Introduction: The Origins of Modern Science

Where did modern science come from? Until very recently, most historians would tell you the following story. Sometime between 1500 and 1700, modern science was invented in Europe. This is a history which usually begins with the Polish astronomer Nicolaus Copernicus. In *On the Revolutions of the Heavenly Spheres* (1543), Copernicus argued that the Earth goes around the Sun. This was a radical idea. Since the time of the ancient Greeks, astronomers had believed that the Earth was at the centre of the universe. For the first time, scientific thinkers in sixteenth-century Europe started to challenge ancient wisdom. Copernicus was followed by other pioneers of what is often called the 'scientific revolution' – the Italian astronomer Galileo Galilei, who first observed the moons of Jupiter in 1609, and the English mathematician Isaac Newton, who set out the laws of motion in 1687. Most historians would then tell you that this pattern continued for the next 400 years. The history of modern science, as traditionally told, is a story focused almost exclusively on men like Charles Darwin, the nineteenth-century British naturalist who advanced the theory of evolution by natural selection, and Albert Einstein, the twentieth-century German physicist who proposed the theory of special relativity. From evolutionary thought in the nineteenth century to cosmic physics in the twentieth century, modern science – we are told – is a product of Europe alone.[1]

This story is a myth. In this book, I want to tell a very different story about the origins of modern science. Science was not a product of a unique European culture. Rather, modern science has always depended upon bringing together people and ideas from different cultures around the world. Copernicus is a good example of this. He was writing at a time when Europe was forging new connections with Asia, with caravans travelling along the Silk Road as well as galleons sailing across the Indian Ocean. In his scientific work, Copernicus relied upon mathematical techniques borrowed from Arabic and Persian texts, many of which had only recently been imported into Europe. Similar kinds of scientific exchange were taking place throughout Asia and Africa. This was the same period in which Ottoman astronomers journeyed across the Mediterranean, combining their knowledge of Islamic science with new ideas borrowed from Christian and Jewish thinkers. In West Africa, at the courts of Timbuktu and Kano, mathematicians studied Arabic manuscripts imported from across the Sahara. To the east, astronomers in Beijing read Chinese classics alongside Latin scientific texts. And in India, a wealthy maharaja employed Hindu, Muslim, and Christian mathematicians to compile some of the most accurate astronomical tables ever made.[2]

All this suggests a very different way of understanding the history of modern science. In this book, I argue that we need to think of the history of modern science in terms of key moments in global history. We begin with the colonization of the Americas in the fifteenth century and move all the way through to the present. Along the way we explore major developments in the history of science, from the new astronomy of the sixteenth century through to genetics in the twenty-first. In each case, I show how the development of modern science depended upon global cultural exchange. It is worth emphasizing, however, that this is not simply a story of the triumph of globalization. After all, cultural exchange came in lots of different forms, many of which were deeply exploitative. For much of the early modern period, science was shaped by the growth of slavery and empire. In the nineteenth century, science was transformed by the development of industrial capitalism. Whilst in the twentieth century, the history of science is best explained in terms of the Cold War and decolonization. Yet despite these deep imbalances of power, people from across the world made significant contributions to the development of modern science. Whatever period we look at, the history of science cannot be told as a story which focuses solely on Europe.[3]

The need for such a history has never been so great. The balance of the scientific world is shifting. China has already overtaken the United States in terms of science funding, and for the last few years researchers based in China have produced more scientific articles than anywhere else in the world. The United Arab Emirates launched an unmanned mission to Mars in the summer of 2020, whilst computer scientists in

Kenya and Ghana play an increasingly important role in the development of artificial intelligence. At the same time, European scientists face the fallout from Brexit, whilst Russian and American security services continue to wage cyberwarfare.[4]

Science itself is plagued by controversy. In November 2018, the Chinese biologist He Jiankui shocked the world by announcing that he had successfully edited the genes of two human babies. Many scientists believed that such a procedure was too risky to justify trying on human subjects. However, as the world quickly learned, it is very hard to enforce an international code of scientific ethics. Officially, the Chinese government distanced itself from He's research, serving him with a three-year prison sentence. But in 2021, researchers in Russia are already threatening to replicate his controversial experiment. Alongside issues surrounding ethics, science today, as in the past, suffers from deep inequalities. Scientists from minority ethnic backgrounds are underrepresented at the top of the profession, Jewish scientists and students continue to suffer antisemitic abuse, whilst researchers working outside of Europe and the United States are often denied visas for travel to international conferences. If we are to tackle such problems, we need a new history of science, one that better reflects the world in which we live.[5]

Scientists today are quick to acknowledge the international nature of their work. But they tend to think of this as a relatively recent phenomenon, a product of the 'big science' of the twentieth century, rather than something with a history stretching back more than 500 years. When contributions to science from outside of Europe are acknowledged, they are typically relegated to the distant past, not part of the story of the scientific revolution and the rise of modern science. We hear a lot about the 'golden age' of medieval Islamic science, the period around the ninth and tenth centuries, when scientific thinkers in Baghdad first developed algebra and many other new mathematical techniques. There is a similar emphasis on the scientific accomplishments of ancient China, such as the invention of the compass and gunpowder, both well over 1,000 years ago. But these stories only serve to reinforce the narrative that places like China and the Middle East have little to do with the history of modern science. Indeed, we often forget that the notion of a 'golden age' had originally been invented during the nineteenth century in order to justify the expansion of European empires. British and French imperialists promoted the false idea that the civilizations of Asia and the Middle East had been in decline since the medieval period, and so needed to modernize.[6]

Perhaps surprisingly, these stories are still just as popular in Asia as they are in Europe. Cast your mind back to the 2008 Beijing Olympics. The opening ceremony began with an enormous scroll unfolding, signifying the invention of paper in ancient China. Throughout the ceremony, a television audience of over one billion watched as China showcased its other ancient scientific achievements, including the compass. Fittingly, the ceremony closed with a spectacular display of another Chinese discovery. Fireworks lit up the sky above the Bird's Nest Stadium, a nod towards the invention of gunpowder during the Song dynasty. Yet throughout the ceremony, there was very little reference to the many scientific breakthroughs that China has contributed to since then, such as the development of natural history in the eighteenth century or quantum mechanics in the twentieth century. The same is true of the Middle East. In 2016, the Turkish President, Recep Tayyip Erdoğan, gave a lecture at the Turkish–Arab Congress on Higher Education in Istanbul. In his talk, Erdoğan described the 'golden age of Islamic civilization', the medieval period in which 'Islamic cities . . . acted as a science center'. Yet Erdoğan was seemingly unaware of the fact that many Muslims, including those living in what is today modern Turkey, had also contributed just as much to the development of modern science. From astronomy in sixteenth-century Istanbul to human genetics in twentieth-century Cairo, the Islamic world of scientific advance continued well beyond the medieval 'golden age'.[7]

Why are these stories so common? Like many myths, the idea that modern science was invented in Europe did not come about by accident. During the middle of the twentieth century, a group of historians in Britain and the United States started to publish books with titles like *The Origins of Modern Science*. Almost all were convinced that modern science – and with it modern civilization – originated in Europe, sometime around the sixteenth century. 'The scientific revolution we must regard . . . as a creative product of the West,' wrote the influential Cambridge historian Herbert Butterfield in 1949. Similar views were expressed on the other side of the Atlantic. Students at Yale University in the 1950s were taught that 'the West generated the natural sciences . . . the East did not', whilst readers of *Science* – one of the most prestigious scientific magazines in the world – were informed that 'a small circle of Western European nations provided the original home for modern science'.[8]

The politics of all this couldn't be clearer. These historians lived through the early decades of the Cold War, a period in which the struggle between capitalism and communism dominated world politics. They thought about the contemporary world in terms of a strict divide between East and West, and then – whether intentionally or not – projected this back onto the past. During this period, science and technology were widely seen as markers of political success, particularly after the Soviet Union launched Sputnik, the first artificial satellite, in October 1957. The idea that modern science was invented in Europe therefore served as a convenient fiction. For leaders in Western Europe and the United States, it was essential that their citizens saw themselves on the right side of history, as bearers of scientific and technological progress. This was also a history of science designed to convince post-colonial states around the world to follow the path of capitalism, and to steer clear of communism. Throughout the Cold War, the United States spent billions of dollars on foreign aid, promoting a combination of free market economics and scientific development in countries across Asia, Africa, and Latin America. This was intended to counter the foreign assistance programme run by the Soviet Union. 'Western science', when combined with 'market economies', promised nothing less than an economic 'miracle', at least according to American policymakers.[9]

Somewhat ironically, Soviet historians ended up reinforcing a very similar narrative concerning the origins of modern science. They tended to ignore the earlier achievements of Russian scientists working under the Tsars, instead promoting the spectacular rise of science under communism. 'Up to the twentieth century, there was really no physics in Russia,' wrote the President of the Soviet Academy of Sciences in 1933. As we'll see, this was not true. Peter the Great supported some of the most important astronomical observations made during the early eighteenth century, whilst Russian physicists played a key role in the development of the radio in the nineteenth century. Some later Soviet historians did try and highlight earlier Russian scientific achievements.

But at least in the early decades of the twentieth century, it was much more important to emphasize the revolutionary advances made under communism rather than anything achieved under the old regime.[10]

Things played out slightly differently in Asia and the Middle East, although ultimately with similar consequences. The Cold War was a period of decolonization, in which many countries finally gained independence from European colonial powers. Political leaders in places like India and Egypt desperately wanted to forge a new sense of national identity. Many looked to the ancient past. They celebrated the achievements of medieval and ancient scientific thinkers, ignoring much of what had happened during the period of colonialism. It was in fact in the 1950s that the very idea of an Islamic or Hindu 'golden age' started to become popular – not just in Europe, as it had been in the nineteenth century, but also in the Middle East and Asia. Indian and Egyptian historians seized on the idea of a glorious scientific past, one waiting to be rediscovered. In doing so, they unwittingly reinforced the very myth being peddled by European and American historians. Modern science was Western, ancient science was Eastern, or so people were told.[11]

The Cold War is over, but the history of science is still stuck in the past. From popular history to academic textbooks, the idea that modern science was invented in Europe remains one of the most widespread myths in modern history. Yet there is very little evidence to support it. In this book, I provide a new history of modern science, one that is both better supported by the available evidence and more suited to the times in which we live. I show how the development of modern science fundamentally relied on the exchange of ideas between different cultures across the world. That was true in the fifteenth century, just as it is true today.

From Aztec palaces and Ottoman astronomical observatories to Indian laboratories and Chinese universities, this book follows the history of modern science across the globe. However, it is important to remember that this is not an encyclopaedia. I have not tried to cover every country in the world, nor every scientific discovery. Such an approach would be foolhardy, and not particularly enjoyable to read. Rather, the aim of this book is to show how global history shaped modern science. For that reason, I have picked four key periods of world historical change, linking each of these to some of the most important developments in the history of science. By placing the history of science at the heart of world history, this book also uncovers a new perspective on the making of the modern world – from the history of empire to the history of capitalism, if we want to understand modern history, we need to pay attention to the global history of science.

Finally, I want to emphasize that I see science as very much a human activity. Modern science was undoubtedly shaped by wider world events, but it was nonetheless made through the efforts of real people. These were individuals who, whilst living in a very different time and place, were not fundamentally different from you or me. They had families and relationships. They struggled with their emotions and health. And each of them wanted more than anything else to better understand the universe in which we live. Throughout this book, I have tried to give a sense of that more human side of science: an Ottoman astronomer captured by pirates in the Mediterranean; an enslaved African collecting medicinal herbs on a plantation in South America; a Chinese physicist fleeing the Japanese assault on Beijing; and a Mexican geneticist collecting blood samples from Olympic athletes. Each of these individuals, although largely forgotten today, made important contributions to the development of modern science. This is their story – the scientists who have been written out of history.

PART ONE

Scientific Revolution, *c.*1450–1700

1. New Worlds

Stepping out into the Mexican sun, Emperor Moctezuma II could hear the birds calling. His palace – located at the heart of the Aztec capital city of Tenochtitlan – housed an aviary, in which birds from all over the Americas were kept. Green parakeets perched on the latticework, whilst purple hummingbirds flashed through the trees. Alongside the aviary, Moctezuma's palace featured a menagerie in which larger animals lived, including a jaguar and a coyote. But of all the wonders of nature, Moctezuma most appreciated flowers. Each morning, he would take a turn around the royal botanical garden. Roses and vanilla flowers lined the paths, whilst hundreds of Aztec gardeners tended to rows of medicinal plants.[1]

Built in 1467, this Aztec botanical garden predated European examples by almost a century. And it wasn't just for show. The Aztecs developed a sophisticated understanding of the natural world. They categorized plants according to their structure as well as use, particularly distinguishing between decorative and medicinal plants. Aztec scholars also reflected on the relationship between the natural world and the heavens, arguing – much like in the Christian tradition – that plants and animals were the handiwork of the gods. Moctezuma himself took great interest in all this. He commissioned surveys of the natural history of the Aztec Empire and made vast collections of animal skins and dried flowers. An accomplished scholar in his own right, Moctezuma is described in Aztec chronicles as 'by nature wise, an astrologer, a philosopher, skilled in all the arts'. He stood at the head of a vast empire, one in which science reached new heights.[2]

Tenochtitlan was an engineering marvel. Built on an island at the centre of Lake Texcoco in 1325, the Aztec capital could only be reached by crossing one of three causeways, each stretching several miles across the water. Just like Venice, the city was criss-crossed by canals, with Aztec merchants paddling back and forth in canoes as they went about their daily business. An aqueduct provided the city with a supply of fresh water, whilst, out on the lake, farmers tended to strips of reclaimed land, growing maize, tomatoes, and chillies. At the centre of the city stood the Great Temple, an immense stone pyramid, over sixty metres tall. Aztec architects had designed the temple to align perfectly with the rising and setting of the Sun on key feast days. Moctezuma himself would attend ceremonies, praising the gods and offering tribute in the form of flowers, animal skins, and sometimes human sacrifice. By the middle of the fifteenth century, Tenochtitlan had grown to an unprecedented size. With a population of over 200,000, this Aztec megacity was much larger than most European capitals, including London and Rome. Over the following decades, the Aztec Empire continued to expand, stretching right across the Mexican plateau and incorporating over three million people.[3]

All this was made possible thanks to the advanced state of Aztec science and technology. From observing the heavens to studying the natural world, the Aztecs placed great emphasis on the cultivation of knowledge. Unlike most European kingdoms at the time, a significant proportion of Aztec children, both male and female, received some kind of formal education. There were also specialist schools for noble boys who wished to train as priests, a profession that required expert knowledge of astronomy and mathematics in order to compile the Aztec calendar. Alongside priests, there was a special class of people referred to as 'knowers of things'. These were highly trained individuals, the equivalent of a university-educated scholar in Europe. They built up great libraries, often contributing new works themselves. The Aztecs also developed one of the most advanced medical systems in the world at that time. In Tenochtitlan, you could consult a range of medical practitioners, from physicians known as *ticitl*, to surgeons, midwives, and apothecaries. The city even housed a medical market, where traders from across the empire brought herbs, roots, and ointments for sale. Today we know that many Aztec medicinal plants do have pharmacologically active properties. These include a type of daisy that can be used to induce labour, as well as a species of Mexican marigold that helps reduce inflammation.[4]

Much of what we know about Tenochtitlan comes from accounts written by the people who destroyed it. On 8 November 1519, the Spanish conquistador Hernán Cortés entered the city for the first time.

Initially, Moctezuma welcomed the Spanish, housing Cortés and his men in the royal palace. They were overwhelmed by what they saw. Bernal Díaz del Castillo, one of the soldiers who accompanied Cortés, later described Moctezuma's gardens in *The True History of the Conquest of New Spain* (1576):

> We went to the orchard and garden, which was such a wonderful thing to see and walk in, that I was never tired of looking at the diversity of the trees, and noting the scent which each one had, and the paths full of roses and flowers, and the many fruit trees and native roses, and the pond full of fresh water.

Díaz also described the aviary. He recalled seeing 'everything from the royal eagle . . . down to tiny birds of many-coloured plumage . . . feathers of five colours – green, red, white, yellow and blue'. There was also a 'great tank of fresh water and in it all other sorts of birds with long stilted legs, with body, wings, and tail all red'.[5]

The tranquillity did not last. Cortés took advantage of the situation, taking Moctezuma hostage and fighting his way through the city. And although the Spanish were initially repelled, Cortés returned with a far greater force two years later. Ships armed with cannon surrounded the city on the lake, as Spanish soldiers drove through the gates. Moctezuma was murdered and the Great Temple was destroyed. Cortés himself set fire to the palace. The aviary, the menagerie, and the gardens all burned. As Díaz noted, somewhat mournfully for a soldier, 'of all these wonders that I then beheld . . . today all is overthrown and lost, nothing left standing'. The conquest of the Aztecs marked the beginning of the Spanish Empire in the Americas. In 1533, Charles V established the Viceroyalty of New Spain. The capital, Mexico City, was built on the ashes of Moctezuma's palace.[6]

Most histories of science do not begin with the Aztecs in Mexico. Traditionally, the history of modern science begins in sixteenth-century Europe, with what is often called the 'scientific revolution'. We are told that, in the period between around 1500 and 1700, an incredible transformation in scientific thought took place. In Italy, Galileo Galilei observed the moons of Jupiter, whilst in England, Robert Boyle first described the behaviour of gases. In France, René Descartes developed a new way of doing geometry, whilst in Holland, Antonie van Leeuwenhoek first observed bacteria under a microscope. Typically, this story culminates with the work of Isaac Newton, the great English mathematician who set out the laws of motion in 1687.[7]

Historians have long argued over the nature and causes of the scientific revolution. Some see this as a period of intellectual advance, one in which a few lone geniuses made new observations and challenged medieval superstition. Others argue that this was a period of great social and religious change, one in which the English Civil War and the Protestant Reformation forced people to reassess a range of basic beliefs about the nature of the world. Then there are those who see the scientific revolution as a product of technological change. From the printing press to the telescope, this period saw the invention of an assortment of new tools, each of which allowed for the investigation of nature and the dissemination of scientific ideas on an unprecedented scale. Finally, some historians deny that this really was a period of significant change. After all, many of the great thinkers of the scientific revolution continued to rely in some ways on much older ideas, such as those found in the Bible or in ancient Greek philosophy.[8]

Until recently, however, very few historians have stopped to consider whether they are looking in the right place to begin with. Is the history of the scientific revolution really a story about Europe alone? The answer is no. From the Aztec Empire in the Americas to the Ming Empire in China, the history of the scientific revolution is a story which incorporates the entire world. And it isn't just that people in the Americas, Africa, and Asia happened to be developing advanced scientific cultures at the same time as those in Europe. Rather, it is the history of encounters between these different cultures which explains precisely why the scientific revolution occurred when it did.

With this in mind, I want to tell a new history of the scientific revolution. In this chapter, we explore how encounters between Europe and the Americas kickstarted a major reassessment of natural history, medicine, and geography. Much of what we know about the science produced in the New World during this period comes from the perspective of European explorers, a legacy of the history of colonization that this chapter examines. But if we look a little closer, using sources such as Aztec codices and Inca histories, we can also uncover another side to this story, one that highlights the hidden contributions of Indigenous peoples to the scientific revolution. In the next chapter, we move east, revealing how connections between Europe, Africa, and Asia shaped the development of mathematics and astronomy. Together, these chapters represent the beginning of a recurrent theme concerning the importance of global history for understanding the history of modern science. Ultimately, to account for the scientific revolution we need to look, not just to London and Paris, but to the ships and caravans which connected the early modern world.[9]

I. Natural History in the New World

After over two months at sea, Christopher Columbus finally sighted land. Sailing aboard the *Santa María* on behalf of the Spanish Crown, Columbus was in search of a western passage to the Indies. Instead, he encountered a whole new continent. On 12 October 1492, Columbus landed on an island he named San Salvador, part of the Bahamas. This was the beginning of a long history of European colonization in the Americas. Like many subsequent travellers to the New World, Columbus was amazed by the diversity of plant and animal life he encountered. He recorded in his diary that 'all the trees were as different from ours as day from night, and so were the fruits, the herbage, the roots, and all things'. Columbus also quickly recognized the commercial potential of the Americas, noting that there were 'many plants and many trees, which are worth a lot in Spain for dyes and for medicines'. Most alarmingly, the island was inhabited. On landing, the Spanish crew encountered a group of Indigenous people. Still believing he had reached the East Indies, Columbus named them *indios*, or 'Indians'. Encouraged by the abundance of plant, animal, and human life, Columbus continued to explore the West Indies over the following months, reaching Cuba and Hispaniola. He later returned on three separate voyages, travelling as far as Central and South America.[10]

The colonization of the Americas was one of the most important events in world history. It was also an event which profoundly shaped the development of modern science, challenging longstanding assumptions about how scientific knowledge was best acquired. Prior to the sixteenth century, scientific knowledge was thought to be found almost exclusively within ancient texts. This was especially the case in Europe, although, as we'll see in the following chapter, similar traditions existed across much of Asia and Africa. Surprising as it may sound today, the idea of making observations or performing experiments was largely unknown to medieval thinkers. Instead, students at medieval universities in Europe spent their time reading, reciting, and discussing the works of ancient Greek and Roman authors. This was a tradition known as scholasticism. Commonly read texts included Aristotle's *Physics*, written in the fourth century BCE, and Pliny the Elder's *Natural History*, written in the first century CE. The same approach was common to medicine. Studying medicine at a medieval university in Europe involved almost no contact with actual human bodies. There were certainly no dissections or experiments on the workings of particular organs. Instead, medieval medical students read and recited the works of the ancient Greek physician Galen.[11]

Why, then, sometime between 1500 and 1700, did European scholars turn away from ancient texts and start investigating the natural world for themselves? The answer has a lot to do with the colonization of the New World alongside the accompanying appropriation of Aztec and Inca knowledge, something that traditional histories of science fail to account for. As many early European explorers were quick to recognize, the plants, animals, and people they encountered in the Americas were not described in any of the ancient works. Aristotle had never seen a tomato, let alone an Aztec palace or an Inca temple. It was this revelation which brought about a fundamental shift in how Europeans understood science.[12]

The Italian explorer Amerigo Vespucci, after whom 'America' is named, was one of the first to recognize the implications of Columbus's 'discovery' for natural history. After returning from his own voyage to the New World in 1499, Vespucci wrote to a friend in Florence. He reported seeing all kinds of incredible animals, including a 'serpent' – most likely an iguana – which the Indigenous people roasted and ate. Vespucci also recalled seeing birds 'so numerous and of so many species and varieties of plumage that it is astounding to behold'. Most significantly, Vespucci made a direct connection between the natural history of the New World and what was known from ancient texts. He concluded with a damning criticism of Pliny's *Natural History*, the traditional authority on the subject. As Vespucci noted, 'Pliny did not touch upon a thousandth part of the species of parrots and other birds and animals' which were found in the Americas.[13]

Vespucci's criticism of Pliny was just the start. Over the following years, thousands of travellers returned from the New World with reports of things unknown to the ancients. One of the most influential accounts was written by a Spanish priest named José de Acosta. Born to a prosperous merchant family in 1540, Acosta was always looking to escape his comfortable but rather mundane upbringing. At the age of twelve, he ran away from home to join the Society of Jesus, a Catholic missionary organization which played a major role in the development of early modern science. The founder of the order, Ignatius of Loyola, urged his followers to 'find God in all things', whether that was in reading the Bible or studying the natural world. The Jesuits therefore placed great emphasis on the study of science, both as a way to appreciate God's wisdom, but also as a means to demonstrate the power of the Christian faith to potential converts. After joining the Jesuits, Acosta attended the University of Alcalá, where he studied the classical works of Aristotle and Pliny. On graduating, Acosta was asked to go as a missionary to the New World, setting sail in 1571. He spent the next fifteen years in the Americas, travelling across the Andes in search of converts. On returning to Spain, Acosta began to write a book describing everything he had seen, from the volcanoes of Peru to the parrots of Mexico. The finished work was titled *Natural and Moral History of the Indies* (1590).[14]

Acosta witnessed many strange things in the Americas. But perhaps the most important experience Acosta had was during his initial voyage across the Atlantic Ocean. The young priest was anxious about the journey, not least because of what ancient authorities said about the equator. According to Aristotle, the world was divided into three climatic zones. The north and south poles were characterized by extreme cold and known as the 'frigid zone'. Around the equator was the 'torrid zone', a region of burning dry heat. Finally, between these two extremes, at around the same latitudes as Europe, was the 'temperate zone'. Crucially, Aristotle argued that life, particularly human life, could only be sustained in the 'temperate zone'. Everywhere else was either too hot or too cold.[15]

Acosta therefore expected to experience incredible heat as he approached the equator. But this was not the case. 'The reality was so different that at the very time I was crossing I felt such cold that at times I went out into the sun to keep warm,' explained Acosta. The implications for ancient philosophy were clear. Acosta went on, writing:

> I must confess I laughed and jeered at Aristotle's meteorological theories and his philosophy, seeing that in the very place where, according to his rules, everything must be burning and on fire, I and all my companions were cold.

As he travelled across South and Central America, Acosta confirmed that the region around the equator was not always as hot, and certainly not as dry, as Aristotle believed. Indeed, Acosta experienced a great diversity of climates, explaining how 'in Quito, and on the plains of Peru' it was 'quite temperate', whereas in Potosí it was 'very cold'. Not only that, but, most strikingly of all, the region was full of life – not just plants and animals, but also people. As Acosta concluded, 'the Torrid Zone is habitable and very abundantly inhabited, even though the ancients said that this was impossible'.[16]

This was certainly a blow to classical authority. If Aristotle had been mistaken about the climatic zones, what else might he have been wrong about? Worried by this thought, Acosta spent much of his life trying to reconcile what he had learned from ancient texts with what he had experienced in the New World. The diversity of previously unknown animals proved particularly difficult to explain. From sloths in Peru to hummingbirds in Mexico, there were 'a thousand kinds of birds and fowl and forest animals that have never been known before either in name or shape, nor is there any memory of them in the Latins and Greeks, nor in any nations of our world', explained Acosta. Clearly, Pliny's *Natural History* was incomplete.[17]

Acosta understood the implications of his discoveries. However, he wasn't ready to completely abandon classical learning. As a Christian, Acosta still placed great value on ancient authority. The Bible after all was the ultimate classical text. Like many early travellers to the Americas, Acosta therefore mixed the old with the new. In some instances he claimed that, whilst Aristotle might have been wrong, other ancient sources were right. In the case of the torrid zone, Acosta pointed out that the ancient

Greek geographer Ptolemy took a different view, and 'believed that there were commodious habitable regions under the tropics'. Acosta also noted that some ancient texts even suggested the existence of new worlds beyond the known oceans. Plato described the mythical island of Atlantis, whilst the Bible referred to a faraway land called Ophir from which King Solomon received shipments of silver. Indeed, classical texts were full of unknown countries, each of which could easily be interpreted as the Americas. At first, then, encounters in the New World did not lead to a complete rejection of ancient learning. Instead, European scholars were forced to revisit classical texts in light of new experiences.[18]

Bernardino de Sahagún spent most of his life in the Americas. Born in Spain in 1499, Sahagún joined the Franciscan order whilst studying at the University of Salamanca. Like José de Acosta, he received an education typical of the time, studying the ancient works of Aristotle and Pliny as preparation for the priesthood. In 1529, Sahagún crossed the Atlantic and arrived in New Spain, one of the first cohort of missionaries to reach the New World. He spent the rest of his life in the Americas, dying in Mexico City aged ninety. During his time there, Sahagún helped compile one of the most comprehensive accounts of sixteenth-century Mexico. He called it the *General History of the Things of New Spain* (1578). Better known as the *Florentine Codex*, this monumental work described, not only the plants and animals of the New World, but also Aztec medicine, religion, and history. The complete work was made up of twelve books and contained over 2,000 hand-coloured drawings.[19]

The *Florentine Codex* was not the work of Sahagún alone. Rather, it was a collaborative effort with Indigenous people. Shortly after arriving in New Spain, Sahagún took up a post teaching Latin at the Royal College of Santa Cruz in Tlatelolco, on the outskirts of Mexico City. The Royal College had been established in 1534 in order to train the sons of Aztec nobles in preparation to join the clergy. Over seventy Indigenous boys lived at the college, receiving a traditional scholastic education much as Sahagún had in Spain. The boys learned Latin and read Aristotle, Plato, and Pliny. Alongside this, the Aztec students at the Royal College were taught to write their own language, Nahuatl, in the Latin alphabet. This was an important development, as traditionally the Aztecs did not use a written alphabet. Instead, Nahuatl was a pictorial language in which certain images represented different words or phrases. The Spanish often dismissed Aztec pictorial books as primitive, even idolatrous. As another missionary claimed, the Aztecs were 'a people without writing, without letters, without written chronicles, and without any kind of enlightenment'. This, as we now know, was not true. But such attitudes served the Spanish well as they tried to transform the Aztecs into Europeanized Christians. This was part of a broader European attempt to justify the conquest of the Americas under the guise of bringing Christianity to the New World.[20]

Sahagún, however, recognized the value of Aztec culture more than many of his contemporaries. He learned Nahuatl and, in 1547, began work on the *Florentine Codex*. Sahagún realized that, to really understand the natural history of the New World, he would have to learn from the people who already lived there. With this in mind, Sahagún assembled a group of students at the Royal College. We know the names of four of them: Antonio Valeriano, Alonso Vegerano, Martín Jacobita, and Pedro de San Buenaventura. (Unfortunately, their original Nahuatl names are lost.) Together, Sahagún and his party set off across New Spain in search of Aztec knowledge. On arriving in a town, Sahagún would arrange an interview with a group of Indigenous elders. Often, the elders would recite ancient Aztec histories or describe an unknown plant or animal. Sometimes the elders would even bring out a surviving Aztec codex, each page painted with a complex array of glyphs. 'They gave me all the matters we discussed in pictures, for that was the writing deployed in ancient times,' explained Sahagún. As he could not interpret these himself, Sahagún then relied on his Aztec students to translate what they saw into written Nahuatl. Later, back at the Royal College, Sahagún and his assistants translated the Nahuatl into Spanish. He also commissioned a group of Indigenous artists to paint illustrations to accompany the text. In 1578, after over two decades of work, Sahagún finally sent the complete manuscript to Philip II of Spain.[21]

Like Acosta, Sahagún fused the old with the new. The *Florentine Codex* took Pliny's *Natural History* as a model. Indeed, Sahagún's students at the Royal College would have been familiar with this ancient work. Much like Pliny, the *Florentine Codex* is composed of a series of books covering geography, medicine, anthropology, plants, animals, agriculture, and religion. The main book that covers natural history is titled ‘Earthly Things’. On opening this volume, however, we discover a world of plants and animals unknown to the ancients. Appropriately enough, this volume is also the most heavily illustrated, including paintings of 39 mammals, 120 birds, and over 600 plants. The vibrancy of the images is striking, depicting not only the natural world, but also animal behaviour, the uses of plants, and associated Aztec beliefs.[22]

The *Florentine Codex* listed hundreds of New World plants, all divided according to an Aztec system of taxonomy. The Aztecs typically arranged plants into four broad groups: edible, decorative, economic, and medicinal. These divisions were reflected in the naming of plants: for example, plants ending with the suffix -*patli* were medicinal, whereas those ending with the suffix -*xochitl* were decorative. This organization was then reproduced in the *Florentine Codex*. All the medicinal plants are listed together, with names such as *iztac patli* (a herb that could be used as a cure for fever). These are then followed by all the flowering plants, with names such as *cacaloxochitl* (known in Europe as the frangipani, after a sixteenth-century Italian noble who imported it).[23]

1. An illustration of hummingbirds from the *Florentine Codex* (1578). Note the hummingbird hanging from the tree in a state of ‘torpor’.

Animals also feature heavily in the *Florentine Codex*. There is an image of a rattlesnake catching a rabbit and another of ants building a mound. Hummingbirds in particular appear in a number of the illustrations. One depicts a hummingbird extracting nectar from a flower, whilst another shows a group of hummingbirds migrating south for the winter. This focus on the hummingbird in fact reflected an important Aztec belief. Huitzilopochtli, or the Hummingbird God, was the patron deity of Tenochtitlan. The Great Temple in the city was dedicated to Huitzilopochtli, and warriors who died in battle were said to transform into hummingbirds. The Aztecs therefore studied the hummingbird closely. They were fascinated by its ability to enter a state of hibernation known as torpor. No European had ever seen this before, and so Sahagún was relying on the word of his Aztec informants, some of whom had actually worked in Moctezuma's aviary:

> In the winter, it hibernates. It inserts its bill in a tree; there it shrinks, shrivels, molts . . . when the sun warms, the tree sprouts, when it leafs out, at this time [the hummingbird] also grows feathers once again. And when it thunders for rain, at that time it awakens, moves, comes to life.[24]

The hummingbird's behaviour fitted perfectly with an Aztec view of the world, one regulated by a constant cycle of life and death. Warriors, much like the hummingbird, might be reborn. Death was never the end.[25]

II. Aztec Medicine

For Bernardino de Sahagún, the *Florentine Codex* was primarily a religious work. By compiling a comprehensive account of Aztec wisdom, he sought to show 'the degree of the perfection of this Mexican people'. This, Sahagún hoped, would help convince Christians back in Europe that the Aztecs were a 'civilized' race capable of receiving the word of God. Others, however, saw the New World in more commercial terms. In 1580, Ferdinando de' Medici, Grand Duke of Tuscany and head of the famous Italian Medici family, purchased the *Florentine Codex*. He put it on display in the famous Uffizi Gallery in Florence, hence the name by which it is known today. In the Uffizi Gallery, the *Florentine Codex* sat alongside the Medici family's incredible collection of art, sculptures, and curiosities from across the globe. These included a green feather headdress as well as a turquoise Aztec mask. At this time, the Medicis were developing a strong commercial interest in the New World. Ferdinando de' Medici began importing cochineal (used in the manufacture of crimson red dyes) from Mexico and Peru, whilst maize and tomatoes – both native to the Americas – were grown in the gardens of the Medici palazzo in Florence. For Ferdinando de' Medici, the *Florentine Codex* was essentially a commercial catalogue: a list of the most valuable natural resources that the New World had to offer.[26]

It was this commercial attitude towards the New World that really transformed the study of natural history. Merchants and doctors tended to place much greater emphasis on collecting and experimentation over classical authority. American plants represented a potentially lucrative source of revenue, and there was a clear commercial advantage in promoting these discoveries as novel. Tobacco, avocadoes, and chillies were all marketed as incredible new cures, whilst the earliest record of a potato being sold in Europe comes from the account books of a sixteenth-century Spanish hospital. At the same time, universities across Europe started establishing their own botanical gardens. These were not dissimilar from the Aztec botanical gardens the Spanish saw in Mexico, specialist sites for the study and cultivation of medicinal herbs. In 1545, the University of Padua established the first botanical garden in Europe. This was soon followed by gardens at Pisa and Florence. By the middle of the seventeenth century, botanical gardens – all growing New World plants – could be found at every major European university. Some wealthy physicians even started to establish their own private botanical gardens, marketing new medical cures derived from American plants.[27]

Much of what Europeans knew about the medical uses of New World plants was derived from Aztec sources. The Spanish Crown in particular invested enormous effort, not only in collecting and cataloguing specimens from the New World, but also in recording what the Aztecs knew about them. In 1570, Philip II of Spain ordered a major survey of the natural history of the New World. At the head of the survey, Philip appointed his personal physician, Francisco Hernández. Over the next seven years, Hernández travelled across New Spain, collecting herbs and learning about Aztec medical practices.[28]

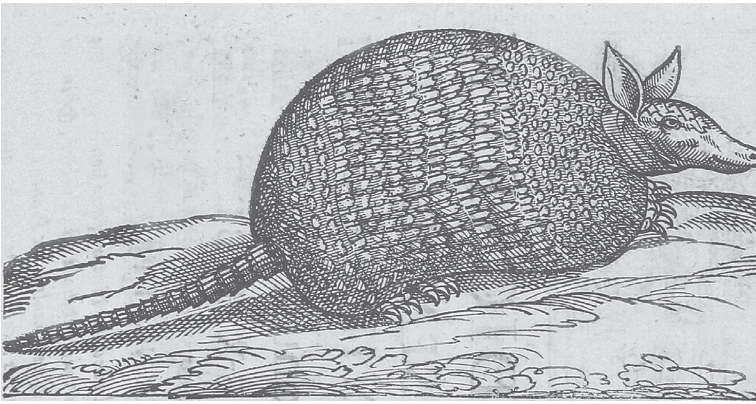
Born in 1514, Hernández studied at the University of Alcalá before setting up a successful medical practice in Seville. Like most sixteenth-century physicians, and as noted earlier, Hernández's medical training involved little more than reading ancient texts. He read the works of Galen and Dioscorides, both ancient Greek physicians. Dioscorides's *On Medical Material* provided a list of herbal treatments for various ailments, whilst Galen's vast corpus described the basic theory underlying ancient Greek medicine. This theory centred on achieving a balance between the four humours: blood, phlegm, black bile, and yellow bile. Bloodletting was commonly recommended to cure fever, whilst laurel leaves could be taken to purge excess yellow bile.[29]

Hernández, however, lived through a time of great medical change. Many physicians began to turn away from ancient authority, instead placing much greater emphasis on dissection and experimentation. Many were inspired by the work of Andreas Vesalius, whose *On the Fabric of the Human Body* (1543) provided a new account of human anatomy based on dissection. Others followed the work of Paracelsus, a controversial Swiss alchemist who promoted all kinds of new herbal and mineral cures. Hernández himself was a great champion of these medical reforms, undertaking dissections and establishing a botanical garden whilst working at a hospital in western Spain. It would be wrong, however, to assume that this new way of thinking about medicine can be explained by looking at Europe alone. Rather, knowledge originating in the New World, produced by the Indigenous peoples of the Americas, helped shape a vision of medicine as an experimental and practical science.[30]

Francisco Hernández arrived in Mexico City in February 1571, accompanied by his son, Juan, and a team of scribes, painters, and interpreters. The city was in the midst of an epidemic, known as *cocoliztli* by the Indigenous people and 'the great pestilence' by the Spanish. Victims died within days of contracting the disease, suffering horrific pain and bleeding from the eyes and nose. Hernández, who had been appointed Chief Medical Officer of the Indies, spent the first few weeks undertaking dissections of the recently deceased. When the outbreak calmed down, Hernández and his party set off on a tour of New Spain, spending seven years scouring the land for new plants, animals, and minerals, anything that might be medically useful. He even visited an abandoned Aztec botanical garden at Texcoco, copying some of the paintings of flowers from the ruined walls. Altogether, Hernández identified over 3,000 plants previously unknown to Europeans. For comparison, the ancient Greek physician Dioscorides only listed 500 plants in his *On Medical Material*. This then really was a complete challenge to the idea that ancient authors knew everything.[31]

In undertaking this survey, Hernández was absolutely reliant on Indigenous people and their medical knowledge. In fact, Philip II had explicitly recommended that Hernández quiz the local population. The official instructions for the expedition ordered Hernández to 'consult, wherever you go, all the doctors, medicine men, herbalists, Indians, and other people with knowledge of such matters'. Hernández took these orders seriously and began to learn Nahuatl. He then set about interviewing Indigenous medical practitioners, carefully recording the names of the plants and animals they described and making sure to use the native terms. Hernández described the properties of *zacanélhuatl*, a kind of root that, when crushed and mixed with water by Indigenous doctors, could help cure kidney stones. Hernández noted that this concoction 'provokes urination and cleans out its tract'. He also learned of a herb called *zocobut* with 'leaves like a peach, but wider and thicker'. It could be used to cure migraines, dampen swelling, and 'combat poisons and poisonous stings and bites'. Indeed, this particular herb was 'highly esteemed by the natives', so much so that 'it is not easy to get them to tell you its properties'. Hernández also investigated the medical uses of New World animals. After describing the possum, he noted that 'the tail of this animal is an excellent medicament'. Ground and mixed with water, 'it cleans the urinary tract . . . cures fractures and colic . . . comforts the belly'. Most intriguingly, Indigenous medical practitioners reported the possum tail acted as an aphrodisiac, Hernández writing that 'it excites sexual activity'. Whilst we can't be sure about every plant listed by Hernández, scientists today have shown that some do indeed have medicinal properties. The leaves of the thorn apple, for example, contain an analgesic. Others, such as the seeds of the Mexican apple, have been shown to help prevent certain forms of cancer.[32]

Describing the appearance and properties of plants and animals was all very well. But when everything was so new, at least for Europeans,



2. An engraving of an armadillo, copied from a drawing made by an Indigenous artist in sixteenth-century Mexico, from Francisco Hernández, *The Treasury of Medical Matters of New Spain* (1628).

only a picture could really communicate the diversity of American natural history. Like Sahagún, Hernández therefore decided to employ a group of Indigenous artists to paint pictures of everything he saw. Over six years these artists – named Pedro Vázguez, Baltazar Elías, and Antón Elías – made hundreds of paintings, all in situ, including one of a sunflower and another of an armadillo. Many of these images were later reproduced in European works of natural history, including Hernández's own publications. In 1577, Hernández returned to Spain with sixteen handwritten volumes along with the paintings. Later published as *The Treasury of Medical Matters of New Spain* (1628), Hernández's manuscript was deposited at the Escorial Palace Library, located just outside Madrid. The royal librarian, José de Sigüenza, was impressed, particularly by the artwork. 'This is a history of all the animals and plants that could be seen in the West Indies, painted in their native colours,' he explained, adding, 'it is something that offers great delight and variety to those that look at it; and no small profit to those whose task it is to consider nature'.[33]

Francisco Hernández's *Treasury* was typical of a new genre of natural histories, ones that repackaged Aztec medical knowledge for European audiences. Nonetheless, it was still ultimately the work of a conquistador.

Hernández was a man who had been sent by the King of Spain on an expedition which, at its core, was about the extraction of knowledge and wealth. Indeed, the choice of title is telling – this really was a 'treasury' for the Spanish. Nonetheless, Europeans were not the only authors of significant works of natural history during this period. At just the same time as Hernández was writing, an Aztec scholar compiled his own natural history of the New World, which later reached Europe and influenced a number of early modern medical texts.

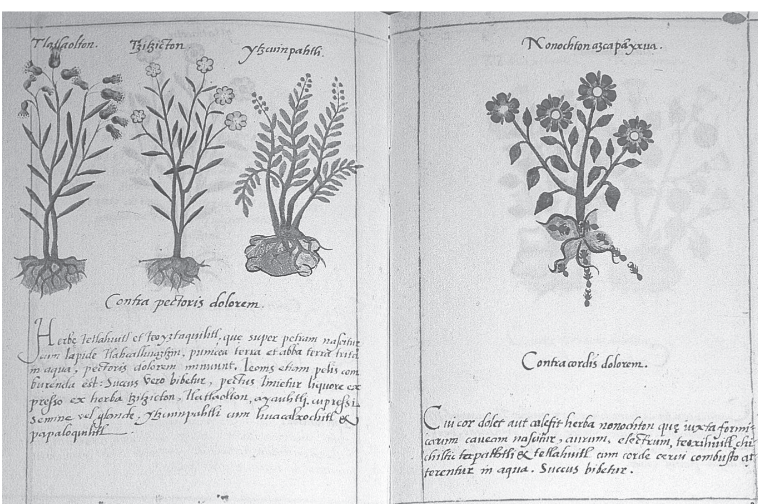
Martín de la Cruz was born in Mexico before the Spanish conquest. Unfortunately, we know little of his early life. We don't even know his Nahuatl name. Cruz later simply described himself as 'an Indian doctor', and was probably a middle-ranking Aztec physician. What we do know is that Cruz converted to Christianity and taught medicine at the Royal College of Santa Cruz in Tlatelolco, the same institution at which Bernardino de Sahagún had begun work on the *Florentine Codex*. On 22 May 1552, he presented a manuscript titled *The Little Book of the Medicinal Herbs of the Indians* to the master of the college. Cruz had originally written the book in Nahuatl, but had it translated into Latin by another Indigenous tutor at the college, Juan Badiano. More than any other work of the period, *The Little Book of the Medicinal Herbs of the Indians* represents a fusion of European and Aztec knowledge. At first glance, it looks much like a typical classical compendium of herbs, not dissimilar from Dioscorides's *On Medical Material*. Cruz divided his book into thirteen chapters, beginning with the head, moving down the body, all the way to the feet. Each page identifies a particular condition, such as 'toothache' or 'difficulty in passing urine', and then describes the preparation of herbs used to treat it. Most pages also feature an illustration of the individual herbs, sketched and painted by Cruz himself.[34]

Look a little closer, however, and it is clear that Cruz was drawing heavily on Aztec medical knowledge. All the plants' names are given in Nahuatl and, like the *Florentine Codex*, reflect Aztec classificatory schemes. In this case, the names not only indicate the use of the plant but also where it might be found: for example, plants with the prefix *a-* (meaning 'water') could be found near lakes or rivers, whereas those with the prefix *xal-* (meaning 'sand') could be found in deserts. Throughout the book, Cruz also draws on traditional Aztec understandings of the body. The

Aztecs typically believed that the body contained three forces, located in the head, the liver, and the heart respectively. Disease resulted from an imbalance of these forces, something that was often caused by an excess of heat or cold in a particular part of the body. (This was not so different from the ancient Greek theory of the four humours.)[35]

Reading Cruz's description of the herbs carefully, we can see that his focus is on restoring this balance. Pain and swelling in the eyes, for example, was understood to be the result of excessive heat in the head. The cure involved preparing a concoction of cooling herbs. Flowers of *matlal-xochitl* (known in Europe as spiderwort) and leaves from the mesquite tree were to be ground up and mixed with breastmilk and 'limpid water'. This ointment would then be applied to the face. Cruz also advised avoiding 'sexual acts' or eating chilli sauce until the condition improved, as both of these could cause an excess of heat as well.[36]

The final clue to Aztec influence is the most important, but also the most difficult to spot. Earlier historians often read Cruz's illustrations as imitations of typical European botanical drawings, with each plant pictured in isolation, roots and leaves visible for easy identification. More



3. An illustration from Martín de la Cruz, *The Little Book of the Medicinal Herbs of the Indians* (1552). The roots on the plant named *itzquin-patli* (*third from left*) feature the Nahuatl glyph for 'stone'.

recently, however, experts in Aztec culture have re-examined the images and noticed that they incorporate Nahuatl glyphs. Cruz was in fact trying to combine the style of European botanical illustrations with a traditional Aztec pictorial codex. He used glyphs throughout to indicate the place at which a plant may be found, reinforcing the naming system described earlier. The specific Aztec glyph for 'stone' appears around the roots of a number of plants in Cruz's drawings, as does the glyph for 'water'. Cruz was ultimately combining European and Aztec traditions, both medical and artistic, in order to create a completely new kind of natural history. In doing so, he was typical of the way in which science was being practised in the sixteenth century, a product of cultural exchange and encounter.[37]

By the end of the sixteenth century, New World plants could be found in gardens across Europe. Sunflowers bloomed in Bologna, whilst a yucca even flowered in London. These plants soon came to feature in new works of natural history and medicine, many of which promoted the value of experience over ancient texts. In London, the apothecary John Gerard described the medicinal uses of tobacco in his bestselling *Herball* (1597), whilst, in Seville, the physician Nicolás Monardes advised patients to buy cacao in his *Medical Study of the Products Imported from Our West Indian Possessions* (1565). (Monardes also ran a successful business growing American plants in his private botanical garden.) Even Andreas Vesalius, probably the most famous anatomist of the sixteenth century, showed an interest in the New World, discussing the possibility that the gum of guaiacum (a flowering plant native to Mexico) could be used to treat syphilis. This idea stemmed from a widespread – although today widely disputed – belief that syphilis itself had originated in the Americas, and hence a cure for it was most likely to be found there.[38]

European naturalists and apothecaries soon amassed vast collections of exotic plants and animals. They were supported by wealthy patrons, like the Medicis in Florence and the Spanish king in Madrid, filling the museums of Europe with objects and specimens from the New World. This new approach to natural history was also reflected in the increasing use of images. Whereas ancient texts on natural history tended not to be illustrated, the new natural histories of the sixteenth and seventeenth centuries were full of drawings and engravings, many of which were