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HOW HUMANKIND CREATED SCIENCE

FROM EARLY ASTRONOMY TO OUR MODERN SCIENTIFIC WORLDVIEW

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Preface

Have you ever found yourself looking up at the night sky in search of your favorite stars? For those living in smog-covered cities drenched in light pollution, this search is much like happening upon a school of rare fish roaming the open ocean—there is very little chance of you coming across your target in such vastness. But if you were to head to the wilderness and gaze into the clear night sky, you would see a galaxy of stars strewn across the heavens; a grand expanse stretched over thousands of miles. Such majesty is a visceral reminder of just how small our world is. It was under these star-filled skies that ancient people living in vast open spaces could not help but explore the mysteries of the cosmos. Their efforts resulted in remarkable achievements that we can still admire today. Our ancestors did not just study the heavens, but put their cosmic knowledge to use as the basis for agricultural cycles, thus formulating calendar systems to gauge nature's rhythmical yearly course. This was humanity's earliest definition of time—a concept completely abstract, but key in determining the nature of our universe. And so, astronomy is considered the very first science advanced by the human race.

This dazzling star-studded sky appears like an abstract painting elucidating four-dimensional information across space and time, bringing generations of scientists, philosophers and poets to show their admiration for its inexplicable beauty. To this day, many of the theories in physics we know of are an accumulation of knowledge stemming from changes observed in the stars above. But what kind of changes did the scientists responsible for this wisdom see? What questions did they think of? What methods did they use? What difficulties did they come across? And what kind of persecution might they have faced on the road to discovering these wonderful, sometimes even mystical, ideas? This book's very purpose is to investigate these questions. It will take you through the stories behind scientific advancements in order to explain their theories, and derive associated examples and propositions. By observing how these theories, propositions and examples appear one after the other, we can get a closer look at what scientists experienced when exploring the natural world, and understand both the substance of these scientific theories and the influence they had. These propositions and examples can also show us real-life instances of scientific theories applied to natural phenomena or commonplace technology.

Whenever we delve into stories about scientific progress or the birth of scientific theories, a closer look at how these achievements were made often leaves us in a state of astonishment. Take, for example, the case of a young graduate, who after offending one of his professors, was unable to find work and had to rely on tutoring to support his wife and daughter. What set the wheels in motion for this young graduate, Albert Einstein, to later embark on his theory of relativity? He had originally intended to go in a different direction—to explore why electrons in an electric field develop a different effective mass when moving parallel or perpendicular to the field.

Einstein took on a unique way of thinking, abandoning typical views held about the study of electricity and magnetism prevailed at the time. He instead began making deductions based on the most basic definition of time and space. This made it possible for Einstein to eventually propose his formula for mass-energy equivalence, unraveling the mystery behind the enormity of energy stored in an object's mass, and giving the world his theory of special relativity.

This, however, was not Einstein's ultimate goal. He could not stop thinking of just where gravity comes from—an issue that Newton had never managed to explain clearly in his law of universal gravitation. When tackling this issue, Einstein's line of thinking regarding time and space was the same as it had been for his mass-energy equivalence formula but for one thing—this time he needed to find four-dimensional mathematical operations that could deal with distortions in spacetime. It took nearly ten years of searching, but Einstein was eventually able to find an equation that could propose rules explaining how celestial bodies move. This led him to the discovery that gravity is not a force exerted by recoiling springs or wrenching muscles, nor is it a result of air or liquid pressure, but is caused by distortions in time and space, with the extent of its force connected to the curvature of spacetime. This was the guiding idea behind Einstein's general theory of relativity.

The equation derived from this theory opened up a number of fields to unprecedented scientific inquiry, such as gravitational waves, gravitational lenses and black holes among others. The hundred years following the general theory of relativity have seen physicists clambering to explore the possibilities Einstein presented them. Each time one manages to prove anything theorized in Einstein's equations, they might as well start preparing an acceptance speech for the Nobel Prize in Physics.

We next turn our attention to the eternal bachelor, the lonely academic: Isaac Newton. How is it that the survivor of premature birth, who had never set his eyes on the sea but could explain how its tides worked, would go on to develop the law of universal gravitation?

It all started with classes at Cambridge being suspended after an outbreak of bubonic plague and its scholars leaving the campus to avoid infection. Newton was on his way back to his countryside home when he turned his head skywards and noticed that the way the moon hangs in the night sky seems quite different to the way an apple falls from a tree. In order to find answers to this enigma that only a mind like Newton's would gravitate toward, he had to stand on the shoulders of a scientific giant—Johannes Kepler. With Kepler's laws of planetary motion, Newton could prove that the snail-like movement of this heavenly body along Kepler's elliptical orbit is precisely the result of the Sun's gravitational force. The principle behind the Moon's orbit was, in fact, the very same as that governing how an apple falls to the ground.

After conceiving of his law in its embryonic form, Newton stashed his findings away in a drawer for twenty years. It was only when Edmond Halley, filled with academic zeal, approached him with questions regarding how comets move in orbit that Newton awoke to the significance of his discovery. He thus dedicated a further two years of his life to the laws of gravity, working eighteen painstaking hours a day and using every conceivable geometric tool at his disposal. Finally, by incorporating the infinitesimal calculus that he himself had conceived of, Newton put forward the law of universal gravitation. This law, in all its elaborate detail, was later inscribed in Newton's most emblematic work: the *Mathematical Principles of Natural Philosophy*.

The emergence of his gravitational law meant that disputes over astronomy that had been raging for millennia were promptly flung out from the halls of academia, replaced with a mathematical equation based on the masses of and the distance between two objects. Newton's discovery showed the world that the universe creator, if there is one, must be a bit of a joker. He (or She) needs a good sense of humor to create a universe in which matter and motion are governed by such a simple equation and one that can be applied to both on earth and in space to boot.

Before Newton and Einstein, there were, of course, numerous other pioneers these two considered scientific giants, who's intellectual odysseys gave rise to vital contributions to our understanding of nature. Giants like Copernicus, the man who opened the door for the astronomical revolution, put his academic integrity on the line in placing the Sun at the center of the universe. He could not bear the cosmic chaos brought on by the ancient Greek scholar Ptolemy's system with more than 80 epicycles jammed into the heavens. Supported by the focus of Neo-Platonism placed on using mathematics to interpret the natural world, Copernicus combined geometry and astronomical data to create a model of the universe with the Sun at its center. With this heliocentric system, he could explain a variety of planetary movements without the need to rely on any of Ptolemy's constructs of epicycles, deferents or equants. From this point on the Earth was removed from its central position, placed behind Mercury and Venus in the pecking order, third on the planetary podium.

And then there was Kepler whose Protestant faith made him a target of the Catholic Church, forcing him into a nomadic lifestyle. He maintained that theories defining how the universe works must be both simple and harmonious—an opinion brought on by his steadfast reverence of God's wisdom. And so, when inheriting Tycho's treasured collection of astronomic measurements and data, Kepler used the variations in the relative positions of the Sun, Earth and Mars to make a model of their orbits. He used over 1000 pages, repeatedly drafting calculations of 19 different orbits in his simulation. After five years of continuous calculations and comparisons, Kepler finally confirmed that Mars travels around the Sun, its focal point, on an elliptical orbit. When the red planet gets closer to the Sun, it moves at a faster pace; when further away, it slows down. He even managed to propose the first quantitative relational equation in all physics: the square of Mars's orbital period is proportional to the cube of its orbit's semi-major axis.

There was also Galilei, who had before earned additional income using the constellations to divine fitting times for medical students to begin bloodletting operations, and invented a refracting telescope to aid naval officers in sighting distant enemy ships. This telescope brought Galilei both wealth and fame, and also gave him a tool with which to observe the night sky and its wandering stars. This led him to the discovery that Jupiter is orbited by four satellites, giving the universe yet another potential center and gob-smacking those in the two opposing schools of thought still arguing over the geocentric and heliocentric models. It was Galilei's immense talent and the obstinate nature that came with it that brought him to offend the Roman Catholic Church with his defense of heliocentrism. In the end, he was sentenced to a life of imprisonment by the Roman Inquisition and forced to publicly declare his research untrue, as well as write daily confessions.

The above-mentioned scientists were all organized and critical thinkers, who, when faced with any challenges would investigate them to their logical conclusions. Their stories often entail wisdom worthy of our admiration along with mind-blowing discoveries, while their achievements have had a far-reaching impact on scientific progress. Inevitably, a desire to understand the laws of nature they uncovered and their associated theories often wells up inside us. If we were to apply these theories to natural phenomena that have consistently attracted humanity's attention, there would surely be endless curiosity over what might be uncovered next.

Attempting to satisfy this craving for knowledge is a key objective of this book. And so it is structured as follows: stories, theories, examples and propositions are combined in a timeline covering 3,000 years of the scientific laws discovered and passed down by these critical thinkers. Cases from the past will be reexamined using modern mathematics, while questions arising from the confirmation of past theories will be proposed, and a reflection-heavy approach will be taken to expose the very essence of these scientific laws. Today the scientists who gave us these discoveries are long gone, looking up at the heavens from their resting places. Whenever we gaze up at the sky, it is almost impossible not to apply their laws to the ocean of stars above and imagine the magnificent four-dimensional image of the universe they painted with such methodical mindsets.

This group of scientists' pursuit of the truth brings to mind a parable written over 1,000 years ago by one of the eight giants of Tang and Song prose—Su Shi. In his piece "The Blind Do Not Know the Sun" Su writes: "People who speak of the Way today, whether they describe what they have seen, or speculate about something they have never seen, all pursue it in the wrong way." We can interpret Su's wisdom as follows: those who seek the truth are either carefully explaining what they have seen or inferring conclusions from what they cannot see, but regardless of how they go about this their methods are all incomplete. Su Shi's writing rings true—history's stargazers were indeed using both what was visible and invisible to them to investigate universal truths. But their results were only just a piece of this puzzle, as later generations of astronomers were handed the responsibility of filling in the missing pieces. It is no wonder that this is the parable Einstein himself quoted when describing his inner feelings regarding the theory of relativity.[1]

Here we suggest you, the reader, look at the stories and facts in this book from your viewpoint. We hope you can rearrange this book's narrative in your way and have a go at inferring information that was not mentioned within. In this way, once you have read this book, you will have embedded 3,000 years encompassing the history of scientific development deep in your mind, able to pull out interesting tidbits to reflect on at your convenience. Reaching this level of knowledge is surely a cause for celebration!

From our point of view, this book is well suited to university students taking subjects like physics, engineering, medicine or agricultural studies as a textbook on general education about the physical sciences. From the lives of these scientists, we can learn how unique environments and opportunities gave them the motivation they needed to explore specific subjects, as well as the problems they faced and solutions they found along their journeys. At selected points, we have included explanations of scientific laws and their related background information, and also use examples and propositions to illustrate the practical applications and scientific value of certain theories. Those who have an interest in scientific development but don't have a background in the above-mentioned fields can choose to skip over some theories and examples as they read, and instead view them as extra information embellishing these stories. These readers still ought to be able to fully experience the emotional voyages this group of scientists went through.

Finally, we must explain the use of mathematics used in this book. Chapters 1–4, none of the mathematical constructs we use are any more complex than Pythagoras' theorem, nor are they any more difficult than first-year university calculus. Chapter 5 when introducing special relativity, we occasionally use some basic tensor symbols. The highest volume of and most complex mathematics appears in Chap. 6 which discusses general relativity. But when deriving field equations we place more emphasis on the deducing and illustration of logical thinking. For example, we will progressively explain questions such as why Minkowski space is not applicable in a gravitational field, and must instead be replaced with curved spacetime and the Riemannian manifold; how the result of this is interchangeable with Newton's gravitational field; and at what point we can introduce the concepts of covariance and invariance in order to comply with the consistent nature of coordinate transformation. Our whole narrative is

[1] Lin Yutang, The Gay Genius: The Life and Times of Su Tung-Po.

focused on explaining the meaning and intention of these mathematical functions, enabling you to have a clearer understanding of the fundamentals of every formula and what role they play in the theory of relativity. We hope our efforts will bring readers closer to these scientific laws as well as allow them to appreciate the immense force of Einstein's intellect. We are not aiming to force readers into learning a load of meddlesome mathematics, as we would not want to extinguish any burgeoning passion they may have for physics.

This book uses several images to explain relevant theories. Many of these images were drafted by Tzu-Chin Lin, Chien-Long Chiang and Chi-Cheng Lin, students of the Institute of Applied Mechanics of National Taiwan University. We want to express our gratitude to them for their assistance.

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Prologue: Our Universe

At 5:51 AM, September 14, 2015, the Laser Interferometer Gravitational-Wave Observatory (LIGO), a four-kilometer long large-scale physics experiment and observatory located on the outskirts of Livingston, Louisiana, in the southeastern US, detected a very weak signal from deep space that lasted only one-fifth of a second. About 6.9 microseconds later at the LIGO Hanford Observatory, located in Washington State, northwestern US, the same signal was also intercepted. The signal detected by these two massive $2-billion[2] observatories was generated and began to transmit about one billion years ago, the result of two 36- and 29-solar-mass black holes on the other side of the distant Universe colliding and merging. The change in gravity due to the conversion of the matter of about 3 times that of the Sun into energy caused a series of distortions of spacetime. These distortions were propagated outward, from the location where the black holes merged, in the form of gravitational waves traveling at the speed of light, and it took one billion years for these waves to reach Earth.

From the amplitude of the gravitational waves measured by the two LIGO sites, estimated to be the diameter of several protons, the gravitational force generated by the merger of the two black holes is about fifty times the sum total of the gravitational force of all celestial objects in the entire Universe. LIGO's detection of gravitational waves confirmed the general

[2] A Special Report, The Discovery of Gravitational Waves—All you need to know about the ripples in spacetime detected by LIGO, Scientific American, February 14, 2016.

theory of relativity proposed by Einstein in 1915 (exactly a century before): the Universe is a spacetime entity formed by gravity, and it is subject to distortion by gravitational force. This distortion is then transmitted in spacetime at the speed of light in the form of gravitational waves. As of the beginning of 2018, three additional instances of such gravitational waves had been detected by LIGO, confirming the predictive power of Einstein's general theory of relativity.

The LIGO observatories in the US are not the only experimental facilities of its kind designed to explore the mysteries of the Universe. Comparable facilities constructed for the purposes of detecting gravitational waves have also been installed in Japan, Germany, Italy and other countries, starting in 2000. Many advanced countries around the world have set up similar expensive instruments or funded experiments of staggering costs since the twentieth century with the aim of confirming the theory of relativity, believed to describe the laws that govern our Universe. For example, HIgh Precision PARallax COllecting Satellite (*Hipparcos*), launched in 1989, was employed to measure the parallaxes of stars caused by gravitational lensing. As of 1996, the parallax data for a million stars had been collected. A gravity probe, equipped with four fused quartz spheres the size of table tennis balls and coated with superconducting materials, was launched in 2004 and has been used to observe the geodetic effect in spacetime and the axial precession effect of stars closely orbiting a supermassive black hole. Another satellite was launched in 2012 to continue with the same experiment; it is known as the Laser Relativity Satellite.

The above examples are just a few of the many costly experiments carried out for the purpose of verifying Einstein's relativistic Universe. The real reason behind these endeavors, of course, is to satisfy our curiosity and ambitions for the Universe. If one day scientists are able to completely reveal the secrets of the Universe, human beings will be able to traverse the vast spacetime with time machines! For now, however, our knowledge of the Universe remains quite limited.

The experiment conducted by LIGO confirmed the existence of gravitational waves, as predicted by Einstein's theory of relativity, and this provides evidence that Universe was formed after the Big Bang that occurred about 13.8 billion years ago. Two hundred million years after the Big Bang, the Universe was still shrouded in darkness and filled with gases and dust clouds (most of which was helium). As the Universe began to cool, these clouds condensed under gravitation and eventually celestial objects were formed. Within these celestial objects, more and more chemical elements assembled and gravitational forces increased rapidly, thus allowing gas molecules to fuse under high pressure. This, in turn, caused the release of massive amounts of energy that continued to fuel the fusion of even larger molecules. The fusion process released huge quantities of energy and light, and the resulting celestial objects became the stars that see today.

Our Sun, for example, was born in this manner 6 billion years ago. Many celestial objects gathered instead to form clusters or nebulae under gravitation. Our home galaxy, the Milky Way, for instance, was born 11 billion years ago. Stars continued to attract the residual substances in the Universe, and these masses would aggregate to form planets, which would in turn orbit the stars in elliptical orbits. In our Solar System, for example, the Sun is located at the center and eight planets revolve around it in elliptical orbits. The Earth's orbital speed around the Sun is about 107,000 km per hour. The Solar System itself also revolves around the center of the Milky Way in an orbit of about 250 quadrillions (10^{15}) km in radius, with an orbital speed of 778,000 km per hour, and it takes about 226 million years for the Solar System to complete one revolution. There are at least 200 billion stars in our galaxy, and each star is revolving around its center in a similar way.

So just how large is the Universe? We know that the light emanating from Earth will reach the Sun in about eight minutes. The same light will leave the Milky Way in about 100,000 years and reach our nearest major galactic neighbor, the Andromeda Galaxy, in about 2.5 million years. If the Universe is regarded as a sphere, then its diameter will be about 100 billion light-years. The Solar System is located about 100,000 light-years from the center of the Milky Way galaxy. When we look up at the night sky, the hazy band of light is actually the side projection of the galaxy on Earth, which indicates that our galaxy has a flat disk-shaped structure but with an incomplete or even fragmented disk. Our galaxy may be located near the edge of the Universe, and it is said to contain hundreds of billions of (sun-like) stars. There are perhaps up to a hundred billion galaxies in the entire Universe. In August 2009, the Fermi Gamma-ray Space Telescope (FGST), launched and operated by NASA, transmitted to Earth the data converted from signals in the gamma-ray bands that it had detected. The data was analyzed by scientists and a hypothesis regarding the existence of a black hole at least four million solar mass at the center of the Milky Way galaxy, now known as the "Fermi Bubbles," which was formed only millions of years ago.[3] Over the past 100 years, the gamma rays emitted by the high-energy jets from the black hole have not been able to penetrate Earth's

[3]The suggestion of the existence of a massive bubble structure at the center of the Galaxy was first published in *The Astrophysical Journal* (U.S.) in May 2010. The article was written by Meng Su, Tracy Slatyer and Douglas Finkbeiner. They named this structure "Fermi Bubbles", a tribute to Fermi Gamma-ray Space Telescope. For this discovery, the authors were awarded the Bruno Rossi Prize, the highest honor for high-energy astrophysics, in 2014.

atmosphere, so they have not been detected by ground-based observatories. With FGST deployed in Earth's low orbit, the discovery was finally made in 2010.

Although scientists have some idea about the shape of the Universe, they remain uncertain about the constituent elements of the Universe. Nowadays, scientists employ different bands of the electromagnetic spectrum to detect the substances present in the Universe, and they have discovered that all visible celestial bodies constitute only 5% of the total mass and energy of the Universe. Two other substances also exist in the Universe: dark matter and dark energy, which account for about 27% and 68%, respectively, of the total mass-energy of the Universe. At present, scientists have been successful in exploring the ordinary (visible) matter, and have developed the so-called Standard Model of particle physics, which states that ordinary matter (5% of the entire Universe), including Earth, the Moon, the Sun, the planets and the galaxies, as well as all creatures that exist on Earth, are made up of twelve elementary particles. The forces that bring together these particles to form matter and those that govern the interaction between matter are the four fundamental interactions (or forces): the electromagnetic force controls the interaction between the electric field and the magnetic field; the strong interaction confines nuclear particles within the atomic nucleus; the weak interaction is responsible for the radioactive decay of atoms. Finally, the universal gravitational force governs the motions of celestial bodies.

On the other hand, although scientists are beginning to explore the nature of the invisible dark matter and dark energy, which constitute 95% of the Universe, what is known is still extremely limited, not unlike the knowledge of prehistoric humans about the sky. What is reasonably certain is that dark matter interacts with ordinary matter through gravity, or else it would not have been discovered in the first place. Dark matter can also collide with itself due to gravity, from which electrons or positrons may be generated, and therefore it is possible that dark matter is also be composed of particles. These collisions, however, do not happen routinely. Nor are the particles produced abundant enough to form anything close to a black hole, so dark matter may also exist in an alternative form at the same time. The scant evidence and conjectures show that our understanding of dark matter is extremely inadequate at the moment, and even the most basic definitions are still lacking. As for dark energy, scientists remain completely baffled as to its very nature. Anything from kinetic energy, momentum and heat in the Universe, or a combination thereof, is a possibility. It will likely also appear in the term in Einstein's field equations that represents the source of gravity, the existence and the variation of which will alter the spacetime curvature of the Universe. In any event, the generation, existence, changes and any other properties of dark energy currently lie in the realm of unknown as far as we are concerned. We have at best barely scratched the surface.

As we explore these unknown areas of science, we are keenly made aware of how ignorant we still are. Apart from such ignorance, there is also one aspect that is difficult to imagine. It is the distortion of spacetime defined by general relativity, which also depicts the depths of space and time. The "depth of space" clearly points to a three-dimensional image of celestial bodies at different distances from Earth. The "depth of time", on the other hand, represents collages of the images of heavenly bodies all created at different points in time. For example, standing on Earth, the sunlight we see constitutes photons emitted from the Sun more than eight minutes ago; an image of Jupiter we see in a telescope is 50 minutes old; and an image of the Alpha Centauri system, our closest stellar neighbor about four light-years away, is actually four years old. Similarly, the starlight from Vega in the constellation of Lyra is about 25 years old, and the light from other stars farther away can be decades, tens of thousands, or even hundreds of millions of years old. This Universe, created with the finite speed of light time and possessing depth in time, constitutes an entity with a distinctive contrast between space and time. Someday if we could take a ride on a spaceship and travel close to the speed of light in this distorted spacetime continuum, how would the Universe appear on our viewscreen is anybody's guess!

Despite the Universe being full of unknowns and hard to imagine, we are going to explore the process by which the development of science has been brought to its current form. In other words, how did science begin as a curiosity of Bronze Age humans about the starry sky and end up with the principles of the theory of relativity that enable us to understand how the Universe works? In the following chapters, we will explore the history of scientific development over a period of four millennia, starting with the Babylonians in 1000 BC and concluding with Albert Einstein's theory of relativity in the early twentieth century. During this time many scientists were inspired by various natural phenomena and proposed theories and hypotheses, many of which evolved into important theorems and scientific knowledge. The occurrences of a series of scientific events allowed us to catch a glimpse of the intelligence, strength and endurance exhibited by previous generations of scientists in successive waves of scientific discoveries, and we will also examine whether human beings have the ability to go forward and proposer in the unknown future.

Contents

1

Ancient Wisdom and Natural Philosophers

人法地.
地法天.
天法道.
道法自然.

He models himself on Earth,
Earth on Heaven,
Heaven on the Tao,
The Tao models itself.
On Nature,
On the So-of-Itself.

From Tao Te Ching, *Chapter 25, by Lao Tzu (571–471 BC), an ancient Chinese philosopher.*
Translated by John Minford (b. 1946).

In 1881, the Assyrian-British archaeologist Hormuzd Rassam (1826–1910) discovered a clay tablet covered with cuneiform inscriptions in the ruins of the ancient city Sippar, some 30 km southwest of Baghdad, the capital of Iraq (then part of the Ottoman Empire). The clay tablet is said to be the oldest map ever discovered in history. On this tablet, now known as the Babylonian "Map of the World" (or *Imago Mundi*), two concentric circles enclose several haphazardly arranged ellipses and arcs, and the circumference of the outer circle touches the bases of eight triangles, each of which is almost equidistant

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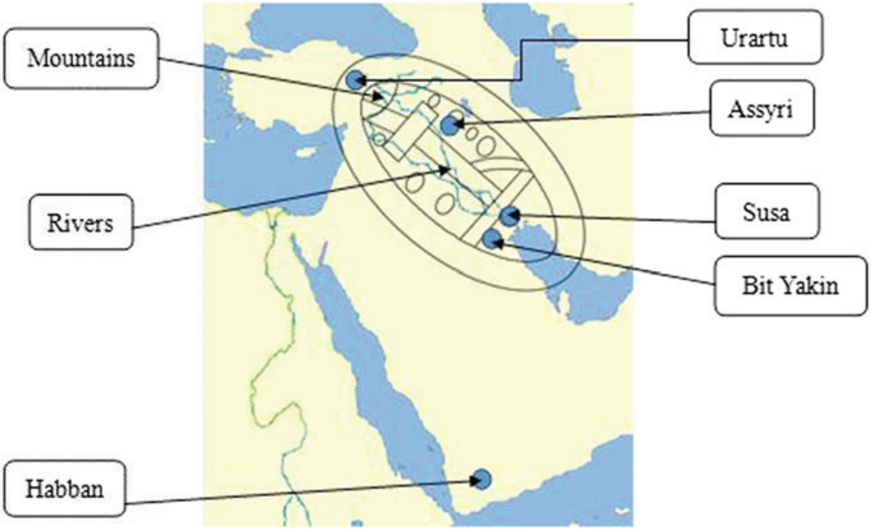

Fig. 1.1 The world of Babylon superimposed on a modern map. Inspired by https://en.wikipedia.org/wiki/Babylonian_Map_of_the_World

from its two triangular neighbors on the circle. The wide belt region between the two concentric circles is labeled as the Aral Sea, which signifies that the world inhabited by humans is surrounded by an ocean. The two arcs in the interior of the inner circle represent the Euphrates, which flows from north to south and passes through Babylon, represented by a rectangle. The mouth of the Euphrates is another rectangle marked "swamp". Placed around Babylon are a number of small ovals, which represent cities, such as Susa, Bit Yakin, Habban, Urartu, Der and Assyria. The map is also marked with animals such as cows, monkeys, lions, wolves, and sheep.

This is an abstract and stylized map. The mapmaker employed triangles, circles and rectangles to signify, respectively, mountains, bodies of water and cities on Earth's surface. The map is centered on the Babylonian world, with text and graphics incorporated into the clay tablet. Based on the names of the cities depicted on the map, we have displayed their locations on a modern map to produce an elliptically shaped region shown in Fig. 1.1. The major axis of the ellipse happens to be superimposed over the Tigris–Euphrates river system, and the high elevations on the outer rim represent mountain ranges in modern-day Turkey and the Caucasus, as well as the Arabian Desert (the triangles on the clay tablet indicating mountains are not shown here). The surrounding bodies of water include the Mediterranean, the Black Sea, the Caspian Sea, the Persian Gulf, and the Red Sea. This area, known as Mesopotamia, was settled by the Babylonians and is a vast floodplain of the

Euphrates and Tigris. It is also known as the Fertile Crescent due to its shape and its fertile soil. This was the world known to the Babylonians, a self-sufficient community surrounded by mountains and seas, where its residents lived and worked in peace.

1.1 The Universe in Mythology: Enlightenment by the Laws of Nature

The multitude of cities marked on the clay tablet was essentially agricultural in nature, developed over a long period of time beginning around 4000 BC. Early settlers discovered the fertile land between the rivers Tigris and Euphrates and decided that the nomadic lifestyle, which they had led for generations, was no longer the only option available to them. They began to build irrigation works and cultivate the land, thus laying down the foundation of an agricultural society. With a more reliable and abundant food supply, raising families became the norm. The higher birth rates and reduced mortality enabled the population to grow rapidly, transforming nomadic existence into settlements, and from tribal societies into cities. Apart from tilling the fields, these settlers also raised cattle, sheep, hog and horses, which provided them with not only meat and dairy products but also woven garments from animal hair. They also learned to produce beer and wine. All the ingredients required for people to live as a cohesive community were at their disposal.

Nevertheless, a prosperous and fast-growing population also necessitated effective administration, and eventually, a loosely structured social hierarchy came into existence. At the very top of the social classes sat the religious authorities who served as an intermediary between ordinary citizens and the gods. In an agrarian society before the emergence of powerful military leaders, the most effective way of governing the populace was to introduce awe-inspiring deities that would instill fear and respect among the people, in response to their anxieties toward the unpredictability of nature. In the beginning, there would be a tutelary deity in each city responsible for all matters great and small, from public administration to household affairs. Citizens would be able to seek guidance and comfort from the deity via their religious authorities, who would intercede on their behalf. The responses communicated by these religious leaders would often become the principles by which ordinary people lived their lives. Over time, religion would transform into an effective means of managing a city, where a majestic temple would be built at its center. The priests of the temple would become what people considered mediatory agents between themselves and the deities, as well as their common leaders. At the height of this theocratic regime, the deities being worshipped in the temple would number in the dozens, ranging from those in charge of agriculture, commerce, craft, wine production and animal husbandry to those who administered justice and even death.

1.1.1 Marduk, Patron Deity of Babylon

To ensure harmony and to maintain social order in the community, relying merely on the admonishments by religious leaders was far from adequate. It was necessary to lay down written rules and regulations for the citizens to follow. The responsibilities of administrators were limited to adjudicating disputes and enforcing judgments. From a modern point of view, this is equivalent to making a set of laws that regulate citizens' behavior and to mete out justice whenever the laws are violated. The establishment and enforcement of these ancient laws depended on religious norms and constraints. In the case of Babylon, the rulers proclaimed that it was the great god Marduk who created the heavens, the earth, human beings and animals out of the chaotic primeval ocean to form a world centered at Babylonia, thus giving the rulers supreme authority to govern the world and to pass judgment on infringements of the law according to Marduk's will. In 1772 BC, Hammurabi (c. 1792–1750 BC), the sixth king of the First Babylonian dynasty, even claimed to have received divine instructions from the great god Marduk to administer justice and to eradicate all evil in the world. He duly promulgated the Code of Hammurabi, one of the first legal codes in human history. King Hammurabi ordered the text of the code carved onto a black basalt stele measuring 2.4 m high, the purpose of which was to make it clear to the subjects of his kingdom that the law was to be obeyed without question.

Currently, on display at the Louvre Museum in Paris, this black stele was uncovered in 1901 by archaeologists at the ruins of the ancient city of Susa (or Shushan, in modern-day Iran). It is said that Marduk not only instructed Hammurabi to enact laws for the purpose of keeping human behavior in check but also lay down a set of principles (or laws) of nature that describe how the natural world actually functions. These laws of nature were quite distinct from the legal code that applied to people because one cannot "order" nature to do or not to do something. Nor could nature be "punished" if it ever violates these laws. What is more unsatisfactory is that these laws, designed to describe how nature works, were not clearly enunciated like its human law counterpart but were instead phrased in very vague terms. From a modern perspective, these were merely a set of self-serving, subjectively determined hypotheses that could never be proven. Below we will elaborate on this point with examples of the "laws" of nature in the Code of Hammurabi.

After the Babylonians founded their kingdom in Mesopotamia in the 18th century BC, they inherited the cosmological view of the Sumerians but replaced the Sumerian gods with their own new deity, Marduk. According to the laws of nature in the Code of Hammurabi, Marduk was born out of the primordial ocean before time, who then proceeded to create the world, took control of power and maintained order in his new realm. In the process of creation, Marduk breathed into the primordial ocean, and after inflating it, he pierced it with an arrow. Half of the resulting fragments became the water of the sky and the ground, and the other half became Earth. The Earth is like a disc surrounded by rivers, and beyond the rivers are impassable mountains, much like the depiction on the clay tablet discovered by Rassam. A cluster of surrounding lofty peaks supports the six-level heavens, the uppermost level of which being composed of special stones. The second level is the throne of Marduk made of lapis lazuli; the third level contains the sacred jasper stars; the fourth level is the land inhabited by humans. The fifth and sixth levels are the middle and lower terrestrial levels where the gods reside. Marduk's abode in Babylon is the center of the Universe, with the second level of the heavens reachable via the high tower atop it. The tower's foundation passes through the lower terrestrial level. This explains why the temples found in West Asia are often tall towers, as the residence of the gods is supposed to span both the heavens and the earth in order to bring people and the gods together.

The temple is also the center of the Universe, and the gods residing in it can therefore maintain the order of the Universe from a divine vantage point. Having been endowed with such superior status and sacred power, this center-of-the-Universe narrative began to be emulated by other peoples. The Hebrews, for example, designated Jerusalem as the Navel of the World, and the ancient Greeks believed Delphi to be the center of the Universe. We have covered in the preceding paragraphs the laws of nature of the Babylonians. The stories, however, contrived they may seem, vividly portray Marduk and the universe he created. Yet they never took the effort to demonstrate or question the veracity of these assertions. This type of culture, where the rulers' words were taken at face value and never challenged, would continue until the inauguration of Greek natural philosophy, at which time the "true" laws of nature were also entirely up to the natural philosophers.

This kind of law of nature indeed carried the ruler's subjective views and self-serving motives, but Hammurabi was far from the first person to have proposed such theocentric laws. The earliest laws of nature may have been established before 3000 BC by the Sumerians, who built large-scale irrigation systems and developed urban cultures in Mesopotamia. In addition, despite having lands that were fertile, irregular flooding, as well as dry seasons lasting six months or longer, the Sumerians were entirely at the mercy of nature and had to learn to tame the lands into submission in order to be productive. For this reason, the Sumerians fashioned a deity that was harsh, short-tempered and mighty, and always strict but fair in meting out rewards and punishments, when they constructed their cosmological view. They believed that when the Universe first came into existence, it was composed of a mixture of primordial waters and solid matter. Then the gods emerged, separated the heavens from the earth, and provided the space on land needed for the growth of seeds (i.e., all forms of life, including humans).

1.1.2 Atum, the Great Egyptian God

Also around 3000 BC, another great civilization was born out of the alluvial plains of the Nile River: ancient Egypt. On these plains, the prosperous inhabitants also established their own set of laws of nature centered on the Nile Delta. The ancient Egyptians lived in an area bordered by the Mediterranean to the north, the Red Sea to the east, and a desert to the southwest. The only external passage was through the Sinai Peninsula to the northeast, which allowed interactions and cultural exchanges with the peoples living in Mesopotamia. The Egyptian laws of nature, therefore, were influenced by the Sumerians, but what distinguished their system from their counterparts in Mesopotamia was that the Nile had regular flooding periods and the river basins received an abundant supply of water, which allowed ample crops to be harvested throughout the year. Also, because of the surrounding natural barriers, the Egyptians encountered few invasions, and the result was a self-sufficient, cyclical view of cosmology. From their observations of natural phenomena, the Egyptians discovered that the Sun, the Moon and the stars follow a regular, routine cycle of movements across the sky. For example, the Sun is “born” from one end of the horizon at dawn and “dies” at the other end at dusk. To them, these cyclical patterns appeared to stay constant and never changed. They subsequently connected human life with the cycle of nature and concluded that the end of human life in this world signifies a rebirth in another, and the ruler is responsible for maintaining order and harmony in the Universe.

With respect to the origins and composition of the Universe, the Egyptians believed that the Universe was at the beginning a chaotic and invisible ocean, from which a mound covered with papyrus, a plant endemic to the Nile Valley, slowly emerged. Then the god Atum appeared. He created light, air