2017 HAWAII UNIVERSITY INTERNATIONAL CONFERENCES
SCIENCE, TECHNOLOGY & ENGINEERING, ARTS, MATHEMATICS & EDUCATION JUNE 8 - 10, 2017
HAWAII PRINCE HOTEL WAIKIKI, HONOLULU, HAWAII

NATURE EXPLAINED NATURALLY (PRE-SOCRATIC PHILOSOPHY VS. CUTTING-EDGE PHYSICS)

NICOLAIDES, DEMETRIS
DIVISION OF NATURAL SCIENCE & MATHEMATICS
BLOOMFIELD COLLEGE
NEW JERSEY

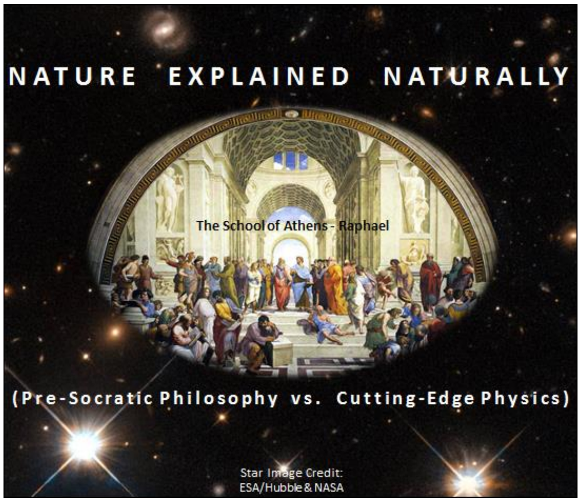
Dr. Demetris Nicolaides
Division of Natural Science and Mathematics
Bloomfield College
New Jersey

Nature Explained Naturally (Pre-Socratic Philosophy vs. Cutting-Edge Physics)

Synopsis:

The scientific theories of the pre-Socratics, natural philosophers from the sixth and fifth centuries BCE, were extraordinary! What were they and how do they measure up with our sophisticated mind-bending modern science after two and a half millennia of scientific progress? The answer will be surprising—scientists today are still pondering the fundamental problems raised twenty-five hundred years ago.

Dr. Demetris Nicolaides
Professor of Physics
Natural Science and Mathematics
Bloomfield College, NJ 07003, USA.



NATURE EXPLAINED NATURALLY

(Pre-Socratic Philosophy vs. Cutting-Edge Physics)

ABSTRACT

Our desire to understand nature is millennial old. It began to develop as our species transitioned from its nomadic hunting-gathering lifestyle to its settled way of life, about ten thousand years ago. Soon, this critical change in lifestyle caused the culturally explosive birth of civilization, also known as the Neolithic Revolution, a phenomenal event that triggered a wealth of new pursuits. With civilization came the remarkable birth of religion and the development of mythological worldviews. Thus nature, initially, was seen as a chaos of random, unpredictable, and incomprehensible phenomena attributed to mysterious supernatural forces through myths, superstition, and the chancy decisions of capricious, anthropomorphic gods. But millennia later a grand ambition evolved to explain nature *naturally*—solely in terms of naturalistic causes *and* in terms of a scientific "Theory of Everything" (TOE), which hopes to establish that everything in nature is explainable by a single overarching principle and its associated equation. Since the pre-Socratics, natural philosophers from the sixth and fifth centuries BCE, contributed considerably to this intellectual evolution from myth to science, this article aims to understand the quest for a TOE as a series of logical progressions (1) by examining the most momentous pre-Socratic scientific theories and (2) by analyzing them within the context of modern physics. It is argued not only that the conceptual breakthroughs of the pre-Socratics anticipated much of later science but that scientists today are still pondering the fundamental problems raised twenty-five hundred years ago.

INTRODUCTION

The article has two main sections: (1) the "A Brief History of the Cosmos" puts things in historical perspective by covering a concise history of the universe from the big bang to "now"; and (2) the "Nature Explained Naturally" discusses the robust scientific program of the pre-Socratics[1] in light of cutting-edge physics (quantum theory, relativity, and in general of our current search for a TOE). We finish with a conclusion.

A BRIEF HISTORY OF THE COSMOS

Our story begins 13.8 billion years ago. Then, it is speculated by the big bang theory,[2] all matter and energy, all of space and time, the absolute wholeness of the universe of today, was contained in just a singular point termed singularity. This primordial point, we must emphasize, was not within the universe; this one point *was* the universe, the *whole* universe; infinitely small, hot, and dense, containing a single type of particle and obeying one grand law—the absoluteness of oneness, with no sense of location or flow of time, with neither here nor there, neither now nor before or after: the whole universe then (and there), was but one place of space and one moment of time, a single spacetime point.

Then, an initial bang, the big bang, is supposed to have happened, causing the expansion of that spacetime singularity into the grand diverse universe we observe today, into a continuum of many spacetime points, creating thus a sense of location and time. A point in the continuum is regarded as an event (something happening somewhere at some instant of time). Two events are separated by their spacetime interval, which involves a spatial distance and a time interval.

What banged (expanded, stretched)? Spacetime did and still does—space has been expanding with time ever since. Specifically, within a minuscule period of time after the initial bang, possibly by a mere 10^{-36} second, the universe underwent an immense faster-than-light expansion, a *big* bang, an idea known as cosmic inflation. In the blink of an eye it expanded by a factor of 10^{30}![3] What caused the bang is still unknown, although it is speculated to have been a kind of repulsive gravity that is predicted by the equations of general relativity, published by Albert Einstein (1879–1955) in 1916.[4] But what is definitely known is that the expansion of the universe has been happening ever since and up until now. In 1929 astronomer Edwin Hubble (1889–1953) confirmed the expansion experimentally when he observed the light emitted by the distant galaxies to be redder (more precisely, to be shifted toward the "red", the longer wavelengths) than expected. The redshift is a measure of the relative velocity between a galaxy and the earth. Specifically, it means that distant galaxies are rapidly receding from us or, equivalently, we are receding from them.

During the first 380,000 years, the young universe was very hot and dense and thus opaque to light—as a foggy day is to visible light—thus light could not travel far. But by the end of this period, the universe expanded more, cooled down and became significantly sparser, and as a result became transparent to light (as a clear-air day is to visible light), allowing for the first time the "afterglow" (the oldest observable light) of the big bang, formally known as the cosmic microwave background, to travel freely through space and time, from there and then to here and now, and to be detected today (by radio telescopes) coming from every direction in the universe—another triumphal proof of the big bang theory; part of the static of an empty TV channel is exactly this afterglow. The 380,000 year-old, relatively cooler universe, also allowed, for the first time, electrons and protons to capture each other via the electric force and form the two simplest and lightest of the chemical atoms, hydrogen (the lightest) and helium (the second lightest). Hence the early universe, before stars and galaxies, contained only these atoms.

Stars and galaxies began to form by about a billion years after the big bang from matter pulled together by gravity. Stars shine because of nuclear fusion, the process via which light nuclei, such as hydrogen, combine to form heavier ones, converting mass into energy (according to $E = mc^2$)[5] and releasing light. So atoms heavier than helium were made exclusively by stars. In particular, nuclei heavier than iron, including silver and gold, are synthesized via fusion when a supergiant star (at least ten times more massive than the sun) becomes a supernova—dies violently in a cosmic explosion, producing as much light as a galaxy of stars!

Its death is also life's birth! For gradually after millions or billions of years, a supernova's scattered debris, an interstellar cloud of gas and dust, collapse again under the crushing force of gravity and grow into a new star with its orbiting planets that may also develop life. A perfect example is our own solar system. It was born much, much later, about 4.5 billion years ago, from the gravitational collapse of a massive interstellar cloud that was composed from the atoms that were synthesized earlier in the universe, including the heavy atoms made in the stars. Thus earth and everything on (and in) it, including us, are all made of these ancient atoms—if you are wearing a gold ring, you are in a sense actually wearing a portion of a star, for your jewelry's atoms were once manufactured in a supernova-destined star! Even more impressive, in the words of the great astronomer Carl Sagan (1934–1996), we are all "star stuff "![6] In other words, most of the atoms we are made of were once made inside stars that lived and died millions or billions of years before we or our own solar system were even born.

Primitive microscopic life on earth was thriving by 3.5 billion years ago but it may have evolved as early as 3.8 billion years ago. Sixty-five million years ago an asteroid collided with the earth and caused the extinction of many species, including the dinosaurs. But that was a good day for primates because that's when they started to evolve. *Homo sapiens,* which are primates and is also the species to which every living human belongs, evolved only two hundred thousand years ago somewhere in Africa.[7]

Our ancestors hunted and gathered to survive. They demonstrated their sensitivity and sensibility by painting fine cave art, some thirty thousand years ago. They domesticated plants and other animals and gave birth to civilization about ten thousand years ago—a consequential event that triggered a wealth of new pursuits including religion. Recorded history, which preceded the construction of the pyramids and Stonehenge by a few centuries, began only about five thousand years ago, and pre-Socratic science was born just 2,600 years ago. Our knowledge in science as well as that knowledge's implementation into useful practical technology have been growing steadily since early twentieth century. However, since the birth of innovative Internet in the 1980s, the inventions of new technologies have been skyrocketing so much that our culture today has been changing faster than ever before—during our species' two-hundred-thousand-year-old existence.

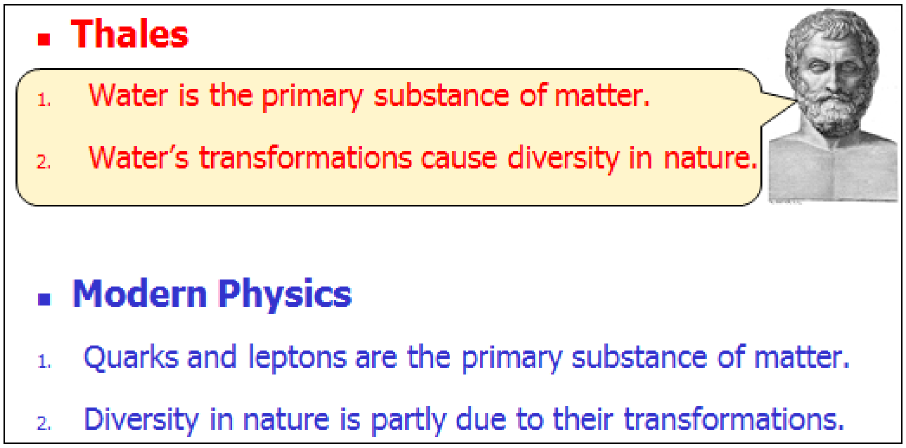
But, within the context of biological evolution, rapid changes can be worrisome, for, the chance a life-form has to adapt to them is generally smaller compared to the chance it has to adapt to gradual changes. If wisdom is, as the wise say, acquired with time, then human wisdom (even assuming we have been collecting it since the birth of civilization) is only infinitesimal, not at all like that of the cosmos, infinitely universal—absolutely complete. "The saddest aspect of life right now is that science gathers knowledge faster than society gathers wisdom"[8] said Isaac Asimov (1920–1992), one of the most prolific writers of all time. Undoubtedly though, the scientific theories of the pre-Socratics, although rather old, were extraordinary and demonstrated wisdom! What were they and how do they measure up with our sophisticated mind-bending modern science after two and a half millennia of scientific progress? The answer will be surprising.

NATURE EXPLAINED NATURALLY

In an attempt to trace the beginnings of science and understand the development of our scientific knowledge about nature as a series of logical progressions, this section introduces the most momentous scientific theories of eleven brilliant pre-Socratics and analyzes them within the context of modern physics. In their quest for the primary substance of matter (for the stuff that all things are made of), and in general, for a TOE, those philosophers had ideas that were so phenomenal, fascinating, unique, strange, and daring that some actually anticipated various aspects of modern science that were well ahead of their time. And some of these ancient ideas, while defying common sense and apparent reality, have not yet been refuted—they remain still unsolved mysteries! Their theories are not as obsolete as is often assumed. They still spark the imagination. Hence our intellectual trip exposes the most beautiful and mind-blowing laws of nature and shows that, despite the two-and-a-half-millennia time difference, ancient and modern science share a fundamental qualitative similarity more often than is usually thought, and they complement each other's scientific uniqueness. We begin with Thales, the first of the pre-Socratics, and finish with Democritus, the last of them.

Thales and Sameness

Thales (ca. 624–ca. 545 BC) was interested in how nature works. He asked what things are made of and what the properties of matter are. These are still the most fundamental and difficult questions of science. His answers were based on solely rational arguments, uncluttered by myths, superstition, or the actions of capricious gods. His approach was therefore the same as that of modern science.



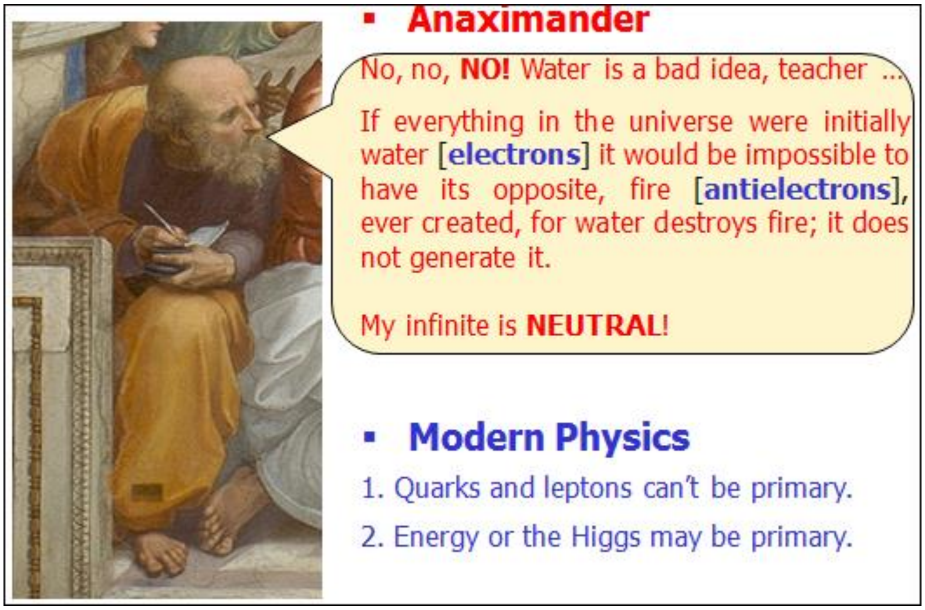
He reasoned that in spite of the apparent diversity and complexity in nature, all things are made from the *same* stuff: water, and all things obey a common set of unchanging basic principles, water's transformations (e.g., its solidification, liquefaction, and evaporation). Thus for Thales nature is characterized by a certain sameness or unity between all things, however diverse they may be, an overall intrinsic simplicity.[9]

While the primary substance of matter is not water, what it is has not yet been discovered. Presently, according to the standard model of physics, the building blocks of matter are microscopic particles called quarks (particles found within protons and neutrons) and leptons (which include the electrons). And the plethora of things is partly due to their transformations (from one type of particle into another), not the transformations of water.

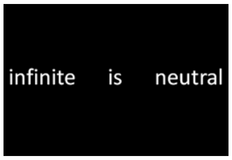
Despite these new discoveries, still, Thales's notions about sameness—that all things are made from one and the same substance—and about the transformations of matter, are of timeless scientific appeal. For, our modern search for a TOE aims at exactly such sameness: it hopes to establish that everything in nature is explainable by one and the same overarching principle.

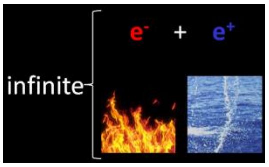
Anaximander and Infinite

Anaximander[10] (ca. 610–ca. 540 BC), Thales's student, thought water is a bad idea because it is not neutral—it has an opposite, fire. Specifically, he reasoned that the primary substance of the universe could not have been any one of the ordinary things, such as water or fire. For they have opposition with one another, and opposites destroy, they do not generate one another. If everything in the universe were initially water, it would be impossible to have its opposite, fire, ever created, for water destroys fire; it does not generate it. The modern physicist's version of Anaximander's reasoning would be that the presently accepted primary particles of matter, the quarks and leptons, cannot really be primary, for they have opposites, the antiparticles of antimatter, the antiquarks and antileptons, and as opposites, a particle and its antiparticle annihilate, not generate, each other.

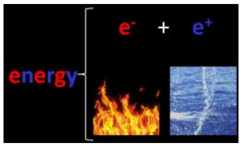


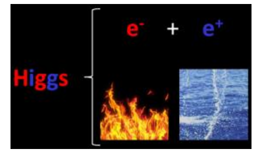
Anaximander taught that the fundamental substance of matter is the *infinite*: a limitless supply of undifferentiated, timeless, *neutral* substance encompassing the entire world and manifesting itself as competing antitheses (e.g., water vs. fire, hot vs. cold). While itself intangible, the infinite transforms into all concrete things of everyday. Being neutral means that the infinite has no competing opposite—it is neutral to itself and to the opposites that it creates, thus it cannot be destroyed. But the opposites it transmutes into are in struggle with one another—water vs. fire, hot vs. cold, wet vs. dry, light vs. darkness, sweet vs. sour. The unjust dominance of one opposite over the other is ephemeral, for eventually it is rectified at annihilation; then neutralized, both opposites transform again into the neutral infinite. And since the effects of one opposite cancel those of the other, their continuous creations and annihilations neither add anything to the infinite nor do they subtract. Thus even through its transformations, the infinite remains eternally conserved.

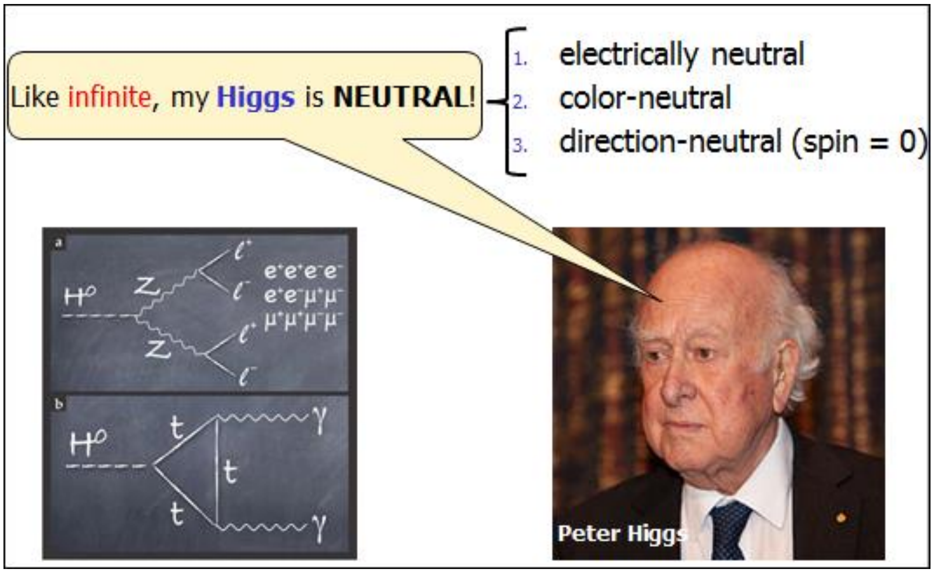




In modern physics, it is energy which is conserved through its transformations into competing opposites, that of matter and antimatter. But what kind of material particle of modern physics has infinite-like properties, including the key property of neutrality? The much-sought Higgs particle does![11] It has been mathematically predicted to exist by various physicists in the 1960s, including Peter Higgs (1929–), from whom it took its official name. It has been discovered in 2012 at the Large Hadron Collider, the most powerful atom smasher in the world. The Higgs is the only particle of the standard model of physics that's neutral in all three following ways: (1) it is electrically neutral, thus it is its own antiparticle—it is both matter and antimatter, and in this respect it has no warring opposite to be destroyed by (note, even when the Higgs particles decay, the Higgs field still endures and is all-pervasive). (2) It is also color-neutral—"color" (or more precisely, color charge) here is a property of the quarks and of the nuclear strong force (like the electric charge that is a property of the electromagnetic force) and not the color of everyday sense. (3) Moreover, its spin is zero, thus it is direction-neutral—its direction of motion through space is not restricted by how it spins; to the contrary, a neutrino, say, is observed to always be left-handed: it advances (moves forward) by spinning counterclockwise.



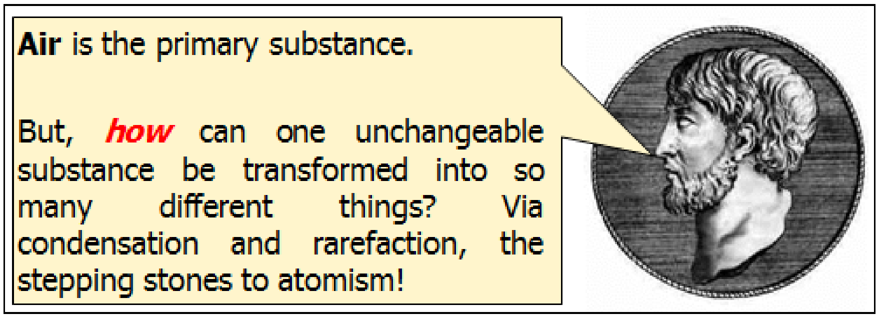




Anaximander modeled change and diversity in terms of the continuous transformations of the intangible, neutral, and conserved infinite into the concrete, competing, and transient opposites of everyday experience—and back and forth and with measure. Nonetheless, it was Anaximenes who formulated the first graspable theory of change—of how matter can transform between its various phases, the gas, liquid, and solid. His theory was the stepping stones to atomism.

Anaximenes and Density

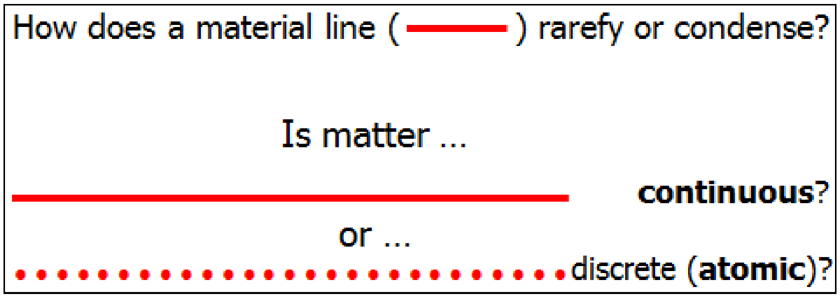
In his search for the primary substance of matter, Anaximenes (who flourished ca. 545 BC) returned to the tangible world and chose air. His main question, however, was: how could a single material, air, be transformed into all other forms of matter and account for the overabundance of dissimilar things, while itself remaining unchanged? What mechanism or processes could be applied to air, keep its substance unchanged, yet convert air into all the different things—solids, liquids, and gases? Change, he proposed, occurs via two opposite processes: condensation and rarefaction of matter.[12] Successive condensations of gases transform them to increasingly denser matter, the liquids and solids, but successive rarefactions of solids transform them to increasingly rarefied matter and once more back to the liquids and gases, an essentially accurate idea. These processes cause changes in the density of matter but do not alter the very nature of matter (its very substance). Thus, for him it was no longer necessary to ascribe all sorts of different properties for each object—such as rigidity, softness, hotness, coldness, wetness, dryness, fluidity, weight, and color—just how dense it is.



This idea in itself has a certain truth—various properties of an object depend on its density. But from a grander point of view, as regards the evolution of science, the challenge to understand how condensation and rarefaction themselves are carried out had surely been catalytic for the discovery of one of the most successful theories in science: the atomic theory.[13] Because it forced Anaximenes' successors to think profoundly about the nature of matter. Consequently they discovered two antithetical views, the continuous and the atomic (the discontinuous).

But, can matter, modeled as continuously distributed in space, really move through other matter in order to condense or rarefy? Can new matter move into and occupy the space which is already occupied by other matter? When matter moves, where does it move into and what does it leave behind? How do condensation and rarefaction really work if matter is continuous? They do not! They work only if matter is atomic, discontinuous: made of disconnected, indivisible, and incompressible pieces—the atoms of Leucippus and Democritus, coming up in the last subsection, *Democritus and Atoms*, of this section—moving in the void, which was required to exist so that matter (1) can be atomic (disconnected) and (2) can move. Rarefaction occurs when the atoms in an object recede in the empty space around them and condensation occurs when they come closer to each other.

To understand a bit more the challenge to explain condensation and rarefaction with the continuous nature of matter versus that of the atomic nature, we use Erwin Schrödinger's (1887–1961) reasoning.[14] We cannot tell how many points a purely mathematical line has. Analogously, if we have a material line (or in general an object), we cannot tell how many material points it has and how these points behave during rarefaction and condensation. How can a material line condense or rarefy? "If it is a *material* line and you begin to stretch it—would not its points recede from each other and leave gaps [implying that matter must be discontinuous, i.e., atomic!] between them? For [now assuming matter is continuous] the stretching cannot *produce* new points and the same points cannot go to cover a greater interval."[15] Incidentally, Schrödinger argues that what must have guided Democritus in conceiving his atomic theory of matter was such type of thinking, a consequence of Democritus's deep insight of mathematics.[16]

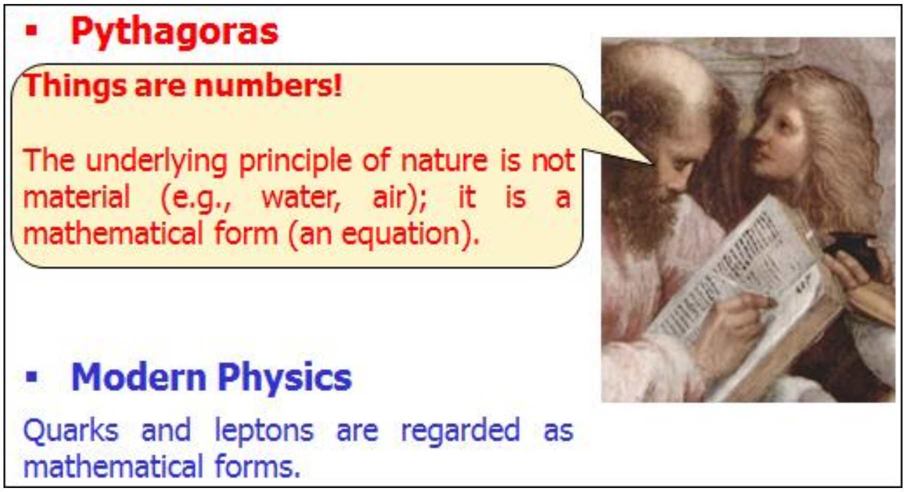


Modeling matter as discontinuous (atomic) constituted the very first quantum theory, the precursor of the modern. In modern quantum theory—that describes successfully the behavior of the microscopic world of subatomic particles—both matter and energy are quantized: matter is composed of disconnected elementary particles, the quarks and leptons, and energy comes in discrete (quantum) bundles (e.g., photons are the quanta of the energy of light).

All challenges of rarefaction and condensation could be accounted for only through atomism (to be introduced fully in the last subsection, *Democritus and Atoms*, because the development of such great idea required first the development of all other great ideas conceived by Democritus' predecessors), but also in the light of mathematics—Democritus, the principal contributor of the atomic theory, was a brilliant mathematician. The significance of mathematics, not just as an abstract field of knowledge but also as a practical method to describe nature, had been realized early on, especially by the great Pythagoras as a consequence of his passion for numbers.

Pythagoras and Numbers

Pythagoras[17] (ca. 570–ca. 495 BC), a pioneer in applying mathematics for the investigation of physical phenomena, consequently initiated the mathematical analysis of nature, a cornerstone practice in modern theoretical physics. “Things are numbers” is the most significant Pythagorean doctrine.[18] While its exact meaning is ambiguous, it probably signifies that the phenomena of nature are describable by equations and numbers. Based on this, the underlying principle of nature is not material (e.g., water, air) but a mathematical form (an equation).



His first application was the mathematical description of mellifluous sounds of music. He discovered that in stringed instruments the blended sound produced by two plucked strings of same tension is more pleasing when their lengths are in ratios of small integers—i.e., 2:1, 3:2, 4:3, and 5:4—thus numbers forming a discrete, a *quantum* set, the 1, 2, 3, 4 and 5.

Being intellectually bold, Pythagoras and his students connected mathematically two seemingly unrelated phenomena: their earthly harmonies with the heavenly motions! How so? First they supposed that, similar to the way an object on earth moving through air can produce a sound (slow movement making a low pitch, fast movement a high one), the stars (including the sun), moon, and planets (including earth), moving through ether (the purer air believed then to fill the universe) can produce their heavenly sounds. But these sounds must blend into a song harmoniously, Pythagoras conjectured, because nature was a “*cosmos*,”[19] a term credited to him, a beautiful and well-ordered universe for which a cacophonous music of heavens was unaesthetic. Hence he and his students reasoned that the ratios of the length of strings that produce the harmonious sounds in string instruments *must be the same* as the various ratios formed by the speeds of the revolving heavenly bodies. This requirement restricts basically the speeds and orbits of the heavenly objects to certain discrete, quantum numbers, an idea that resonates with the essence of modern quantum theory!

Such unusual interconnection was celebrated first in 1619 with the Harmonic Law of Johannes Kepler (1571–1630) when the astronomer discovered that, as planets revolve around the sun in their elliptical orbits, the ratios formed by each planet's fastest speed at perihelion over its slowest at aphelion, are very close to the Pythagorean ratios of pleasing harmonies in stringed instruments. In his book *The Harmonies of the World*, Kepler wrote, "The heavenly motions are nothing but a continuous song for several voices, to be perceived by the intellect, not by the ear."[20]

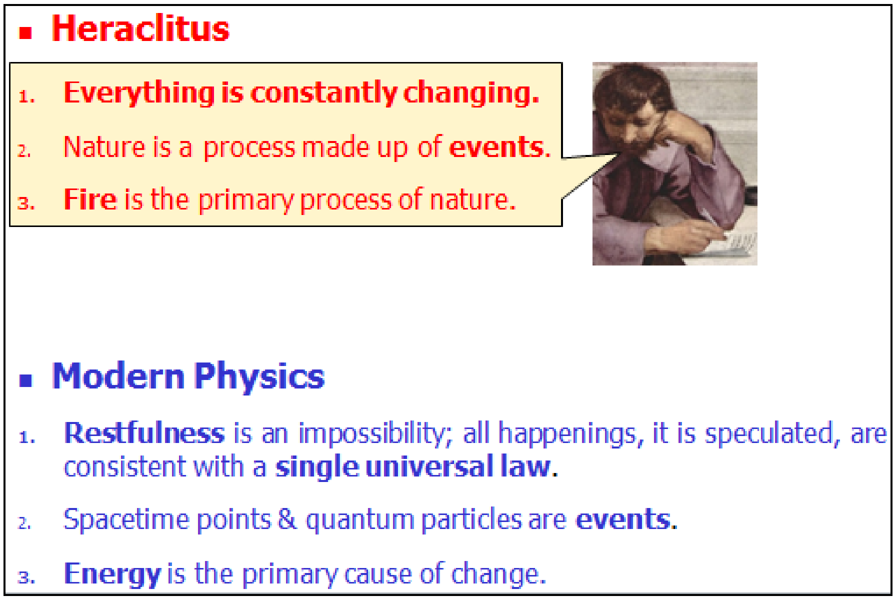
Moreover, in the beginning of the twentieth century, the seminal era of quantum theory, physicists Niels Bohr (1885–1962) and Arnold Sommerfeld (1868–1951) conceptualized the atom as a miniature solar system, with the electrons orbiting the nucleus of an atom like the planets are orbiting the sun. In their theory the orbits of the electrons are restricted to certain discrete speeds and sizes (as were the heavenly bodies in the Pythagorean theory) that are expressible in terms of specific integers called quantum numbers that "display a greater harmonic consonance than even the stars in the Pythagorean music of the spheres [heavenly bodies]."[21] Remarkably, unlike the Pythagorean theory of planetary motion, which was quantized, the Newtonian theory was not: planets, according to Isaac Newton's (1642–1727) theory of gravity, do not have a restriction in their speeds or orbital sizes. But they should, according to quantum theory, although their quantum behavior is negligibly small because of their large mass.

The most advanced theory of matter is quantum theory. According to it the microscopic particles of matter (the quarks and leptons) are regarded as mathematical forms. These forms are really the solutions of the equations of quantum theory and are useful for calculating numerically the average values of various particle properties (e.g., position, velocity, and energy). Now, since every macroscopic object in nature is composed of these microscopic particles, (which are regarded as mathematical forms that generate numbers), then indeed all "things are numbers."

Also, many apparently unrelated things (phenomena) have already been unified; they are found to obey the same fundamental mathematical equation and thus the same natural law—e.g., James Clark Maxwell (1831–1879) unified successfully the electric and magnetic forces by proving mathematically that they are really two manifestations of the same force, the electromagnetic. These findings point clearly to the subtle cosmic interconnection (of mathematical nature) anticipated by Pythagoras—physicists today wish to explain nature in terms of a TOE, of a single idea and its accompanying master equation. But in addition to the aid of mathematics, to find the logos (cause) of such inconspicuous connections one needs to be unconventional, able to unite diverse fields of knowledge, and be keen of the elusive. For only then one may unveil the common characteristics that different phenomena have in all of nature's changes, the perceptible but also the discreet.

Heraclitus and Change

Everything is constantly changing, and nothing is ever the same, Heraclitus[22] (ca. 540–ca. 480 BCE) proposed, and in accordance with Logos, the intelligible eternal law of nature. Thus everything is in a state of becoming (in the process of forming into something) instead of being (reaching or already being in an established state beyond which no more change will take place). This means that things, *permanent* things, no longer exist—for they contradict his theory of constant change—only events and processes exist. His doctrine has found strong confirmation in modern physics, for, according to it, absolute restfulness and inactivity are impossibilities; and all happenings, it is speculated, are consistent with a single universal law.



To avoid violating the Heisenberg uncertainty principle of quantum theory—which discusses how nature limits our ability to make exact measurements regardless of our smartness or the sophistication of our experimental apparatus—motion in nature must be perpetual. If a particle could sit still, it would mean that our knowledge of its velocity is absolute (because we would know that its velocity is exactly zero) and the principle would not hold. Now since motion is perpetual, so is change. Furthermore, change is not merely constant; it is also unidirectional, meaning nothing is ever the same. This is a result of the second law of thermodynamics according to which, net entropy—the degree of disorder (randomness) in the universe—is always increasing—the arrow (direction) of time, which is closely related to the entropy of the universe, is flowing toward increasing disorder. Thus, nature is in a state of becoming, but it is a disorderly becoming.

A profound consequence of the Heraclitean theory of universal constant change is the view of nature as a process made up of events. For the notion of "a thing" is inconsistent with a theory of constant change. To be able to be spoken of and defined, the thing must remain absolutely the same for at least a period of time; it must have some permanence and must be identifiable. But the notions of sameness and changelessness are contradictory to a theory of *constant* change.

Consequently, it is more appropriate to consider a thing as an event (something happening somewhere at some instant of time) and not as something permanent. Thus, what changes is not something material or initially permanent; what changes are the events. Groupings of events constitute processes, which in turn make nature the ultimate process.

This notion is supported by both the macroscopically successful general relativity and the microscopically successful quantum theory. In the former, points in the spacetime continuum are considered as events, and in the latter, microscopic particles are better understood to be events rather than permanent things. Nature is a process and therefore is in a state of becoming; nothing ever *is*.

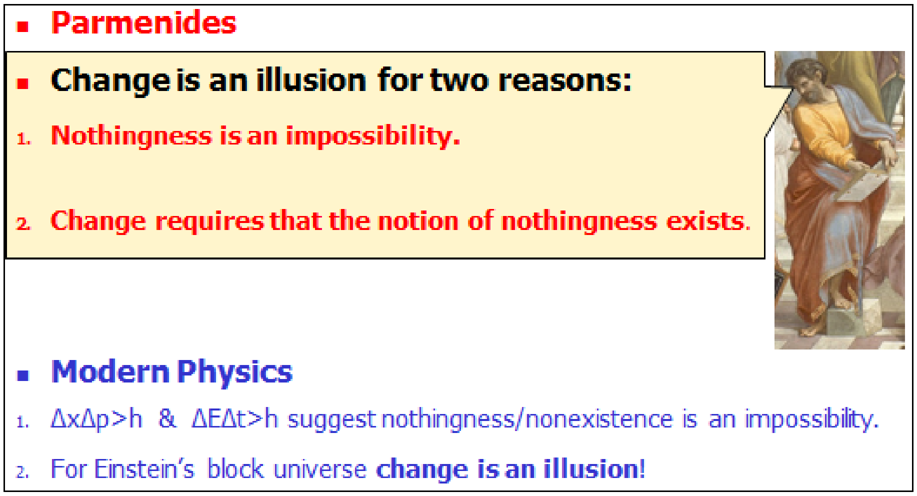
A permanent primary substance of matter is contradictory to a theory of constant change. The only element of permanence in such theory is change itself. What really causes change then? Putting it differently, what is the primary process of nature? For Heraclitus it was the "everlasting fire,"[23] and for modern physics the eternal energy. Fire and energy represent particular processes. They cause cooling and condensing or heating and rarefying or, generally, forming and dissolving.

Heraclitus declares the being (that which exists, nature) but identifies it with becoming. All follows from that: everything is constantly changing, material sameness is impossible, there is a plethora of different events that make nature a process, and described by warring opposites that nonetheless obey Logos. But Parmenides declares just the *Being*; only what is, is, what is not, is not. All follows from that: change, he argues, is logically impossible and so what is, is one and unchangeable! This dazzling and absolute monism is in daring disagreement with sense perception.

The Heraclitean and Parmenidean worldviews are therefore antinomies (contradictions), for starting from a being the two philosophers developed a unique series of logical arguments and arrived at opposite results: for the Heraclitean, being is becoming, but for the Parmenidean, Being just is. It is Heraclitean change and plurality versus Parmenidean constancy and oneness. But it is a controversial oneness, for Being's exact nature is uncertain.

Parmenides and Oneness

Philosophy was seriously shocked by the logic of Parmenides[24] (ca. 515–ca. 445 BCE). He reasoned that change and plurality are illusions for two reasons:



(1) Nothingness is an impossibility. First he argued that we can think only about that which exists, the *Being*, "for the same is the thinking and the Being."[25] On the contrary he thought, we can neither speak about nor think about something that does not exist, *Not-Being*. For if we could it would mean that Not-Being had properties (those mentioned speaking or thinking about it). But true nothingness is property-less. Therefore the notion of nothingness (Not-Being) is impossible! This is in fact the critical premise of Parmenides's theory. And to understand his arguments we must always remember that for him what does not exist, does not exist, neither now nor before or after, neither here nor there; that is, we cannot assume what does not exist now (or here), could exist later (or there), or could have existed before somewhere. No! Only what is, is—only Being exists. What is not, is not—Not-Being does not exist.

(2) Change requires that the notion of nothingness exists. But since such a notion is an impossibility, so then is change; Being is unchangeable—for if it could change, it would change into something that Being is not already, into something new that does not yet exist, thus into Not-Being, but this is an impossibility, for Not-Being does not exist ever anywhere. Analogously, if it could change, it would cease to be what it once was, thus what once existed (Being) would no longer exist; it would become Not-Being, but this is again an impossibility for Not-Being does not exist. In other words, that which exists (Being) cannot change because change requires that the notion of nothingness (Not-Being) exist. Because only then could Being have been it (Not-Being) and could have again become it. Equivalently, we can say that change is impossible because it requires that something is either created from nothing or destroyed into nothing, but since the notion of nothingness does not exist, change does not exist either. Below we use modern physics to reexamine the above two conclusions of Parmenides: (1) that **nothingness is an impossibility** and (2) that **change is an illusion**.

(1) Is nothingness an impossibility for modern physics?

Indeed, nonexistence (nothingness) is an impossibility even in modern physics, and the uncertainty principles of quantum theory (see next paragraph) may be considered as statements in support of that. Why use these principles? Because these principles are relationships between space, time, matter, and energy, concepts that constitute the essence of nature (of something-ness). And if we hope to prove that the notion of nothingness is an impossibility—that nothingness is not derivable from something-ness—well, we had better begin from an analysis of principles that describe the essence of something-ness.

So to argue for this (that nonexistence/nothingness is an impossibility) we first recall the position-velocity uncertainty principle, $\Delta x \, \Delta v > h/m$. It states that the product of the uncertainties in the position and in the velocity of a particle must be greater than Planck's constant divided by the particle mass—that is, such product is greater than zero. Analogously there exists the time-energy uncertainty principle, $\Delta E \, \Delta t > h$. It states that the product of the fluctuations in the energy of a particle and the time interval that the particle endures must be greater than Planck's constant—again such product is greater than zero. Now, since these uncertainty principles are inequalities, which must be greater than zero, then to hold, spatial distances, time intervals, velocities, and energies are forbidden from ever being absolutely zero—that is, their nonexistence is forbidden—because otherwise the left side of these inequalities would be zero, not greater than zero. For example, the smaller the confining space of a particle is (or the briefer the time interval the particle endures in such confinement), the more frantic its motion and energy are. But neither the confining space nor the time interval can ever be exactly zero, for if they were, the uncertainty in position and the uncertainty in time would have been zero, too, and consequently both uncertainty principles would have been in violation—the product of the uncertainties in position and velocity, and in time and energy, would have been zero, too (instead of greater than zero). Similarly, both uncertainty principles would have been in violation if a particle had zero velocity or energy. The principles hold only if spatial distances, time intervals, velocities, and energies are nonzero; they must exist; they cannot be nothing! (In a sense such result is expected because our physics relationships, equations or inequalities, are in the first place conceived to describe *something*, not nothing; the notion of nothingness is indescribable.) Hence, as per Parmenides's reasoning and as per the uncertainty principles, nothingness is not only not allowed to exist—for *nothing* comes from it (e.g., the uncertainty relationships are violated and thus cannot be used to account for what exists)—but, equally profoundly, existence is *required*, that is, spatial distances, time intervals, velocities, and energies must be nonzero (for only then do the uncertainty relationships, which describe something-ness, hold).

Quantum theory (the essence of which is the uncertainty principles) is then in accordance with Parmenidean philosophy, "for the same is the thinking and the Being": for we can think only about that which exists, in other words, the uncertainty principles describe only somethingness and forbid nothingness. With this in mind Parmenides's main question, How can something exist? may now be answered: within the context of either modern physics or the Parmenidean theory, something (Being) must exist because nonexistence (Not-Being) is impossible. There is no mechanism in modern physics that violates the basic Parmenidean idea that something can neither be created from nothing nor pass away into nothing. All interactions require something, energy (or matter, since they are equivalent), but also space and time.

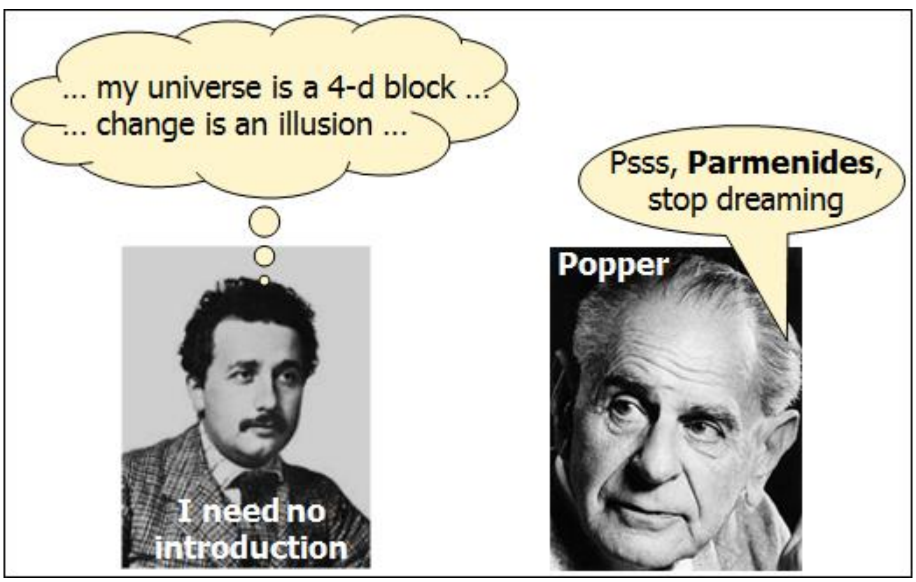
(2) Is change an illusion for modern physics?

So the uncertainty principles of modern science suggest nothingness/nonexistence is an impossibility. What does modern science say about change: does it occur or is change too an impossibility? Does the universe change or not?

In his deterministic conviction of nature, and having his special and general theories of relativity in mind, Einstein considers the universe as a four-dimensional "block" (spacetime continuum) that, interestingly, contains at once *all* past, present, and future moments of time, and in which change is an illusion. "For we convinced physicists, the distinction between past, present, and future is only an illusion, however persistent" Einstein said once.[26] Not only all locations are ever present in the continuum but so are all moments of time, Einstein thinks. The notion that only the present exists, that the past has ended and no longer exists—that, in Parmenidean logic, what once existed as the present, as Being, no longer exists because it became the past, it became Not-Being (for, the past no longer exists)—and that the future is yet to come thus it does not yet exist—that, in Parmenidean logic, what does not yet exist, the future, Not-Being, will become the present, will become Being; or, alternatively, what exists as the present, as Being, will cease to be (the present will become Not-Being) because it will be replaced by the future, by Not-Being (for, the future does not yet exist)—is false, for Einstein! (Parenthetically, as seen by the simultaneous Einstein-Parmenidean analysis of the previous sentence, it is also false in the Parmenidean view; for recall, change for Parmenides is impossible as it requires that something is either created from nothing or destroyed into nothing, but since the notion of nothingness does not exist, change does not exist either.) To the contrary, in Einstein's view (and also within the context of the Parmenidean theory), all moments of time (of past, present, and future) exist, are real, and are continuously part of the spacetime continuum—they neither come to be (as if Not-Being became Being) nor cease to be (as if Being became Not-Being)!

Let's understand this further by first thinking conventionally (by momentarily ignoring Einstein's relativity). So, conventionally, only the present exist; the past is gone and the future is yet to come, so neither the past nor the future really exist. But within the context of relativity that's not the case: all of time—past, present, and future—exists in the block universe, even if we insist on the strict definition that, what truly exists must be part only of the present (e.g., must be happening now). And this (that, all of time exists in the block universe) is so because of the relativity of simultaneity (a phenomenon predicted by Einstein's relativity): events that are simultaneous for me are not so for someone else in relative motion with respect to me. So there is no such a thing as absolute time—absolute past, present, or future. An event of my past, is not gone—it actually exists as a spacetime point in the block universe—for it could be part of another observer's present in relative motion with respect to me. And for yet another observer in different relative motion with respect to me, an event of my future could be part of her present, thus such event too exists as a spacetime point in the block universe. In a more concrete example, I am still a baby relatively to an observer moving away from me—that is, my past is part of that observer's present; and my present is part of that observer's future. Yet, relatively to another observer, moving toward me, I am the older person I will grow up to be—that is, my future is part of that observer's present; and my present is part of that observer's past. Thus, not only all of space is out there (in existence) but so is all of time—all time moments are part of the continuum, part of, to say the least, someone's present, so they do exist. General relativity is then in accordance to one of the Parmenidean inferences, that change, at least in some sense, is an illusion: in the block universe, the present doesn't change into past, and the future doesn't change into present; to the contrary, in the block universe, the past is not gone, it is present; and the future, like the present, is, well, present too. Since the block universe contains all of space and all of time, then spacetime too, in some sense, is conserved, not just energy.

Furthermore, in addition to its property of unchanging, the Parmenidean Being is also often interpreted to imply that nature is one, uninterrupted, indestructible, indivisible, eternal, and material whole; a kind of full and solid block of matter without parts (uniform). For this interpretation of Being and for Einstein's view that the universe is a four-dimensional unchanging block, philosopher Karl Popper (1902–1994) nicknamed Einstein, "Parmenides": "I [Popper] tried to persuade him [Einstein] to give up his determinism, which amounted to the view that the world was a four-dimensional

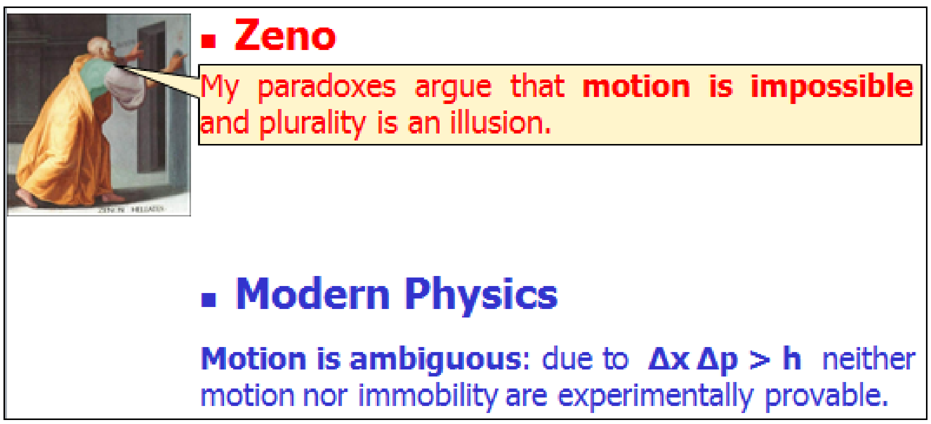


Parmenidean block universe in which change was a human illusion, or very nearly so. (He agreed that this has been his view, and while discussing it I called him ‘Parmenides’.)”[27]

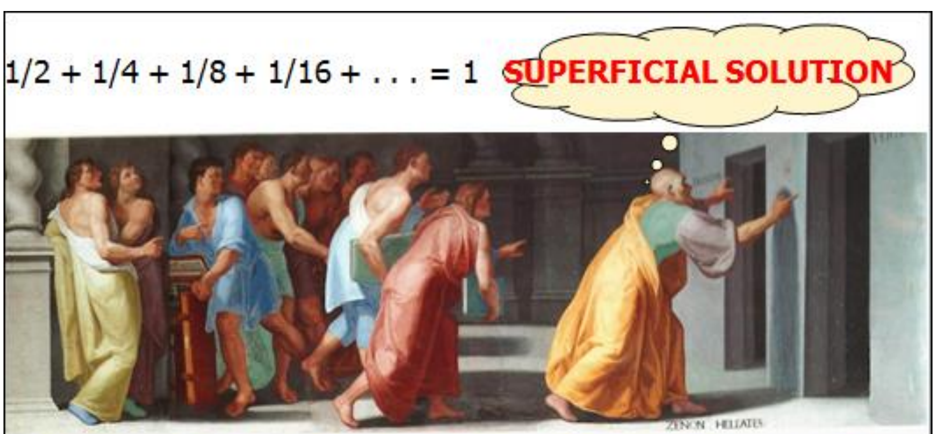
After Parmenides, any new natural philosophy would be considered incomplete unless it could address successfully his various conclusions, which, though unconventional, were logical. And as if that by itself was not a formidable task, Parmenides’ best student, Zeno, assertively supports his teacher’s views by adding to the complexity with his famous paradoxes that question the very nature of plurality, space, and time, and the reality of apparent motion.

Zeno and Motion

Through a series of so-called paradoxes, Zeno (ca. 490–ca. 430 BC) tried to argue the astonishing conclusion that motion is impossible and plurality is an illusion. Could he be right? Proposed solutions to some of his paradoxes have often aimed to prove that motion is real. I will argue in favor of Zeno, that at best whether motion occurs or not, is not experimentally provable.



The dichotomy paradox is his most famous. According to Aristotle’s account, Zeno said “Nothing moves because what is traveling must first reach the half-way point before it reaches the end.”[28]



Doors to Truth and Falsity (*Veritas et Falsitas*). Fresco in the Library of El Escorial, Madrid.

One interpretation of the paradox is this: assuming a traveler can somehow start a trip, can he ever finish it? To finish a trip of a certain distance a traveler must first travel half of it, then half of the remaining distance, then half of the new remaining distance, ad infinitum. Since there will always exist a smaller last half to be traveled last, Zeno questions whether a traveler can ever finish a trip. So the paradox is this: while on the one hand Zeno's argument, which questions the very ability to finish a trip, is logical; on the other hand, all around us we see things moving, finishing their trip. Hence either Zeno's reasoning is wrong or what we see is false.

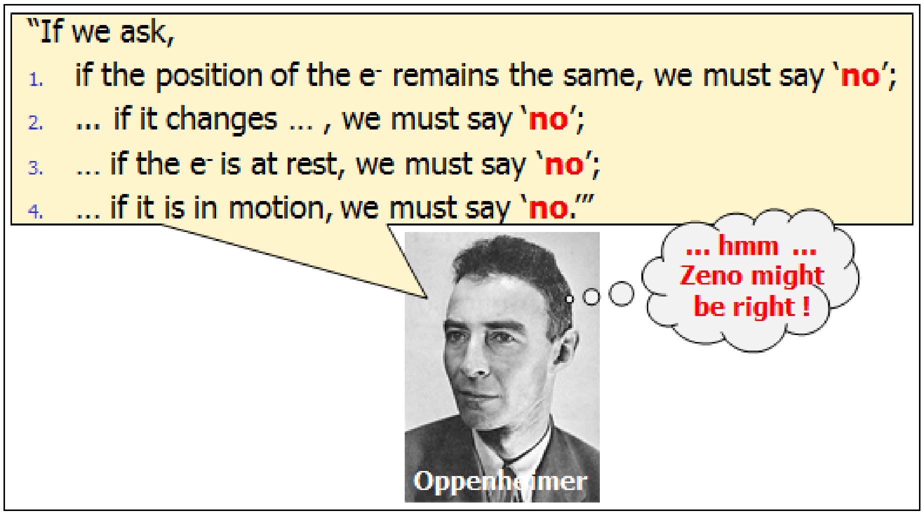
Often an answer of the paradox is sought through calculus. Suppose the trip distance is 1 meter. Then a traveler first travels half of the trip distance, that is 1/2 of a meter, then half of the remaining distance, that is, an additional 1/4 of a meter, then half of the new remaining distance, that is, an additional 1/8 of a meter, ad infinitum. To find out if the traveler covers the trip distance of the 1 meter, we must add all the segments traveled by him, that is, 1/2 + 1/4 + 1/8 + 1/16 +. . . . Because the sum of this infinite geometric series converges on 1, some argue that the distance traveled by the traveler after infinite steps is 1 meter, thus he has moved and the paradox is resolved. But this argument has a flaw hidden in the details of calculus. To be able to do calculus (i.e., calculate series sums like the one in hand) irrational numbers, which have no precise numerical value, must be approximated with rational. And there exist infinitely many irrational numbers along any space distance. For example, between the point zero (the beginning of the trip distance) and the point of 1 meter (the end of the trip distance), there are infinitely many irrational numbers—such as $\sqrt{2} - 1 = 0.414213562 \ldots$, or half of it, or one third of it, and so on—that must be approximated with rational numbers before any sum is calculated. For example, approximated to four decimal places, the rounded-off value of $\sqrt{2} - 1 = 0.4142$. Zeno, however, seems to tacitly question these very approximations that are required in mathematics to make the series convergent to a practical and calculable answer. Because nature, he would claim, does not have to behave according to the result of such convenient and ambitious human approximations. Now, since the actual value of the series in hand is, in the strictest sense, indeterminable—for, the true numerical value of every irrational number in the series is itself indeterminable, and the convergence of the series to number 1 is correct only through approximations—a better conclusion would be that, indeterminable must also be the status of the trip (whether the trip can ever begin or finish). Thus the notion of motion is, to say the least, ambiguous!

What does modern physics say about motion? Does it agree with Zeno that nothing moves? While motion is part of apparent reality and is also the very premise of important theories of physics, on a fundamental level (i.e., concerning the motion of microscopic particles, to say the least) motion has not yet been experimentally proven, and in fact never can be! Therefore, motion is essentially a postulate inferred from sense-perceived experiences, but its truth is actually ambiguous. This is so because inherent in the Heisenberg uncertainty principle observations, *any* observations of both the microscopic and macroscopic world, are always disconnected, discrete events! Consecutive observations have time and space gaps—we can observe only discontinuously; roughly speaking, it is as if we are observing nature by continuously blinking and turning our head. The concept of continuity in observation must be dismissed. It is a false habit of the mind created by the observations of daily phenomena—as of an arrow in flight (although the arrow's apparent continuity of motion is an illusion due to its large mass that makes the time and space gaps between consecutive observations undetectably small). Hence we can watch the arrow move (seemingly continuously) and even predict its path of motion. But if instead we had a small-mass object, such as a microscopic particle—an electron—nor could we observe it in a path of motion or predict its path, says the uncertainty principle, its effects of which are much more noticeable and consequential for microscopic particles. Before the uncertainty principle was discovered, absolute accuracy in a measurement (observation), at least in theory, was considered axiomatic, but not anymore. Now without the ability to observe continuously, motion not only *is observed* to be discontinuous but the very notion of motion *itself* becomes ambiguous. How so?

Motion occurs when during a time interval a particle (e.g., an electron) changes positions; a particle should be now here and later there in order to say that it moved. But since nature does not allow us to keep a particle under continuous observation and follow it in a path, and also since a particle is identical to all other particles of the same family (for example, all electrons are identical), it is impossible to determine whether, say, an electron observed in one position has moved there from another, or whether it is really one and the same electron with that observed in the previous position, regardless of their proximity. Since observations are disconnected and discrete events—with time (and space) gaps in between, during (and within) which we don't know what a particle might be doing—subsequent observations of identical particles might in fact be observations of two different particles belonging in the same family and not observations of one and the same particle that might have moved from one position (that of the first observation) to the next (that of a subsequent observation). Without the ability to determine experimentally whether a particle has changed position, its motion—and motion in general—is a questionable concept.

In summary, (1) without the ability to keep a particle under continuous observation (2) it is impossible to establish experimentally its identity, and therefore (3) it is also impossible to prove experimentally that it has moved. Reinforcing this conclusion is the fact that, when we observe a microscopic particle all we see through a microscope is just a flash of light, and somewhere within it is the particle. But where exactly within it the particle is each moment of time, and whether it is at rest or in motion, are all indeterminable; while we do detect a particle, we detect it neither at rest nor in motion. Hence indeed, neither immobility nor motion are experimentally provable. Motion is ambiguous.

Trying to capture the peculiar consequences of the Heisenberg uncertainty principle concerning motion, physicist J. Robert Oppenheimer (1904–1967) wrote: "If we ask, for instance, whether the position of the electron remains the same, we must say 'no'; if we ask whether the electron's position changes with time, we must say 'no'; if we ask whether the electron is at rest, we must say 'no'; if we ask whether it is in motion, we must say 'no.'"[29]



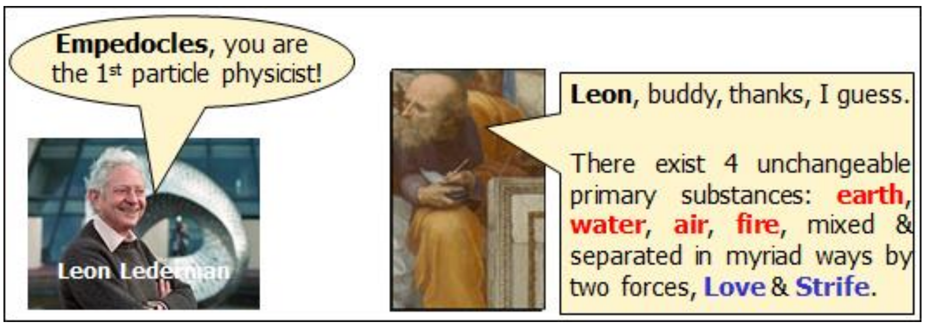
Still, to make sense of the phenomena, we often assume certain causal chains of events. For example, an electron here collides with a photon and recoils there (as if the electron is identifiable, endures and moves). Thus while, according to quantum theory, neither a cause nor an effect are certain, and motions are untraceable, still the assumption of a certain chain of events and of motion is often an adequate way to model a practical explanation. Supposing that particles endure (appear as *permanent things* at least for some time and within some region of space), we have previously (in subsection, *Heraclitus and Change*) argued that they are constantly moving. Of course, to be a bit more precise, we should treat particles as events, and realize that when subsequent events describe observations of identical particles, such events can create the illusion of both, continuity in observation (of one and the same particle) *and* continuity of motion, provided of course that the space and time gaps between these observations (events) are small enough to *not* be sensed by our senses.

But while motion may be an *adequate* and useful concept in devising a certain practical explanation of nature—especially so for macroscopic objects such as arrows, cars, and planes—as a *true* property of nature it is, to say the least, an ambiguous concept, for it lacks the support of experimental confirmation from the microscopic constituents of matter that make up all macroscopic objects. Therefore, the merit of modeling an object (an electron or an arrow) as moving is a practical necessity of everyday life, not a confirmable truth. Zeno's dichotomy paradox is still an open question!

Zeno's paradoxes challenge our views on the very nature of space, time, and matter. Are these notions somehow connected? Is there just one primary substance of matter, or are there many? Is the nature of matter continuous—spread everywhere and also infinitely divisible for which matter can be cut to ever smaller pieces? Or is the nature of matter atomic—and so finitely divisible, for which matter cannot be cut beyond some fundamental pieces that are spread unconnectedly because they are surrounded by void? In 1916 Einstein addressed successfully the first question with his theory of general relativity, in which spacetime is a continuum in constant and intricate interaction with matter. Empedocles, Anaxagoras, and Democritus (the remaining pre-Socratics that this article considers) took up the other three. Matter is atomic for Democritus but continuous for Empedocles and Anaxagoras. And while plurality in the number of primary materials is possibly speculated first by Empedocles, all three philosophers had a unique take on it.

Empedocles and Elements

Empedocles (ca. 495–ca. 435 BCE) managed to reconcile the antinomies between the



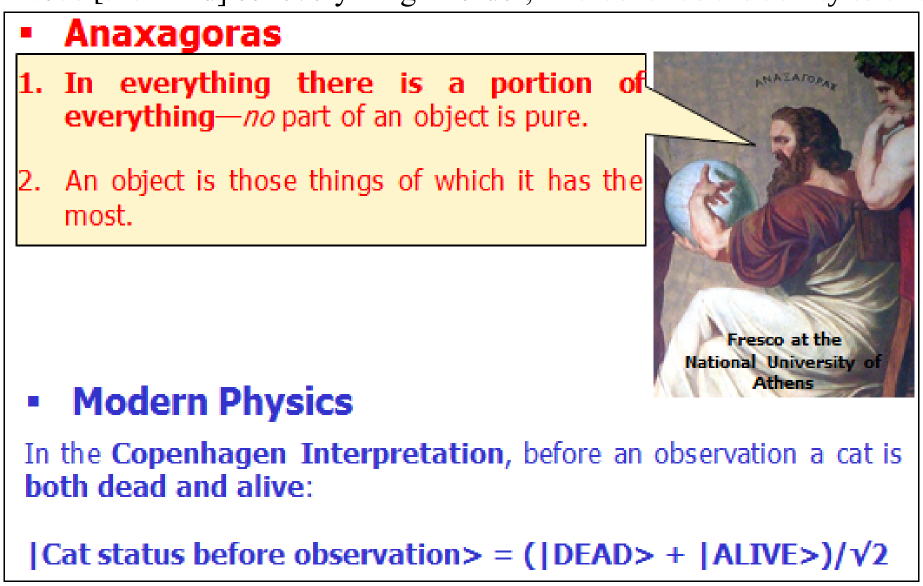
Heraclitean becoming (the constant change) and the Parmenidean Being (the constancy) by introducing four unchangeable primary substances of matter: earth, water, air, and fire, later called elements, and two types of forces, love and strife, which cause attraction or repulsion between the elements.[30] Change was produced when the opposite action of the forces mixed and separated the unchangeable elements in many different ways, an idea in basic agreement with modern chemistry or, more fundamentally, with the standard model of particle physics.

Whereas Empedocles proposed two forces and four primary elements (renamed "particles" by physicist and Nobel laureate Leon Lederman [1929–], who, incidentally, implied that Empedocles is the first particle physicist),[31] the standard model considers three fundamental forces—the electromagnetic, the nuclear weak, and nuclear strong (recall gravity is not part of the standard model)—and twelve types of particles of matter—the six quarks and six leptons (even though various other considerations, such as these particles' antiparticles, can increase the total number of particle types). Of course, unlike Empedocles's elements, in modern physics quarks and leptons are changeable—they transform to energy or from one material particle into another. Still quarks and leptons are brought together by the forces in a multitude of combinations and proportions to form atomic nuclei, atoms, molecules, flowers, books, readers, stars, and in general all the plethora of small and large objects, animate and inanimate, similar and dissimilar; but the forces can also break down larger objects into smaller ones. Analogously, in Empedocles's theory every object is made by a unique mixing proportion of the elements—for example, a bone, he says, is two parts earth, two parts water, and four parts fire (though the sources do not explain how he derived that)—achieved via the constant competition of love and strife.

Empedocles's pluralistic philosophy was a crucial turn away from the monistic philosophies we have discussed so far (i.e., those that considered water, the infinite, or air as the only primary substance of matter, or the philosophy of Parmenides about oneness), for it paved the way for the most successful ancient pluralistic philosophy, the atomic theory of Leucippus and Democritus. Their theory required myriad particles: the atoms. But before the theory of atoms, pre-Socratic philosophy had to go through yet another theory of remarkable originality; four primary substances of matter for Empedocles, but infinitely many for the nous of Anaxagoras.

Anaxagoras and Nous

"Nous [the mind] set everything in order,"[32] thus it has the ability to understand nature rationally, Anaxagoras (ca. 500–ca. 428 BCE) proposed. Order though, according to him, is not achieved through the consideration of just one primary substance or even four but through a countless number of them, including things such as gold, copper, water, air, fire, wheat, hair, blood, bones, and in general all other existing substances. However, unlike Empedocles's four elements, which are pure, Anaxagoras's substances are not; "in everything there is a portion of everything,"[33] a notion as bizarre as one of the most popular interpretations of quantum theory, the Copenhagen.



Every piece of substance, however large or small, contains some portion of everything—portions can be large but infinitesimally small, too, because for Anaxagoras matter is infinitely cuttable. Hence, no one substance is more fundamental (that is, smaller, simpler, purer) than any other. But "each thing is most manifestly those things of which it has the most."[34] A piece of gold, for example, contains gold as well as everything else—copper, wheat, hair—but appears as a distinct golden object because its gold content is the greatest. This does not mean, however, that this golden object contains the substances in pure form, side by side, separated, and identifiable, and the amount of pure gold in it happens to be more. No! To the contrary, no matter how small a bit we may cut from such golden object, it will still contain a portion of everything—it will never be pure gold. Therefore, despite that this is a golden object, *every part* of the object is also *simultaneously* watery, woody, milky, bloody, bony, hairy, and every other material, but not just that—it gets stranger.

An object has not only a portion of each type of substance but also a portion of all opposite qualities. Now, as with the substances, these qualities are not to be assumed to be side by side in an object or separated somehow, as if, say, an object has its right side wet and its left dry. Rather, "Things in this one cosmos are not separated from one another, nor are they split apart with an axe, neither the hot from the cold nor the cold from the hot."[35] So every part of an object is all the qualities simultaneously. For example, something hot is to some degree also cold. Or white snow, Anaxagoras argued, is to some degree simultaneously black, too—a statement of the same unusual meaning as Schrödinger's cat being simultaneously both dead and alive (coming up).

So for Anaxagoras an object is simultaneously hot, cold, wet, dry, hard, soft, sweet, sour, black, white, bright, dark, dense, rare, dead, alive, spinning clockwise, spinning counterclockwise, and all other opposite qualities. This is a peculiar interpretation of nature, for before we observe an object, the most we can say about the state of its existence is that it is a mix of all possible outcomes—of all opposite qualities though each with a different degree (portion) of contribution. Only after we observe the object can we describe it in a specific way, in terms of "those things of which it has the most," say, as golden, yellow, dry, cold, and heavy.

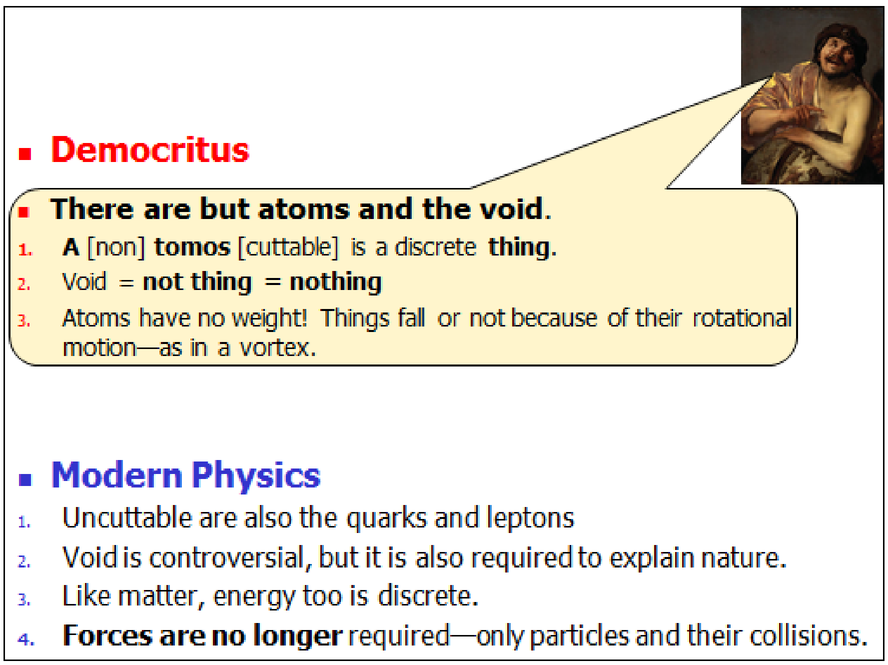
Remarkably, such interpretation of nature by Anaxagoras is similar to the most popular interpretation of quantum theory, the Copenhagen. According to it, before we observe something, the state of its existence is a mix of all possible outcomes (qualities), each of which has its own quantum probability to actually occur. If the idea of portion in Anaxagoras's theory is roughly associated with the idea of probability in quantum theory, then indeed, "in everything [a system of interest] there is a portion [is described by the quantum probabilities] of everything [of every possible outcome]." Before an observation Schrödinger's cat (a thought experiment which captures the peculiarity of the Copenhagen interpretation) is simultaneously both dead and alive (or an electron spins simultaneously both clockwise and counterclockwise). And each of these potential outcomes has its own probability to actually happen. Only after we observe, the Copenhagen interpretation states, can we determine whether the cat is definitely either dead or alive (or whether the electron spins definitely in the one or the other direction), and in general, whether an object is, as Anaxagoras states, definitely golden, yellow, dry, cold, and heavy.

Whether the nature of matter is infinitely cuttable (without smallest pieces) or finitely cuttable (with ultimate smallest pieces that make up everything) is still an open question. Anaxagoras held the former, but Leucippus and Democritus held the latter: namely, matter is atomic and thus made up of disconnected, indivisible pieces known as the atoms and surrounded by empty space. What revolutionized science was the atomic theory of matter, an idea that is two and a half millennia old.

Democritus and Atoms

Introduction

Perhaps the greatest scientific achievement of antiquity, possibly of all time,[36] was the realization of the atomic nature of matter. "There are but atoms and the void" Democritus (ca. 460–ca. 370 BCE) proposed.[37] And he understood the great diversity of material objects as complex aggregations of uncuttable atoms, the building blocks of matter, moving in the void, the empty space between them. Leucippus, who flourished between 440 and 430 BCE, invented the atomic theory, and Democritus, a true polymath and a prolific philosopher, developed it extensively. Uncuttable (the actual meaning of *atom* in Greek) are also the modern elementary particles of matter, the quarks and leptons, and although void is a controversial concept still, a kind of void is required to explain nature.



Ancient Atoms

Atoms, in the ancient atomic theory, are the uncuttable smallest pieces of matter, disconnected from each other because they are surrounded by void, space devoid of matter that was required to enable the atoms to move. Atoms are invisible, impenetrable, solid (absolutely rigid), indestructible, eternal, unchangeable, unborn (not generated by something else more fundamental), and imperishable (they do not transform into something else more fundamental). Atoms are therefore like many Parmenidean Beings. All atoms are made from one and the same type of material (although not from any particular one of the everyday, such as water or air). Atoms have no internal structure (they are homogeneous) but differ from each other only as regards their size and shape. Their only behavior is motion. Roaming around in the void of an infinite space there exist infinitely many atoms of various shapes: angular, concave, convex, smooth, rough, round, sharp, and so on. Their motion is perpetual (so, then, is change in accordance to the Heraclitean worldview). Atomic motion is also thought random because space was correctly assumed to be isotropic (having no special location or direction, i.e., space has no absolute up, down, right, left, in, out, center, or edge). As they move, atoms collide with each other, bounce, rotate, some hook together (whenever their shapes are complementary) and assemble in a multitude of arrangements, forming all kinds of macroscopic (compound) objects, or unhook and disassemble, deforming (destroying) the objects.

Atoms have none of the conventional properties of matter such as color, taste, smell, sound, temperature, or even weight. Democritus explained the conventional properties in terms of the shape of the atoms and their motion in the void. For example, the atoms of a hard object are more closely packed with less empty space (void) between them than the atoms of a soft object. Now, since the atoms of a soft object have more void to roam around they can be pushed there more easily. Hence, such objects feel squeezable and soft. Metals are made of atoms with hooks that hold them firmly interlocked, but liquids are made of round atoms so they can flow by each other easily. Even light was made of atoms (particles)—incidentally, Einstein won the Nobel Prize in Physics by interpreting light in terms of discrete particles: the photons. Black, white, red, and yellow were considered primary colors and associated with different shapes and arrangements of atoms.[38]

Democritus worked out a detail theory on sensation. In general he argued that the constant motion of the atoms, which persists even when a composite object is seemingly at rest, causes some of them to be emitted by the object. Flying through the void, these atoms in turn ultimately collide with the atoms of a sense organ and create a unique sensation (a flavor, smell, color).

All changes of the apparent world of sense perception, animate and inanimate, were reduced to the irreducible atoms and their motion in the void. This scientific reductionism is ambitious. In principle, it is also the goal of the modern theory of the elementary particles of matter, the quarks and leptons. But while there are striking similarities between these modern particles of matter and the ancient atoms, there are also serious differences. Only for purposes of comparison let us call the ancient atoms Democritean or D-atoms, and today's building blocks of matter, the quarks and leptons, QL-atoms.

D-Atoms and QL-atoms: Similarities and Differences

Before we proceed with this comparison let us first clarify something: D-atoms must not be confused with today's chemical atoms of the periodic table, such as hydrogen, carbon, and oxygen, since chemical atoms are not the real *fundamental particles* (the smallest cuts of matter as envisioned by Leucippus and Democritus). Chemical atoms can be cut into smaller pieces because they have substructure—they are made of the QL-atoms. Unfortunately the term "atom" has been undeservingly stuck on chemical atoms but it's actually a misnomer when used to refer to them.

On the other hand, both D- and QL-atoms are fundamental because they are not made from other particles; they are disconnected pieces of matter, indivisible (uncuttable), invisible, and the smallest, and their various combinations make up all material things in the universe. Neither the D-atoms nor the QL-atoms have any of the conventional properties of composite objects. These properties are really a consequence of the collective behavior of the D- and QL-atoms that make up these objects.

D-atoms are unchangeable, they do not transform, but QL-atoms do; they transform from one type of material particle to another and also into and from energy (although they do not transform into something more fundamental). But like matter, energy also comes as discrete bundles, as particles (e.g., photons), and so Leucippus's and Democritus's notion of discreteness as a property of nature is preserved. Furthermore, like D-atoms, which are made of the same substance, QL-atoms are made of the same substance, too, mass and energy (which are equivalent as per special relativity). And since D-atoms are indestructible, so is their substance, but so is the substance of QL-atoms, for the total amount of mass-energy in the universe is constant (as per the law of conservation of mass-energy). So the substance of both, the ancient and modern atoms, endures, while nature is constantly changing.

Weight or gravity (that is, the tendency of objects to fall or the property of heaviness) was not one of the primary characteristics of atoms but a property that was accounted for by Democritus ingeniously through motion, in particular rotational motion.[39] Let's explain.

Though motion is chaotic, Democritus argued, in an infinite space with infinite atoms there is always a chance that the bulk of the atoms of a certain region move collectively in a preferred direction of motion, rotational in particular, and produce a vortex. The rotational motion of such a vortex, Democritus thought, ultimately causes the bigger atoms (the more massive, the heavier, as we would say today having gravity in mind) to move toward its center, ultimately forming the earth and the water on it, and the smaller atoms (the lighter) to move toward its outskirts, ultimately forming the air, the sky, and the stars. Because the dynamics of our world system is still rotational (e.g., the sky rotates, relative to us, and so in a sense do the moving clouds), objects made of the bigger atoms, like a rock, still fall, and objects made of the smaller atoms, like steam, smoke, or fire, still rise, Democritus argued. Air, on the other hand, generally does not fall, he thought, because of its rapid revolution, just as water does not spill from a cup when it is rapidly spun around. His analysis was logical as regards observation because the earth, which (for him) is made of the bigger atoms, formed in the center of his vortex, water, made of smaller atoms, is on earth, and air, made of even smaller atoms, is above water and earth.

Now, concerning the dynamics of a vortex, in reality it is the reverse that happens: massive objects tend toward the outskirts of a vortex, and lighter ones toward the center (this, for example, happens in a centrifuge, a device employed to separate different substances). Nonetheless this error in Democritus's explanation is really a minor point compared to the fact that he managed a reasonably clever explanation of the world only in terms of a basic property that atoms have, namely, their motion in the void. Thus he saw no need of a force of a weight, of gravity, despite that apples fall as if a force is pulling them through space. The latter, legend says, inspired Newton to conceive his theory of universal gravitation for which gravity *was* a force, only to be abolished as a force by Einstein's theory of general relativity.

An apple and the earth, or the sun and the earth, feel a force of attraction from each other, Newton thought, as a consequence of a mysterious action at a distance that he himself admitted he did not understand. How is gravity transmitted if the interacting objects do not touch each other? How does one body feel the other, how do they communicate, if nothing but empty space exists between them and if nothing specific is really exchanged by them? Einstein provided the answer through his theory of general relativity. He eliminated the need for an action-at-a-distance type force by recognizing that the agent that transmits gravity is space itself when distorted by matter.

Moreover, according to the standard model of quantum theory, the particles of matter, the QL-atoms, combine with one another via the continual exchange of the particles of force (e.g., photons, gluons). Even gravity is hypothesized to work via the exchange of gravitons. Matter and force are no longer distinct notions. Instead, forces are really expressions of complicated particle collisions. And so, as is the view of Democritus, nature can be understood in terms of just particles and their complex collisions—forces were never required in the theory of Democritus and are no longer required in modern physics! How about the void? Is it required? Does it exist or not? Is it needed, or can it be avoided?

Void or Not?

The atomists Leucippus and Democritus called an atom a *thing*, Being (what-is), and the void *nothing* (*not thing*), Not-Being (what-is-not).[40] And they agreed with one interpretation of the theory of Parmenides: that if Being is a kind of full and solid block of matter without a void (i.e., if the nature of matter is continuous), then it is difficult, if not impossible, to explain motion and change. For the easiest way to understand the occurrence of motion and thus change, too, is to imagine the existence of empty space within which things could move—recall subsection *Anaximenes and Density* where we imagined rarefying or condensing a material line.

But whereas Parmenides denied the existence of the void by considering it Not-Being, the atomists postulated the opposite: Not-Being, the void, exists, for only then, they thought, can motion and change be accounted for. It is the place to put the atoms and enable them to move. For the atomists the void is empty space, and so *in* it there is nothing. But for Parmenides *it, the void, empty space itself*, is nothing, Not-Being; not *in* it there is nothing. The nature of the void has created mind-boggling debates since the time of Parmenides. For if something, for example, the void, is really nothing, how can it exist? How does one define "nothingness"? The answer is not easy.

Now what does modern physics think of the void? Does it exist or not? Is it a true nothing, the Parmenidean Not-Being, or something else? While "nature abhors a vacuum,"[41] a popular phrase since the Renaissance, yet "nothing works without, well, nothing."[42]

On the one hand, void is still a useful concept for the understanding of many phenomena. According to quantum theory, electrons in a chemical atom, for example, "move" around their nucleus by keeping their distance from one another as if space between them is empty, devoid of matter—"a regulation against overcrowding"[43] formally known as the Pauli exclusion principle. Had the exclusion principle not been true, the QL-atoms, which obey it, would not endure as disconnected pieces of matter, thus nuclei would not form, nor would chemical atoms or the molecules of organic chemistry, and consequently nor would the matter that living things are made of; generally, *all* matter in such a scenario would collapse into a uniform, undifferentiated, and lifeless state. The diversity in nature is in a sense a consequence of the exclusion principle: diversity is a law of nature!

On the other hand (that is, to be able to explain other phenomena), in the quantum realm the void is not really devoid of matter but a very busy place, seething with all-pervasive fields of energy (e.g., light and gravity waves, even the much-required Higgs boson field that explains mass), known as vacuum energy. These fields cannot be zero, even in seemingly empty space, because the time-energy uncertainty principle would be in violation. And they are actually fluctuating constantly, creating and annihilating pairs of particles with their corresponding antiparticles. These particles, called virtual, are not created out of nothing or annihilated into nothing but are made out of energy and return to be energy (the vacuum energy). Space, even "empty" space, is a place of constant, frantic activity of virtual particles, light, gravity, dark energy, dark matter, ordinary matter, of Higgs particles, possibly strings (from string theory), and who knows what else. It is certainly not the Parmenidean Not-Being (the *absolute* nothing). In fact even Leucippus's and Democritus's nothing (their notion of void) is really not nothing, since from the point of view of modern physics "it [their void] was the carrier for geometry and kinematics, making possible the various arrangements and movements of atoms."[44]

Conclusion

In an attempt to understand nature in a logical and causal manner, the search for the primary substance of the universe and for a TOE in pre-Socratic philosophy comes to an end with the atomic theory of Leucippus and Democritus. Their notion of indivisible, discrete particles without substructure has endured and, according to modern physics, is still one of the most remarkable properties of nature. Could spacetime form a type of discreteness, too? Interestingly, the hypothesis of space discreteness has been an innovation of Epicurus (341–270 BCE), a post-Socratic, who continued the remarkable work of Democritus.

CONCLUSION

Science has evolved significantly since the pre-Socratics, some two and a half thousand years ago. Nonetheless its ultimate goal still remains essentially the same: to understand nature rationally and to reduce the explanations of all natural phenomena to the least possible number of basic assumptions (first causes, axioms)—ideally to just one, which should be expressible both in words but also in terms of one master equation. Now, say that has been achieved, will the human intellect be satisfied?

References

[1] Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010); G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle* (New York: W. W. Norton & Company, 1970); G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers* (Cambridge: Cambridge University Press, 1983); John Burnet, *Early Greek Philosophy* (London: A & C Black, 1920); Alexander P. D. Mourelatos, *The Pre-Socratics: A Collection of Critical Essays* (Garden City, NY: Doubleday and Company, 1974); Gregory Vlastos, *Studies in Greek Philosophy*. *Vol. 1: The Presocratics* (Princeton: Princeton University Press , 1993).
[2] Jeffrey Bennett, Megan Donahue, Nicholas Schneider, and Mark Void, *The Essential Cosmic Perspective 7th Edition* (Boston: Pearson, 2013).

[3] Jeffrey Bennett, Megan Donahue, Nicholas Schneider, and Mark Void, *The Essential Cosmic Perspective 7th Edition* (Boston: Pearson, 2013), p. 450.
[4] Albert Einstein, *Relativity: The Special and the General Theory* (Amazon Kindle Direct Publishing, 2011).
[5] Brian Cox and Jeff Forshaw, *Why Does E=mc^2? (And Why Should We Care?)* (Boston: Da Capo Press, 2010).
[6] Carl Sagan, *Cosmos* (New York: Random House, 1980).
[7] Ian Tattersall, *The World from Beginnings to 4000 BCE* (Oxford: Oxford University Press, 2008).
[8] Isaac Asimov and Jason A. Shulman, *Isaac Asimov's Book of Science and Nature Questions* (New York: Weidenfeld & Nicolson, 1988), p. 281.
[9] Aristotle *Metaphysics* 983b6–13, 17–27. See Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), p. 29 (text 15); Aëtius 1.31, 1.10.12. See Graham, *Texts of Early Greek Philosophy*, p. 29 (text 16); Simplicius *Physics* 23.21–29. See Graham, *Texts of Early Greek Philosophy*, p. 29 (text 17).
[10] Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), p. 45; G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers* (Cambridge: Cambridge University Press, 1983), Kindle Locations 2625–3787.
[11] Leon Lederman and Dick Teresi, *The God Particle: If the Universe Is the Answer, What Is the Question?* (Boston: Houghton Mifflin, 1993), p. 56.
[12] Simplicius *Physics* 24.26–25.1, Theophrastus frag. 226A. See Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), p. 75 (text 3).
[13] Erwin Schrödinger, *Nature and the Greeks and Science and Humanism* (Cambridge: Cambridge University Press, 1996), pp. 62–65, 84–86, 157–62.
[14] Erwin Schrödinger, *Nature and the Greeks and Science and Humanism* (Cambridge: Cambridge University Press, 1996), pp. 160–62.
[15] Erwin Schrödinger, *Nature and the Greeks and Science and Humanism* (Cambridge: Cambridge University Press, 1996), p. 160.
[16] Erwin Schrödinger, *Nature and the Greeks and Science and Humanism* (Cambridge: Cambridge University Press, 1996), p. 84.
[17] G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers* (Cambridge: Cambridge University Press, 1983), Kindle Locations 5753, 8524.
[18] Aristotle *Metaphysics* 987b22. See Erwin Schrödinger, *Nature and the Greeks and Science and Humanism* (Cambridge: Cambridge University Press, 1996), p. 35.
[19] Aëtius 2.1.1, trans. Demetris Nicolaides. See Greek book Βας. Α. Κύρκος, *Οι Προσωκρατικοί: Οι Μαρτυρίες και τα Αποσπάσματα τόμος Α* (Αθήνα: Εκδόσεις Δημ. Ν. Παπαδήμα, 2005), p. 247.
[20] Johannes Kepler *The Harmonies of the World*, quoted in George N. Gibson and Ian D. Johnston, "New Themes and Audiences for the Physics of Music," *Physics Today* 55, no. 1 (January 2002): p. 44.
[21] Arnold Sommerfeld quoted in George N. Gibson and Ian D. Johnston, "New Themes and Audiences for the Physics of Music," *Physics Today* 55, no. 1 (January 2002): p. 43.
[22] G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers* (Cambridge: Cambridge University Press, 1983), Kindle Locations 4811–5726.
[23] Clement *Miscellanies* 5.103.6, trans. Demetris Nicolaides. See Graham, *Texts of Early Greek Philosophy*, p. 155 (text 47).
[24] G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers* (Cambridge: Cambridge University Press, 1983), Kindle Locations 6479–7034.

[25] Clement *Miscellanies* 6.23, trans. Erwin Schrödinger, *Nature and the Greeks and Science and Humanism* (Cambridge: Cambridge University Press, 1996), p. 27.

[26] Albert Einstein quoted in Brian Greene, *The Fabric of the Cosmos: Space, Time, and the Texture of Reality* (New York: Vintage, 2005), p. 139.

[27] Karl Popper, *Unended Quest: An Intellectual Autobiography* (London and New York: Routledge Classics, 2002) p. 148; or see: https://books.google.com/books?id=NyCEnehPMd8C&pg=PA148&lpg=PA148&dq=popper+einstein+parmenides&q=&hl=en#v=onepage&q=popper%20einstein%20parmenides&f=false (accessed January 9, 2017).

[28] Aristotle *Physics* 239b9–14, trans. Daniel Kolac and Garrett Thomson, *The Longman Standard History of Philosophy* (New York: Pearson, 2005), p. 33.

[29] Robert J. Oppenheimer, *Science and the Common Understanding* (New York: Simon & Schuster, 1954), p. 40.

[30] G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers* (Cambridge: Cambridge University Press, 1983), Kindle Locations 7538–8517.

[31] Leon Lederman and Dick Teresi, *The God Particle: If the Universe Is the Answer, What Is the Question?* (Boston: Houghton Mifflin, 1993), p. 340.

[32] Simplicius *Physics* 164.24–25, 156.13–157.4, 176.34–177.6. See also Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), p. 291 (text 31).

[33] Simplicius *Physics* 164.23–24, trans. G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle* (New York: W. W. Norton & Company, 1970), p. 44; Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), p. 291 (text 31).

[34] Simplicius *Physics* 27.2–23. See Gregory Vlastos, *Studies in Greek Philosophy. Vol. 1: The Presocratics* (Princeton: Princeton University Press , 1993), p. 319.

[35] Simplicius *Physics* 176.29, 175.12–14. See Richard D. McKirahan, *Philosophy before Socrates* (Indianapolis/Cambridge: Hackett Publishing, 2010), p. 194 (Kindle ed.).

[36] Richard P. Feynman, *The Feynman Lectures on Physics* (Boston: Addison-Wesley Publishing Co., Inc., 1963), p. 1-2.

[37] Sextus Empiricus *Against the Professors* 7.135, trans. Erwin Schrödinger, *Nature and the Greeks and Science and Humanism* (Cambridge: Cambridge University Press, 1996), p. 89.

[38] Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), pp. 579–95.

[39] Aëtius 1.4.1–4. See Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), pp. 541–45.

[40] Aristotle *Metaphysics* 985b4–20. See Daniel W. Graham, *The Texts of Early Greek Philosophy: The Complete Fragments and Selected Testimonies of the Major Presocratics* (Cambridge: Cambridge University Press, 2010), p. 525 (text 10).

[41] Isaac Asimov, *Understanding Physics* (US: Dorset Press, 1988), p. 7.

[42] Leon Lederman and Dick Teresi, *The God Particle: If the Universe Is the Answer, What Is the Question?* (Boston: Houghton Mifflin, 1993), p. 44.

[43] Banesh Hoffman, *The Strange Story of the Quantum* (New York: Dover Publications Inc., 1959), p. 68.

[44] Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science* (New York: Harper Torchbooks, 1962), p. 40.

The images of the various scientists and philosophers are from the public domain of Wikipedia.