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It's Not About You

Chapter 4 of...
YOU ARE HERE: A Portable History of the Universe

Not at first did the gods reveal all things to mortals, but in time, by inquiry, they made better discoveries.

Xenophanes

Our understanding of how the contents of the large-scale universe are arranged – as a hierarchy of stars in motion – is the result of hundreds of years of scientific investigation. Whatever the scientific method has become, it was not always as it is now. It has evolved over time, in tandem with our understanding of the universe, and doubtless will continue to evolve as our understanding of the universe deepens. Science and the universe are inseparable.

To get to the edge of the universe we must take a long route through history. To answer those nagging questions: where did the universe come from? and what is made out of? we need to go back to the beginning of the scientific venture in order to find out how we have arrived at our current understanding.

In broad terms, both science and the universe have an ancient and a modern past.

Science is a collective endeavour, without a written constitution, whose meaning has emerged over time. Whatever science is now, its history stretches back to a time when the word was meaningless. Today we know how the stars are arranged, which makes it easy enough to see that we are not at the centre of the universe. But it wasn't always so. Ancient science started out with the opposite idea. By the time of Aristotle (*c.* 384–322 BC) the earth was firmly fixed at the physical centre of the universe, part of a cosmological description that has a history stretching back to the beginnings of whatever we mean by civilisation.

Whatever we mean by civilisation appears to have arisen in city-states in the Near East. The most influential ancient civilisation (in Western history) was in Mesopotamia, a fertile region bounded by the Tigris and Euphrates rivers in what is modern-day Iraq. The word Mesopotamia is derived from Greek words meaning between two rivers. There is evidence that there was farming here from 10,000 BC, around the time the earth became as warm as it is today, and warmer than it had been for almost 2 million years. Nomadic humans, who had moved around in groups of between 20 and 30, settled down as communities that began to grow in size. There is evidence that by 7000 BC there was a fortified farming community at Jericho of some 74 acres.

A tribe called the Sumerians arrived in Mesopotamia around 5000 or 4000 BC, but it is not known from where. The Sumerian society was the first to learn to read and write. The oldest known story, dating from the third millennium BC, is the *Epic of Gilgamesh*, a summary of legends from Babylonia, a state in the south of Mesopotamia. It is the story of the King of Uruk and mentions many of the first city-states around which civilisation evolved: Ur, Eridu, Lagash and Nippur. It also contains the first account of a great flood, and the first account of a dream. In the Bible we are told that Abraham, the father of the Hebrew and Arab nations (the Israelites were descended from his son Isaac, and the Ishmaelites from his son Ishmael) travelled from Ur of the Chaldees. Chaldea was a region of Babylonia.

A creation story from perhaps the eighteenth century BC, called *Enuma Elish*, tells of the creation of Mesopotamia and of man. It was recited in temples for hundreds of years. These first creation stories are both the first religious accounts and the first cosmologies. Aspects of the *Enuma Elish* were absorbed into Hebrew cosmology and the biblical account of creation. The earth is a flat disc surrounded by water, above and below. The firmament keeps the water above from deluging the land, but allows rain through. From below, the water rises up as rivers and seas. The Sumerians studied the skies as astrologers and astronomers. They could see portents from the gods and predict eclipses.

Other civilisations were also developing across the world: in Egypt from around 3000 BC, the Indus Valley from 2700 BC, China from 2100 BC. But for whatever reasons (and many reasons have been put forward) the history of science is largely a story that came to be told in the Western world. Eastern modes of thought seem to be in opposition to the idea of progress that is at the heart of science. It has been suggested that the Chinese pictogram did not encourage abstract thinking, with the result that, as the philosopher John Gray tells us: 'Chinese thinkers have rarely mistaken ideas for facts.'[1] The Egyptians and Babylonians seem to have left nothing that could be counted as a description of the material world, though the Babylonians did develop a counting system based on the number 60, a legacy we see today in the 60 minutes that make an hour and the 360 degrees that complete a circle. The Egyptians had a calendar that was based on observation of the stars. The earliest recorded date in history we know of is Egyptian: either 4236 or 4241 BC according to how their calendar is interpreted.

There were Greek tribes adrift in the Aegean from 2000 BC, eventually settling as city people. The so-called Mycenaean civilization flourished from around 1600 BC before collapsing in 1150 BC. Greek history entered a Dark Age for some 300 years. The Olympic games were founded in 776 BC, and Homer (who may have been a tradition rather than a single writer) cannot have been around before the eighth century BC. And so began the civilisation the German philosopher Friedrich Nietzsche (1844–1900) called 'the most accomplished, most beautiful, most universally envied of mankind'.[2] Some historians say that Greek philosophy started on 28 May 585 BC. It was on this date that Thales of Miletus (*c.*624–*c.*546 BC), the first of the Presocratic philosophers, is said to have predicted an eclipse. It is now thought that Thales observed the eclipse rather than predicted it, and that his knowledge of it was passed down from the Babylonians. Chaldean wise men travelled abroad taking their knowledge of astrology and early astronomical observations into the Greek and Roman empires.

Whatever claims were made for him, Thales certainly eclipsed his precursors, and for this reason he is often called the father of science. It was he who introduced the word *cosmos* to describe the universe, which as well as being the Greek word meaning order also has the meaning of something that beautifies, as in the word cosmetic, and is the opposite of the Greek word *chaos*.

Thales believed that everything is made of water in one form or another. It was he who began the search to find the physical components that make up the world: materialism started here. He made no distinction between the living and inanimate. For Thales, even magnetic rocks possessed soul, a mystical idea that persisted into the sixteenth century in the work of the English physician and scientist William Gilbert (1544–1603), who was an ardent and early supporter of the sun-centred Copernican model of the universe, and one of the first to use the word 'electricity'.

Early Greek philosophy can be traced through teacher and pupil in a mentoring tradition. The word 'mentor' is taken from Homer's *Odyssey*. Mentor stands in as father to Telemachus when his real father, Odysseus, is away at war. Thales was mentor to Anaximander (*c.*610–*c.*546 BC), and Anaximander to Anaximenes (*c.*585–*c.*525 BC), all three of whom came from Miletus, an ancient town in what is now modern-day Turkey, then part of the Greek world. Anaximenes continued the search for simple descriptions of the world. Rather than water, he said that air was the principle from which everything sprang.

The most famous of the Presocratics is Pythagoras (*fl.* sixth century BC), the first to call himself a philosopher, literally a lover of wisdom. He had studied with wise men in Egypt, and later in Phoenicia (an ancient civilisation that is now the coast of Lebanon and Syria). It may have been in Egypt that he became interested in geometry and trigonometry.

Pythagoras founded a school that lasted a millennium, though the Pythagoreans were perhaps more a brotherhood than a school. Named *mathematikoi* (literally, those who study everything), they were strict vegetarians, living a monk-like existence. They made a particular study of arithmetic, geometry, music and astronomy: the basis of education until well into the Middle Ages, by which time it was called the quadrivium[3] (a Latin word meaning where four roads meet). They believed that at bottom reality is mathematical, a belief that has persisted to the present day. An important distinction is that though we take shape and number to be attributes of things, for the *mathematikoi* shape and number are the essence of things. Numerology was part of the Pythagorean tradition. In the ancient world the modern distinction the scientific method makes between mysticism and mystery was meaningless. Numerology is at the heart of the book of Chinese divination the *I Ching* (probably compiled in the ninth century BC but mythologically dated to 2800 BC), and the body of Jewish esotericism called the Kabbalah dating from around AD 1000.

For the Pythagoreans, the most perfect shape of nature was the circle. Pythagoras put the earth at the centre of a spherical universe, and simple numbers were used to describe the motion of some of the known planets. Because he did not leave any writings (nor are many writings left by his followers), what has been ascribed to Pythagoras has been much debated. We only know about Pythagoras from contradictory accounts written 200 years after his death. It is now known that he did not discover the theorem that is named after him,[4] nor the relationship between musical intervals and simple numbers that is usually attributed to him.[5]

Heraclitus (*c.*535–475 BC) described how the cosmos is created out of pre-existing chaos. The cosmos is order imposed on chaos, which we witness as the material world. The ordering principle is called *logos*, from which the suffix -ology is derived. *Logos* is sometimes translated as 'word', as it is at the beginning of the English translation of the original Greek version of the gospel according to St John: 'In the beginning was the word.' Chaos is a condition in which there are no things, a world in which whatever there is is without a name. No thing and nothing are quite different ideas. It is the naming that makes the separation out of chaos into cosmos. This was clearly the original meaning of the account of creation in Genesis, when God separated out from chaos what then became things with names (light, the earth, Heaven, night, day, and so on). Medieval theologians imposed on this creation story the idea that the world was created *ex nihilo* (out of nothing).

Heraclitus wrote that change (also characterised as fire) is the fundamental quality of the world, an idea that resonates with the modern understanding that everything is a form of evolved energy.

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Fragments of a single poem are all that have survived of the philosophy of Parmenides (*c.*510–*c.*450 BC). He wrote that existence is eternal and unchanging: what we perceive as change, as in the motion of things, is an illusion. He denied the existence of nothingness and wrote that reality is an unchanging whole. His ideas influenced the philosophy of Plato, who acknowledged him as 'our father Parmenides'. His philosophy was reduced to the Latin tag *ex nihilo nihil fit* (nothing comes from nothing).

Empedocles (*c.*490–430 BC) synthesised earlier philosophies. For him the cosmos is made of earth, air, fire and water, and two principles: attraction and repulsion, also seen as love and strife. These four elements were the building blocks of the material world until the time of the European Renaissance.

Leucippus lived in the first half of the fifth century BC. Nothing survives of his own writings, and we only know of him because he was the mentor of Democritus (*c.*460–*c.*370 BC), who propounded the philosophy of atomism, which he may have taken from his teacher. Aristotle was an admirer of Democritus, and it is only because Aristotle criticises Democritus' atomism that we know about it at all. Again, mere fragments of Democritus' vast output survive and his work is mostly known of through the writing of others. Atomism tells us that everything is fashioned out of small, indivisible and eternally existing particles called atoms. Some atoms might, for example, have hooks on them and others be round. The differences between atoms, their different textures and shapes, and how they attach to each other, explain why different substances have different qualities. The atoms from which different foods are made affect the tongue in various ways, which explains the subjective experience of taste. The taste is not the essential quality of food. The essential quality is its atomic nature. Even the soul has an atomic structure, made out of the finest atoms.

Democritus was the first to assert that there are other worlds in other parts of the universe, with other suns and other moons.

Philosophy as practised by the first Greeks was the belief that wisdom is the essence of the cosmos. The Presocratics inherited a 2,000-year-old tradition of wisdom poetry from the Sumerians. If the Presocratics only occasionally presented their work in the form of poetry, it often has the force of poetry.

Ecclesiastes, Proverbs, Job, the Song of Solomon, and other wisdom books of the Bible were written around this time. Confucius (551–479 BC) was a near contemporary of Pythagoras. The Buddha is said to have lived from around 563 to 483 BC, though modern scholarship suggests a later date is more likely, on either side of 400 BC. According to Chinese tradition, the philosopher Lao-tzu lived in the sixth century BC, though he has now been dated to the fourth century BC by historians. It is conceivable that the Persian poet and prophet Zoroaster was alive in this era, though his dates are highly contested. He may have lived, though it is highly unlikely, as early as 6,000 BC.

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Socrates (*c.*470–399 BC) was named as the wisest of all the Greeks by the Delphic Oracle, and was mentor of perhaps the most famous philosopher of all. The English mathematician Alfred North Whitehead (1861–1947) famously said of Plato (*c.*428–*c.*347 BC) that all contributions made after him are simply footnotes to philosophy. Plato founded his Academy in a grove of trees belonging to a man called Academos, hence the word, and the phrase groves of academe. The Academy existed until AD 529, that is, for over 900 years. Oxford and Cambridge universities received their charters in 1231. Not until around AD 2180 will they have outlasted Plato's school.

For Plato, the material world decays and disappears, and so is temporary and illusory. The real world, he argued, is a world of so-called ideals, and is eternal. The material world is an imperfect representation of these ideals. Perfect geometrical shapes, for example, exist in this Platonic world. The motion of the heavens is circular, as in the Pythagorean philosophy, because a circle is the perfect, idealised shape. The bodies of the heavens are spheres for the same reason. The knowledge that planetary orbits are ellipses and not circles still has the power to shock even today, so instinctively do we respond to the idea that the motion of the heavens must be circular as the ancients believed.

Plato developed Pythagoras' spherical universe as a series of nested spheres rotating inside each other with the earth at the centre. There were seven celestial spheres carrying the known planets and the moon. God was just beyond the seventh heaven. For Plato nature is impure. Perfect forms are not to be found there. How things really are can only be reached through reason, or wisdom. For him the

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cosmos is a place of order and goodness, a philosophy also inherited from Pythagoras. The universe is musical and has soul. It is dynamic and living. Plato was the first to ask why there is a universe at all.

Plato insisted on a mathematical underpinning of nature that was of little interest to his pupil Aristotle (*c.*384–322 BC). Aristotle was more interested in how the celestial spheres moved inside each other than in their ideal nature. There are 54 spheres in his cosmology, including an outer sphere that carried the so-called fixed stars. Aristotle took up the four elements of Empedocles' philosophy, and added his own fifth element: subtle stuff called aether (or quintessence), out of which the heavenly spheres and bodies are constructed. By medieval times aether had hardened into crystal.

For Aristotle the world of change happened in a region that extended from the earth to the moon. Beyond this sublunary sphere was the ethereal world of eternal unchanging things. In the world below, heavy objects fall to the earth because they have more earth in them than lighter objects, and so find their way back to where they should naturally reside. Objects with more airy natures, like feathers, would tend to be attracted to a more airy environment. Aristotle's accounts of the world are more discursive than the modern scientific method allows. To make such an account a modern and rigorous scientific description, we would seek to quantify the amounts of earth, air, fire and water that objects are said to contain, and would search for a mathematical relationship that unites the phenomena and makes predictions.

Like many disciples, Aristotle reacted against his mentor. Aristotle believed that the world was best understood by observing it. 'Nothing is in the intellect that was not first in the senses' is the motto that the thirteenth-century theologian Thomas Aquinas invented to describe Aristotle's methodology. Nevertheless, Aristotle's observations did not amount to scientific investigations of nature in the modern sense. He looked at the world from a distance and drew conclusions about how it must be. He did not look at the world closely, which is what we do when we perform an experiment. Aristotle claimed, for example, that men and women have a different number of teeth, though it takes only a little investigation of nature to show up the error. Aristotle's belief in a physically existing world that could be observed in order that it might be understood is, however, a step towards the modern scientific method. His method differs in that it emphasises human perception of how the world appears to be over investigation of how it actually is. For Aristotle, it was clear that heavier objects fall faster than lighter ones. It would take another 2,000 years of investigation of the world to show that this is not the case.

In the fourth century BC, Aristotle's most famous pupil, Alexander the Great (356–323 BC), captured Mesopotamia. The region had served as the hub of the Akkadian, Babylonian and Assyrian empires, but its historical significance had begun to fade by this time. In 331 BC Alexander founded the city of Alexandria. From the beginning of the third century BC a library was built there called the temple of the muses (from which we derive the word museum). The first librarian was called Demetrius, another pupil of Aristotle's. The library grew to be the largest body of knowledge in the world at that time, comprising perhaps half a million manuscripts. The great mathematician Euclid was active at the library in around 300 BC.

One of its most famous librarians was Eratosthenes (*c.*276–*c.*194 BC), who made the first accurate measurement of the circumference of the earth. For some time, the Greeks had known that the earth must be a sphere given that it casts a

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curved shadow on the moon. Using a piece of information brought to him by a traveller to the library – that the sun at midday shone directly over a well near Aswan – Eratosthenes realised that he could calculate the circumference of the entire world. Using the known distance between Alexandria and Aswan, the angle of the shadow cast by a marker at midday at Alexandria and the fact that there was no shadow at Aswan, Eratosthenes was able to calculate how much the earth curved between these places. From that piece of information it is easy to calculate how large the whole circle must be of which the curve between Aswan and Alexandria is a segment. That circle is the circumference of the earth.

He measured the circumference as 250,000 stadia, though there has been historical disagreement as to exactly how long a stadium is. Modern archaeological research suggests that if Eratosthenes had used an Egyptian stadium as his measurement then he may have been within 1 per cent of the true measurement (which is a little over 40,000 kilometres). This measurement was the most astonishing (most likely a fluke) of a series of accurate measurements made by the Greeks, measurements not repeated until modern times.[6]

The library burnt down when the city was attacked by Julius Caesar in 48 BC, but was rebuilt. Most of the contents perished in the third century AD on the orders of Emperor Aurelian. And in AD 391 manuscripts that had been hidden away were found and destroyed as part of the campaign of the then bishop of Alexandria, Theophilus, to raze all pagan temples. The last librarian was a man named Theon, father to Hypatia, a Platonist, mathematician, astronomer and high priestess of Isis. Hypatia was murdered – flayed by oyster shells[7] – by a gang of Christian monks in AD 415 at the age of 45. In AD 642 the last few remaining manuscripts were said to have been used as fuel to heat the baths of Egypt's Arab conquerors. The story is almost certainly apocryphal, probably put about by later generations to discredit the Muslim conquerors. By the end of the eight century AD the library's 1,000-year history had faded away to nothing.

Though the library at Alexandria was not the only depository of ancient knowledge – there was a rival at Pergamum from 200 BC – by the time the library was in its final decline, much of what the ancient world had learned had either disappeared forever or was about to be lost to the West for centuries. In the late fourth and early fifth centuries St Augustine worked Plato's ideas into a Christian belief system. The sixth-century Roman philosopher Anicius Manilus Severinus Boethius (*c.*480–524) devoted his life to the preservation of ancient classical knowledge, translating many Greek texts into Latin. He was one of the last scholars proficient in Greek before the West lost historical contact with the classical world. Boethius is sometimes described as the last of the classical writers. His masterwork, *Consolatio Philosophiae,* was writtenn prison while he awaited execution. It was translated from Latin into English (as *The Consolation of Philosophy*) in the fourteenth century by Geoffrey Chaucer (*c.*1343–*c.*1400), at a time when the Western world, particularly in Italy, began to re-establish its connection with the classical world.

The Renaissance – that great flowering of the intellect that followed the Dark Ages – marked not only the West's rediscovery of classical knowledge but in addition the discovery and synthesis of the body of knowledge that had grown up in the Arab world over hundreds of years. Baghdad had become the centre of the civilised world within a century of the death of the Prophet Muhammad (*c.*570–632), and that world was largely impregnable to the West. For centuries, much of what survived from the classical world was protected and added to in the Arab world. The story of science has largely been told as a story of the Western world, and 400 years or more of Arab thinking has been sidelined. Sometimes the 'we' that science means to be universal isn't even global.

For a time, knowledge was Arab knowledge. It found particular expression as alchemy, from an Arab word *al-kimiya,* itself derived from an Egyptian word *keme,* meaning black earth, after the fertile black silt that is carried by the annual Nile floods. Alchemy studies the workings of spirit and matter as part of a unified system. It is only in modern times that the two systems have been separated. Newton wrote a million words on alchemy, including a commentary on the *Emerald Tablet,* a text that purports to reveal the secret of the transmutation of the cosmos's primordial substance into other forms. The *Emerald Tablet* was supposedly written by the Egyptian god Thoth (in his incarnate form of Hermes Trismegistus), and was once housed at the library in Alexandria. It was influential in the West and led to the development of a system of enquiry based on secrecy and obscurity called the hermetic tradition. Newton's contemporary Robert Boyle, the father of modern chemistry, was also interested in alchemy and hermeticism. His *Dialogue on the Transmutation of Metals* was lost but later pieced together from fragments. If nothing else, the etymology of chemistry can be traced back to alchemy.

During the Renaissance, many of the classical works that had been protected and interpolated by the Arab world were translated into Latin, not from the original Greek but from Arabic. For a period the art of translation was one of the high arts of the Renaissance. A collection of hermetical writings called the *Corpus Hermeticum*, Greek texts from the second and third centuries, was translated into Latin in AD 1460 by the Florentine philosopher Marsilo Ficino (1433–1499), who put aside his translation of Plato's dialogues in order to work on them. Florence was the centre of the humanistic tradition and of the Renaissance throughout the fifteenth century, and the *Corpus Hermeticum* was enormously influential for hundreds of years during and after the Renaissance. The philosophy of humanism – the idea that mankind is responsible for its own destiny – can be traced back to this body of work. Surprisingly, perhaps, humanism was not condemned by the Church. Rather the opposite: Christian and hermetic knowledge were synthesised as humanistic Christianity. Ancient Greek anatomies of love (eros, agape, pothos and himeros: the Greeks had words for it) were re-examined and integrated into a humanistic philosophy. Plato tells us of the rare regard in which Socrates held his pupil Alcibiades, a form of love that came to be known as platonic love, and which was re-expressed during the Renaissance as the love between man and God. Humanism does not deny God so much as assert the belief that, when it comes to the workings of the world, belief is not enough, what is required is rational thinking and observation. The laws of nature are God's laws, or they stand on their own. Either way, man might come to understand them by thought and measurement. The divine mind, on the other hand, is sought out and understood through contemplation.

For hundreds of years, the Greek language itself had been lost to the West. The Italian poet Petrach (1304–1374) had tried to learn Greek but failed. Dante knew of Homer but couldn't read him. The Italian writer Boccaccio (1313–1375) was one of the first to learn Greek in modern times, and he ensured that Greek was taught at the University of Florence. Greek was re-established in Italy by the mid-fifteenth century. In the first part of the sixteenth century, it was his study of Greek religious manuscripts that led Martin Luther (1483–1546) to reformulate Christianity as Protestantism.

In the thirteenth century the philosopher and theologian Thomas Aquinas (*c.*1225–1274) had almost single-handedly created a synthesis of Christian theology and Aristotelian philosophy. In the fifteenth century the Western world was dominated by the Catholic church and still firmly in the grip of Aquinean thinking. Aquinas's philosophical system survived well into the sixteenth and seventeenth centuries; indeed it could be said to have survived into the present day. Aristotle's cosmology was how the universe was described, with some modifications along the way, even at the height of the Renaissance.

The Church was the final authority in all things spiritual and material, and if the authority of God was first embodied in the Pope, its second embodiment was in Aristotle. To look it up in Aristotle was the unthinking end of most debate. Where Aristotle proved to be of no use to the Church was in accounting for the fact that Easter was drifting in the Church's calendar and no one seemed to be able to do anything about it. After 1500 years, the vernal equinox had moved from 21 March to 11 March. (Solving the calendar problem is part of the history of science, but the search for a solution arose out of the history of Christianity.)

There were hopes that the rediscovery of Ptolemy's lost works might help solve the problem. Aristotle's cosmology had been enlarged on and somewhat improved by Claudius Ptolemy (*c.*AD 100–170), an Egyptian astronomer working in Alexandria and writing in Greek. A ninth-century translation into Arabic of his major work, the *Almagest*, had only mythological status in the West; a twelfth-century Spanish translation and a later Latin translation both failed to render many of the technical aspects of Ptolemy's cosmology. It wasn't until the rediscovery of the Greek language in the fifteenth century that Ptolemy's work began to make an impact.

Ptolemy had been both an astronomer and a mystic. Like Aristotle, he placed the earth, and thus mankind, at the centre of his cosmology, and it is likely that Ptolemy meant to place mankind at the spiritual centre of the cosmos too. He also seemed to be aware, in a modern way, of mankind's insignificance in the face of an overwhelming universe. He wrote that the earth, though centrally placed, could be taken to be nothing more than a mathematical point (that is, without size or dimension) in relation to the universe as a whole.

It isn't known how original Ptolemy's ideas were. He appears to be greatly indebted to Hipparchus (190–120 BC), who lived three centuries earlier and whose writings are lost. The *Almagest*, a Latin form of an Arabic rendering of the title *The Great Book*, is a condensation of 800 years of astronomical observations, and gives a sense of what the Greeks knew about astronomy. Ptolemy, a follower of Plato, undermined the physical reality of Aristotle's cosmology by adding epicycles into the description of perfectly circular planetary orbits. An epicycle – an idea taken from Apollonius of Perga of the third century BC – is a small additional circular orbit somehow described on the main circular orbit. It can have no physical meaning but is a way of ensuring that the model works mathematically. The addition of any number of epicycles ensures that the observed motion of a planet can always be described by circles. A cheat in other words.

Ptolemy never claimed his model as anything but a mathematical (or Platonic) description. His system used different formulae for calculating the position of each planet. In some ways it was barely more than tables of processed data, and not always

very accurate data at that. There is no deep unification in Ptolemy's system, something we expect of a modern scientific theory. It is said that there were even epicycles on the epicycles, though there seems to be no evidence that this is true. In the thirteenth century, the astronomer and king of Spain, Alfonso X, is reported to have said of epicycles that if he had been at the Creation he might have given better advice. Although Aristotle's system is even weaker at describing the observed phenomena than Ptolemy's system, Aristotle's does at least have the advantage of possessing physical reality. By the sixteenth century it was clear that Ptolemy's great work was not all that it was hoped it would be.

The Church blessed the search for an improved cosmology that might establish a more reliable calendar. The obvious place to look for fresh ideas was to explore other newly rediscovered ancient writers. The Polish astronomer and cleric Nicolaus Copernicus (1473–1543) appeared to have found inspiration in Aristarchus from the third century BC, whose ideas (the original texts are lost) are preserved in the writings of Archimedes (*c.*287–*c.*212 BC). Aristarchus was the first person to argue for a sun-centred cosmos. He was even aware that a moving earth tells us that the stars must be a long way away, given that they do not appear to move. In ordinary life, when we move around objects that are near to us, we are aware that they change their spatial relationship to each other. This phenomenon is called parallax: simply an acknowledgement that there is a shift in perspective when we move between things. In the Aristotelian model of the cosmos there is no parallax between the earth and the stars because both are fixed: the earth unmoving at the centre of the universe, and the stars pinned to an outer moving celestial sphere some distance beyond the sun and planets. Any theory that has an earth that moves must account for the fact that the stars appear to be held in a fixed pattern (the constellations) that circles the earth every 24 hours. The fact is that there *is* parallax between the earth and the stars, but because the stars are so very far away they *appear* not to move. The tiny change of perspective is so difficult to measure that stellar parallax was not observed until the nineteenth century, when there were telescopes sufficiently powerful to make the sensitive measurements required. For many centuries, most thinkers took Aristarchus' argument that all stars are far distant as a reason to discount his sun-centred theory rather than as support of it.

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Copernicus, who knew Ptolemy's *Almagest* inside out, realised that he could make Ptolemy's earth-centred model simpler if he, too, placed the sun at the centre of the cosmos. His model, like that of Aristarchus, is not strictly a heliocentric one so much as a heliostatic one: the unmoving earth is replaced by an unmoving sun. Copernicus continued to believe that the spheres were made of crystal, but he reduced the number of them from about 80 in the Ptolemaic system (the number had grown over the years) to 34.

Copernicus knew of Aristarchus' heliocentric system and obliquely refers to it in a surviving manuscript, but for some reason he does not cite the passage in the printed edition of his great work: *De revolutionibus orbium coelestium*. It is possible that he came across the ideas via the works of Arab writers. He delayed publication of *De revolutionibus* until after his death. It is often said that he did so in order to protect himself from the wrath of the Church, but it seems that he delayed because he hoped to first find proof, and because he feared the reaction of colleagues. It also seems likely that he was too busy, since as well as being an astronomer and Catholic cleric, he was also a classicist, physician, diplomat, philosopher, translator, jurist and governor. Copernicus had no more idea than Aristarchus how to account for the apparent lack of motion of the earth. Nor, since there is no fixed point from which to judge up and down, could he explain why heavy things fall to the earth. Any new theory that replaced a static earth with a moving earth would need to account for why objects fall to earth, as Aristotle's description does. Copernicus posited the existence of an attractive force that anticipates gravity, but he wasn't able to work it into a theory that could make measurable predictions. His force was mystical: 'but a natural inclination, bestowed on the parts of the bodies by the Creator, in order to combine the parts in the form of a sphere and thus contribute to their unity and integrity'. Nor is it entirely clear that his system was any simpler or more accurate than Ptolemy's. In any event, when his work was published it met with almost no reaction and was not banned until 1616, over 70 years after it was first published. Rather than cause a revolution, Copernicus's ideas may well have disappeared without trace had Galileo not taken an interest.

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It was known from the thirteenth century that lenses could make distant objects appear nearer, but there were no telescopes until the Dutch invented them in the seventeenth century: novelty items made for spying on people across the street. Galileo Galilei (1564–1642) made his first telescope out of a verbal description given to him of the Dutch invention, and although he soon made telescopes superior to any in Holland, even his improved arrangement of lenses produced only hazy impressions, a world away from the crystal-clear images of modern instruments. Galileo may have trained his telescope across the street, but he made history when he trained it on the heavens and made sense of what he saw there. The English astronomer Thomas Harriot (1560–1621) was probably the first person to use a telescope for astronomical purposes.[8] In 1609, and subsequently, he began to map the moon, but it was Galileo who first realised that the moon had mountains and valleys.

In Aristotle's cosmos, the sublunar world is where things become degraded: because this is where change happens. Far from being the centre of the cosmos, the earth was the bottom of the universe, the place to which earthly objects fell. This was a view that found its way into Christian theology, certainly from the time of St Augustine (AD 354–

430). In his *Divine Comedy*, the Florentine poet Dante Alighieri (1265–1321) places hell at the centre of the universe with Satan at the absolute centre. Even in the seventeenth century during the Reformation, the earth was regarded by some as the most unworthy of all the planets. Humanism was a reaction against this dismal theology and an attempt to find a more elevated placing for man in the cosmos.

In Aristotle's cosmology the heavens are to be found at and beyond where the moon is, a region that is both unchanging and spotless, literally immaculate. In Christian theology Heaven is, of course, seen as the most worthy of all locations. When Galileo described a moon that has mountains on it, and a sun that is spotted, here is evidence that Aristotle's cosmology is flawed, or at least in want of further elaboration.

This was the moment we began to trust technology to extend the reach of our senses, and when we began to believe that the universe has many of the same qualities that are evident on earth, that the heavens are not separate.

On 7 January 1610 Galileo identified three 'stars' close to Jupiter. On subsequent nights he saw that

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they changed position relative to each other, ruling them out as fixed stars. On 10 January he discovered that one of them had disappeared. Galileo had discovered three of the moons of Jupiter, one of which was now hidden on Jupiter's far side. On 13 January he identified a fourth moon. In less than a week Galileo had collected the first convincing evidence that not all heavenly bodies orbit the earth as they should according to the Ptolemaic system. Later in the year, Galileo observed that Venus has phases like our moon does. The Copernican and Ptolemaic systems make different predictions about how these phases should look when observed from earth. Galileo's observations favoured a system in which Venus orbits the sun, not the earth. As Galileo continued to collect evidence, the Ptolemaic system began to fail.

The Church did not ignore Galileo's discoveries, but it did reject the Copernican model as an explanation. The Church favoured a different model that was also in agreement with the new discoveries.

Tycho Brahe (1546–1601) was a Danish nobleman, astronomer and astrologist, whose most significant contribution to the history of science was the accuracy of his astronomical observations. It was on the foundations of Brahe's observations that the German astronomer, mathematician and astrologer Johannes Kepler (1571–1630) discovered his eponymous laws of planetary motion. In his description, astronomical bodies execute elliptical orbits, something that Galileo was not prepared to accept. (Kepler's laws were confirmed later, once Newton's law of universal gravitation was in place.)

Tycho Brahe believed that the cosmos is earth-centred, and devised a model that protects this aspect of Ptolemy's model. It was also used to explain the observations that Galileo would make after Tycho's death. In Tycho's model (for some reason Tycho, like Galileo, is known by his first name) it is conceded that Venus, Saturn, and the other known planets revolve around the sun, but the sun continues to revolve around the fixed point of the earth. Mathematically, Copernicus's and Tycho's models are equivalent. In fact the Copernican system has the disadvantage that the supposed motion of the earth and stellar parallax need to be explained.

It was Galileo's assertion that the earth does in fact move that the Inquisition forced him to renounce in 1633, and to which he is, famously and apocryphally, said to have added in a whisper: 'And yet it still moves!' *(E pur si muove!)* Effectively, Galileo was forced to deny his new scientific method, which held that the more elegant mathematical symmetry of the Copernican system made it a truer system than Tycho's. Galileo's attempt to ascribe physical reality to the Copernican model pitted mathematical elegance against the authority of the Church (as vested in the Bible, and certain classical ideas the Church had ossified). Galileo may have been forced to back down but his direct appeal to mathematical elegance as a final authority set science on a new course.

Perhaps it does not seem so unreasonable that the Church judged this a step too far. In a way, the Church was only doing what science does, refusing to accept a new model until the new model clearly describes more phenomena, and for which there is experimental evidence. It takes a brave soul to challenge the authority of the Church, just as it takes a brave soul to challenge the authority of science: neither embrace innovation with open arms. The difference is that no matter how dogmatic the tendency of the scientific establishment, the methodology of science ensures that all theories are provisional, and all theories must ultimately be replaced by new theories if progress is to be made.

Out of fear of the Inquisition, scientific investigation ground to a halt in the Catholic world and moved to England and Holland. The Church might have put its faith in the Tychonic system, but in the everyday world the Copernican system was quietly taken up, notably by navigators, and for the entirely practical reason that it was easier to use. Why put the earth at the centre if the mathematical calculations produce the same results but are more straightforwardly computed when the sun is placed there? But what the Copernican system could not yet address was why the sun should now be what was fixed at the centre.

Modern science could be said to have begun in that year 1543 when Copernicus removed the earth from the centre of the universe and put the sun there. With this single act he set out a principle by which science has been guided ever since: that not only is mankind not at the physical centre of the universe it is not at the centre in any fashion, literally or metaphorically. What launched the scientific revolution was not the placing of the sun at the centre of the cosmos (from where, anyway, it is later removed) so much as the *removal* of the earth. It's not about us.

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[1] John Gray, *Straw Dogs* (2002).

[2] Friedrich Nietzsche, *The Birth of Tragedy* (1872).

[3] The trivium (where three roads meet, and from which we also derive the word trivial) was grammar, rhetoric and logic. The quadrivium and trivium together make up the seven liberal arts.

[4] Pythagoras' theorem, as every schoolboy knows, tells us that in right-angled triangles the square on the hypotenuse is equal to the sum of the squares on each of the other two sides.

[5] For example, a string can be plucked at the octave by dividing it in half. A fifth is found by dividing the string in the proportions 3:2, and a fourth in the proportions 4:3.

[6] Christopher Columbus (1451–1506) ignored measurements made by Eratosthenes and others, arguing that the earth must be much smaller. He might never have set out if he had been persuaded otherwise.

[7] The Greek word is *ostrakois*, which also means roofing tile. So perhaps broken tiles were used to flay her. (The Greeks had a system by which citizens could be expelled by the casting of votes. The votes were written on roofing tiles, hence the word 'ostracise'.)

[8] He may also have been the man who first introduced tobacco to the British Isles.

After reading, answer the following questions in 2 or 3 sentences:

1. What is the connection of Mesopotamia and its relevance to the development of civilization?

2. In detail describe the argument/debate regarding Pythagoras and his theorem.

3. Considering medieval theologians, what is the clear and original meaning of the account of creation in Genesis?

4. According to atomism, what is the essential quality of matter?

5. How do geometrical shapes relative to the Pythagorean philosophy apply to our world according to Plato?

6. What was the clash between Plato and Aristotle's interests?

7. How are their visions of the world different from each other? State the differences and similarities.

8. How did scientific knowledge of the Western and Arab world differ at the time of Muhammad (c. 570-632)?

9. What impact did the philosophy of humanism have on Christianity?

10. How was Ptolemy similar to Aristotle in terms of his work?

11. What fear did Copernicus have with regard to his work, *De revolutionibus orbium coeltium*?

12. Briefly describe Aristotle's cosmologies.

13. How did Galileo's discoveries affect Aristotle's cosmologies?

14. How did Tycho Brache differ to Aristotle in terms of their respective cosmologies?

15. What role did the Church play on the topic of science?