equally revolutionary and no less philosophical—even theological—at its core. We see this clearly in the stories of German astronomer Johannes Kepler (1571–1630) and English chemist Robert Boyle (1627–1691). Each saw himself as a "priest" in the divinely created "temple" of nature.

PRAISED THROUGH ASTRONOMY

Kepler was born into an important Swabian family that had fallen on hard times. His father was a mercenary soldier and his mother a healer and herbalist, who as an old woman was formally accused of witchcraft and threatened with torture; her son successfully defended her. A brilliant child, Kepler received a splendid education in Latin schools established by enlightened dukes in that part of Germany and studied theology at the famous Lutheran seminary in Tübingen—also learning astronomy from one of the earliest followers of Nicolaus Copernicus, Michael Maestlin (1550–1631).

It soon became evident that Kepler's greatest talent lay in mathematics, not theology. He spent the rest of his life trying to understand the subtleties and intricacies of planetary motion, making profound discoveries essential for Isaac Newton's later discovery of the law of universal gravitation. Ultimately Kepler found his faith only strengthened by his scientific work—leading him to say, "I wished to be a theologian; for a long time I was troubled, but now I see how God is also praised through my work in astronomy."

Kepler wanted to know why science is possible at all. (Einstein later put it, "The most incomprehensible thing about the world is that it is comprehensible.") Unlike Einstein, Kepler had a deep faith in God the Creator making us in his image and placing mathematical patterns into creation. He wrote to his Catholic friend Herwart von Hohenburg, chancellor of Bavaria, "For God there are, in all his corporeal work, corporeal laws . . . laws moreover most excellent and well ordered." They are "within the grasp of human reason," and "God wants us to know them, since he created us in his image, so that we might think the same thoughts God has revealed to us, and thus commune with God through reasoned thought."

For Kepler our ability to do mathematics, especially geometry, was a divine gift. Influenced heavily by Plato's *Timaeus*, Kepler believed that "geometry, being

part of the Divine mind from time beyond memory, from before the origin of things, has provided God with the models for creating the world, models that have been implanted in human beings, together with the image of God."

Here Kepler echoed the great Lutheran theologian Philip Melanchthon (1497–1560), without whose legacy it is doubtful that Kepler would have been able to learn about Copernicus in the first place. Melanchthon never accepted the Copernican system as an accurate description of the solar system—almost no one born before 1500 did—but nevertheless he admired its mathematical elegance and encouraged its teaching at Lutheran universities as a hypothetical, but useful, theory.

Melanchthon held that God "implanted in the minds of men" the principles of arithmetic, geometry, and logic; *and* that our knowledge of them—unlike our knowledge of morality—had been unaffected by the Fall. Kepler believed the same thing. Because "man is the image of God," he told Herwart on another occasion, "it is quite possible that in regard to certain things that make the ornament of the Universe, he has the same opinions as God." This had important consequences for Kepler's notion of how science should be done—mainly by abstract analysis of the pure mathematics that God had built into nature and placed in our minds.

GENUINE HUMILITY

Boyle's background was very different. His father, Richard Boyle, first Earl of Cork, had made an enormous fortune as an adventurer in Ireland. Robert and his many siblings inherited great wealth and never had to work for a living. However, instead of wasting his time on womanizing and idle pursuits, as some other members of his family did, the intensely pious Boyle practiced and promoted Christian virtues while helping to create the modern scientific laboratory.

PRIESTS OF NATURE Boyle (*above*) and Kepler (*above left*) both allowed their theology to inform their science in nuanced ways.

Reports of his experiments on air and many other chemical substances circulated widely in England and on the Continent, making him one of the most famous scientists of the latter part of the seventeenth century—yet the sincerity and depth of his Christian faith were equally well known at home and abroad. Many in his own day and for generations afterward read his numerous works on morality, the Bible, and apologetics with appreciation, including hymn writers and theologians Richard Baxter (1615–1691) and Isaac Watts (1674–1748).

In keeping with his genuine humility, Boyle grounded his view of scientific knowledge in our status as finite creatures with a limited capacity to probe the deepest secrets of nature. Where Kepler believed we could obtain fully reliable knowledge of nature through mathematics, Boyle did not view the conclusions of reason as unquestionable truths: "Intelligibility by us men is no necessary condition of the absolute truth of a Thing." God's thoughts are higher than our thoughts: we are merely "purblind [dim witted] mortals" who are "incompetent judges" of God's power, which reaches "farther than our limited intellects can comprehend." After all, Boyle thought, God made the rest of the world before making humans, and he did not ask our opinion on how the job should be done.

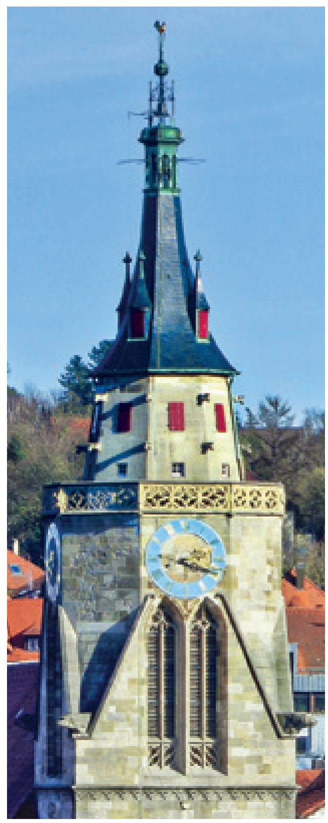
Furthermore God had created freely, not out of logical necessity. God did not have to create anything; he

created the world and human beings entirely of his own volition. Boyle believed that a free and sovereign God imposed the "laws of nature" upon matter. They "did not necessarily spring from the nature of matter, but depended on the will of the divine author of things."

Boyle took seriously the possibility that God might have made worlds other than our own—not entirely unlike the modern notion of a multiverse. This idea arose from *theological*, not *scientific*, speculation. For all we know, such worlds "may be framed and managed in a manner quite differing" from our "part of the universe," even to the extent of having different laws of motion. Likewise for the new heaven and earth promised in Scripture, where "the nature of things corporeal may be very differing from those that obtain in the present worlds."

What about the only world we know, the one in which we live? God alone "knows particularly both *why* and *how* the universal matter was first contrived into *this* admirable universe, rather than a world of any other of the numberless constructions he could have given it." Overall Boyle believed God created for reasons that are ultimately "undiscoverable by us," and "the only reason we can assign, is that it pleased God at the beginning of things" to make it in one way rather than another.

Consequently Boyle's idea of how science should be done differed markedly from Kepler's: slowly building a picture of nature from the ground up by hard experimental work—not from the top down by abstract mathematics. He thought we needed carefully designed experiments and observations of the nature God has actually made, not speculations about what God must have done.



AN ASTRONOMER'S LIFE Kepler saw the comet of 1577 (*above*) as a small child; it made a deep impression. Later he went to seminary in Tübingen and worshiped in the Stiftskirche (*left*). It was also at Tübingen that his *Mysterium Cosmographicum* was published in 1596—featuring a geometrical model of the solar system (*above left*).

REASON AND EXPERIENCE

Scientists today use insights from both Kepler and Boyle because each was partly right. Both reason and experience are needed to understand the contingent order imposed on the world by a free and rational God. Here again Boyle and Kepler as Christians engaged a deep philosophical issue that also fascinated the agnostic Einstein: "What I'm really interested in is whether God could have made the world in a different way; that is, whether the necessity of logical simplicity leaves any freedom at all."

Christian beliefs also made some theories more attractive than others. For instance, Kepler found Copernicus's picture of the sun in the center powerfully attractive theologically. It matched his Neoplatonic belief that the Sun, the source of light in the universe, symbolizes God's presence in the universe. Similar

A CHEMIST'S AGENDA Boyle's original and widely imitated research included a famous exploration of the properties of air through an air pump (*left*) and experiments in hydrostatics—the properties of fluids (*above*).

ideas had been articulated by earlier Christian thinkers, including Augustine, Robert Grosseteste, and Roger Bacon; the great poet Dante (1265–1321) held that heaven was a region of "pure light, intellectual light, full of love." In *The Discarded Image*, C. S. Lewis would later picture the medieval universe as filled with light emanating from the sun—even the large, high windows of Gothic churches were meant to fill the space with light to manifest God's presence.

Kepler also saw the Copernican universe as a three-dimensional representation of the Trinity; older Earth-centered cosmology lacked this crucial feature. Explaining this in the *Epitome of Copernican Astronomy* (1617–1621), the first textbook ever written about the solar system, he found "the center, [symbolic] of the Father; the surface, of the Son; and the intermediate space, of the Holy Spirit." This motif, which he originally took on board as a university student, drove him for the rest of his life as he tried to prove the Copernican theory.

Boyle's view of the universe was also theological at the core. The way scientific and medical practitioners of his day held tenaciously to pagan Greek conceptions of nature deeply troubled him. They often spoke of "Nature" as if it were a semidivine being overseeing natural processes—"Nature does nothing in vain," or "Nature abhors a vacuum," or "Nature is the best healer." Noting that the Bible has no "Hebrew word that properly signifies Nature, in the sense we take it in," he sought to drive the word out of science.

Instead he promoted the alternative notion of the creation as a vast, intricate, subtly designed machine that functions according to properties and powers given to it by God. Because an impersonal machine cannot be offended by human efforts to imitate and even surpass its capabilities, such a nature is more consistent with God's command to rule over creation. The great complexity of the "great automaton," the whole world itself and its various intricately constructed parts, cried out for a designing intelligence. He also thought that the more clearly we understand what created natural mechanisms can and cannot do, the more readily we can recognize genuine miracles that exceed the power of those mechanisms, such as those of Jesus and the apostles.

Although theology rarely rises to the surface in scientific debates today, it is still there, silently influencing philosophical ideas upon which the future of science depends. Kepler and Boyle would remind us that not only does God not play dice with the universe; he has created an admirable world and filled it with light. CH

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The "religion of geology": Edward Hitchcock

Edward Hitchcock (1793–1864) was the son of a poor farmer, hatter, and soldier in the American Revolution. In his twenty-first year, a serious attack of mumps damaged his eyesight permanently, ruining his plan to study astronomy at Harvard. It also left him with a heightened sense of his own mortality—at his death, funeral orator William Tyler said, "Throughout his entire public life he preached and taught as a dying man." His brush with death brought him into a closer relationship with his father's Calvinist branch of Congregationalism, instead of the Unitarian branch he had explored hitherto.

Despite his lack of college training, he became preceptor of his alma mater, Deerfield Academy, at 23. Two years later he left to study theology at Yale, where he also attended the lectures of Benjamin Silliman (1779–1864) on chemistry and geology.

SECOND CAREER Hitchcock (*above*) became a highly accomplished field geologist and a voracious reader of theology.

A PIOUS ALLY

In 1821 Hitchcock married Orra White. A prolific artist, she drew hundreds of images for her husband's lectures, books, and articles, as well as illustrating the natural beauty of the Connecticut River Valley. That same year he was ordained a Congregationalist pastor, but ill health soon forced his church to dismiss him. After further study with Silliman, he was appointed professor of chemistry and natural history—a standard combination then—at Amherst College in 1825. Twenty years later he became president and professor of natural theology and geology. The change in titles indicates the importance of Christianity both to the man and to the institution.

Hitchcock served as official geologist for Massachusetts and Vermont, was first president of the Association of American Geologists, and was voted a charter member of the National Academy of Sciences in 1863. His *Elementary Geology* (1840), an enormously successful textbook, contained a chapter about the connections between geology and Christian beliefs. At the height of his career, he published *The Religion of Geology and Its Connected Sciences* (1851)—his most complete statement of natural theology, the subject closest to his heart:

> Geology makes other economies of wide extent to pass before us, opening a vista indefinitely backward into the hoary past; and it is gratifying to witness that same unity of design pervading all preceding periods of the world's history, linking the whole into one mighty scheme, worthy its infinite Contriver. . . .

Hitchcock vigorously promoted geology as a pious ally of the Christian:

> Geology . . . was regarded with great jealousy, as a repository of views favorable to infidelity, and even to atheism. But if the summary which I have exhibited of its religious relations be correct, from what other science can we obtain so many illustrations of natural and revealed religion?

In the preface of the book, he spelled out a prophetic vision for Christian education. Given the use of science by skeptics as "batteries erected with which to assail spiritual religion," would the Christian minister, only "slightly familiar with the ground chosen by the enemy be able not only to silence his guns, but, as every able defender of the truth ought to do, to turn them against its foes?" Surely, he said, the church "needs a professor of natural theology in our theological seminaries . . . to teach those who expect to be officers in the sacramental host how to carry on the holy war."

Though he wrote frequently and with scientific precision about the vast age of the earth, Hitchcock rejected Darwin's theory of evolution when *On the Origin of Species* appeared in 1859. Hitchcock died in 1864, but his favored interpretation of Genesis (the gap theory) together with his forthright defense of "the great fact of man's creation" inspired conservative Protestants right down to the 1960s. *—Edward B. Davis; adapted and reprinted from BioLogos.com with permission*

MICHAEL FARADAY (1791–1867) LECTURING IN THE THEATRE AT THE ROYAL INSTITUTION, C.1856 (COLOURED LITHOGRAPH) / BRIDGEMAN IMAGES

Drinking from a fount on Sunday

MICHAEL FARADAY'S EXPERIMENTS ADVANCED THE STUDY OF ELECTRICITY

Geoffrey Cantor

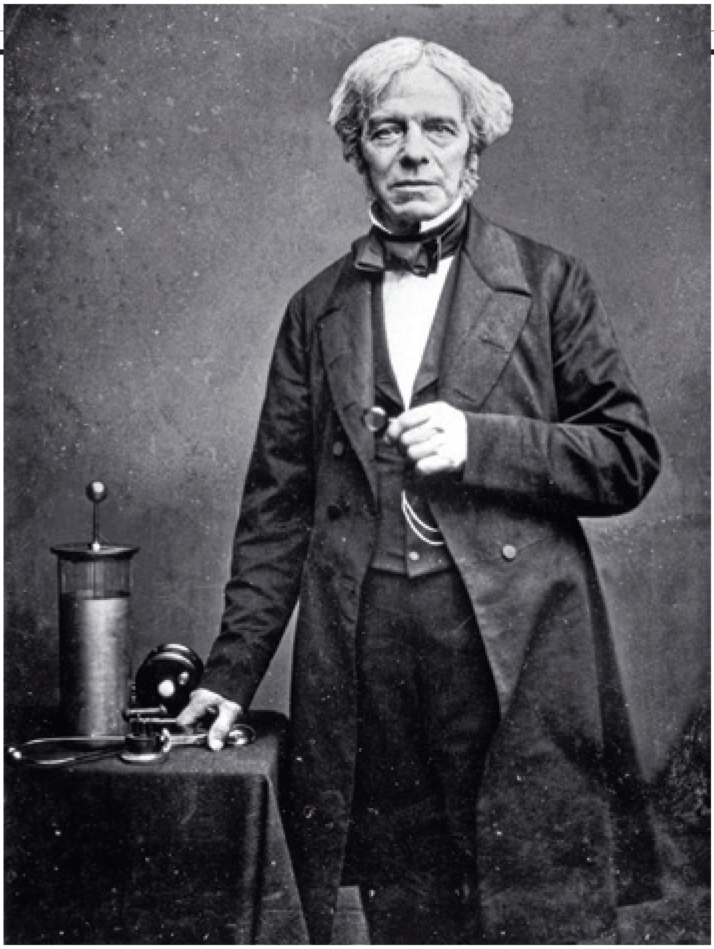
STANDING ROOM ONLY In this painting, Faraday delivers a Christmas Lecture (see p. 41) in December 1855 before Prince Albert.

MICHAEL FARADAY (1791–1867) pursued distinctive paths in both science and religion. In science he was largely self-taught, being the son of a blacksmith; he eschewed the more mathematical approach adopted by many contemporaries, especially those with university training. He viewed himself as a natural philosopher, and he did not wish to be described as either a scientist or a physicist—he felt those terms were too utilitarian, focusing on ends above means. In religion he cleaved to a small, dissenting sect—the Glasites or Sandemanians—whose members separated themselves from the established churches and from other Christian denominations.

PRIMITIVE CHRISTIANITY

The Sandemanians trace their ancestry to John Glas (1695–1773). After criticizing the Church of Scotland for failing to adhere to the dictates of the Bible, Glas was suspended from his parish at Tealing (near Dundee) in 1728. He formed an independent congregation and preached what he saw as true, primitive Christianity based firmly on the Bible. Other Glasite communities were soon founded in Scotland; Glas's son-in-law, Robert Sandeman (1718–1771), helped establish meeting houses in England and later in New England.

Faraday's father—but not his mother—was a member of the London church of the Sandemanians, which Michael attended as a child and young adult. In 1821, aged 29 and recently married to a member of the congregation, Faraday made his confession of faith, undertaking to live according to the precepts laid down in the Bible and in accordance with Christ's exemplary behavior. He later served as both a deacon and an elder in the London meeting house.



INVESTIGATING GOD Fellow scientists admired Faraday, pictured here with some of his equipment, for his moral uprightness.

The roles of deacon and elder were those specified in 1 Timothy 3:2–13; the deacon serving the congregation's physical needs, while the elder taught and led the congregation. Like other elders Faraday often delivered exhortations—sermons consisting almost wholly of Bible passages. His fellow Sandemanians highly respected him for his piety. However, for a few weeks in the spring of 1844, they excluded him from the church owing to an internal dispute over church discipline. This affected him deeply; he explained to a scientific correspondent, "certain private troubles have brought me low in health and spirits."

Reliance on the Bible permeated every aspect of Faraday's life. John Tyndall, his younger colleague at the Royal Institution, remarked that he drank "from a fount on Sunday which refreshes his soul for a week." He displayed a humble persona and, in line with Christian convictions, distanced himself from many worldly activities; for example he avoided party politics and refused the offer of the presidency of the Royal Society, the foremost position in British science, stating he would "remain plain Mr. Faraday to the end."

Although a number of Faraday's discoveries had practical applications that would have made him rich, he did not patent or manufacture any of them. Instead he insisted (in accordance with Matthew 6) that "money is no temptation to me. In fact, I have always loved science more than money." He also tried to avoid disputes over who had made scientific innovations first and instead viewed the scientific community as "a band of brothers" who should work together to expand human knowledge.

ELECTRIC DISCOVERIES

Faraday's scientific career began in 1813 when he was hired to assist eminent chemist Humphry Davy (1778–1829) by performing experiments in the laboratory of the Royal Institution in London. (Davy had damaged his sight in an explosion.) Faraday made several chemical discoveries, including isolating and identifying benzene. However, his first major discovery in electricity was electromagnetic rotation—the rotation of a current-carrying wire round a magnet—in 1821. This later became the basis of the electric motor.

A long series of further electrical discoveries followed, including electromagnetic induction, which underpins the modern transformer and generator. Much of his research was contained in papers read before the Royal Society and subsequently collected in three volumes entitled *Experimental Researches in Electricity* (1839–1855). Faraday was also a sophisticated theoretician; for example in two insightful papers published in the mid-1840s, he laid the foundation of field theory, which James Clerk Maxwell (see p. 42) subsequently reformulated mathematically.

Through experiment Faraday investigated the structure of the world God had created. Just as he read the Bible carefully and plainly, in his scientific investigations, Faraday read the Book of Nature with similar precision and earnestness. These experiments produced facts which, when collected together and compared, sometimes enabled him to articulate the laws of nature. Believing strongly that "the Creator governs his material works by *definite laws* resulting from the forces impressed on matter" at the Creation, Faraday sought these God-given physical laws connecting electricity, magnetism, and chemical action. Most famously he discovered laws governing electromagnetic induction and electrochemical decomposition—now known as *Faraday's laws* of induction and of electrolysis.

In conceiving of the physical world as God-created, Faraday imported certain religiously based assumptions into his science. One was the widely accepted notion that matter is conserved: the matter that had been formed at the Creation was the same stuff that currently exists, neither depleted nor augmented over time. He also recognized that the quantity of force that God had imparted to matter at the beginning was likewise conserved.

HOME SWEET LAB Faraday lived and worked in the Royal Institution, founded in 1799.

In an 1857 discourse at the Royal Institution, he explicitly supported this conservation of force on theological grounds by arguing that it is "only within the power of Him" to create or destroy force, so force must be quantitatively conserved in all physical processes, though its form may change. For example in a battery, chemical force is converted into electrical force; the quantity of electrical force produced by the battery is equal to the amount of chemical force it loses. (This is not dissimilar to current ideas about the conservation of energy.)

The Royal Institution provided Faraday with living accommodation and a laboratory for his experiments; it also contained a large and imposing lecture hall where he and other scientists gave lectures to members and guests. He delivered a number of Friday evening discourses (including the discourse on the conservation of force) as well as lecture series on scientific topics. He was a highly successful lecturer; one member of his audience noted, "His lectures were *'mind addressing mind,'* and you felt he was full of sympathy with his audience; and with his fellow creatures."

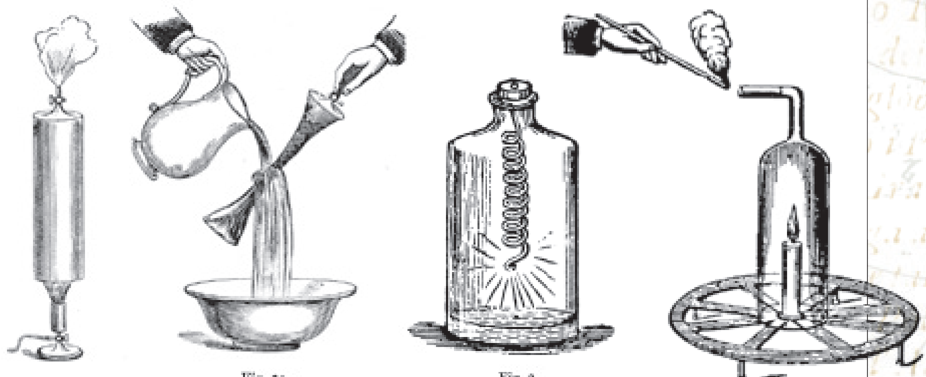


Fig. 2. Fig. 32. Fig. 3. Fig. 23.

THIS LITTLE LIGHT OF MINE These diagrams illustrate Faraday's published lecture on the chemical history of a candle.

HISTORY OF A CANDLE

In 1825 Faraday inaugurated the Christmas Lectures on scientific subjects, directed to children. These continue to be delivered and are now broadcast throughout the world. Probably the most famous is "A Chemical History of a Candle," first delivered in 1848 and published in 1861. Often cited as an exemplary scientific text addressed to children, it has never been out of print and has been translated into several languages.

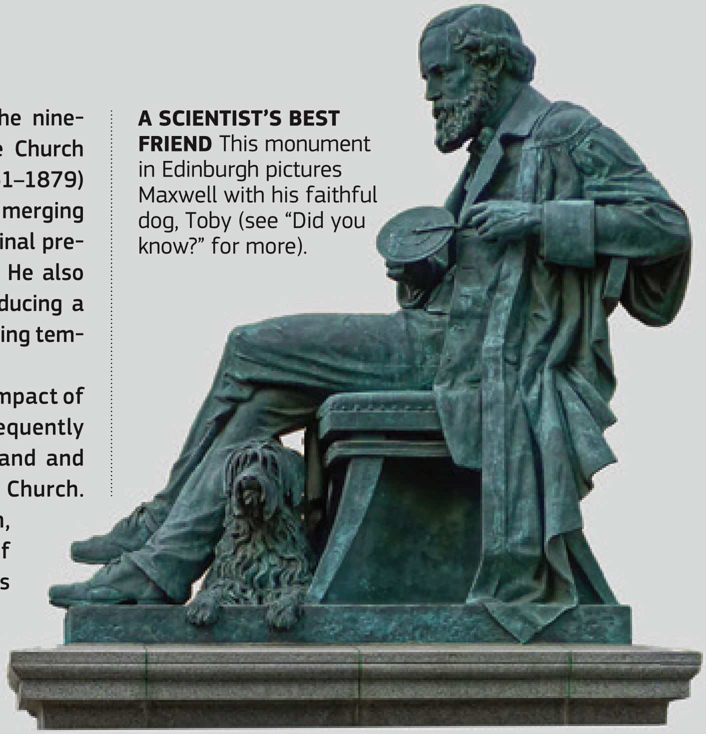
Using the thoroughly familiar example of a candle, Faraday proceeded to show, with simple but impressive experiments, that the candle exemplifies a number of scientific principles. He established a close rapport with the juvenile audience at his lectures, some of whom attributed their later participation in science to Faraday's influence.

In an 1854 lecture delivered at the Royal Institution before Prince Albert and other dignitaries, Faraday attacked the prevalent contemporary fascination with table-turning at séances, usually explained by evoking a spiritual agency that acted on the table via the hands of the assembled sitters. Faraday argued, using a simple experimental setup, that the movement came from "a *quasi* involuntary muscular action" exerted by the sitters. Thus to prevent people from being seduced by the fantasies of the spiritualists, he advocated a solid, critical scientific education for all. Faraday also opposed spiritualism as incompatible with his religious convictions, citing the "unclean spirits" proscribed in Acts 8:7.

Faraday died in 1867 and was buried in the unconsecrated area of Highgate Cemetery (the consecrated area being reserved for Church of England burials). In line with the simple Christian values by which he had lived, there was no burial service. His tombstone bore only his name and the dates of his birth and death. In 2006, when an institute for the study of science and religion was founded in Cambridge (UK), it was named the Faraday Institute. CH

Geoffrey Cantor is emeritus professor of the history of science at the University of Leeds and honorary senior research associate at UCL Department of Science and Technology Studies at University College London. He is the author of Michael Faraday: Sandemanian and Scientist *as well as many other works on eighteenth- and nineteenth-century science.*

Freedom from dualism



A SCIENTIST'S BEST FRIEND This monument in Edinburgh pictures Maxwell with his faithful dog, Toby (see "Did you know?" for more).

Perhaps the most brilliant physicist of the nineteenth century was also a pillar of the Church of Scotland. James Clerk Maxwell (1831–1879) unified studies of electricity and magnetism, merging equations that now bear his name into an original prediction that light is an electromagnetic wave. He also added considerably to thermodynamics, introducing a revolutionary statistical approach to investigating temperature and particle speeds in gases.

As a youth in Edinburgh, Maxwell felt the impact of the Free Church movement, and he was subsequently raised in both St. Andrew's Church of Scotland and the catechetical class at St. John's Episcopal Church. At 16 he entered the University of Edinburgh, later continuing his studies at the University of Cambridge. While preparing for Cambridge's demanding Mathematical Tripos exam in 1853, he fell ill. Under the care of a Reverend Charles Tayler, he experienced what a friend later described as "a new perception of the love of God." This event seems to have sharpened his sense of Christian service; he wrote to Tayler, shortly after the episode, that he was "committing [himself] to God as the instrument of His will."

"UNSEARCHABLE WISDOM"

On several occasions Maxwell cautiously indicated his view on the relationship between his faith and physics. In his 1856 inaugural lecture as professor at Marischal College in Aberdeen, Scotland, the young scholar relayed his conviction that the laws of nature are not arbitrary and unconnected, but that they work together to reveal "unsearchable Wisdom and external Truth."

Later, reflecting on kinetic theory, he argued that the apparently unalterable nature of matter's fundamental particles make us ultimately unable to attribute them solely to natural causes. He further claimed that the "exact equality" among molecules of the same kind indicates they were manufactured, not self-existent. "Science," Maxwell proposed, being "incompetent to reason upon the creation of matter itself out of nothing," has pushed us to "the utmost limit of our thinking faculties when we have admitted that because matter cannot be eternal and self-existent it must have been created."

Commenting in an 1867 letter on the significance of the recently propounded second law of thermodynamics, Maxwell wrote that "our experience of irreversible processes . . . leads to the doctrine of a beginning and an end," though this end of the cosmos entails "not a destruction of matter or of energy but such a distribution of energy that no further change is possible without an intervention of an agent who need . . . only direct the energy into new channels." It is possible that Maxwell had the Christian concept of new creation in mind.

Having returned to Cambridge in the early 1870s to take the position of first Cavendish Professor, Maxwell became a member of the informal and diverse Eranus Club, attended by New Testament scholars B. F. Westcott, J. B. Lightfoot, and F. J. Hort. Hort would later reflect on Maxwell's freedom from the "mental dualism" he thought was often observed in physicists: "It would have been alien to his whole nature to seclude any province of his beliefs from the free exercise of whatever faculties he possessed."

Hort likely had in view, among other things, Maxwell's request during the construction of Cavendish Laboratory that above the entrance be inscribed the Latin text of Psalm 111:2, *Magna opera Domini exquisita in omnes voluntates ejus* ("The works of the Lord are great, sought out of all them that have pleasure therein.")—*Tom Topel, who holds masters' degrees in physics and theology and intends to do a DPhil at Oxford*

"I know that my Redeemer liveth"

GEORGE WASHINGTON CARVER SOUGHT TO UNDERSTAND GOD'S CREATION AND DEVELOP ITS BENEFITS FOR OTHERS

Jennifer Woodruff Tait

CARVER WITH TUSKEGEE STAFF MEMBERS, 1902—FRANCES BENJAMIN JOHNSTON / [PUBLIC DOMAIN] WIKIMEDIA

THE QUIET, unassuming African American scientist in the well-worn suit, flower in his lapel, stood before the House Ways and Means committee in Washington, DC, on January 21, 1921, to speak on behalf of the United Peanut Growers Association. He was granted only 10 minutes, and one of the representatives asked him if he wanted a watermelon (stereotyped as an African American food) to accompany the peanut samples he had brought. He refused the watermelon and soon so enthralled the committee that they let him speak for over an hour and even attended to the brief sermon he concluded with:

> If you go to the first chapter of Genesis we can interpret very clearly, I think, what God intended when he said "Behold, I have given you every herb that bears seed upon the face of the earth…" There is everything there to strengthen and nourish and keep the body alive and healthy.

READY TO TEACH Carver (*center, bottom row*) poses with other Tuskegee faculty in 1902.

From that day on, George Washington Carver (c. 1864–1943) was known as the Peanut Man. As one of his biographers put it, he had won "a tariff for the peanut industry and national fame for himself." But peanuts were actually only a small part of his mission.

THE NAME OF EVERY STONE

Despite Carver's fame information about his life is difficult to come by. He never knew his birthdate, and although he adopted the middle initial W to distinguish himself from another George Carver, it's unclear when anyone began claiming it stood for Washington.

Carver was born in Missouri just as the Civil War was ending; his mother, Mary, was enslaved by Moses and Susan Carver. (The Carvers had generally opposed slavery, but they were growing older and needed household help.) When George was an infant, a raiding party kidnapped him and his mother. Moses's neighbor tracked down George (for which Moses supposedly gave him a racehorse), but Mary was never found.

The Carvers raised George and his brother Jim in their own home; Susan taught the frail George "indoor" skills such as cooking and laundry. When he was 12, his desire for education led him to cross the border to Kansas (public schools in Missouri had largely refused to admit him). He wrote later about his childhood: "I wanted to know the name of every stone and flower and insect and bird and beast. I wanted to know where it got its color, where it got its life—but there was no one to tell me."

Carver attended school with mostly white classmates. He supported himself by doing laundry, "fooled around with weeds," tried to homestead, and joined the Presbyterian Church. Highland College accepted him by mail, thinking he was white, but refused to admit him when he showed up. Finally he wound up at Simpson College in Iowa where his natural talent as an artist was recognized. Ultimately he decided to go to Iowa State and study agriculture to benefit other African Americans.

NATURAL BEAUTY Carver was a talented painter, composing studies of the the natural world throughout his life.

At Iowa State Carver trained as a botanist and agriculturist, studying with one of the nation's most famous experts in fungi. He also met James Wilson, director of the Iowa Agricultural Experiment Station, who began a prayer group that Carver attended. Wilson recalled that as new students arrived, "Carver and I would sit down and plan how to get boys who were Christians to go down to the depot to meet them." They became lifelong friends—and Wilson became secretary of agriculture in 1887, the year after Carver graduated from Iowa State.

THE CHICKEN YARD

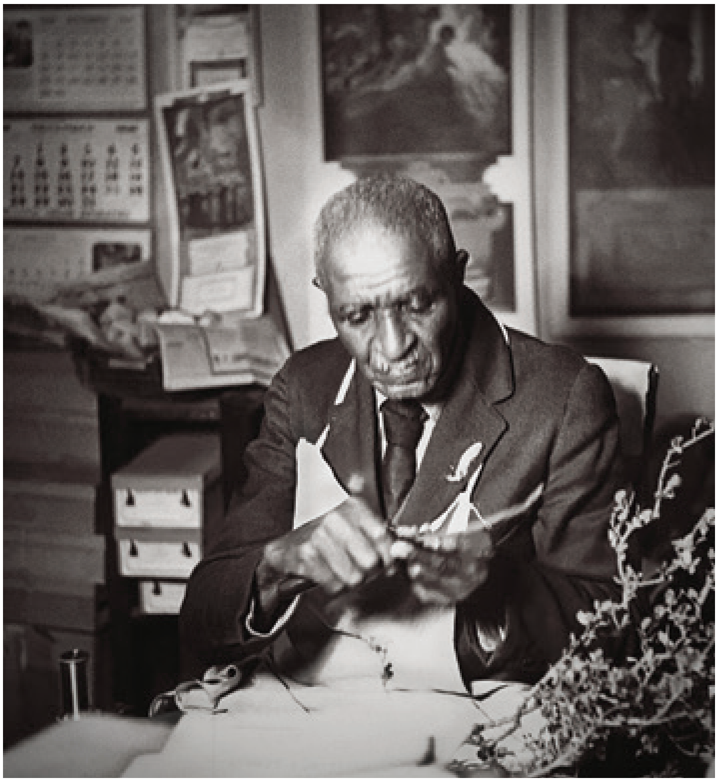
The young scientist had several job offers upon graduation, including one to stay at Iowa State. He somewhat reluctantly accepted the invitation of Tuskegee Institute, a new all-black educational institution in Tuskegee, Alabama, headed by Booker T. Washington (1856–1915). Washington wanted badly to begin an agricultural department, and Carver was the best-trained African American agriculturist in the nation.

But the adjustment proved hard. Carver was culturally midwestern, educated in primarily white environments. His demand for one room for him and one for his specimens rubbed other faculty the wrong way. He also battled frequently with Washington. Carver wanted to research, develop a well-stocked laboratory, paint, and mentor. Washington wanted his star professor for more pressing matters: teaching a full load, serving on committees, and managing the Tuskegee experiment station's farm and chicken yard. The demands of each on the other never really ceased until Washington died in 1915 and his successor released Carver from all teaching except for summer school.

By all accounts Carver was a gifted and engaging teacher, but not systematic. He focused on hands-on collection and study of specimens. Students loved him as a mentor, and in this capacity he started a Bible study on campus in 1907—beginning with a talk on

GEORGE WASHINGTON CARVER AS ARTIST—THE TUSKEGEE UNIVERSITY ARCHIVES, TUSKEGEE UNIVERSITY
PAINTING BY GEORGE WASHINGTON CARVER. ACCESSED FEBRUARY 24, 2020, HTTPS://PETERDBURCHARD.TUMBLR.COM/POST/42337284103/PAINTING-BY-GEORGE-WASHINGTON-CARVER

EXAMINING CREATION Carver studies a specimen in his rooms in 1938.



Genesis 1, illustrated as always with his beloved specimens. He taught the study for 30 years, until shortly before his death. He wrote to a YMCA official in 1927 about his students:

> I want them to see the Great Creator in the smallest and apparently the most insignificant things. . . . How I long for each one to walk and talk with the Great Creator through the things he has created.

Carver also worked with local farmers to increase sustainability and self-sufficiency. He could do nothing about unjust systems that kept them in debt, but he could do something about soil and crop rotations. He encouraged planting a diversity of crops, using crops in recipes (which he provided), and using local products to beautify homes and yards. His lectures at farmers' conferences and articles in numerous agricultural bulletins included references to Scripture, such as *Are We Starving in the Midst of Plenty? If So Why?*, which began with Proverbs 13:23: "An unplowed field produces food for the poor, but injustice sweeps it away."

This work led to new products made from peanuts, sweet potatoes, and cowpeas, which grew well in Alabama. Carver tried repeatedly but without success to arrive at commercial applications. Eventually the national trend moved toward larger, industrialized agriculture; it would be decades before modern agrarian movements rediscovered his ideas.

"MEN OF SCIENCE NEVER TALK THAT WAY"

After Washington's death Carver began to spend more and more time away from Tuskegee lecturing. His appearance before the Ways and Means Committee made him famous. He had already been named a Fellow of the Royal Society of Arts in London, but he soon collected the Spingarn Medal for Distinguished Service to Science as well as several honorary doctorates.

In 1924 Carver was asked to demonstrate his products at Marble Collegiate Church in Manhattan; there he remarked that to facilitate inspiration from God "no books ever go into my laboratory," which prompted a scathing editorial from the *New York Times*, "Men of Science Never Talk That Way." His response circulated informally, arguing that a proper view of divine inspiration would allow that inspiration to influence scientific discoveries. To a friend he wrote that the criticism was directed not at him, but "at the religion of Jesus Christ. Bro., I know that my Redeemer liveth."

Carver always remained a gifted popularizer and interpreter of science, but as he aged, he grew more distant from mainstream research. His religious fame, though, only grew; many Christians saw his deep and oft-stated faith as a refutation of the atheistic turn they feared was emerging in twentieth-century science. Carver's faith was truly foundational to his science—both were based in, and constantly renewed by, close observation of the natural world. To his YMCA correspondent he wrote:

> Just last week I was reminded of [God's] omnipotence, majesty, and power through a little specimen of mineral sent me for analysis . . . lo before my very eyes, a beautiful bunch of sea-green crystals have formed and alongside of them a bunch of snow white ones. Marvel of marvels, how I wish I had you in God's little workshop for a while, how your soul would be thrilled and lifted up.

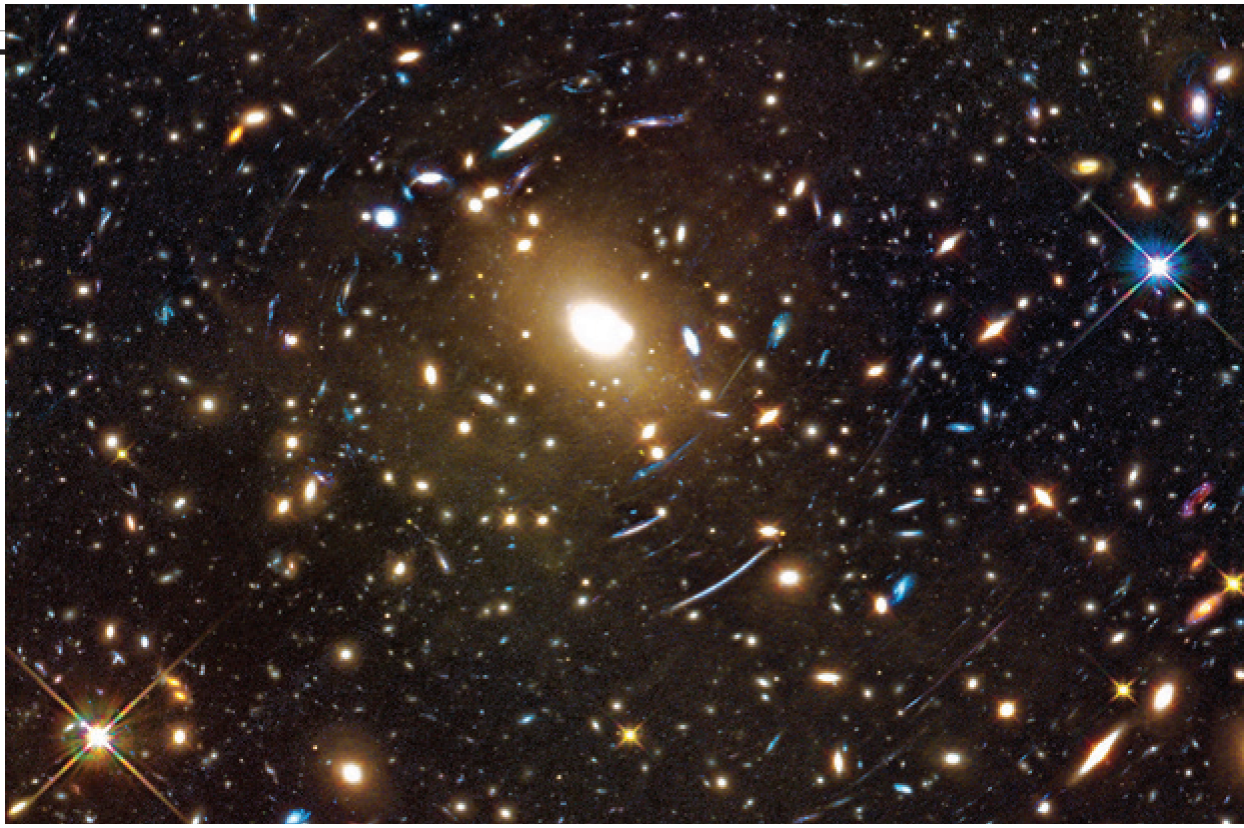
In 1940, when friends sent him a gift of dahlias, he thanked the great Creator for the gift; God had

> made man in the likeness of his image to be co-partner with him in creating some of the most beautiful and useful things in the world. . . . You both are stronger and better from growing these beautiful messages from the Creator.

Many have claimed Carver's story since his death—fervently if not always accurately. Most recently we have begun to rediscover his ecological wisdom and his Christian mysticism—and to understand that they were intimately related. We would do well to remember him as a man who partnered with God to create things both beautiful and useful from God's world full of dahlias and sea-green crystals—and yes, even peanuts. CH

Jennifer Woodruff Tait is managing editor of Christian History.

DR. CARVER AT WORK AT TUSKEGEE INSTITUTE IN SEPTEMBER 1938. *ALPHA HISTORICA* / ALAMY STOCK PHOTO



GOD MADE IT This image from the Hubble Telescope is of the Frontier Field, about 4 billion light years away.

GALAXY CLUSTER ABELL 370 AND BEYOND. HUBBLE SPACE TELESCOPE. NASA, ESA, JENNIFER LOTZ AND THE HFF TEAM (STSCI) / PUBLIC DOMAIN—NASA

God made it, God loves it, God keeps it

SCIENTISTS SPEAK ABOUT HOW THEIR FAITH AND RESEARCH INTERACT

We talked to four scientists who are believers—three with distinguished careers and one embarking on the journey. Francis Collins led the Human Genome Project and is now director of the National Institutes of Health in Bethesda, Maryland. William Phillips is a fellow at the National Institute of Standards and Technology and received the 1997 Nobel Prize in Physics. Katharine Hayhoe is an atmospheric scientist and the Political Science Endowed Professor in Public Policy and Public Law at Texas Tech University. Allison Greenplate is a postdoctoral fellow in immunology at the University of Pennsylvania.

***CHRISTIAN HISTORY:* What led you to become a scientist, and how did this intersect with your faith journey?**

FRANCIS COLLINS: I fell in love with science in a high school chemistry class. I was captivated (and still am) about how the tools of science can lead to reliable knowledge about how nature works. I started out in chemistry, but later switched to medicine because I hoped that I could contribute to ways to alleviate suffering.

My faith journey had a different timetable. I was an agnostic in college and an atheist in graduate school—but those positions weren't very well thought through. Then as a medical student I had to face the reality of life and death in the patients I was caring for, and I realized I wasn't really sure what I believed.

I dug into arguments about why people believe in God, and to my surprise came to the conclusion that faith is more rational than disbelief. Over two years of struggle, I came to believe in God, and ultimately to see the person of Jesus as an answer to all my questions. I have been a deeply committed Christian since age 27. To this day I have never encountered a situation where my faith and my science are in conflict. I wrote about that in *The Language of God* and founded an organization called BioLogos that has become the most heavily traveled meeting site for people looking for harmony of science and faith. Their motto is "God's words, God's works."

WILLIAM PHILLIPS: I was interested in science almost as far back as I have any memories. I remember making myself a "chemistry set" from common things around the house and seeing what happened when I mixed them together—luckily nothing I combined was really dangerous. My parents were social workers, but they encouraged my curiosity and recognized my interest in science. By the time I was 10, I had an idea that physics was where I wanted to be.

I was born into a family that took faith seriously. My earliest memories involved going to church every Sunday, praying daily. It never crossed the minds of my parents that there was any conflict between science and faith. By the time I met people who thought there was a conflict, I'd already developed enough grounding in my science and my faith that it never bothered me.

I've always been Methodist, but I went to Juniata College, a church-related college started by the Church of the Brethren. We had required religion courses. They were among the most important classes that I took because they taught me to look at the Bible in a different way: here were scholars talking about how the Bible came to be, who wrote it, who edited it, who translated it, how the culture impacted the passages we were studying.

I went through a time in graduate school where I didn't go to church. I didn't feel distant from God, but graduate school is pretty consuming when you're a physicist. When I came to NIST, a colleague invited me to his church, an incredibly ethnically diverse church. I walked in and thought—this is what I've been looking for all my life: this is the place I want to raise my kids.

Francis Collins


William Phillips


Katharine Hayhoe


Allison Greenplate

WORDS AND WORKS Despite differing areas of expertise, these four Christians echo many scientists in church history in seeing their research as compatible with their faith.

KATHARINE HAYHOE: My dad was a science teacher, so some of my earliest memories include learning binary numbers before regular ones and how to find the galaxy Andromeda with a pair of binoculars. He was also a teacher in our local church, so I took for granted his perspective: what is science, other than trying to figure out what God was thinking when he created the universe? And if our science and the Bible appear to be in conflict, it must be our limited understanding that's at fault. If they were created by the same person, how could they possibly conflict?

It's no surprise that with this background I was planning to become an astrophysicist, but once again faith stepped in. Needing an extra credit to complete my undergraduate physics degree, I spotted a new course on climate change. It completely changed the trajectory of my life. I learned that climate change is not only an environmental issue; it is, as the US military now calls it, a threat multiplier, making issues of poverty and hunger, insecurity and injustice, worse. As a Christian who believes that we are called to love others, to act justly, and to walk humbly in this world, I couldn't avert my eyes and pass this by.

It turned out that my physics background had given me the exact skill set I needed to work on this urgent global problem; and my heart said, how can I not? Caring about God's creation, which includes the poor and the vulnerable as well as every other living thing, is a faithful acceptance of our God-given responsibility and a genuine expression of God's love.

ALLISON GREENPLATE: As a child I spent a lot of time reading books about how the natural world worked—how ozone protected the earth, how the bubonic plague spread, how black holes formed. By my senior year of high school, I was hooked on the science of human health and the immune system. Around that time, I spent a day shadowing scientists at a local research lab that specialized in understanding the immune system and developing new medical interventions. I loved how they worked together to solve problems and help patients. Because of that experience,

GOD LOVES IT Research done by scientists we've discussed throughout this issue has led to technological advances, from eyeglasses (*left*) to medicinal preparations (*below left*) to LED lights (*below*).

I pursued a bachelor's degree in biology and, later, a PhD in microbiology and immunology.

A favorite quote of mine comes from Frederick Buechner: "The place God calls you to is the place where your deep gladness and the world's deep hunger meet." Science is the perfect intersection between my deep gladness and the world's deep hunger. I have the pleasure of studying the fascinating, complicated immune system while also helping improve medical care. On difficult days in the lab, what carries me through is my unwavering belief that I am called to love and care for my neighbors.

***CH:* How would you describe the compatibility of science and faith to a layperson?**

FC: Science and faith are designed to answer different questions. If it's a "how" question about nature and how things work in the universe, science is the way to approach it. If it's a "why" question like "Why am I here?," "Why is there something instead of nothing?," or "Why is the universe fine-tuned to make life possible?," then reductionist science doesn't help very much; one needs to search for truths that can come from faith.

WP: Sometimes questions require the perspective of both disciplines—for example, if you're asking about the possibility of making genetic changes to our makeup. You want to understand the science well, and also religious thought about the nature of humankind. I have a hard time reading the first few chapters of Genesis without crying—they are so beautiful. But the Bible is a book that tells us what our relationship is to God and what God expects of us, not a scientific textbook.

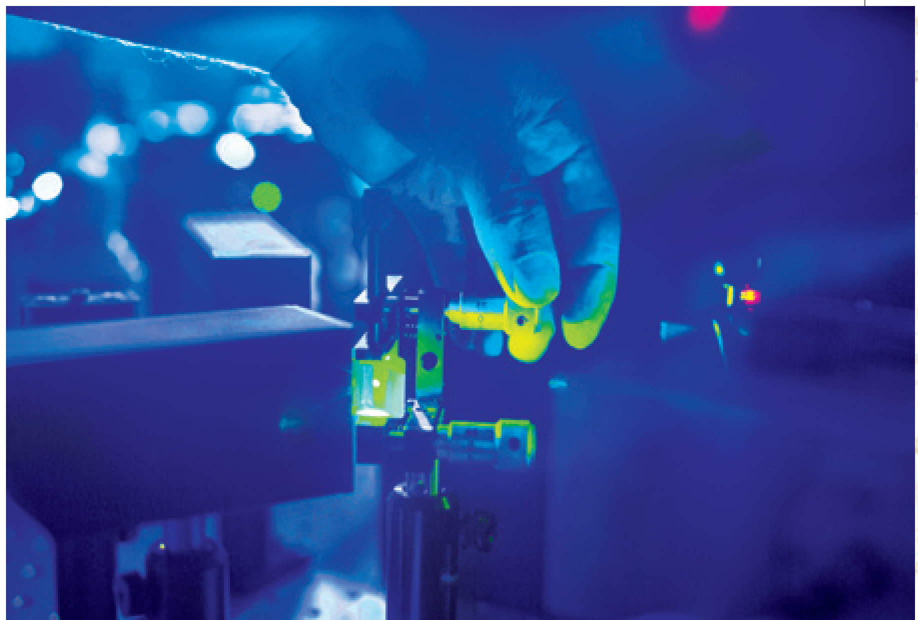
KH: Faith, the author of Hebrews tells us, is the substance of things hoped for, the evidence of things not seen. And what is science, other than the substance of things that are here and now, the evidence of what we see and measure? They both serve a purpose, but a distinct and unique one. For difficult, thorny issues with ethical or moral implications, we need both. Science can tell us that climate is changing, that humans are responsible, that the impacts are serious, and that our choices matter. But which solutions should we prioritize? It's our values that guide our answers to these questions, not our science: and for the vast majority of us around the world, our values come from our faith.

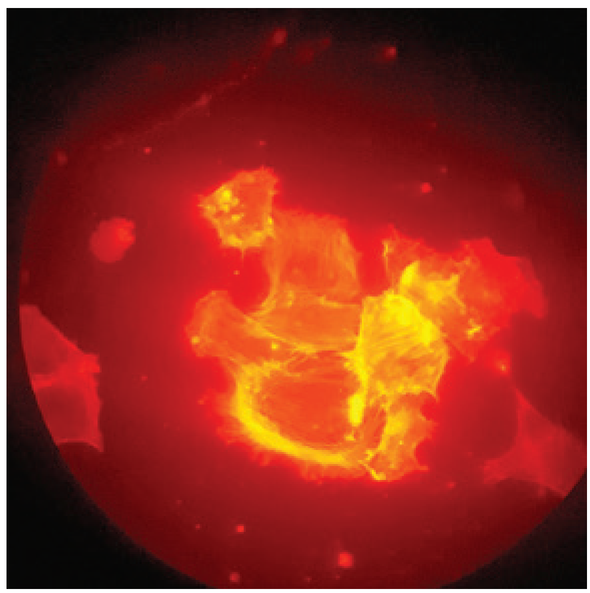
AG: In science the pursuit of knowledge and truth relies on the data we can observe within the physical universe; it is not fit to answer questions like "Does God exist?" or "How can I best love my neighbor?" In the Christian faith, knowledge and truth are based on special and natural revelations, given to us by God. We look to the Bible to answer questions like those.

But the Bible does not provide an exhaustive list of observations about the physical world and cannot help us answer "How do immune cells recognize cancer cells?" or "How do plants convert sunlight into energy?" Faith has led me to believe that all truth is united in Christ. As I learn new scientific knowledge through my experiments or reading scientific publications, I rejoice in seeing a new facet of God. For me, to understand the details of his creation is to grow closer to the Creator.

GLASSES ON BIBLE—IMAGE BY DAVID LEDBETTER FROM PIXABAY
LED LIGHTS—JUSTIN LANE / UNSPLASH
HERBAL MEDICINES—HANABISHI / [CC BY-SA 3.0]—WIKIMEDIA

GOD KEEPS IT Scientists still seek to understand God's creation as they study topics from quantum optics (*right*) to cancer cells (*below*).





***CH:* Can you give a specific example of how your faith and research have influenced each other?**

FC: When I look at the complexity of living things, I am in awe. But as a scientist, I am convinced that once the first self-replicating life forms appeared, evolution has been fully capable of generating that complexity. That doesn't mean the awe is reduced, however! I am in support of the synthesis known as "evolutionary creation," where God is the author of the whole process, including all the exquisitely mathematical natural laws, but used evolution as the means of creation.

WP: I believe that the universe I am privileged to explore is the work of a loving creator; it gives a sense of holiness to my profession. When the Smithsonian came into being, they decided the ideal first director would be Joseph Henry, the great nineteenth-century physicist. People from Washington went to Princeton to see him. He invited them into the laboratory and said "We are about to ask God a question. Let us pray that we can understand that answer." I'm asking God questions and getting the answers. I think scientists are tremendously privileged because they get to understand something about the nature of God that others don't get. Unless you're a physicist you don't understand how beautiful James Clerk Maxwell's equations are. There are things artists and poets and musicians understand that I will not get. But science helps me to understand God in a way that's really amazing.

The question of theodicy is for me one of the most troubling questions of religious faith: why, if God is good, is there suffering unrelated to the bad choices that free creatures make? However, as a physicist, I am keenly aware that there are questions like "What are the position and velocity of this particle?" that seem reasonable and meaningful, and yet are clearly not meaningful in the context of quantum mechanics. Knowing this makes it easier for me to accept that there may be questions to which I cannot expect an answer in this lifetime because of a lack of understanding of the larger picture—which may be analogous to the lack of understanding that existed in physics in the nineteenth century before quantum mechanics was discovered.

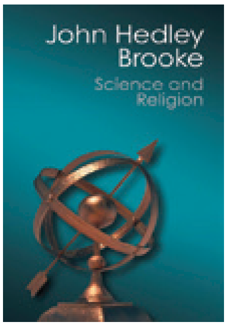
KH: John Holdren, a physicist who served as President Obama's science advisor, says about climate change, "We have three choices: mitigation, adaptation, and suffering. We're going to do some of each. The question is what the mix is going to be. The more mitigation we do, the less adaptation will be required and the less suffering there will be." I study climate impacts to quantify the benefits of mitigation and to inform adaptation, trying to prevent as much suffering as possible because I believe that we as Christians are called to love others as we've been loved ourselves by God.

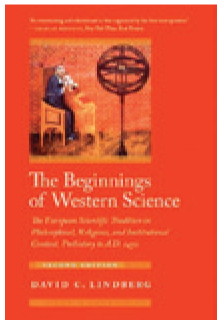
AG: In one of my college classes, we studied the work of Julian of Norwich. She famously wrote of a revelation from God in which she held a hazelnut that represented all of the created universe, and in it saw three properties: "The first is that God made it. The second that God loves it. And the third, that God keeps it." Like Julian I found myself holding (in a glove-covered hand) a tube filled with tiny immune cells. I marveled at the complexity and improbability of these cells and felt, in that moment, the weight of what it meant to be created, loved, and sustained by God. CH

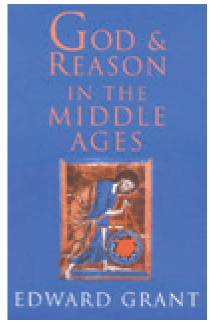
QUANTUM OPTICS—HAND OF A RESEARCHER ADJUSTING A LASER BEAM IN A LAB—VIKTOR CAP / ALAMY STOCK PHOTO
CANCER CELLS GROWING IN MEDIA CONTAINING BLEBBISTATIN—NEVENA MOREL, WITH MY TEAM LISA BOURNE AND NICOLAS JACQUEMIN / [CC BY 4.0]—WIKIMEDIA

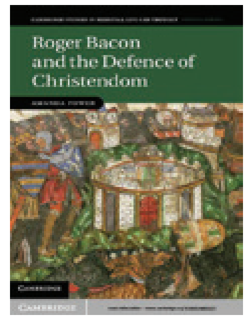
Recommended resources

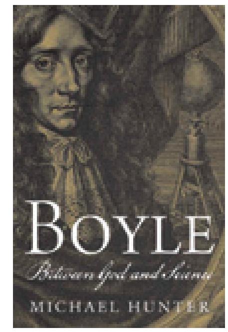
LEARN MORE ABOUT CHRISTIAN SCIENTISTS AND INVENTORS THROUGHOUT CHURCH HISTORY WITH THESE RESOURCES SELECTED BY THIS ISSUE'S AUTHORS AND EDITORS.











BOOKS

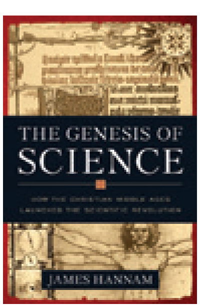
Several books on the relationship between **Christianity and science throughout church history** include David Lindberg and Ronald Numbers, eds., *God and Nature* (1986); John Hedley Brooke, *Science and Religion* (2014) and, with Geoffrey Cantor, *Reconstructing Nature* (2001); and the *Dictionary of Christianity and Science* (2017) edited by Paul Copan, Tremper Longman III, Christopher Reese, and Michael Strauss.

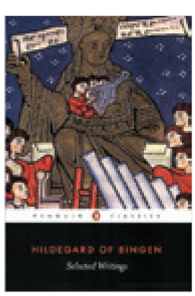
Read more about the **flourishing of science in the Middle Ages** in Edward Grant, *God and Reason in the Middle Ages* (2001); Peter Harrison, *The Fall of Man and the Foundations of Science* (2007); James Hannam, *The Genesis of Science* (2011); and David Lindberg, *The Beginnings of Western Science* (2010).

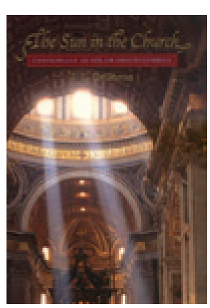
Studies of **Hildegard of Bingen** abound; you can start with Fiona Bowie and Oliver Davies, ed., *Hildegard of Bingen: An Anthology* (1995); Priscilla Throop, trans., *Hildegard von Bingen's* Physica (1998); Mark Atherton, *Selected Writings: Hildegard of Bingen* (2001); Bruce Hozeski, trans., *Hildegard's Healing Plants* (2002); Carmen Acevedo Butcher, *Hildegard of Bingen* (2009); and Beverly Mayne Kienzle, Debra Stoudt, and George Ferzoco, eds., *A Companion to Hildegard of Bingen* (2013).

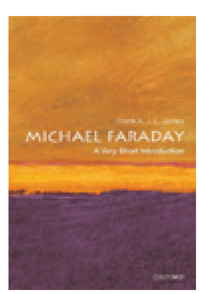
To learn about **Albert the Great**, read Irven Resnick, ed., *A Companion to Albert the Great* (2013). For more on **Robert Grosseteste,** consult *Robert Grosseteste on the Six Days of Creation* (1996); F. A. C. Mantello and Joseph Goering, translators, *The Letters of Robert Grosseteste, Bishop of Lincoln* (2010); and Jack Cunningham and Mark Hocknull, eds., *Robert Grosseteste and the Pursuit of Religious and Scientific Learning in the Middle Ages* (2016). For **Roger Bacon**, check out Jeremiah Hackett, ed., *Roger Bacon and the Sciences* (1997); and Amanda Power, *Roger Bacon and the Defence of Christendom* (2013).

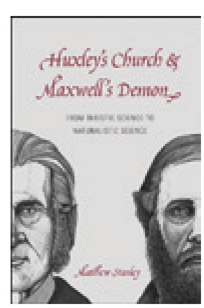
To understand the **Scientific Revolution**, look at Charles Hummel, *The Galileo Connection* (1986); J. L. Heilbron, *The Sun in the Church* (1999); Kenneth J. Howell, *God's Two Books* (2004); Floris Cohen, *How Modern Science Came into the World* (2012). To understand **Kepler** in more detail, check out James R. Voelkel, *Johannes Kepler and the New Astronomy* (2001); and James A. Connor, *Kepler's Witch* (2004). A good book on **Boyle** is Michael Hunter, *Boyle: Between God and Science* (2009). You can also look at David Livingstone, D. G. Hart, and Mark Noll, eds., *Evangelicals and Science in Historical Perspective* (1999) for more on science and belief in European and American church history.

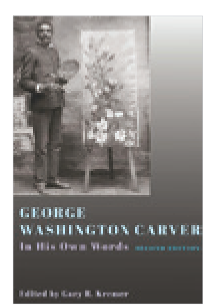












To learn more about **Michael Faraday**, consult Geoffrey Cantor, *Michael Faraday: Sandemanian and Scientist* (1991); and Frank A. J. L. James, *Michael Faraday: A Very Short Introduction* (2010). For **James Clerk Maxwell**, look at Ivan Tolstoy, *James Clerk Maxwell, A Biography* (1981); and Matthew Stanley, *Huxley's Church and Maxwell's Demon* (2016).

George Washington Carver has attracted many biographers: some good places to start are Linda McMurry Edwards, *George Washington Carver, Scientist and Symbol* (1989); John Perry, *Unshakable Faith* (1999), which also profiles Booker T. Washington; Mark Hersey, *My Work Is That of Conservation* (2011); and the second edition of *George Washington Carver: In His Own Words*, ed. Gary Kremer (2017).

CHRISTIAN HISTORY ISSUES

Read these related issues of *Christian History* on our website. Some are still available for purchase.
73: *Thomas Aquinas*
76: *The Christian Face of the Scientific Revolution*
101: *Healthcare and Hospitals*
107: *Debating Darwin*
119: *The Wonder of Creation*

VIDEOS FROM VISION VIDEO

Videos on the theme of this issue include *Has Science Killed Christianity?*; *Philosophy, Science, and the God Debate*; *More Than My Brain*; *Reasonable Doubt*; *Stumbling Blocks to Faith*; *The Call of the Cosmos*; the *Faith and Science Lecture Forum* series; and *Towards Belief*.

WEBSITES

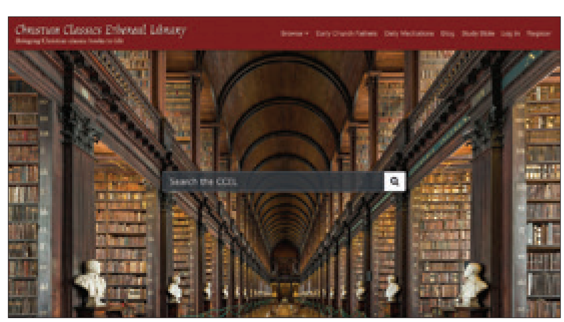
Most of the thinkers discussed in this issue can be found in the Stanford Encyclopedia of Philosophy, which will give you good brief introductions to their lives and thoughts. The History of Science department at Oklahoma University has a wealth of resources

(including many images we've used in this issue!). BioLogos has several series of articles on the history of religion and science in America; you can also read about Hitchcock in particular at DinoTracks Discovery.

The Counterbalance Foundation, which we recommended in issue #76, is still around (as is its companion website for the PBS documentary *Faith and Reason*) and

has articles on a number of topics linking science and faith. James Hannam maintains a website on science and faith at Bede's Library.

As always, primary source works of many notable people we've profiled are available at the Christian Classics Ethereal Library, Project Gutenberg, and the Medieval Sourcebook and Modern History Sourcebook. CH



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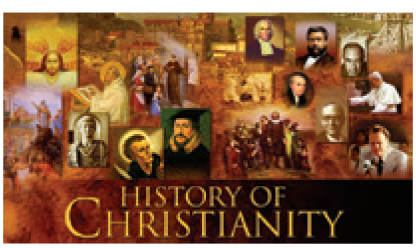

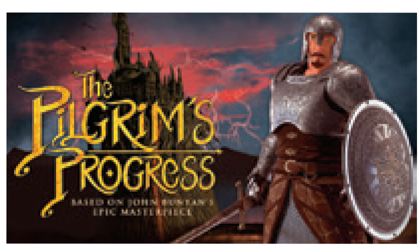

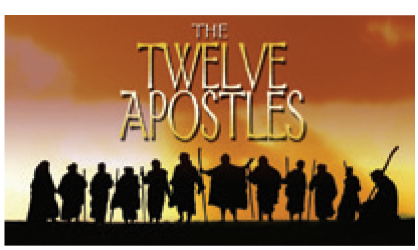

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