Fundamental Themes in Physics from the History of Art

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Mindful of a stated Project 2061 goal of the American Association for the Advancement of Science, emphasizing that “scientific literacy includes seeing the scientific endeavor in the light of cultural and intellectual history,” and in the continuing spirit of narrowing the gap between the “two cultures” by enhancing STEAM awareness and education, this essay illustrates, quite literally through well-known works of Western art, the striking parallels between fundamental themes in physics and the visual arts through history. These connections include: the identification of microcosm–macrocosm analogies in prehistoric proto-science; the beginning of the appreciation in pre-classical antiquity of the lawfulness of nature under the aegis of a Divine Lawgiver; the rise of rationalism and the first theories of the architecture of matter during the so-called “Greek miracle”; the overlapping role of theology’s “handmaiden” during the emblematic medieval Age of Faith; Renaissance renovations and the triumph of the “mechanical universe” as the capstone of the scientific revolution in the early modern period; the influence on physics of the Romantic notion of an underlying unity in all of nature, and the increasing abstraction in both art and physics during the nineteenth century; and, finally, the parallels between twentieth-century art and the physics of relativity and quantum theory, concluding with examples from modern cosmology.

Key words: History of ideas; history of physics; art history; art-science connections.

It is amazing how compact a unity every historical epoch presents throughout its various manifestations.

—Spanish philosopher and essayist, José Ortega Y Gasset (1883–1955)

Introduction

Everything is, to some degree, characteristic of the setting in which it takes place. Both art and science, two of the most profound of all human activities, each attempting in its own way to interpret the world and our place in it, are cultural artifacts, socially situated and dynamically integrated within the total intellectual

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and cultural activity of their time. Not surprisingly, with each rooted in a common culture sharing common values, common concerns can often be identified when retracing the historical development of art and physics within their broader cultural compass. Looking primarily at painting and sculpture from the Upper Paleolithic through the modern period, this essay, examining art history as physics history, highlights the historical development of fundamental themes in physics beautifully reflected in the history of Western art.

Prehistoric Proto-Science: Microcosm–Macrocosm Analogies

The oldest artifact with possible scientific underpinnings, a small, roughly 25,000-year-old limestone relief sculpture from southwest France known as the *Venus of Laussel* (figure 1), is also the earliest evidence we have that our ancestors may have recognized a resonance between celestial and human cycles. Her large, pendulous breasts, exaggerated hips, and left hand placed so delicately over her slightly swollen womb, clearly identify this as a “Venus” fertility figure, a motif

![The Venus of Laussel](image_url)

*Fig. 1.* The *Venus of Laussel*, a fertility figure from the Upper Paleolithic discovered in the Dordogne department of southwest France, now residing in the Musée d’Aquitaine in Bordeaux, is the earliest of several works of art through history portraying a connection between the celestial macrocosm and the terrestrial/human microcosm. *Credit:* Wikimedia Commons, user 120, licensed under CC BY 3.0: [https://creativecommons.org/licenses/by/3.0/deed.en](https://creativecommons.org/licenses/by/3.0/deed.en)
common to this early period of art often found as freestanding figurines such as the famous Venus of Willendorf. In her right hand she holds a bison’s horn shaped like a crescent moon, both symbols of fertility. The mythic association of the moon with fertility is well known and probably originated with our early recognition of the correlation between the moon’s cycle of phases and a woman’s menstrual cycle, each lasting approximately one month. (The words moon, month, and menstrual derive from a common Indo-European root.) It has been suggested that the thirteen notches in the horn may represent the approximate number of lunar cycles—months or “moons”—in the annual solar cycle, or may perhaps mark the number of days taken by a reborn dark “new” moon to reach its fully illuminated phase. Faith in the rule of celestial bodies over our lives was not unreasonable given the cyclical governance evident in all aspects of the seasonal year. The importance of astrology for the birth of science should not be overlooked: it encouraged careful observation and record keeping, often resulting in the recognition of patterns in nature, the likes of which in more modern times are sometimes elevated to the status of “laws of nature,” and sanctioned action-at-a-distance cause and effect, all significant legacies of this ancient proto-science to modern science.

The Venus of Laussel is the earliest surviving evidence for the likely assignment of astrological influences on the human condition, and the concomitant acknowledgment of fundamental sympathies and correspondences between the terrestrial/human microcosm and the celestial macrocosm—a microcosm–macrocosm analogy—whereby the small mimics in miniature the large: as above, so below. This idea resurfaces throughout the history of art and physics: in art, Helen Lundeberg’s 1937 painting Microcosm and Macrocosm, now in the Los Angeles County Museum of Art, depicts the human observer positioned between the microcosm below and the macrocosm above; in physics, the continuing search for a theory of quantum gravity, unifying the physics of the very small with that of the very large (formalized in Albert Einstein’s theory of general relativity) in a so-called “theory of everything” remains the Holy Grail of modern physics, a trend initiated by Isaac Newton, who unified the previously distinct physics of the celestial (macro) and terrestrial (micro) realms. The Fermilab Cosmic Physics Center is just one institutional example of our continuing realization that our understanding of nature at the smallest and largest scales imaginable goes hand in hand. An early record of the human attempt to observe and interpret the workings of the world we are a part of, the Venus of Laussel reveals a bold self-confidence in our ability to understand the world around us and the prospect of a connection—a

* Another early example is the exquisitely fashioned pendant found in the tomb of Tutankhamun, now in the Egyptian Museum in Cairo, depicting the solar disk being propelled across the sky by Khepri, the scarab beetle manifestation of the sun god Ra rolling the sun before him like a ball of dung, with egg-encrusted dung appearing to give life to beetle progeny in the microcosm just as the sun was revered for promoting life in the macrocosm.
resonance—between the way we think and the way the world works, the very prerequisites for a scientific understanding of the world.

Later, with the invention of agriculture, Neolithic proto-scientists, motivated by a practical—indeed life-dependent—reason for figuring things out, exploited the orderliness of nature by noticing various celestial patterns that could be used to construct accurate calendars to keep track of the times for planting and harvesting various crops. Standing stones and other forms of megalithic architecture scattered across the world, the most famous being Stonehenge in England, testify to the ingenuity of these preliterate—but not pre-scientific—sky watchers of antiquity.

**Pre-Classical Antiquity: The Divine Lawgiver**

The concept of a transcendent Divine Lawgiver, wherein a deity hands humanity a set of laws to govern human behavior, originated in the ancient Near East, with the Code of Hammurabi (figure 2) and Moses receiving the Ten Commandments being two of the earliest and most famous exemplars. It was only natural to extend the compass of divine legislation to include laws governing the behavior of all of nature. Monotheistic religions, which conceive the world as governed by only one omnipotent deity, thereby eliminating the potential capriciousness of a pantheon of competing gods with divergent agendas, reinforced the notion of lawful order and stability in nature, thus opening the door to the concept of a monistic, unified, science of the natural world. Originating in this theological–juridical context, the concept of natural law is, of course, fundamental to science.

**The “Greek Miracle”: The Rise of Rationalism and Theories of Matter**

The ancient Greeks were the first to understand the world in universal, naturalistic terms through careful observation, speculative thought, and quantitative model building. As depicted in Raphael’s *School of Athens* (figure 3), there were two competing Greek schools of natural philosophy: mathematical idealism as championed by Pythagoras, the first to appreciate mathematical order in nature, and Plato, stressing the reality and permanence of Form and Idea with knowledge coming introspectively through reasoned intellect; and material realism, the reality of matter with knowledge supplied by the senses, as exemplified by Aristotle’s comprehensive and systematic philosophy of nature, which influenced the development of science for two thousand years. Today we appreciate the merits of both approaches: critical thinking and evidence; rationalism and empiricism. Raphael’s fresco, painted between 1509 and 1511, documents the longstanding Platonic–Aristotelian, rational–empirical, tug-of-war that persisted through the centuries and continues unabated in contemporary times: witness the 1988 article in the *American Journal of Physics* interrogatively titled “The New Physics—Physical or Mathematical Science?”
Pre-Socratic philosophers offered the first rational representations of the natural world around them, stripped bare of personal or divine agency. They attempted to identify an archē, the basic substance or substances from which the world is made—variously identified as earth, water, air, or fire, or some combination thereof (figure 4)—and struggled to understand change and transformation in that world, issues fundamental to the Western scientific tradition. Although these ideas seem rather immature to the modern mind—and have

* To these four terrestrial elements, Aristotle added an ethereal “fifth essence”—the quintessence—a pure, immutable substance filling the celestial realm above the terrestrial sphere (defined by the orbit of the moon; the word is used today to denote the most perfect manifestation of a quality or thing). Interestingly, these five elements are analogous to the four states of ordinary matter recognized today—solid (earth), liquid (water), gas (air), and plasma (fire)—with the quintessence finding its modern counterpart in the dark matter/energy that accounts for nearly all of the “stuff” in the universe.
their developmental counterpart in the increasing realism of contemporaneous Greek sculpture—it is important to note that in their search for an underlying unity and order below the surface of diversity and change, these early protophysicists anticipated the modern-day search for the unification of all of physics in a grand theory of everything. Of course, the claim that a single substance underlies all change in physical phenomena suggests a law of conservation of “stuff” (matter), and is in this sense the first of many important conservation laws in physics.

The geometry that helped render Raphael’s fresco so realistic was also a Greek invention, a creation to which, according to Einstein, science owes half its legacy. In a letter to a friend, Einstein wrote: “The development of Western Science has been based on two great achievements, the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility of finding out the causal relationship by systematic experiment (at the Renaissance).”\(^9\) Einstein admired Euclid’s demonstrated “certainty of proof,” the ultimate rhetorical form cast in the language of deductive logic. The style of Newton’s *Principia* and the “self-evident” truths outlined in the American Declaration of Independence are decidedly Euclidean. Often employing its principles in their work, artists, too, have appreciated the value of geometry (for example,
Allegory of Geometry painted after 1649 by Laurent de la Hyre or a follower; geometry is represented in Raphael’s School of Athens (figure 3) by Euclid at lower right drawing geometric figures on a slate below the artist himself peering out over shoulders at the viewer).

Like Roman copies of Greek statues, Roman science—what little there was of it—was, with very few exceptions, essentially Greek science (hence “Greco-Roman”) written in Latin. Arguably the most important legacy of ancient Rome to science is their establishment of a liberal-arts education that would influence the entire Western educational tradition and that remains recognizable in the liberal-arts curricula of today’s colleges and universities (figure 5). Appropriate subjects of study for the “free” (in Latin, liber) man, as distinguished from the “servile” manual arts of the slave, by late antiquity they numbered seven and included the three (trivium) verbal arts—grammar, rhetoric, and logic—and the four
quadrivium mathematical arts—arithmetic, geometry, music (harmonics), and astronomy—these latter so important to science today and commonly tied together in a musically themed “Harmony of the Spheres” cosmology that remained popular through the early modern period.10

Medieval Age of Faith: Emblematic Nature and Overlapping Magisteria

The medieval Western world was dominated by religious sensibilities for well over a millennium. It was a great Age of Faith when earthly matters were not nearly as important as heavenly salvation, an allegorical, emblematic world full of symbols to be interpreted religiously, rather than a collection of facts to be understood scientifically: nature was a mystical cryptogram that, when decoded by the faithful, revealed God’s symbolic presence.11 The Christian aesthetic deemed naturalism—in both artistic expressions (notably manuscript illuminations and, on a much grander scale, the great Gothic cathedrals) and science (a metaphysical amalgam of Christianity and Aristotelian science—faith and reason—that flourished even in the time of Galileo)—far less important than religious significance (figure 6).

Fig. 5. Originally in the Villa Lemmi near Florence, now in the Paris Louvre, Sandro Botticelli’s ca. 1483–85 fresco depicts a young man presented by Venus (or possibly Minerva) to personifications of the seven liberal arts, one of many renditions of this popular theme in the history of art. Raphael’s School of Athens (figure 3) brings together the quadrivium component of the Liberal Arts, with arithmetic and music represented by Pythagoras on the side of Apollo, god of music and poetry, standing high on the outward facing wall on the left, and geometry and astronomy beneath Athena, goddess of reason and wisdom, on the right. Credit: Courtesy of Wikimedia Commons

Credit: Courtesy of Wikimedia Commons
An important—and importantly different—figure from the thirteenth century, St. Francis of Assisi taught that all of nature was created by God and is therefore important and interesting in and of itself and therefore worthy of respect and attention. For Francis, the creatures of the world were autonomous and important quite apart from humanity’s spiritual needs, and not merely symbolic entities in an anthropocentric universe. Giotto’s ca. 1300 St. Francis Preaching to the Birds, now in the Paris Louvre, is a beautiful example of this new, Franciscan naturalism. Historian Lynn White called St. Francis nothing less than “the greatest revolutionary in history: he forced man to abdicate his monarchy over the creation, and instituted a democracy of all of God’s creatures.... Modern science ... as it first appeared in the later Middle Ages ... was one result of a deep-seated mutation in
the general attitude towards nature, of the change from a symbolic-subjective to a naturalistic-objective view of the physical environment.”

**Renaissance Renovations and the Scientific Revolution: The Mechanical Universe**

Appealing directly to nature as the foundation of their science, Renaissance artists were among the first of their time to carefully observe the world around them: thus did art promote the development of data visualization in science. The archetypal Renaissance man Leonardo da Vinci, a consummate artist and vigorous investigator, the pioneer of technical drawing and scientific illustration who once called wisdom “the daughter of experience—the common mother of all the sciences and arts,” stressed the importance of both mathematics and empiricism in both art and science. With mathematical precision, a new technique of linear perspective based on classical optics, in which parallels appear to converge at a remote “vanishing point” behind the picture plane, was employed in Renaissance painting to provide the *trompe l’œil* illusion of real, three-dimensional space on an otherwise two-dimensional surface. (Note the architectural elements in Raphael’s *School of Athens* in figure 3 that provide the sets of orthogonals and transversals—the “force of lines”—yielding the powerful sense of recession and illusion of depth.) Satisfying the new craving for realism and exactness, this new method of painting, rationalizing the representation of space through the mathematization of seeing, was the result of a carefully calculated mathematical fusion of art and optics. Studies of perspective impacted the development of natural philosophy, as the concept of infinity, first realized in a picture plane, was later extended to the universe itself.

Expanding on these Renaissance renovations and innovations, the scientific revolution is the name given by historians to the period in European history when, during the long seventeenth century, the conceptual, methodological, and institutional foundations of modern science swept away the scientific heritage of the ancient and medieval worldviews (figure 7). It has been proclaimed “the most profound revolution achieved or suffered by the human mind,” indeed “the most important event in Western history.” A civilization organized around Christianity was transformed into a modern world centered on science through the important work of some of the most notable scientists in history including Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, Galileo Galilei, René Descartes, Robert Boyle, Robert Hooke, Christiaan Huygens, and, standing on the shoulders of them all, Isaac Newton, whose crowning tour de force, *Philosophiae naturalis principia mathematica* (*Mathematical Principles of Natural Philosophy*), established, at last, the principles of natural philosophy in 1687, formulating the framework for a clockwork, mechanical universe (figure 8) that set the game plan of physics until supplemented by the sciences of thermodynamics and electromagnetism in the
mid-nineteenth century, and subsequently modified by the new physics of relativity and the quantum early the following century.

Several new instruments—the telescope (see figure 4), the microscope, the thermometer, the barometer, the pendulum clock, and the air pump (figure 9)—products of the craft tradition and explicit manifestations of both the experimental and mechanical philosophies associated with the new science, were instrumental, literally and figuratively, to this new understanding of nature. Indeed, it may be said that the new mechanical philosophy legitimized the use of instruments in natural philosophy: if the natural world is a machine, then certainly it can best be examined and understood with the tools and techniques of the mechanician. Conversely, and just as importantly, a familiarity with mechanical devices prepares the mind for constructing explanations of a mechanical universe running with clockwork precision. These six important scientific instruments, material manifestations of the mechanical philosophy to which they contributed so much, provided the solid, empirical foundation of the scientific revolution.

Fig. 7. *The Three Philosophers* (1508–9) by Giorgione, now in the Kunsthistorisches Museum, Vienna. Three generations of philosophers represent the continuity of science from antiquity through the Middle Ages to the modern period. Ancient science is represented by the old, bearded philosopher standing at the edge of the painting holding a compass and a scroll with astronomical drawings, medieval science by the turban-topped Arab philosopher, appropriately positioned in the middle of the group, and the new science is symbolized by the seated youth with compass and square in hand, contemplating a picture space teeming with nature—and who, it has been suggested, bears a striking resemblance to Nicolaus Copernicus, one of the founders of the new science. In this interpretation, the sun on the horizon representing the change of day could signify the changing science through these three periods of history. The new art and science would stress direct, individual—even asocial—experiential engagement with nature, rejecting traditional interpretations based on the authority of the Ancients. Credit: Courtesy of Wikimedia Commons
It is not at all surprising and certainly not coincidental that the fascination with light and optics, literally reflected in the paintings of the Flemish Primitives—Jan Van Eyck’s 1434 *The Arnolfini Portrait*, now in London’s National Gallery, is an early masterpiece of realism with close attention to light and shadow, including a small convex mirror that reflects in detail the entire scene filled with full-bodied figures—as well as in those by Dutch masters such as Rembrandt and Johannes Vermeer two centuries later, led to the Dutch invention of two of the most important optical instruments in the history of science, the telescope and the microscope, each of which extended our scope to realms unimaginable even today, a fascination that led also to the discovery in 1621 of the law of refraction by the Dutch mathematician and astronomer Willebrord Snel. Nor is it surprising that the great Dutch microscopist Antoni van Leeuwenhoek acted as an executor of Vermeer’s will: artists and scientists enjoyed close relationships particularly during the seventeenth-century Dutch Golden Age. 

Fig. 8. Joseph Wright of Derby’s *A Philosopher Giving a Lecture on the Orrery* (1766). The orrery was an eighteenth-century device used to illustrate Newton’s mechanical clockwork universe. Note the pensive expression on the man seated to the right, who seems to be contemplating the deeper implications of this new, deterministic, clockwork universe, perhaps recalling the biblical passage “What hath God wrought?” For examples of Newton-in-art, Eduardo Paolozzi’s 1995 bronze *Newton* outside London’s British Library is modeled on William Blake’s 1795–1805 *Newton* in London’s Tate Gallery. Credit: Derby Museum and Art Gallery, England, courtesy of Wikimedia Commons.

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Romanticism: Unity and Abstraction in Art and Physics

The Romantic movement was, in part, a reaction against an overly rational and overtly mechanized world, an emotional outcry against the Enlightenment mechanical model of physical and social reality that ended, at last, the hegemony of the rationalist tradition.\textsuperscript{17} It was the heart turning against the head, emotion crying out against reason, elevating the subjective above the objective and preferring the organic over the mechanical, world soul over world clock, and feeling over logic, an “intelligence of the heart” that promoted a more intuitive way of thinking. One of Romanticism’s defining characteristics was the belief in the polarity and dynamic unity—the interconnectedness—of the phenomena of

\textbf{Fig. 9.} Joseph Wright of Derby’s \textit{An Experiment on a Bird in the Air Pump}, first exhibited in 1768 and now in London’s National Gallery, is very similar in composition to his orrery painting (figure 8) referencing the new mechanical universe. Note the realistic depiction of the refracted light coming from the immersed slender rod; indeed, the overall realism of the entire composition is striking, particularly Wright’s characteristic attention to light and shadow, with the concentration of light dramatically conveying the process of scientific enlightenment that is taking place here. The enigmatic, Newton-looking lecturer displays a most haunting expression, while the man seated at the right, perhaps pensively fretting the destructive power of the new science, wonders, as is his counterpart in figure 8, “What hath God wrought?” Depicting subjects new to British art, Wright’s science-themed paintings exemplify best, in both style and subject matter, the enlightened Newtonian spirit in the fine arts, radiating the “Century of Light” emphasis on the realistic and the natural. (For more on this most science-minded painter in this most science-conscious century, see Stephen Daniels, \textit{Joseph Wright}, Princeton University Press, 1999). \textit{Credit:} Joseph Wright of Derby, \textit{An Experiment on a Bird in the Air Pump}, 1768. Presented by Edward Tyrrell, 1863, The National Gallery, London, courtesy of Wikimedia Commons
nature. Scientists and artists alike were tasked with demonstrating the interrelations of polar forces, the dynamism of every department of nature, and the underlying unity and continuity of nature, as depicted, for example, by the absence of a clearly defined horizon and the resultant unity of sea and sky, a harbinger of Impressionism and abstraction in art and an expression of the awesome infinity of a boundless universe. Credit: Courtesy of Wikimedia Commons

Fig. 10. The Slave Ship, painted in 1839 by J. M. W. Turner, now in the Boston Museum of Fine Arts. This painting, as are many of Turner’s, is Romantic through and through, in both content (storm at sea with the resultant loss of life) and style (for example, the hazy indistinctness of forms and abbreviated treatment of details, such as the absence of a clearly defined horizon and the resultant unity of sea and sky, a harbinger of Impressionism and abstraction in art and an expression of the awesome infinity of a boundless universe). Credit: Courtesy of Wikimedia Commons

Elements of Romanticism impacted nearly every branch of early nineteenth-century science in a rather rare and fruitful confluence of philosophical speculation and scientific discovery, yet another of many milieu resonances in the history of science.\textsuperscript{18} The appreciation of the intimate connection between electricity and chemistry and between electricity and magnetism in the new unified fields of electrochemistry and electromagnetism—the terms themselves betray the underlying unity—and of the inter-convertibility and hence conservation of various forms of energy in the new science of thermodynamics (another unifying neologism), and of Earth’s dynamic history and life’s constant struggle for survival, are just a few of the fruitful scientific ideas that are tied to the tenants of Romanticism. Reasoning as a Romantic that since magnetic fields are produced by moving electric charge (that is, electric current), as discovered earlier by Hans Christian
Oersted, who was also motivated by the Romantic conviction of the unity of all forces in nature (“It is ... my firm conviction ... that a great fundamental unity pervades the whole of nature”19), then moving magnets should therefore produce electric current, Michael Faraday discovered electromagnetic (“Faraday”) induction, the basis of today’s electrical power industry and hence modern civilization, arguably the single most enabling scientific contribution to our modern world (figure 11).

The field concept Faraday devised as an intermediary to Newton’s occult-like, invisible, action-at-a-distance forces emerged in the context of the holistic emphasis of Romanticism, the feeling that an underlying unity and interrelatedness pervades all of nature. It reflected an understanding of the mutual interactions between electricity and magnetism, formally related by Maxwell’s theory of a
combined electromagnetic field, which also encompassed the science of optics with Maxwell’s realization that light is an electromagnetic wave. The Romantic notion of an underlying unity in all of nature, reflected in Faraday’s thoughts—“the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related and mutually dependent, that they are convertible, as it were, one into another, and possess equivalents of power in their action”—remains a powerful force in physics today in the search for a unified theory of everything, a quest initiated by Newton in his unification of celestial and terrestrial physics. “It is a glorious feeling to discover the unity of a set of phenomena that seem at first to be completely separate,” wrote Einstein, who spent the last thirty years of his life in an unsuccessful attempt to unify electromagnetism and gravity in a unified field theory, to his friend Marcel Grossman early in his career, expressing a feeling that underlay his lifelong scientific mission.

Modern Art and Physics

Just when physicists thought their subject dead—that the “future truths of Physical Science are to be looked for in the sixth place of decimals”—the discovery of X-rays and radioactivity (the latter, as an example of numismatic science art, was depicted on the former 500-franc French banknote honoring the work of Marie and Pierre Curie) in the closing years of the nineteenth century demonstrated that physics was far from finished. The same can be said of art, as the ethereal, atmospheric paintings of J. M. W. Turner (recall figure 10), characterized by their indistinct forms and lack of detail announcing a very painterly style of subtle abstraction, matured into the movement known as Impressionism later in the century and Cubism early in the following century before becoming fully non-representational—nonfigurative and nonobjective—through the twentieth century (as illustrated, for example, by the paintings of Wassily Kandinsky and Jackson “the Dripper” Pollock). Relativism, in both art and physics, replaced long-standing classical absolutes. Unlike modern physics, which, however abstract its increasingly mathematical formalism may seem, still aimed to describe and understand the natural world, modern art, forsaking representation for presentation, was no longer obliged to represent it. New and increasingly abstract ideas of matter-energy and of space-time explored by quantum physics and relativity theory profoundly shaped the increasingly abstract art of the modern period. The non-visualizability of modern physics—Werner Heisenberg warned that the program of physics “ought, above all, to give up totally on visualizability”—is mirrored in the abstraction of modern art, a literal reflection of the analytical, reductionist position of post-Newtonian science. Relativity and quantum theory softened the contours of physical reality, just as the contours in art softened into abstraction; just as physicists could offer only an abstract concept of atoms and electrons, not a
visualizable picture, artists were content to express concepts of objects instead of records of their appearance.

Paul Cézanne’s tilted tabletop and tipped *Still Life with Fruit Basket (The Kitchen Table)*, painted during the period 1880–90 (figure 12), displays the fracturing of space challenging the old Renaissance rules of linear perspective. Multiple perspectives presented simultaneously in art coincidentally presaged similar ideas at the heart of Einstein’s theory of special relativity, based as it is on the concept of simultaneity, and mimicked the warped space of general relativity, both of which followed in the early twentieth century. The fractured forms of cubism (figure 13)—a style, considered the most influential art movement of the new century, involving the break-up and arbitrary yet orderly and calculated rearrangement of form, often in an attempt to show multiple sides of an object at simultaneously—while originally influenced by the X-rays and aether of physics, as well as the then-popular notion of a fourth spatial dimension, resonate with the concept of simultaneity in relativity theory, and display the discontinuity of nature at the quantum scale. In an attempt to display the progression of time via higher-dimensional forms representing the space-time continuum of relativity theory, Russian artist Kazimir Malevich’s *The Knifegrinder* (figure 14) fractures time just as Cézanne had fractured space, a motif further explored by futurism, which compiled a sequential series of still figures to suggest movement as a measure of the passage of time, as opposed to cubism’s use of time as a means to gather multiple views of an object (whence “cubo-futurist”).
Fig. 13. Pablo Picasso’s *Portrait of a Woman* (1940; Berggruen Museum Berlin). Note the twisted—and hence multiple—perspectives of the woman’s facial features. *Credit:* Reproduction permission kindly provided by Nationalgalerie Staatliche Museen zu Berlin

Fig. 14. Kazimir Malevich’s *The Knifegrinder* (1912–13) displays the fourth dimension of time in a sequential series of stop-action images of an abstracted human form grinding a knife in an Einsteinian space-time continuum. The Futurists were inspired by early stop-motion photography that was soon superseded by motion-picture cinematography. Marcel Duchamp’s 1912 *Nude Descending a Staircase* (Philadelphia Museum of Art) is a more famous example of this. *Credit:* Courtesy of Wikimedia Commons
In sculpture, there arose a so-called “piercing of the mass”—the injection of empty space into the sculptor’s domain, perhaps best exemplified by the work of British sculptor Henry Moore, such as his UNESCO Reclining Figure 1957–58. As in general relativity where space and mass are co-joined, space now joined mass as an object expression of the sculptor’s craft with empty hollows as meaningful as solid mass.

A mere dozen years before the advent of quantum theory, Georges Seurat, a partisan of the particulate no less than Planck and Einstein, pioneered, in a scientific reform of Impressionism, his “pointillist” style of applying point-like atomistic dots of colors to the canvas to be mixed optically in the viewer’s eye rather than on the palette (figure 15). The grainy discontinuity of a pointillist painting, like that of an ancient Roman mosaic or a magnified newsprint photo, mimics the fuzzy graininess of nature on the small, quantum scale, and, at the same time, its pixilated, digital-like, particles-of-paint style prefigured the discovery of the first fundamental particles in physics at the end of the century. The bold color field of much of the new art (for example, Henri Matisse’s The Dessert: Harmony in Red (The Red Room), painted in 1908–9 and now in the St. Petersburg’s State Hermitage Museum) foreshadowed the use of false color in scientific illustrations.

Einstein himself has inspired countless pieces of art, one of the most impressive being Robert Berks’s impressionistic, larger-than-life bronze sculpture of Einstein outside the National Academy of Sciences building in Washington, DC (figure 16), depicting the scientist holding papers engraved with the three equations summarizing three of his most important scientific achievements: the field equations of general relativity, the photoelectric effect, and, arguably the most famous equation...
in science, $E = mc^2$; he was also immortalized as a secular saint in stone at New York City’s Riverside Church (figure 17).

Nuclear art includes Salvador Dalí’s *Melancholic Atom and Uranium Idyll* (1945; Museo Nacional Centro de Arte Reina Sofía, Madrid, Spain), a surrealistic work laden with the existential angst accompanying the nuclear anxiety of the time. His *Three Sphinxes of Bikini* (1947; Morohashi Museum of Modern Art, Fukushima, Japan, ironically the site of the nuclear disaster at the Fukushima Daiichi Nuclear Power Plant in 2011), painted one year after a series of atomic bomb tests at the Bikini atoll, features three mushroom-shaped “sphinxes” projecting from a typically surrealistic, dreamlike landscape. British sculptor Henry Moore’s *Nuclear Energy* (1964–66) is located on the campus of the University of Chicago at the site of the world’s first nuclear reactor where the first human-made, self-sustaining nuclear chain reaction was initiated on December 2, 1942, as part of the Manhattan Project to build an atomic bomb during World War II. Atomium, a 100-meter-tall, stainless-steel model of the atomic crystal structure of iron that towered over the 1958 World’s Fair in Brussels, Belgium, still stands today as an emblem of postwar progress in the new atomic age.

Cosmological themes in modern art, inspired by Einstein’s general theory relativity, include the work of the American artist Josiah McElheny, such as his 2008 *Island Universe*, a glass and metal sculpture inspired by the multiverse scenario of eternal cosmic inflation, and *Cold Dark Matter; an Exploded View* by the English artist Cornelia Parker, a domestic-scale big bang created from pieces of an exploded garden shed, this one addressing one of the two enigmatic “dark” forms
Fig. 17. Einstein immortalized as a secular saint in stone at New York City’s Riverside Church (1927–1930) designed by the American architects Charles Collens and Henry C. Pelton. “I might have imagined that they could make a Jewish saint of me,” Einstein joked, “but I never thought I’d become a Protestant one!” It is difficult to avoid the saintly connotations that hang over the man, most literally in his halo of silvery hair and in view of the scientific miracles he performed in his *annus mirabilis* (“miracle year”) of 1905. Even his preserved brain and eyes remain behind like saintly relics. *Credit:* Photo by the author

Fig. 18. Detail of Paul Gauguin’s *D’où Venons Nous/Que Sommes Nous/Où Allons Nous* (*Where Do We Come from/What are We/Where are We Going*). *Credit:* Museum of Fine Arts Boston; Wikimedia Commons
of matter and energy that make up nearly 96% of the universe, unexplained still today.

**Concluding Remark**

We end where we began, with the female nude (recall figure 1). Paul Gauguin’s monumental 1897 *D’ou` Venons Nous/Que Sommes Nous/Où Allons Nous* (*Where Do We Come from/What are We/Where are We Going*; figure 18) reflects contemporary views on human history and destiny. We know from a surviving manuscript in which he extolled his philosophical musings about human destiny, that Gauguin considered the role that new scientific knowledge might play in resolving these “ultimate” questions. In any case, it is significant that when Gauguin posed them, science was not in a position to provide answers, and one would have had to consult philosophers or theologians. Today, however, more than a century later, physics—and art—have come a long way in answering these most profound of questions.

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**References**

1. Alexander Marshack, *The Roots of Civilization: The Cognitive Beginnings of Man’s First Art, Symbol and Notation* (New York: McGraw-Hill, 1972), 335.
2. E. C. Krupp, ed., *In Search of Ancient Astronomers* (New York: Doubleday, 1979); Evan Hadingham, *Early Man and the Cosmos* (Norman: University of Oklahoma Press, 1985).
3. Francis Oakley, *Natural Law, Laws of Nature, Natural Rights: Continuity and Discontinuity in the History of Ideas* (New York: Continuum, 2005).
4. See for example David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 B.C. to A.D. 1450*, 2nd ed. (Chicago: University of Chicago Press, 2007).
5. Christiane Joost-Gaugier, “Plato and Aristotle and Their Retinue: Meaning in Raphael’s School of Athens,” *Gazette des Beaux-Arts* 137, no. 1593 (2001), 149–64.
6. Robert L. Oldershaw, “The New Physics—Physical or Mathematical Science?,” *American Journal of Physics* 56, no. 12 (1988), 1075–80. Obi-Wan Kenobi’s warning to a young Luke Skywalker that “Your eyes can deceive you. Don’t trust them!” is Hollywood’s nod to the debate, taking place in this case a long time ago in a galaxy far, far away.
7. Lindberg, *Beginnings of Western Science* (ref. 4); Daniel W. Graham, *Explaining the Cosmos: The Ionian Tradition of Scientific Philosophy* (Princeton, NJ: Princeton University Press, 2006).
8. Emanuel Loewy, *The Rendering of Nature in Early Greek Art*, trans. J. Fothergill (London: Duckworth & Co., 1907); David Park, *The How and the Why: An Essay on the Origins and Development of Physical Theory* (Princeton, NJ: Princeton University Press, 1988), 68–70.
9 Albert Einstein, letter to J. S. Switzer, April 13, 1953. Quoted in Alice Calaprice, *The Quotable Einstein* (Princeton, NJ: Princeton University Press, 1996), 180.

10 Jamie James, *The Music of the Spheres: Music, Science, and the Natural Order of the Universe* (New York: Springer-Verlag, 1993).

11 William B. Ashworth, Jr., “Natural History and the Emblematic World View,” in *Reappraisals of the Scientific Revolution*, ed. David C. Lindberg and Robert S. Westman (Cambridge: Cambridge University Press, 1990), 303–32.

12 Lynn White, Jr., “Natural Science and Naturalistic Art in the Middle Ages,” *American Historical Review* 52, no. 3 (1947), 421–25.

13 J. V. Field, *The Invention of Infinity: Mathematics and Art in the Renaissance* (Oxford: Oxford University Press, 1997).

14 See for example Laurence M. Principe, *The Scientific Revolution: A Very Short Introduction* (Oxford: Oxford University Press, 2011).

15 Maurice Daumas, *Scientific Instruments of the 17th & 18th Centuries and Their Makers* (London: Portman Books, 1972).

16 Laura J. Snyder, *Eye of the Beholder: Johannes Vermeer, Antoni van Leeuwenhoek, and the Reinvention of Seeing* (New York: W. W. Norton & Co., 2015).

17 John H. Randall, Jr., *The Making of the Modern Mind: A Survey of the Intellectual Background of the Present Age* (1926; New York: Columbia University Press, 1976), 389–426.

18 Andrew Cunningham and Nicholas Jardine, eds., *Romanticism and the Sciences* (Cambridge: Cambridge University Press, 1990).

19 Quoted in R. C. Stauffer, “Persistent Errors Regarding Oersted’s Discovery of Electromagnetism,” *Isis* 48, no. 1 (1957), 33–50; quote from Hans Christian Ørsted, *Selected Scientific Works of Hans Christian Ørsted*, ed. and trans. Karen Jelved, Andrew D. Jackson, and Ole Knudsen (Princeton, NJ: Princeton University Press, 1998), xxix.

20 Michael Faraday, *Experimental Researches in Electricity*, vol. 3 (London: Bernard Quaritch, 1855), 1.

21 Walter Isaacson, *Einstein: His Life and Universe* (New York: Simon & Schuster, 2007), 67.

22 Albert Michelson, 1894 address at the dedication of the University of Chicago’s Ryerson Physical Laboratory, reproduced in *The University of Chicago Quarterly Calendar* 3, no. 2 (August 1894), 12–15, on 15.

23 Emilio Segré, *From X-Rays to Quarks: Modern Physicists and Their Discoveries* (New York: W. H. Freeman, 1980).

24 See for example Lynn Gamwell *Exploring the Invisible: Art, Science, and the Spiritual* (Princeton, NJ: Princeton University Press, 2002).

25 Quoted in Arthur Miller, *Imagery in Scientific Thought: Creating 20th-Century Physics* (Boston: Birkhäuser, 1984), 148.

26 Leonard Shlain, *Art & Physics: Parallel Visions in Space, Time & Light* (New York: William Morrow and Co., 1991); Arthur Miller, *Einstein, Picasso: Space, Time, and the Beauty That Causes Havoc* (New York: Basic Books, 2001).

27 Linda Dalrymple Henderson, *The Fourth Dimension and Non-Euclidean Geometry in Modern Art*, rev. ed. (1983; Cambridge, MA: MIT Press, 2013).

28 Linda Dalrymple Henderson, “Italian Futurism and ‘The Fourth Dimension,’” *Art Journal* 41, no. 4 (1981), 317–23.

29 William Innes Homer, *Seurat and the Science of Painting* (Cambridge, MA: MIT Press, 1964).
30 Peter Blanc, “The Artist and the Atom,” *Magazine of Art* 44 (1951), 145–52.