CHEMISTRY: WHAT DOES ONE NEED TO KNOW?

by Allen R. Utke

Abstract. The general knowledge and understanding that every teacher of religion and science should have relative to chemistry can be found in the answers to three major questions. In my own response to the first question, How did chemistry emerge as a discipline? I trace the origins, establishment, and subsequent historical significance of cosmology. I contend that chemistry is "the obvious, oldest science" and, as such, has played a key role among the sciences in agelong human efforts to understand reality. In my response to the second question, How do chemists currently view (cosmic) reality? I outline three prominent examples in support of my contention that chemistry, despite being "the obvious, oldest science," is seen by some as playing only a tacit role in current efforts to (re)integrate religion and science. In my response to the third question, How do chemists currently view ultimate reality and meaning? I argue that "unifiers" in chemistry can also now play a key role in a reality revolution that is pointing humankind not only toward a possible historical (re)integration of religion and science but also toward a return to cosmology.

Keywords: breakdown of cosmology; chemistry; cosmology; IRAM; reality; (re)integration of science and religion; return to cosmology; URAM.

It can be argued that we humans are conceptual as well as perceptual reality seekers and that this is the most significant difference between ourselves and all other forms of life. However, our seemingly ageless, apparently innate human need to know about reality can be viewed as reducible to two fundamental, polarized, and yet complementary conceptual questions. The first question, How does reality function? is at the heart of our universal, timeless quest to understand *immediate reality and meaning,* a quest that I designate IRAM. The second question, Why

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does reality exist? is at the heart of our complementary universal, timeless quest to understand *ultimate reality and meaning*, a quest I designate URAM.

It is far easier superficially to define the word reality (e.g., everything that is, the way things are, and so on) than it is to answer the two penetrating questions about reality just posed. One reason for this is that every attempt to understand reality begins with a serious misunderstanding. For, throughout history, everyone has begun with the obvious "given" perception that matter is *the* seen, visible, visualizable, tangible, foundational "stuff" of reality. Unfortunately, the perception that unseen, invisible, nonvisualizable energy, space, and time are also major parts of reality has usually been far less obvious to most. In fact, humankind has begun to understand the roles of energy, space, and time significantly, in a seemingly materialistic reality, only in the last two hundred years or so!

How Did Chemistry Emerge as a Discipline?

A scientist might be defined as someone who specializes in attempting to answer the question of how reality functions. A chemist might be defined as someone who specializes in attempting to define the role matter plays in the functioning of reality but within the context of the related roles that energy, space, and time also play. Thus, chemistry might be defined as what chemists do within science. (Note: The words *chemist* and *chemistry* are modern derivatives of the words *Al Khyma*, used by Arabian alchemists over a thousand years ago to denote metal working and metal workers. The words *science* and *scientist* were apparently coined by William Whewell in 1840. Before the mid-nineteenth century, scientists were usually called natural philosophers.)

Extrapolating current terms and definitions just outlined back through human history, one might ask, Who were the first "scientist" and "chemist"? Interestingly enough, today's terms and definitions argue against the presence of any "scientists" and "chemists" in human history before 10,000 B.C.E. The discoveries of weapons, clothing, utensils, fire, and the wheel were apparently pragmatic solutions to the problem of survival rather than conceptual answers to the question of how reality functions. In fact, survival was such a critical problem (as evidenced by short average life spans) in the first 4 million or so years of human history that the more prominent of the two reality questions asked by early humans was probably why reality exists. And thus it was that early religious conceptual thought (as evidenced in primitive art, ritual, and burial of the dead) apparently characterized early human history rather than early scientific conceptual thought.

From about 10,000 to 500 B.C.E., there apparently were no "scientists"

and "chemists" either. It is true that a warmer global climate, coupled with an evolved brain, enabled humans in this period to alter their materialistic reality dramatically with an array of collective societal discoveries, ranging from metallurgy (the consecutive use of gold, silver, copper, tin, lead, bronze, and iron) to medicine and surgery. However, these tremendous accomplishments were pragmatic rather than theoretical in nature and thus did little to answer the question, How does reality function? But, by making life much easier than formerly in terms of survival, the accomplishments did provide human beings with increased time to think about why reality exists.

That increased time, coupled with the unique human ability to use "revealed" myths, fables, legends, and symbols to turn a limited understanding of why reality exits into formalized concepts of ultimate reality and meaning, led to the general development of religious animism, mysticism, idolatry, polytheism, monotheism, and Hinduism prior to the sixth century B.C.E. And in Confucius, Buddha, Zoroaster, Lao-Tzu, and the Jewish prophets, religious thought subsequently reached an anomalous zenith point in the sixth century B.C.E., a zenith point in terms of Judaism, which also later played a major role in the subsequent development of Christianity and Islam.

Of course, once such religious thought had been widely established through prophecy, revelation, and scripture, it usually was verified and codified through faith and ritual. And thus, prior to 500 B.C.E., once the question of why reality exists had seemingly been satisfactorily answered, the answers were invariably deductively extrapolated to also answer the complementary question of how reality functions, if, when and where that question was asked.

There was, however, one place in the world where the rapid general ascendency of religious thought in the sixth century B.C.E. was not only checked but also dramatically altered. That place was known as Ionia. The Ionians originally inhabited Attica in mainland Greece. However, in 1104 B.C.E., a nomadic, barbarous Iron Age people known as the Dorians invaded and conquered Bronze Age Greece. For the next several hundred years Greece remained under the brutal yoke of the Dorians in a reality-shattering period of time known as the Dorian Captivity. About 1000 B.C.E., the Ionians who survived the Dorian Captivity emigrated to the Asia Minor shores of the Aegean Sea, now part of Turkey. By 550 B.C.E., Miletus, the southernmost of the cities known as the "Ionian Twelve," had become an industrialized, wealthy port and center of trade (for both goods and conceptual ideas) of the known world. A highly sophisticated, urbane, educated leisure class had arisen, who were well acquainted with the most recent knowledge to come out of Egypt, Lydia, Babylonia, Phoenicia, and elsewhere.

The time was ripe for an anomalous, fresh reappraisal of the overall nature of reality. About 550 B.C.E., the Ionians became the first people in history to holistically seek both the overall mechanism of reality (how it functions) and also its underlying basis (why it exists) *without relying on prior religious thought, myths, poetry, and so on for help and answers.*

The Ionians sought the interrelated oneness of reality; their search was undergirded by the conviction that universal reality is a single, integrated reality system, unified and controlled by universal principles and laws, and that all things in universal reality (including humankind) purposively share in a common "good" order. Such a reality system was called the *Cosmos* by the Ionians, and the study of the cosmos became known as *cosmology.*

The Ionians, on the basis of today's definitions, developed the first science, the first philosophy, and the first natural theology, and subsequently combined them with various religious concepts to practice the first cosmology. However, they also practiced the first chemistry, by today's definition. For their first major conceptual question about how reality functions was, Is there a fundamental element or "stuff" at the heart of all matter that serves as the underlying, fundamental basis of the material cosmos?

It is generally acknowledged that Thales of Miletus was the first scientist, chemist, philosopher, natural theologian, and thus cosmologist, in history. On what is his nomination based? About 550 B.C.E., he proposed that water was the fundamental universal form of matter, he discovered magnetism and static electricity, he discovered Thales' Proposition (the earliest principle of occidental mathematics), he hypothesized that reality is permanent, and he hypothesized that God is immanent in reality!

In the next seven hundred years, Thales of Miletus was followed by such Greek cosmologists, philosopher-scientists, and philosophers as Anaximander, Anaximenes, Pythagoras, Parmenides, Heraclitus, Leucippus, Democratus, Empedocles, Anaxagoras, Diogenes, the Stoics, the Epicureans, the Sophists, Socrates, Plato, Aristotle, Ptolemy, and many others.

A detailed discussion of the reality-shattering, conceptual accomplishments of these Greek scholars, and their subsequent impact on human history, is beyond the scope of this essay. However, it would be misleading to summarize that impact broadly, as many have, by saying only that Greek thought helped both to set the historical stage and to write the script for the scientific revolution and the development of the scientific method in premodernity (before 1600–1650), the subsequent development of modern science and technology since then, and the currently unfolding play of modernity. Such an oversimplified depiction of history leaves three very important summations unsaid.

First of all, the nature of the fundamental material element, or "stuff," of reality remained a central question at the heart of Greek thought. The nomination of water as the fundamental element eventually evolved into the four elements (fire, water, earth, and air) and four qualities (hot, cold, wet, and dry) of Aristotle's and others' theories. Democritus was the first "scientist" and "chemist" in history to propose that atoms were the fundamental form of both matter and reality (atoms plus the "void"), but his atomic theory was rejected by most other Greeks. The four element and four quality theory was subsequently employed in a two-thousand-year pragmatic quest to turn the base metals into gold and silver. That quest, which overall became known as alchemy, was practiced as Eastern alchemy from about 300 B.C.E. to 600, then as Arabic alchemy from about 600 to 1200, and finally as European alchemy from about 1200 to 1600.

Second, it was Eastern and Arabic alchemy that subsequently kept early Greek "science" and cosmology alive (after the Greeks were conquered from without by the nonscientific Romans, the Romans were conquered from within by the nonscientific Christians, and the Christians passed through the Dark Ages) until they were rediscovered by Europeans in Arabic lands during the Crusades.

A subsequent medieval attempt to unite Greek thought with Christian belief became known as Scholasticism and was carried out after about 1100 in the first newly established European universities. However, the incorporation of experimentation into early Greek science by Roger Bacon, about 1250, and subsequently by others (e.g., Tycho Brahe, Johannes Kepler, Galileo, Copernicus, and Francis Bacon) created a rift and then a widening chasm between "early empirical science" and religion over the next five hundred years. But, buttressed by other major contemporary intellectual and social developments, beleaguered science gradually matured and grew in acceptance, influence, and power. Despite the fact that it lost the early conceptual reality battles with religion, it finally won the overall war about 1600–1650 and helped usher in the modern age.

Third, the evolving, accelerating, exponential success and power with which modern science increasingly has been able to answer the question of how reality functions now stands in sharp contrast with the traditional, seemingly static answers that religion and philosophy continue to give to the question of why reality exists. This increasing dualism and polarity, and resultant decreasing complementarity, has already resulted in the breakdown and fragmentation of Ionian cosmology in our age. In other words, that which the Ionians holistically put together in a premodern age that increasingly emphasized URAM has now been reductionistically rent asunder in our own modern age, which increasingly emphasizes IRAM.

In summary, I have now answered, even if briefly, the question, How did chemistry emerge as a discipline? However, beyond that, I also have attempted to superimpose and briefly defend my unusual hypothesis that chemistry is "the obvious, oldest science" and, as such, has played the longest and perhaps even the key role among all of the sciences in human attempts to understand reality. And, of course, overall, I have also attempted to "set the stage" for asking the remaining two questions, which follow.

How Do Chemists Currently View (Cosmic) Reality?

Space limitations in this paper preclude, not only a detailed answer to this question, but even a broad overview. The story of the interrelated, accelerating growth of an increasingly specialized chemical view of reality, within the context of a similarly growing and yet increasingly fragmented modern scientific view of reality, is so extensive and so complex that by necessity it must remain largely untold here. However, three perspectives in particular illuminate current developments in scientific thought about the nature of immediate reality and meaning (IRAM).

Holism. First of all, it should be pointed out that an increasing number of scholars, from diverse backgrounds, have been contending in the latter half of the twentieth century that they have discovered a "new reality" within modern reductionistic science. In that "new reality" the universe is viewed as being a single, orderly, integrated, holistic reality system, unified and controlled by universal laws and principles, within which humankind plays a significant role. In other words, more and more scholars are beginning to realize that the Ionians were right! In support of the aforementioned scholars, and out of respect and admiration for the Ionians, I will hereafter refer to the universe as the cosmos and the "new reality" as cosmic reality.

Some scholars are even now maintaining that cosmic reality can, or even should, serve as a basis for a historical reappraisal of the current relationship between science and religion, a possible reintegration of the two, and perhaps even a "return to cosmology." Growing evidence for cosmic reality (and the associated dramatic contentions it is prompting) is currently being drawn from twentieth-century science, particularly the "new physics," biology, genetics, and the neurosciences. The "new physics" is a term applied collectively to relativity, quantum theory, and recent discoveries about the origin, nature, and functioning of the cosmos, as provided by astronomy, astrophysics, and particle physics.

Chemistry generally seems to be relegated to a supportive role in most of the evidence currently being presented for cosmic reality. That's odd,

because if chemistry really is "the obvious, oldest science" as I have claimed, doesn't it also have its own unique story to tell about cosmic reality, and shouldn't it possibly have a bigger role in this regard in the evidence being presented?

Hierarchical Matter, Entropy, and Negentropy. As another facet of the largely untold story of how chemists and scientists in general interrelatedly view cosmic reality, it might be pointed out that not only have chemists always viewed matter as being the obvious major part of reality, but they currently also view it as being the only hierarchical major part or the only major part that consists of parts within parts within parts within parts. . . .

From that unique chemical perspective, the unfolding, overall account of cosmic reality as it is currently being related by the "new physics," biology, genetics, and neurosciences takes on a chemical essence that may have been previously unclear or even overlooked. The present account, ranging from the Big Bang to the historical appearance of human beings capable of conceptually seeking cosmic reality, clearly becomes more than merely a depiction of a cosmos that continually becomes more disorderly and less informational (more entropic) in terms of energy, in accordance with the second law of thermodynamics. The account also becomes a depiction of a cosmos that, in a countertrend sort of way, also becomes more orderly and more informational (more negentropic) in terms of matter, in accordance with what might be termed the cosmic evolution of matter.

Thus, the existence of hierarchical matter (electrons, quarks, neutrons, protons, atomic nuclei, atoms, molecules, objects, and living objects) clearly reveals the presence of a complementary, evolutionary, dual directionality in the cosmos as a major answer to the question of how reality functions. Furthermore, it can then be pointed out that DNA is the most orderly informational molecule known in the cosmos (there may be as much as 100,000 volumes of information stored in the DNA of a human fertilized ovum). It also can be pointed out that the human brain is the most orderly informational object known in the cosmos (the 100 billion information-processing, conceptualizing neurons present in the human brain can be connected in more possible ways than there are atoms in the universe). And thus it can be argued that the emergence of life and human conceptual thought may actually be the ultimate purpose of the functioning of the evolving cosmos. At a minimum, the hierarchical nature of matter raises the provocative question, Why is the human brain the only object known in the cosmos that is aware of the cosmos?

Matter, Energy, and Periodicity. As a third facet of the aforementioned, largely untold story of how chemists and scientists interrelatedly

view cosmic reality today, it might be pointed out that very few scholars and lay persons outside of chemistry seem currently to have a clear understanding of how matter and energy are complementary cosmic partners in the periodic law and the periodic table. In order to see why such a lack of understanding is so significant, it's necessary first to review several related segments of chemical history.

In 1649, Robert Boyle, the "skeptical chemist," dramatically refined and redirected Ionian thought and also historically sealed the coffin of alchemy by postulating that iron, sulfur, copper, and other substances are actually the fundamental elements of matter, rather than fire, water, earth, and air—which had been considered the fundamental elements for the previous two thousand years.

In 1869, Dmitry Mendeleev discovered that every such element belongs to one of seven "families" of elements, and each family is characterized by similar physical and chemical properties. In fact, Mendeleev furthermore found that each family was divisible into an A and a B subfamily. This summarization of the nature of matter became known as the periodic law, and Mendeleev's graphic representation of the periodic law became known as the periodic table. Like the Ionians, Mendeleev never knew how all matter was related, for the underlying basis of the periodic table, the electron, wasn't discovered until the end of the nineteenth century by J. J. Thomson and others.

In 1912, Lord Rutherford conducted his famous gold foil experiment, and on this basis formulated the solar system model of the atom, in which electrons revolve around a nucleus composed of protons. In 1932, the nucleus was found also to contain neutrons. In 1913, one of Rutherford's students, Niels Bohr, in a single stroke of conceptual genius, combined all previous understanding of matter with all previous understanding of energy to propose the existence of a complementary universal pattern of quantized (set) energy levels around the nucleus of every atom in the universe. Bohr further postulated that each electron in an atom, in violation of the laws of classical physics, remains in its own place in the pattern in one of the energy levels unless it is promoted to a higher level with an injection of energy from outside the atom. However, when the electron strangely "jumps" back down to where it belongs, in what might be described as a "cosmic dance," it emits the energy it previously absorbed as light of a certain set wavelength and frequency. In other words, Bohr discovered that light originates on earth and often elsewhere through electron "jumps" in atoms!

In the 1920s, Bohr and many other investigators, notably P. A. M. Dirac, Werner Heisenberg, and Erwin Schrödinger, developed quantum mechanics, a mathematical extension of Bohr's work. In one application of quantum mechanics, one can calculate the "address" and shape of

every "electron orbital" in any atom. Overall, it can then collectively be seen that Bohr's originally proposed electronic pattern actually consists of intricate energy levels within levels within levels, and thus order within order within order.

When one fits into Bohr's pattern the differing number of electrons (one to ninety-two) that each of the ninety-two natural elements in the universe has in its atoms, one sees another amazing repetitive pattern emerge. Eight families (each comprising A and B subfamilies) of elements arise, with all of the atoms of the elements in any particular family having the same number of outer-level electrons, albeit in a different outer energy level for each element. Since all of the families also are related by sequential numbers of outer-level electrons, ranging from an "extreme" of one electron to an "extreme" of eight, every element in the universe has a unique but related role to play, relative to all of the other elements. In other words, by revealing the underlying basis of the periodic table and the periodic law (discovered in 1869 by Dmitri Mendeleev), quantum mechanics actually revealed the cosmic blueprint underlying all matter in the universe.

What's the overall significance of the periodic law, the periodic table, and periodicity (the many orderly trends present in the periodic table)? I believe that it's only when one significantly understands the universal electronic energy blueprint based on light underlying all matter, as briefly outlined, that one can truly appreciate the "awesome" complementary way in which matter and energy function in the cosmos. For example, one then understands how the cosmic evolution of matter in general and the cosmic evolution of the elements takes place in the cosmos. One also then understands why carbon is the "cosmic elemental star" (the most unusual element) in the periodic table and the only element that can produce life and allow the evolution of life within the larger scheme of cosmic evolution.

An understanding of the periodic law, the periodic table, and periodicity also enables one truly to appreciate as well as simply to explain both the orderly way in which the cosmos unites atoms through the formation of chemical bonds to form molecules and the subtle chemical "tricks" the cosmos plays to bestow peculiar properties on certain molecules—"tricks" involving hydrogen, multiple and coordinate covalent bonds, bond angles, molecular geometry, molecular polarity, and so on. For example, "tricks" involving carbon allow the formation of carbon dioxide, amino acids, proteins, and DNA and thus the formation of both terrestrial and extraterrestrial life. In this regard, carbon dioxide and DNA might be called "cosmic molecular stars."

However, water could be viewed as being the biggest "cosmic molecular star" of all, and an understanding of the periodic law, the periodic

table, and periodicity enables one to understand why. In that regard, whenever and wherever two hydrogen atoms combine with one oxygen atom to form a molecule (particle) of water, the uniqueness of the resulting molecule is synergistically greater than the sum of the uniqueness of each of the two elements. The unique electron pattern in oxygen atoms dictates that water molecules are bent in terms of their two intramolecular chemical bonds rather than linear. And hydrogen's elemental uniqueness dictates that water molecules have a much greater intermolecular attractability than might be expected because of a rare type of chemical bond that only hydrogen atoms can form (with only three elements, including oxygen), known as a hydrogen bond. The remarkable story of chemical bonds, one of the four forces that hold the cosmos together, and the role of light in those bonds will unfortunately have to be omitted here because of space considerations.

Working in unison, the bent shape and unusually high attractability of water molecules produce liquid water rather than gaseous water at room temperature and also more than twenty other highly unusual properties of water, properties that, when added to those of carbon, make possible life in the cosmos.

In summary, I have been able to outline only briefly three isolated fragmentary facets of the vast, still largely untold story of how chemists and scientists currently interrelatedly view cosmic reality. However, I nonetheless hope that the reader has at least caught some significant glimpses of the important and yet often overlooked contributions that chemistry can make to the story.

How Do Chemists View Ultimate Reality and Meaning?

Ironically, chemistry ("the obvious, oldest science") has played a major role both in the establishment of cosmology about twenty-five hundred years ago and also in the polarization of science and religion and the breakdown and fragmentation of cosmology in our own modern age. Is it possible that the pendulum of history is now swinging back toward a (re)integration of science and religion and even a "return to cosmology"? And is it possible that chemistry could once again play a major role in such a historic swing?

The answers to these two questions depend, of course, on how a chemist (or any scientist) views the question of ultimate reality and meaning (URAM). Some chemists (and other scientists) might be called scientific diversifiers in this regard, for they largely are interested only in the polarized, reductionistic, immediate reality and meaning side (IRAM) of chemistry (or science) and thus only in the question of how reality functions. However, other chemists (and other scientists) might be called scientific unifiers, for they are also interested in the URAM

side of science. They view the questions of how reality functions and why it exists as complementary polarities in the human need to know about reality.

The currently unfolding account of cosmic reality seems to be defining an increasingly mathematical, nonvisualizable, holistic, interrelated, complementary, unified, systematic, finely tuned, informational, lawlike, recursive, temporal, nonlocalized, dynamic, creative, evolving, and even mindlike cosmos in which humans play a significant role and may even be its purpose. It's a cosmos much as the Ionians generally viewed it. However, if the overall holistic oneness of the cosmos increasingly is being revealed, is the oneness itself ultimate reality and meaning, or does the oneness actually point to deeper reality and meaning, a One?

Scientific diversifiers still tend to agnostically or atheistically view the cosmos just outlined as being a random, accidental, anthropic "universe." However, scientific unifiers tend to see a planned, designed, theistic, anthropic cosmos. Overall, it's an exciting time to be alive, for the scientific unifiers seem to be gaining in number and conceptually gaining historical ground. In fact, the questions of a possible (re)integration of science and religion, and even of a possible "return to cosmology," seem now to be coming into increasingly sharp focus on the frontiers of thought. And once again, chemistry seems to be playing a major role in a "reality revolution" that is pointing us toward the future. The Ionians *were* right!

REFERENCES

Anderson, Byron D., and Nathan Spielberg. 1995. *Seven Ideas That Shook the Universe.* New York: Wiley.

Brown, Theodore L., Bruce E. Bursten, and H. Eugene LeMay. 1991. *Chemistry: The Central Science.* Englewood Cliffs, N.J.: Prentice-Hall.

Clarke, R. E. D. 1961. *The Universe: Plan or Accident?* Exeter: Paternoster Press.

Cobb, Cathy, and Harold Goldwhite. 1995. *Creations of Fire: Chemistry's Lively History from Alchemy to the Atomic Age.* New York: Plenum.

Davies, Paul, and John Gribbon. 1992. *The Matter Myth.* New York: Simon and Schuster.

Horigan, James E. 1978. *Chance or Design?* New York: Philosophical Library.

Life in the Universe. Special Issue. 1994. *Scientific American* 271, no. 4.

Murchie, Guy. 1980. *The Seven Mysteries of Life.* Boston: Houghton-Mifflin.