SYNCHRONICITY

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SYNCHRONICITY

The Epic Quest to Understand the Quantum Nature of Cause and Effect

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BASIC BOOKS
NEW YORK

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Basic Books
Hachette Book Group
1290 Avenue of the Americas, New York, NY 10104
www.basicbooks.com

Printed in the United States of America
First Edition: August 2020

Published by Basic Books, an imprint of Perseus Books, LLC, a subsidiary of Hachette Book Group, Inc. The Basic Books name and logo is a trademark of the Hachette Book Group.

Print book interior design by TK.

Library of Congress Cataloging-in-Publication Data has been applied for.

ISBNs: 978-1-5416-7363-2 (hardcover), 978-1-5416-7364-9 (ebook)

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Dedicated in honor of my father, Stanley Halpern,
and to the memory of my mother, Bernice Halpern

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INTRODUCTION

Mapping Nature's Connections

I cannot seriously believe in [quantum mechanics] because the theory cannot be reconciled with the idea that physics should represent a reality in space and time, free from spooky actions at a distance.

—Albert Einstein to Max Born, March 3, 1947

OUR QUEST TO UNDERSTAND HOW THE COSMOS IS INTERCONnected begins with light. Light races along nature's fast track. It travels through empty space at a phenomenal rate.

Crossing the vast divide between the Moon and Earth, for example, takes less than a second and a half. Compare that to the roughly three days the astronauts of the Apollo 11–manned lunar mission took for their return in 1969. In other words, a light beam is about two hundred thousand times swifter than that groundbreaking space voyage. No wonder we've learned far more about the vast universe by collecting light with telescopes and other instruments than via space journeys.

Nevertheless, Apollo 11 proved vital for science. On that mission, Neil Armstrong and Buzz Aldrin, the two members of the landing crew, left behind a designated bank of mirrors. The reflectors form a critical component of the Lunar Laser Ranging Experiment. Present-day knowledge of the speed of light is so precise that scientists can now aim a laser pulse toward those mirrors on the Moon to measure its distance with stunning accuracy. Such tests rely on our absolute certainty that light's velocity in empty space is extremely fast, but not instantaneous. Rather it is finite and constant.

For millennia, our ancestors lacked confidence about light's finite speed. The ancient Greeks debated whether light took any time at all to travel through space. Asserting that sunlight must take some time to traverse the space between the Sun and the Earth, the philosopher Empedocles argued for a finite speed of light. While recognizing Empedocles' line of reasoning, Aristotle rebutted that if light traveled through space we would see its intermediate stages. Rather, it must arrive from the Sun instantaneously. In effect, according to Aristotle's views, the speed of light would be infinite.

It was only by the mid- to late nineteenth century that scientists firmly established light's finite velocity. French researchers Armand Hippolyte Fizeau and Jean Bernard Léon Foucault developed two different means of measurement, surpassed in precision by the later techniques of American physicist Albert Michelson. Meanwhile, the theoretical methods of Scottish physicist James Clerk Maxwell proved that light is an electromagnetic wave (disturbance due to the interplay of electric and magnetic forces), possessing a constant, finite speed in empty space.

The speed of light has profound importance. As Albert Einstein emphasized in the special theory of relativity, proposed in 1905, it sets the maximum pace of causal interactions in ordinary space. That is, an effect cannot transpire in less time than it would take for its cause, journeying at light speed, to reach the place where it happens. For example, you couldn't somehow rattle a moon rock remotely faster than a laser could reach it. In general, no transaction involving matter or energy might exceed the speed of light traveling through a vacuum. Moreover, anything with mass, meaning most elementary particles, must travel slower than light. It would take an infinite amount of energy to accelerate a massive, subluminal particle up to light speed, which would clearly be impossible.

Though well established by means of numerous experiments, the speed limit for the transfer of matter and information is unintuitive. Why should natural transactions have absolute bounds? In races, records are meant to be broken. With spaceflight, we aspire to travel faster and faster. Banks reward loyal customers by raising their credit limits—offering them a sense of financial freedom, whether real or illusory. No one likes to be fenced in. We like to breach any frontier. Yet, like a sleepy town hoping to slow the pace of tourists rushing through, special relativity imposes a universal cosmic speed limit.

And why that particular value? Did an early, dynamic process cement the speed of light cap, or was it always unwavering? Could there conceivably be other versions of the universe (or universes parallel to ours) where the speed of light is very different? Could there be any enclaves of reality where it is unlimited? Special relativity assumes that the vacuum speed of light is fixed and finite, but doesn't fully explain why.

In 2011, a startling headline in the prestigious journal *Nature*, "Particles Break Light-speed Limit,"[1] describing a new research claim, jolted the scientific community. Physicists could scarcely believe the news. Given the overwhelming support for the basic precepts of special relativity, including the speed-of-light barrier, many were dubious.

The type of particle in question was the extremely lightweight neutrino. First hypothesized by the brilliant quantum physicist Wolfgang Pauli, the neutrino is nearly (but probably not quite) massless and electrically neutral. Consequently, it rarely interacts with other particles—doing so almost exclusively by means of what is called the "weak interaction": a type of interaction involved in certain kinds of radioactive decay.

Neutrinos are exceedingly common. Nuclear reactions in the Sun generate them constantly. They travel rapidly through space and flood Earth every single moment. However, because they interact so rarely, the vast majority simply pass through. Thus, precisely measuring their speeds is challenging. We couldn't simply bounce them, for instance, as we would photons (particles of light), off lunar reflectors and time their return.

The method used by the OPERA (Oscillation Project with Emulsion-tracking Apparatus) team of physicists was to record the time of flight of neutrinos produced at the LHC (Large Hadron Collider) and detected at the Gran Sasso Laboratory, a special facility housed in a highway tunnel to protect from the interference of other particles. The group reported that the neutrinos completed the journey in about 60 nanoseconds' (billionths of a second) less time than the speed of light would predict. While they published their results only after allegedly ruling out a wide range of possibilities for experimental error, alas, other competing teams couldn't reproduce their supraluminal value. Eventually the supposed finding turned out to be purely a glitch in the timing system. Alas, the so-called faster-than-light neutrinos were merely a mirage.

The OPERA experiment notwithstanding, we cannot assume that any scientific hypothesis will last forever. As sacrosanct as Einsteinian special relativity seems today, scientists might someday find a way to circumvent the speed-of-light barrier. Indeed, general theory of relativity, introduced by Einstein a decade after special relativity, contained an important loophole. If space is curved sufficiently due to the matter and energy within in, it might connect up with itself, potentially enabling faster-than-light connections between two otherwise widely separated points. Einstein and his assistant Nathan Rosen formalized that idea in a 1936 paper. The physicist John Wheeler later dubbed such spatial shortcuts "wormholes." While the notion of wormholes remains purely speculative—no one knows if they could be used to bend causal order or if, alternatively, the laws of physics might somehow prevent that—their existence as theoretical solutions to general relativity raises important questions about how nature is connected.

Our intuitive notions about how the universe is organized don't always match its actual structure. Throughout history, widely held conceptions based on common perceptions have crumbled again and again, from Earth-centered models of the solar system to the idea that space is static. Just when we think we have a firm grasp on reality, something wholly unexpected, such as the discovery in the 1920s that the cosmos is expanding, has shattered our confidence.

Perhaps quantum mechanics, with its enigmatic rules that seem to defy physical expectations, drives home that message most starkly. It shows how elementary particles, without communicating through a medium, can nevertheless coordinate their properties over vast distances. Matching such "entanglement" with the evidence of our senses has been an ongoing struggle, since the development of the notion in the 1920s and 1930s.

Entanglement is not an exchange, but rather a correlation of quantum features. In some cases, it acts faster than purely causal communication (involving a chain of intermediate steps taking place at light speed or less) would permit. It allows for two "pipelines" in nature: the information conduit, that operates at the light-speed limit or less, and quantum correlations, which might manifest themselves immediately upon observation.

For all practical purposes, there is no clash between the two. Physics has learned to encompass both. As quantum theorist Časlav Brukner has remarked, "I do not think that quantum entanglement is in any way in contradiction with general relativity. After all, we have quantum field theory on curved spacetime, which is a perfectly functioning theory."[2]

Nonetheless, over the years many scientists have pondered whether or not a fundamental theory that transcends both relativity and quantum physics might offer a unified explanation of how things are connected in nature—from the microscopic scale to the cosmos as a whole. Rather than sew the relationships of quantum physics onto a general relativistic canvas, a unified field theory would start from simple mathematical threads and weave a fully integrated fabric. The result would be a fully quantized theory of gravitation, along with all other interactions and relationships.

Along that vein, one line of reasoning is to posit locality (the properties of each object are determined by conditions in its immediate neighborhood) and causality as emergent phenomena that while absent from the quantum world on its deepest level, arise naturally from the concerted application of its internal logic. Imagine a pointillist painter dabbing on dots seemingly haphazardly, while her audience watches in amazement as an intricate masterpiece, with patterns and themes that unite the entire canvas, unfolds. Similarly, it is conceivable that a nonlocal, acausal, fundamental reality could develop into a web of causal connections between local entities, including the structures of general relativity.

Alternatively, one might propose that the strange features of the quantum world are simply illusions due to our lack of knowledge. In that case one might assume that the rules of classical physics hold sway and try to model entanglement by means of unseen links set in the background—like a sturdy steel skeleton furtively supporting a gossamer skyscraper.

Enacting such a "hidden variables" strategy without violating the results of countless quantum entanglement experiments turns out to be a tall order. However, some stalwart researchers continue to try.

Such unification efforts date back to the work of Einstein, who was frustrated by what he saw as the incompleteness of quantum mechanics. Decrying entanglement as "spooky action at a distance," Einstein argued for a causal web connecting all processes in the universe. If the property of one object is contingent on that of another, one should be able to demonstrate a domino-like series of causes and effects linking them. For that, he drew on common experience. If a volcano erupts on an island hundreds of miles from your beach house, and sometime later your kitchen starts to shake, you might reasonably deduce that a seismic wave passed from the former to the latter. If the rumbling of a nearby construction project turned out to be the true culprit, that would still be an example of causality. In other words, for any given effect, there must be some chain of causes that produced it.

Moreover, according to Einstein, the physical properties of any object should in principle be completely knowable (presuming perfect instruments) and wholly dependent on conditions in its vicinity—a set of criteria called "local realism." Like a weather vane, anything properly measured should reveal where it is perched, how fast it moves, and what in its surroundings causes that motion. However, numerous experiments have shown that quantum entanglement is real, local realism doesn't fully describe quantum interactions, and that the brilliant physicist's intuition about that subject was incorrect. His commonsense views about how natural events must be linked proved deficient. He was right, though, in identifying the issue as a serious philosophical conundrum that shouldn't simply be swept under the rug.

Our hunches about how things are connected often serve us well. Yet at times they are absolutely wrong—not just in physics, but also in our daily life experiences. When our perceptions are correct, it is a marvel to behold. The power of cognition is an extraordinary tool. Keeping an eye toward the future—by collecting data and using it to shape mental models—is a hallmark of our species. Yet, as in optical illusions, our senses can deceive. As the eighteenth-century Scottish philosopher David Hume emphasized, our belief in causal connections stems from our impressions, but those can mislead. Consequently, to map out the complex skein of connections in physics, taking into account the not-so-intuitive rules of relativity and quantum mechanics, we need to make sure we know how to separate the real from the illusory—true patterns from meaningless coincidences—a task that is not always simple.

Many great thinkers over the ages have conflated valid, testable scientific connections with pseudoscientific analyses. The Pythagoreans introduced important insights about mathematics (famously, a critical theorem involving the sides of right triangles) along with specious numerology (extolling certain numbers). German mathematician Johannes Kepler based an early model of the planets on his intuitive sense of geometric simplicity, before turning to experimental data and realizing his initial hunch was wrong. He also sold horoscopes to earn extra income. Nevertheless, once he applied a more systematic approach to planetary data, his theories were right on target. The great English biologist Alfred Russel Wallace discovered the scientific notion of evolution by natural selection, independently of Darwin, but also embraced pseudoscientific beliefs in the power of spiritualist mediums and the validity of séances. The list of those who found both valid and false connections goes on and on. Even scientists can't always separate the real from the illusory.

Consider the idea of synchronicity: a term coined in 1930 by Swiss psychologist Carl Jung as an "acausal connecting principle." Though he'd attribute the idea to dinner discussions with Einstein about relativity, along with personal analyses of dreams, coincidences, and cultural archetypes, the notion took flight after discussions with Pauli about novel aspects of quantum physics that distinguished it from classical mechanistic determinism. In retrospect, Jung's insights about the need for a new acausal principle in science were brilliant and prescient. Nonetheless his low threshold for accepting anecdotal evidence about "meaningful coincidences" without applying statistical analysis to rule out spurious correlations was a serious failing in his work. Jung trusted his intuitive sense of when things were connected. But in light of the mind's capacity to fabricate false linkages at times, pure intuition on its own is not genuine science.

In that case, as pointed out in a famous 1935 paper by Einstein, Boris Podolsky, and Rosen (often called “EPR”), how do two widely separated, but entangled, particles anticipate which property an observer is about to measure? If, for instance, one of the particle’s momentum is measured, instantly revealing the momentum of the other one, how did the second one immediately prepare itself? Did it engage in a kind of “mind reading”? Einstein thought not, and argued for a more complete explanation in which physical values objectively exist before they are measured—even if practical device limitations preclude their measurement.

Coincidentally, around the same time that Einstein dismissed the orthodox description of quantum entanglement as a kind of “mind reading” that had no place in objective science, trained botanist J. B. (Joseph Banks) Rhine argued vehemently that purported psychic’s claims of mind reading needed to be scientifically explored. For example, could “psychically gifted” individuals guess the images on cards concealed from them at a rate higher than chance would indicate? To that end, Rhine founded the field of parapsychology.

Rhine’s arguments caught the interest of several quantum physicists, including Pauli and his friend Pascual Jordan. While Pauli was generally careful not to broadcast his interest in parapsychology, he became passionately interested in the notion of unseen connections. In many areas of physics, such as in his critiques of Einstein’s attempted models for unifying the laws of nature, Pauli was a hardheaded skeptic. Yet, in the case of parapsychology, Pauli was surprisingly very willing to believe, at least for a time. Introduced to Jung when the Swiss psychologist psychoanalyzed him, the two embarked on an exploration of the notion of synchronicity, hoping to establish the reality of an acausal connecting principle.

While Jung and Pauli correctly pointed out that science needed to move beyond expectations of determinism and causality, they became overeager in their quest to find examples of acausal connections in nature. They attempted to draw parallels between quantum entanglement and coincidences in the everyday world, including premonitions in dreams, commonalities in culture (what Jung called “archetypes” and attributed to a "collective unconscious"), and so forth. In making such linkages, they unfortunately conflated a genuine scientific enigma—why both deterministic causality and acausal correlations, involving elements of chance, exist side by side in nature—with unproven pseudoscientific speculations. People—even trained scientists—are not always adept at gauging which connections are genuine and which are spurious. In truth, experimentally confirmed long-distance interactions bear nothing in common with the mere feeling that two events share a hidden linkage. Reproducible results, confirmed by the efforts of numerous teams, are the genuine litmus tests; mere hunches are not enough.

Despite its bizarre aspects, quantum physics is far from being fluffy and vague. On the contrary, within the context of its hybrid framework that includes an odd mixture of chance, correlation, and continuity, it produces extraordinarily precise predictions. These include practical applications, such as MRI (Magnetic Resonance Imagery) used every day in hospitals, and SCMaglev (Superconducting Magnetic Levitation) trains, suspended above their tracks for incredible speeds, being tested in Japan.

A research group based in Vienna, led by innovative physicist Anton Zeilinger, has been doing exciting work for years in the areas of quantum teleportation and cryptography. Making use of quantum entanglement, they have been able to teleport information about the quantum states of photons from one place to another across record distances. Among the team's recent ventures is to send photon state information to the Chinese satellite "Micius" with the goal of exploring how entangled systems might be used in cryptography to create nearly undecipherable codes. Their work shows how acausal connections, such as quantum entanglement, are vital and practical.

While theorists scratch their heads over the meaning of the rules for calculation in quantum physics, experimentalists delight in its bull's-eye measurements. To fathom the entirety of nature, we must learn to reconcile the steely girders of relativity with the pliable, but nonetheless powerful, mesh of the quantum world. Sometimes the same system might have causal and synchronous features.

Consider, for example, the Sun. Its light and heat are generated through nuclear mechanisms that rely on quantum rules, yet are released through space at the rate of causal interactions: the speed of light. While philosophers have contemplated the nature of the Sun's energy for millennia, only in the past century have scientists offered a satisfactory solution that involves a medley of processes.

1

TOUCHING THE HEAVENS

Ancient Views of the Celestial Realm

The Sun, seated in the middle of them, looked at the boy, who was fearful of the strangeness of it all, with eyes that see everything, and said "What reason brings you here?"

—Ovid, *Metamorphoses* (translated by Anthony S. Kline)

MAPPING OUT THE WORKINGS OF THE COSMOS HAS BEEN humanity's long-standing quest. The wheels within the wheels of astral motions—from the Moon to the Sun to the starry dome, each as seen from Earth—set our calendars, which, in turn, govern our lives in integral ways. From ancient times until the present, we've tried to find relationships between the behaviors of these bodies—first through speculation and then through science.

Understanding such interactions requires gauging their speeds. A connection involving a delay is fundamentally different than one that is instantaneous. Over the ages, as we've learned about the monumental scope of the universe, fathoming which interactions operate at various rates has become paramount. After all, swiftness is relative to size. Any lagging for a brief interval, presuming the rate stays the same, becomes increasingly significant for longer and longer spans.

To model how a city functions, an engineer would need to understand its networks of transportation and communication. A city restricted to pedestrians would have a wholly different character than one laced with multilane highways—especially in terms of how rapidly products would be delivered from place to place. A community in which mobile phones are banned or restricted would operate at a different pace than a locale in which everyone is carrying a phone at all times.

Similarly, deciphering the dynamics of the web of forces and other interactions in the universe requires a precise comprehension of their operating speeds. We now know that the speed of light in a vacuum serves as an important upper limit for causal interactions between objects in ordinary space. By causal, we mean obeying an order of events in which each effect (something being pulled, for example) is preceded by its cause (the thing doing the tugging).

The ancient Greeks understood the critical importance of light. Applying pure deduction, many philosophers of that era associated it with abstract qualities such as love and goodness, as well as physical properties such as brightness and warmth. Trying to fathom how light was conveyed, they debated whether or not it had a finite speed. Lacking modern instruments and methods, they were unable to resolve that question.

Indeed, because light is so swift, even during the time of the Renaissance, roughly two millennia later, scientists such as Galileo Galilei fared little better in ascertaining its speed. He proposed a method of two observers, separated miles from each other, flashing lanterns in succession and seeing if the timing of the light bursts depended on distance. Though his idea was clever, in practice it wasn't precise enough to distinguish between instant and very slightly delayed (by a tiny fraction of a second) signals. Luckily, thanks to nineteenth-century innovators such as Albert Michelson and continued improvement in techniques and technology, we now know its velocity with great precision.

The speed of light is not just important for astronomy. It has turned out to be a critical component of modern theories of how forces work. Comprehending the forces of nature demands models of how they are conveyed through space. Not all forces involve contact. In fact, two of the four fundamental forces, electromagnetism and gravitation, can act over considerable distances. Do they somehow vault instantly from one point to another, or do they take some time? The electromagnetism interaction, as it turns out, involves the exchange of light. The gravitational interaction, though comprising a different mechanism, happens to occur at the same speed. Consequently, knowledge of the speed of light underpins the study of nature's interactions.

Finally, pinning down a finite speed for light has raised profound questions about the nature of communication and causality. In general, speed limits don't seem very natural. As any hurried driver on a long, empty stretch of motorway would attest, on a day in which traffic police were on strike and nowhere to be seen, temptation to push past the barriers would reign over caution.

If the law of cause and effect is bounded by light-speed influences, as it seems to be, what would happen if that speed limit could somehow be circumvented? Might backward causality be possible? Quantum physics includes coherent states and long-distance correlations that operate faster than a causal chain of events, transpiring at light speed, would seem to permit. How does quantum entanglement, and other remote effects, mesh with the light-speed limit?

In short, the discovery of the finiteness of the speed of light sparked multiple chains of scientific inquiry that have continued until this day. Pure philosophy could not pluck that precious fruit. Rather, it needed to be cultivated and harvested through the development of precise scientific techniques.

Touching the Sky

The blazing light shone on our ancient ancestors stemmed from the same sources as the light that shines today. Yet back then, in stark contrast to our modern sense of the extraordinary remoteness of the astral dome, it seemed far more immediate. The ancient Greeks, for example, developed a detailed mythology about the Sun and the heavens that closely connected heavenly doings with terrestrial events.

In some parts of the Greek world, the Sun was worshipped as the god Helios, child of the titans Theia (goddess of sight) and Hyperion (god of

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celestial light). As Hesiod's *Theogony* relates, Helios's sisters were goddesses Selene (the Moon) and Eos (Dawn). Like siblings sharing a play space, the three immortals took turns dominating the sky.

More insight about the adoration of Helios derives from the Homeric hymns, a compendium of thirty-three poems of unknown authorship, similar in style to Homer's works and likely written starting in the seventh century BC. One such hymn celebrates the Sun god as an exalted driver with a shining golden helmet, steering a quadriga (racing chariot driven by four horses) across the sky:

> [Helios] rides in his chariot, he shines upon men and deathless gods, and piercingly he gazes with his eyes from his golden helmet. Bright rays beam dazzlingly from him, and his bright locks streaming from the temples of his head gracefully enclose his far-seen face: a rich, fine-spun garment glows upon his body and flutters in the wind: and stallions carry him. Then, when he has stayed his golden-yoked chariot and horses, he rests there upon the highest point of heaven, until he marvelously drives them down again through heaven to Ocean.

Personifying the Sun greatly restricted the ancients' ability to study its properties. By purporting that Helios had volition, including the capacity to interact with mortals according to his will and whim, no one could study the body he represented as an actual, steady source of energy. Humans, after all, couldn't fully grapple with the nature of a god's power. Consequently, the road to understanding the Sun in a scientific way, including the process by which its light travels through space, began with the Greek rejection of Sun worship.

It would be in the cultural center of Akragas, near the coast of Sicily, where in the fifth century BC, progress would be made in understanding the Sun and its illuminations. By then, although the image of Helios driving the quadriga was still widely known—appearing for example on a gold coin—historians surmise that Sun worship was no longer prevalent. While in Akragas there were prominent temples dedicated to Zeus, Hercules, and other gods, there were none specifically devoted to Helios.

In some parts of the Greek empire, the role of Helios was subsumed by Apollo, a widely worshipped, far more complex deity. A source of harmony, culture, and prophecy, Apollo was far more than just a light-bearer. Curiously, Akragas, unlike other, more central Greek cities such as Delphi, apparently did not have a temple dedicated to Apollo either.[1]

For Empedocles, a learned native of that city, the Sun was a source of philosophical speculation, rather than veneration. He wished to understand the ingredients of reality. The Sun, with its ceaseless fire, seemed an important part of the puzzle.

Dawn in the Valley of the Temples

Dawn comes to Akragas each day in the form of blanched pillars, blistering pavements, and a blinding glow. Far from Mount Olympus, but still part of the ancient Greek dominions, the disk of the Sun makes sure to announce its presence there on its daily rounds. The gleaming temples with their monumental Doric columns reflect an ancient truth. While they purportedly mirror the energy and wisdom of the gods, no one could guess that they actually scatter photons produced tens of thousands of years earlier inside an unimaginably hot nuclear cauldron, before leaping millions of miles across empty space to reach terrestrial structures such as the temples. Reality is often stranger than myth.

The "Valley of the Temples" at the heart of Akragas is, in truth, situated on a plateau, nestled between a ridge and hills; its location chosen for protection against invaders. In most ancient Greek cities, the orientation of each temple aligns specifically with the direction of the rising Sun during times of ritual importance, such as equinoxes—permitting the greatest illumination of its façade during religious ceremonies. In Akragas, however, the situation is more complicated. With a regular grid pattern of streets, oriented to the plateau's topography, the city is an emblem of functionality. Rather than aligning all the temples according to ritual calendars, at least some of them seem to be arranged for practicality—aligned with the city's lattice, rather than with the Sun's arc.[2] Those alignments further suggest a diminished role for the Sun in worship, offering a greater opening to secular analysis of its properties, including the influential speculations of Empedocles.

Born in Akragas around 492 BC, when the city was less than a century old, Empedocles grew up in a family blessed with great wealth. As with other aristocratic Greek youth of his day, numerous servants waited on him hand and foot. He took to wearing flamboyant clothes, including a flowing purple robe, bronze sandals, and a laurel wreath on his head. The extravagant outfit gave him a regal air, with divine pretentions. Not wanting to be seen as a mere mortal, he presented himself as a mystic and healer. Surprisingly, however, rather than scorning the less fortunate, he did the opposite. Politically, he became a strong advocate of equality and democracy (within the context, that is, of his own hierarchical society that discriminated against women). He worked in his community to pass ordinances guaranteeing equality for free citizens. How could someone profess equality while acting like a holy sage? To paraphrase Walt Whitman, his personal contradictions reflected that he "contained multitudes."

The young Empedocles had a ravenous appetite for poetry and philosophy, ingesting the best works of his day, including the philosophical poem "On Nature" by Parmenides, which had a profound influence on his ideas and style, the natural speculations of Anaxagoras, and the musings of the school of Pythagoras. His readings motivated him to scribe his own meditations about the natural world.

Cosmic Ingredients

As in the case of many pre-Socratic Greek philosophers, much of what we know about the views of Empedocles derives from fragments of his writings and secondhand sources that reference his works. One of his works, "On Nature," directly addresses, and in certain ways rebuts, the monist (single substance) worldview of his mentor Parmenides. It also draws a marked contrast with the numerological views of the Pythagoreans, followers of the philosopher Pythagoras. Parmenides had characterized the cosmos as essentially static—composed of one eternal substance that morphs into various guises but remains fundamentally the same over time. Change,

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therefore, is a complete illusion. Empedocles, in contrast, argued for a dynamic universe composed of multiple interacting elements.

The Pythagoreans contended that numbers and geometry were the fundamental building blocks of the universe. The integers from one to ten and the regular shapes, such as circles and spheres, had a particular significance as the key components of a hallowed natural order. They ascribed to "one," the "Monad," the property of unity, and "two," the embodiment of divisiveness. In general, odd numbers, connected in their mind with masculinity, brought harmony (the Pythagoreans were an all-male group and thereby biased), and even numbers, linked with femininity, led to clashes of opposites. However, "ten," the "Decad," despite being even, represented the sum of the first four numbers, and thus represented inclusiveness and totality.

One of the most sacred symbols of the Pythagoreans was the Tetractys, a representation of the first ten numbers as an equilateral triangle of points arranged in four rows, with one point on the first row, two points on the second, three points on the third, and four points on the fourth. It wonderfully connects the first four numbers, symbolizing various components of nature, with the cosmic wholeness denoted by the number ten.

Ratios of those first four numbers came into play when the Pythagoreans promoted the idea of harmonious musical scales. Simple ratios of tones, they argued, sounded best. They based their cosmic models, involving concentric spheres of celestial orbits surrounding a "central fire" (not the Sun, but an unseen power source, called "Guard," Zeus's watchtower), on such pleasing combinations of musical notes: dubbed "harmony of the spheres."

The Pythagoreans spoke of eight celestial orbs: the Sun, the Moon, Mercury, Venus, Mars, Jupiter, Saturn, and the dome of the stars. Earth's orbit around the central fire was the ninth sphere. To complete the sacred Decad they also lumped in a tenth body, called the "counter-Earth," which orbits the central fire on the opposite side and thus remains forever invisible.

Mathematics is indeed the language of nature. However, by postulating that "all is number," composed of simple integers and shapes, the