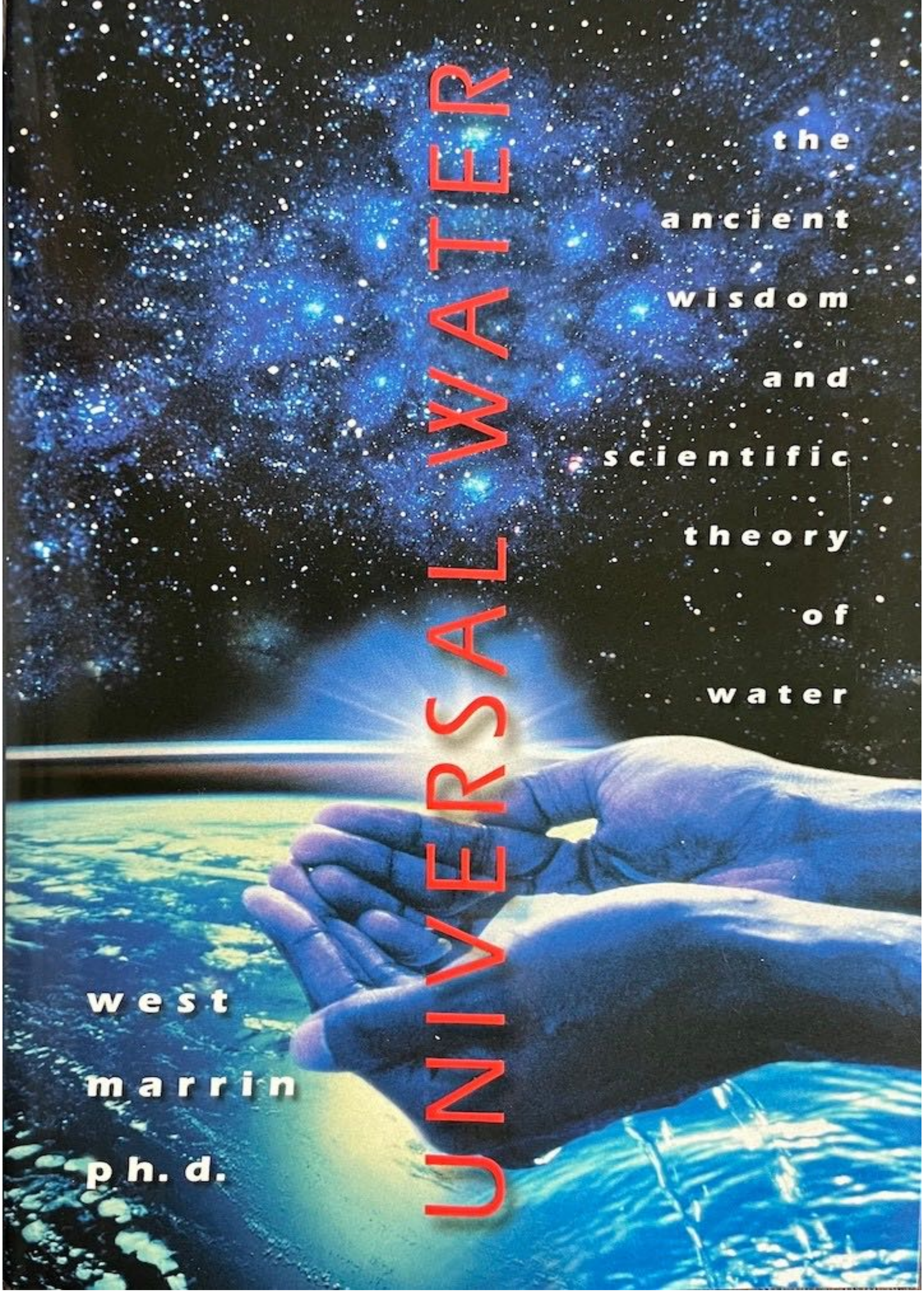
UNIVERSAL WATER
the ancient wisdom and scientific theory of water
west marrin ph. d.

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The Ancient Wisdom and Scientific Theory of Water

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DEDICATION

To my mother, Dorris, and to Meridith and Alandra,

whose support made this book a reality.

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ACKNOWLEDGMENTS

This is a book that draws upon the works and insights of countless human beings over millennia. I offer my sincere appreciation and heartfelt thanks for their wisdom, intuition, intellect, creativity, and persistence in addressing the mysteries of the universe, not the least of which is water. Because much of my inspiration for writing this book lies within the non-human realm, I also offer my gratitude to the Earth, to our fellow species, and to the water that serves as a never-ending source of wonder and joy for me.

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INTRODUCTION

The water of life is easily had: everybody possesses it, though without knowing its value.
Carl Jung, *The Water of Life*

We twenty-first century humans are facing some monumental decisions regarding water. Our decisions will affect not only the future quality of our lives, but also the very survival of many species that share this watery planet with us. These decisions must address issues that are well known to most of us. Will there be enough water? Is our water clean? Who will pay to treat the polluted water? Will transnational corporations ultimately control and distribute the world's water supplies? As we prepare ourselves to address these critical issues, largely on the basis of economics and politics, maybe it is time to ask more difficult questions. What is water, really, and is its role in our lives and within our universe much more fundamental than we currently perceive? In other words, might our common perception of water actually restrict our ability to make wise decisions regarding this substance? While such a question may not be fully answerable at present, its serious consideration could not be more timely.

How could we possibly fail to perceive water? After all, water is the major component of our physical bodies and a part of our everyday lives. We drink it (perhaps not enough of it) and irrigate our crops with it. It comprises the rain on our umbrellas and the snow beneath our skis. It is the familiar stuff of rivers, lakes, springs, and the oceans. We seem to be continually touching, hearing, tasting, and seeing water in our lives. Of course we know water. Don't we? Well, we believe that we know water through our five physical senses and through our intellectual understanding of it as a commodity (both financial and aesthetic). However, these human "faculties" may represent a relatively narrow window through which to perceive water. The people of many ancient cultures, as well as modern naturalists and scientists, suggest that water is substantially more essential to our life processes and fundamental to our universe than most of us realize.

Water is one of the most puzzling of all substances in the universe. The ubiquity of water on our planet, combined with its bizarre physical properties, has made it a favorite topic of philosophers, naturalists, scientists, priests, sages, and shamans throughout the ages. It sometimes seems that the lore and mystique of water has been reiterated so often and by so many sources that the whole subject has become rather commonplace. The unique and sacred nature of water has been proclaimed so often that it tends to bounce off us like an advertisement that we have seen or heard for the hundredth time. While we may believe that water's sacred nature is somehow true, we are not certain of exactly why it is true or what relevance this truth (assuming we knew it) has to our lives. I believe that the relevance comes right back to the far-reaching decisions that humanity is facing with regard to water. Indeed, our perception of water might have been a key to creating our self-imposed challenges with this substance, and it might also be a key to meeting those challenges.

If so, what might prompt us to question our usual perception of water or, at least, to entertain a different perception—whether or not we actually adopt it? The answers to this question are many and varied. In my case, the combination of modern science and ancient wisdom, along with various personal experiences and insights while working with or playing in water, has shaped my perception of water. While my focus in this book is not on my sharing the details of those experiences, their profound influence on my perception of water will be evident from the interpretations and questions that I present. Instead of simply reviewing our challenges with water and suggesting possible solutions to meet those challenges, I propose that expanding our usual perception of water may serve us in a more fundamental sense. That is to say, we can continue to formulate solutions from essentially the same perception of water that created our challenges, or we can approach these challenges from a different perspective. My intent in writing this book is to confront our postmodern perception of water by presenting interpretations of history, naturalism, and science that portray water in admittedly unfamiliar ways.

Almost invariably, ancient and indigenous cultures considered water to be sacred. It was sacred not only because it was required to maintain their physical bodies, but also because it was a link to the divine. Their knowing was based not on an intellectual understanding of water's unique physical and chemical properties, but rather on an intimate relationship with or experience of water's essence. Ancient and indigenous peoples' perceptions of the world were often based upon a perception of oneness, within which everything is an aspect of Spirit or an integral component of the *Great Chain of Being*. The Great Chain of Being is usually defined as the ancient and immutable knowing that Spirit both transcends and imbues all levels of the universal hierarchy (e.g., rocks, water, humans, stars).

Science is a primarily intellectual endeavor that is usually defined as describing the physical world on the basis of proposing hypotheses, testing those hypotheses, and interpreting the results of testing. While scientific interpretations are constantly changing, science represents one of the modern era's most powerful tools for understanding both water and the greater universe. Yet most of us are unaware of the unusual places that water exists and of its role in facilitating events on galactic and molecular scales. Although scientific descriptions of water differ markedly from ancient descriptions, both ways of perceiving water suggest that "ordinary" water is perhaps the most extraordinary substance in the universe. While searching for a connection between modern science and ancient wisdom is a fascinating endeavor, I believe that the real value in exploring these two ways of perceiving water may be to provide a forum for asking unusual questions and trying out perspectives that lie beyond the recognized boundaries of either.

Water is already being referred to as the most critical resource of the twenty-first century. In my view, water's status on this planet will likely remain critical until it is no longer perceived exclusively as a resource or commodity, but instead as an essential player in creating and sustaining our universe. Water is not only mysterious in fulfilling its universal mandates; it is also supremely subtle. Much of water's magic escapes our recognition unless we intentionally look for it. Perhaps our perceiving water with such intent will foster a reverence (rather than just an appreciation) for water, encompassing not only the precious freshwater resources that we depend upon, but also the earthly and cosmic water that we rarely have occasion to consider.

There are many paths to perceiving and experiencing water. Perhaps in this new millennium we will choose to seek out different paths to "knowing" water. Along the way, we may catch a glimpse of our ancestor's experience of sacred water, even if we never fully realize their perception of water as a living and sentient entity. Our sacred connection to water may emerge from the postmodern combination of science, naturalism, spirituality, and whatever other modalities we eventually use to explore and experience water. Although nothing in this or any other book will substitute for a personal experience of water, exploring the ancient wisdom and modern science of water's magic may serve to open us to such an experience.

While this book draws upon the disciplines of science, naturalism, and history, it actually does not represent any of these disciplines. It is a journey into the beliefs, experiences, hypotheses, theories, and associated interpretations of water that have been shared over time. Some interpretations I have cited from water-related inquiries, while others I have adapted from theories that were not originally developed to address water (at least not in the way that I have addressed it). Because this book touches upon many fields within each discipline, readers may find particular sections of the book challenging due either to their complexity or oversimplification. In either case, I encourage you to make the effort to sample the ways in which others (including me) have perceived water—not to adopt their perceptions, but instead to glimpse the sacredness and profound mystery of water while forming your own perception.

West Marrin
Kaua'i, Vernal Equinox 2002

PART ONE

ANCIENT WISDOM

History itself involves the human imagination reflecting on events and on patterns of cause and effect.
Douglas Davies, *Myth and History*

The first three chapters explore ancient wisdom as conveyed by philosophical insights, sacred truths, and myths. Rather than scholarly knowledge or the possession of facts, ancient wisdom is often associated with a perception that has stood the test of time.

CHAPTER 1

ANCIENT MYTHOLOGY
Pantheistic Insights

I am one thing. I am many things. I am water. This is my dance through our world.
Thomas Locker, *Water Dance*

Ancient people generally "knew" water as the living and conscious entity that gave rise to the material world. It was not viewed as an inanimate liquid, but rather as a symbol for the primordial "non-stuff" from which the Creator manifested everything in our universe. Within these very human insights lie the roots of today's scientific and non-scientific understandings regarding water's ubiquity, indispensability, mediation, and perhaps even its role in cosmology. Although the ancient myths themselves are seemingly no longer relevant to modern humans, the messages behind those myths may be quite relevant. While reading this chapter, note the similarities among different cultures' perspectives of water in the seen and unseen worlds. The pantheons represent more than just an assortment of strange characters, they are the story of how our ancestors experienced and intuited the world around them, including water.

RECORDED HISTORY

Since the beginning of recorded history, water has held a special place in the spiritual, physical, and intellectual lives of people who represent an amazing diversity of cultures and civilizations. While rituals, languages, beliefs, and "scientific" prowess among the cultures differed greatly, there are some basic understandings regarding water that seem to transcend both culture and time. I will refer to these tenets or understandings as ancient "insights" about water, many of which have been passed down to us in the form of myths. I am not a historian, and this look at myth is not meant to represent an exhaustive search into the multicultural meaning of water throughout human existence. Instead, my intent is to focus on a few persistent insights about water that have surfaced repeatedly throughout history, including during the twentieth century.

A link between water and Earth, life, and humans was instinctively known by ancient peoples, who expressed their reverence for the life-giving substance at places where it was released from the body of the Earth. These places included springs, wells, lakes and rivers, which became sacred sources of nourishment and the site of rituals, prayer, and gift giving. Evidence for this type of water worship has been found in most of the major civilizations of the world, including those of Egypt, Greece, Troy, Babylon, and Rome, as well as in the indigenous cultures of the Australian Aborigines, American Indians and some of the African tribes.[1] As discussed in the Introduction, these ancient and indigenous cultures experienced water in a different manner than do we in today's postmodern world. Hence, their rituals were not simply activities prescribed by a particular belief system, but rather were intended to give thanks to an entity or essence with which they felt a connection.

As is the case with all forms of written history (e.g., mythological, philosophical, biblical), the meaning of symbols, metaphors, and passages are not unequivocal. The intent of the original writer, artist, or storyteller is very difficult to discern due, in large part, to the inherently ambiguous nature of language as a means of describing phenomena. This is particularly true for phenomena that lie beyond the world of our five senses. Moreover, most of written history has been subject to numerous translations, each of which requires a subjective interpretation of the previous translator's words. The challenge is that words have multiple meanings and the context within which they appear does not always discriminate among meanings.

Choosing Some Words

Throughout the first three chapters, we will repeatedly encounter concepts such as God, heaven, Spirit, and the processes of creation and/or manifestation. It could be argued that these terms merely relate different aspects of an energy or beingness that pervades everything in existence; however, some distinction is necessary in order to examine such concepts as they appear in ancient worldviews. Without embarking on a long explanation of how these terms may vary their meaning, I have arbitrarily selected a set of words that seem to best describe the concepts under discussion.

I will refer to the energy state as *the Absolute*, because it designates an unmanifested and inseparable state. In the literature, this state is variously referred to as the Absolute, the Unlimited, Source, pure consciousness, unlimited potential, infinite energy, and innumerable others. The process of manifesting matter, energy, or various fields from the Absolute I will refer to as *creating*, and the intelligence or knowledge that is associated with the Absolute and is responsible for creation will be designated as *the Creator*. The Creator is also referred to as God, Great Spirit, the Supreme Being, Divine Love, and many other names denoting an ultimate deity. While the terms I have selected necessarily reflect some "lumping or splitting" depending on one's viewpoint, a rough definition of terms is required to discuss the spiritual aspects of water and of the universe.

In addition to the spiritual terms, it is important to understand that my use of the word *manifested* refers to something that exists in the physical world, whether or not we perceive it with our five senses. While most people readily identify matter (at least that in the macroscopic world) as a component of manifestation, they are less likely to recognize energy and fields as manifestations, because they cannot be readily detected without instruments. The most common types of energy are mechanical and electromagnetic, such as sound and light, respectively. A field is actually a collection of numbers that describes the direction and intensity of a force at every point in space. Forces exert their influence over matter and energy through so-called *field effects*. The nineteenth century British scientist Michael Faraday introduced the concept of fields as they related to electricity and magnetism; however, the concept of fields has since been extended to include other forces (e.g., gravity, vorticity) and energy.

A PANTHEISTIC PERSPECTIVE

Almost all ancient civilizations explained creation, their existence, and the world in which they lived through the persona of gods, goddesses or other deities that symbolized the universe. Whether these deities represented actual beings or fictional characters is not known for certain. In either case, *pantheism* refers to the doctrine that God (including aspects that I referred to as the Absolute and Creator) is not a personality, but rather the combined laws, forces, and manifestations of the universe. Mythical characters and events were generally woven together in the form of a story, serving as a means to orally share an experience or insight about reality. These stories were often rich in symbol and metaphor, whereby familiar events and objects represented unfamiliar or unseen aspects of the world.

Sumerian and Babylonian

The first generally recognized written history comes from the Sumerians, who inhabited the Mesopotamian region more than 5000 years ago. According to mathematician Ralph Abraham, there were four gods that endured throughout Sumerian history who represented heaven, earth, air, and water.[2] *Enki*, who represented both water and wisdom, apparently evolved from the same underworld ocean that created heaven in the persona of *Anu*. Anu is the prime mover in creation and took over heaven when it was separated from Earth (*ki*), creating the universe as we know it.[3] The underworld was sometimes referred to as a river and apparently existed beneath the surface of the Earth as a freshwater (not saline) body of water. The Sumerians believed that the saltwater oceans were created from this freshwater sea or river, as was everything in manifestation. Enki, a son of Anu, was the god of this watery underworld and is often depicted as a being with streams of water flowing from his arms while he receives worshippers.[4] Notice that even in the earliest Sumerian pantheon, water is associated with heaven and is worshipped as substance of wisdom and magic.

Moving forward in time to the Babylonian civilization, the Sumerian name of Enki evolved into the Semitic name of *Ea*, which remained the personification of water or the deep. Ea's home was the waters of chaos that existed before creation. Actually, there were three watery beings that Ralph Abraham refers to as the "trinity of chaos," which included *Apsu* (the sweet water), *Tiamat* (the sea) and *Mummu* (the clouds and mist).[5] Apsu was located just above the river or sea of the underworld and was believed to be the source of springs, wells, rivers, lakes, and other freshwater sources on the Earth's surface. Tiamat was the tumultuous and dragon-like god of the sea, which was believed to encircle the Earth. Apsu and Tiamat were depicted as a male-female pair who mingled their waters and engendered a line of gods including Enki and Anu.[6]

In the Babylonian epic of creation, the only entities in existence before the separation of heaven and Earth were Apsu and Tiamat, each of whom represented one half of the pre-creational chaos. Hence, only water (as the combination of freshwater and a sea) existed before the division of heaven and Earth. Born from Apsu and Tiamat, Mummu represented the water above the Earth but under heaven. Note the similarity between this myth and the biblical account of God dividing the primordial waters, via the firmament, into heaven and the Earth (including the waters and dry land under heaven). It is also interesting to note that, according to Mesopotamian mythology, the waters were associated with the "chaos" that existed before creation. Tamra Andrews notes that myths from around the world recognize that creation was preceded by an original state of chaos, which defined a state of formlessness and was often identified as a void, abyss or primordial sea.[7] She further observes that, with respect to the ongoing battle between order and chaos, the former was essential for survival and the latter facilitated cyclic renewal via its constant intrusion.

Egyptian

Relocating from Mesopotamia to North Africa, we next encounter the ancient Egyptian civilization. In the Egyptian pantheon, water in the form of moisture is personified in the god *Tefnut*, who was symbolized by the moon. Tefnut was the twin sister of the god *Shu*, who represented the sky and, perhaps, the air as well. The twin siblings separated the sky from the Earth and engendered a number of the great gods, including *Osiris* and *Isis*.[8] Together, Tefnut and Shu represented the left and right eyes of *Temu* and, in doing so, combined some aspect of the air or sky with water or moisture. Temu represents the oldest of the Egyptian creation gods, who made a home for himself in the celestial waters from which he created the heavens, stars, planets, gods, men, animals, and plants.[9]

Notice that the Egyptians, similar to the Sumerians and Babylonians, believed that the heavens and Earth (including all the inhabitants of this planet) were created from the primordial or celestial waters. According to both the Babylonian and Egyptian myths, the mist or airborne moisture was created from the primordial waters and was figuratively positioned between heaven and Earth. Mists or airborne water apparently occupied an intermediary position between heaven and Earth and was not a component of the original waters of chaos.

The Egyptian pantheon introduces us to an insight that surface consistently in ancient cultures, namely that the interaction between water and the Sun (or fire) is fundamental to all earthly forms. Even the ancient creation god, Temu, like all the gods of ancient Egypt, is less well known than the great Sun god, *Ra*. Ra created both Shu and Tefnut, and was considered by the Egyptians to be intimately involved in the process of creating the manifested world. Ra's Sun disk supposedly appeared above the waters of chaos as one of the first acts of creation, thus signaling the beginning of time.[10] Ra made his journey over the water in a boat because the Sun was made of fire and, therefore, could not have risen out of the waters of chaos on its own. Similar to the Egyptians, the ancient Aztecs of present-day Mexico described the interaction or union of fire and water as the basis of all creation.[11]

In the Egyptian pantheon we again encounter the belief that everything is created from the waters of chaos by a being that, similar to God in the Bible's Book of Genesis, appears above or within the waters. Ra was considered by the Egyptians to be the source and center of all life, thus imparting the universal harmony of the cosmos to all of manifestation. In both the Egyptian and Mesopotamian traditions, water (as the waters of chaos) was considered to be the primary cosmic Element from which all life emerged. The subsequently created (i.e., physical) seawater often represented vastness and unpredictability, whereas freshwater usually represented wisdom, fertility, and life. Throughout this book, the capitalized word "Element," will refer to the original substances (e.g., fire, air, water, and earth), while the lower case "element" will refer to components of a system or to atoms comprising modern chemistry's Periodic Table.

The most ancient references to water are those of pantheistic characters who represented both the wisdom and primordial nature of this substance. Water was associated with the unmanifested chaos from which the heavenly and earthly realms were created and with the physical substance that linked the seen and unseen worlds.

The Greek Trinity

The next great civilization of the world was that of ancient Crete and Greece, whose pantheistic characters are probably the most colorful and well known in history. Before examining the litany of gods and goddesses who represented various aspects of water, let's take a look at the deities known as *Chaos*, *Gaia*, and *Eros*. While the names of these pantheistic characters are derived from the Greek language, Ralph Abraham has traced the concepts of chaos, eros, and gaia throughout human history. He has found that they underlie the Trinity, which appears in the writings of almost all ancient cultures.

In other words, the Greek trio of Chaos-Gaia-Eros may simply represent the best known of the holy Trinities. However, the understandings that separateness is nothing more than an illusion in our world and that the Trinity is actually an aspect of the One are not unique to the ancient Greeks. Other well known Trinities include the Hindu trio of *Brahma-Vishnu-Shiva*, the Hawaiian trio of *Kane-Ku-Lono* and the Christian trio of *Father-Son-Spirit*.

Abraham found that Chaos represents the Absolute (i.e., the creative source of all form), Gaia represents physical manifestation (i.e., the form of living Spirit and the world) and Eros represents the spiritual medium connecting Chaos and Gaia (i.e., the creative impulse).[12] Chaos has also been interpreted to mean "space" in the sense of the place where everything originated, including all other Greek deities.[13] Hence, the ancient reference to the "waters of chaos" may have had nothing to do with the colloquial interpretation of chaos as disorder, randomness, or confusion. Instead, the chaos of primordial or celestial waters describes the formless matter and infinite space that existed before the creation of a material universe.

It is worth noting that the word "gas" was apparently derived from chaos, perhaps reflecting Aristotle's mistaken view that all space or voids would necessarily be filled with air or gases. However, it is clear the earliest and most pervasive of ancient myths link chaos to water, not to air. Perhaps because water vapor and suspended liquid water (e.g., clouds) are components of air on this planet, the ancient Element of water was sometimes portrayed in an airy setting.

Greek Water Deities

Born from this primordial Chaos (or water) was Gaia, who was the first of all the Greek gods and who inhabited our planet after it was formed.[14] Gaia breathed life into a lifeless planet and created the mountains, rivers, oceans, plains, and other recognizable features that we now refer to as *Earth*. It is interesting to note the distinction between the living spirit (Gaia) and the planetary form that serves as her physical body (Earth), not unlike the classic distinction of soul and body in humans. Gaia (as the Earth mother) gave birth to

Uranus or *Ouranos* (as the sky) who became the lover and consort of his mother. Together, Gaia and Uranus gave birth to three sets of children, which include the pantheistic characters that represent water.

Because the Greek pantheon is so detailed in comparison to its predecessors, water is now divided among various deities who represent different aspects of this Element. Among the most powerful and well known of these watery gods is *Oceanus*, who is generally considered to be the Greek personification of water. The god known as Oceanus is, of course, at the root of our English word "ocean," where most of the water on Earth is contained. In addition, *Poseidon* ruled over the ocean tides and rivers, *Tethys* was a primordial force that personified the fertility of the seas, and *Achelous* was the oldest of the river gods who oversaw the largest freshwater river in Greece.

While there are still more Greek gods and goddesses who had dominion over various hydrological or spiritual aspects of water, I will not attempt to identify all of them. There are two insights regarding the ancient Greek's understanding of water that are relevant to our discussion. First, they believed that water not only was everywhere but also constituted everything, such that all things manifest in this world (e.g., stones, clouds, people) represented transformations of water.[15] In other words, all things manifest on Earth were simply water that was structured or molded into different external forms. Second, the Greeks associated various aspects of water with the Sun, which is personified by *Helios* as a god of light who sees and knows everything. The interaction (either cooperative or antagonistic) between an all-knowing Sun and a transformative water appears to be a ubiquitous theme in the ancient cultures of both the Old and New Worlds.

The interaction between an all-knowing Sun (or fire) and a transformative water appears to be common among ancient cultures. An interaction between chaos and order may have symbolized the universal balance that exists between the Absolute and manifested forms.

Chinese

Mythical insights regarding water also have origins in the Far East. For instance, an ancient Chinese water god known as *Long Wang* possessed the ability to divide himself into countless forms, including dew, floods, landscape features, and even various animals.[16] Here again, the act of dividing water is related to the creation of vastly different forms, which simply represent different transformations of water. Another Chinese water god known as *Gong Gong* was supposed to have quarreled with the god of fire at the beginning of creation. Gong Gong's actions tilted the universe and caused everything to slide into chaos.[17] As appears to be case for Chinese, Greek, and Egyptian pantheons, the interaction between water and fire has something to do with the universal balance that exists between chaos (as the Absolute) and order (as manifested forms).

Interestingly, the Chinese was one of only a few cultures that did not associate the primordial chaos with water in the form of a sea. Instead, the ancient Chinese apparently portrayed the chaos as a misty vapor that embodied the cosmic energy governing space, time, and matter.[18] Nor did the Chinese invoke a divine will or anthropomorphic deity (i.e., a Creator) to manifest the material world, as did most other ancient cultures. The formless misty vapor, from which the duality of *Yin* and *Yang* were born, gave rise to all earthly life forms. Misty vapors are not uncommon among ancient myths (e.g., Mummu in the Babylonian pantheon), particularly with regard to a universal etheric substance. A mist usually represents liquid water that is suspended in air rather than a gaseous component of the air itself (e.g., water vapor), which would have been nearly impossible for ancient people to visually distinguish. Is it possible that this misty vapor is simply a different watery metaphor for the Absolute? Perhaps the Chinese preferred a boundless mist to a boundless sea in describing the primordial chaos.

Dragons are undoubtedly the most famous of pantheistic beings in Chinese mythology. While dragons represent evil in most ancient traditions, Chinese dragons were benevolent spirits of the waters that often represent rain and the fecundity of Nature.[19] It is believed that dragons represented supernatural beings who were renowned for their miraculous changes or transformations. Once again (this time as the personification of dragons), water may be associated with the transformations that ultimately create the many life forms on this planet. It has been suggested that even the spirit world was divided into a Ministry of Waters, whereby seawater is overseen by four dragon-kings representing the cardinal directions and freshwater is ruled by four dragon-kings representing each of the major rivers of China.[20] These dragon-kings may have represented "components" of the larger water gods that were discussed.

WATER, SEAWATER AND SEAS

Most references to water in ancient myths either refer specifically to freshwater or do not differentiate between freshwater and seawater. However, some cultures left us insights that speak directly to seawater or, more commonly, to seas in both a literal and symbolic manner. Perhaps the most universal of these references is to the *primordial* sea that existed before the creation of the material world. The primordial seas were often associated with the serpent, symbolizing the formless chaos and undifferentiated matter of the underworld waters that comprised the cosmos before its division into realms. Tamra Andrews observes, "The concept of such a sea reflected the fact that ancient people recognized creation as the emergence of form from formlessness. Water, it seemed, was formless. So from the water, earth and life emerged."[21] She also speculates that the concept of a primordial sea was founded on the notion that water held all possibilities within itelf. Herein lie two important clues as to why ancient people may have selected water (and seas) as a metaphor for the Absolute.

The *cosmic* sea apparently stems from a belief in a heavenly ocean that is related both to a primordial sea and to the knowledge of Earth's physical oceans. In other words, the structure and function of the oceans on this planet were analogous to those of the cosmic sea in the celestial realm. In fact, ancient cultures apparently recognized that there was an exchange of water between these two fluid realms[22]. Dew and mist seemed particularly good examples of the exchange between aqueous and celestial realms. Here again, the mist or moisture seems to occupy an intermediate position between earthly waters and the celestial or heavenly realm.

The perceived fluidity of both water and the heavens is another reason why ancient people may have referred to the Absolute as a sea. The oceans were perceived as an animate being that could be recognized by waves, tides, and other types of rhythmic communication. A plethora of shape-shifting and mood-swinging sea gods were recognized by the various ancient cultures. Many of these sea gods were also responsible for the world's climate, which is an interesting observation given the ocean-climate interaction that has been described by modern science and will be discussed in Chapter 7.

One interpretation of Hawaiian mythology maintains that the primary creational god, Kane, manifested heaven and earth from the primordial chaos with assistance from the other two members of the Trinity, Ku and Lono.[23] *Kanaloa*, who is often associated with the squid, was the first leader of the spirits placed on the Earth after it separated from heaven. It is interesting that Kane is believed to personify freshwater and Kanaloa to personify seawater. Hence, the primary creational god is associated with freshwater on the earthly realm, perhaps indicating a connection between earthly freshwaters and the primordial chaos. By contrast, the god of seawater was created as part of Earth and is clearly not associated with the primordial chaos. While Kane was sometimes characterized as being in conflict with Kanaloa during the act of creation, the two established an amicable relationship after creation (e.g., as fellow drinkers, travelers, and water finders) and were often considered as a watery duo.

One of the ancient Polynesian chants that refers of the water of life is dedicated to Kane. The recognition of and search for the water of life (or *living water*) is one of the most pervasive themes among ancient cultures. In most ancient traditions, living water refers to a magical or extraordinary form of the liquid that imparts life, rather than to the "ordinary" liquid that sustains life. The perceived difference between these two forms of water is a topic that we will explore from a myriad of viewpoints. The last stanza of the ancient chant, *The Water of Kane*, is translated as follows:

> One question I put to you:
> Where, where is the water of Kane?
> Deep in the ground, in the gushing spring,
> In the ducts of Kane and Loa [Kanaloa],
> A well-spring of water, to quaff,
> A water of magic power —
> The water of life!
> Life! O give us this life![24]

Use of the words "waters" and "sea" as ancient metaphors for the Absolute (unmanifested chaos) may be related to their connoting formlessness, boundlessness, fluidity, limitless possibilities, and perhaps a forgotten or unknown attribute of the physical substance, H_2O.

Water That Remembers

After listening to the stories of and being initiated into the indigenous Maori culture of New Zealand, former archeologist Barry Brailsford has published a series of books that relate the Maori view of the world. Of interest to our discussion is their view of water. The Maori word for water is *wai*, which also means remembrance or the recollection of something that has been. Water is referred to as the memory of all that has ever been and will be. In a discussion between two characters in Brailsford's book, *Song of the Whale*, reveals the Maori belief that water is both of the stars and of the Source.[25] Like so many ancient and indigenous cultures, the Maori consider water's memory to serve as the spark of life and to be intimately associated with the process of creation.

How water is able to retain or access memory is not a component of ancient or indigenous myths; however, the almost universal insight that such memory is constrained neither by space nor time is one that has stirred considerable controversy in the scientific world. The Maori say that water, while traveling through space and time, remembers its journeys among the stars and into the many compartments of the Earth's body.[26] Water's ability to recall its travels suggests that it physically retains, rather than just accesses, memory. Myths that delve into water's memory usually bestow either one or the other of these two abilities upon water.

The Maori tradition recognizes two "ancestors" of the water.[27] The Ocean Maiden, *Hine Wainui*, is the body of the waters whose vibrations (represented by a voice or waves) are bounded only by the land. She reaches from the parent rock on the seabed to the mists in the skies, thereby forming the vast oceans that are recognized as the greatest crystal in the world. The Ocean Maiden gives birth to the Rain Maiden, who is lifted from the ocean waves by the wind and is carried overland in forming the rain. Water from the Rain Maiden is always returned to the ocean, where it began its journey. The notion that oceans serve as a reservoir for earthly water is common knowledge today; however, the notion that they function as a planetary-scale crystal certainly is not. The Maori myth is unique in its suggesting that seawater functions as a crystal, rather than as just the source of all earthly (not cosmic) waters. What functions might a planetary-scale crystal perform? We will consider this question in later chapters.

Mythical Waters

Pantheistic myths seemingly indicate that the "waters" were associated with the home of a creational god who existed before the world was manifested. While these waters may not refer literally to the H_2O molecule, they probably depict an energy or substance that is either analogous to or best represented by the essence of water. It has been suggested that as a source of life and a means of purification, water is the prototype for spiritualized matter.[28] The notion that water has been used throughout history as a metaphor for the sacred and indefinable "non-stuff" of the universe is one that we will encounter repeatedly. Assuming that water has indeed been used as a metaphor, what is the relationship between metaphoric water and the substance that is composed of

H_2O molecules? Is there, in fact, any relationship between the two? And, if so, how does any relationship between the two play out in the manifested world?

Perhaps the relationship is that the substance of water mediates an exchange between manifested and unmanifested realms. Does the association between water and the Absolute in so many ancient traditions constitute a case of identifying the manifested mediator with the unmanifested potential? By analogy, have ancient people used the courier (the substance of water) to represent the unseen sender of a package (the Absolute)? If this is true in even the minutest sense, our modern-day view of water would seem to be very restricted. Perhaps that is why ancient traditions considered water to be a sacred substance, while modern society considers it to be a financial and aesthetic commodity.

The primordial sea, from which everything was created, is most often associated with freshwater, as opposed to seawater. Seawater was understood to have been created from the "waters of chaos" and to serve as the reservoir for all earthly water.

CHAPTER 2

THE SACRED CHAOS
Philosophical and Biblical Insights

And the Spirit of God was hovering over the face of the waters. . . Then God said, "Let there be a firmament in the midst of the waters, and let it divide the waters from the waters." Thus God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament; and it was so.
Book of Genesis, *Holy Bible (King James Version)*

Building upon the portrayal of water as pantheistic characters, ancient humans began to incorporate their intuitive or experiential "knowings" of water into a more intellectual and, from a modern perspective, comprehensible format that constituted philosophies and religions. These philosophies and religions often echoed the message of ancient myths; however, they began to explain water's mysteries in a more pragmatic manner and to define its relationship to other aspects of the physical world. While losing little of its mystique as a symbol of the Universal non-stuff, water was now associated with geometries, numbers, vibrations, and even atmospheric or geologic structures. Not only was water being defined in the physical world, it was being classified on the basis of the functions that it was believed to perform. There was no longer one "all-purpose" water, but instead there were many types of water—few of which could be seen, collected or created. Hence, ordinary water was routinely used as a surrogate for these magical waters. Eventually, the association between the two was largely forgotten and all water became ordinary water.

ANOTHER WORLDVIEW

In addition to their eloquent and complex pantheistic characters, the ancient Greeks began to express their understanding of Nature in an entirely new way. The prominent philosophers of ancient Greece were the first to apply what we might refer to as a *pseudo*-scientific explanation to creation and to various natural phenomena. In particular, the understandings put forth by Thales of Miletus, Empedocles, Paracelsus, Pythagoras, and Plato are of fundamental importance to any discussion of water. It is worth noting that the Greeks were the first to separate *mythos* from *logos*, with the former representing fantasy or fiction and the latter representing rational argument or truth.[1] This separation is the basis of today's pervasive view that myth, which originally denoted a sacred narrative, stands in opposition to both reason and religion. Myth is almost never revered in an intellectually based culture.

A sixth century B.C. philosopher named Thales, who lived in the region now known as Turkey, hypothesized that water was the primary substance of all being.[2] He believed that the Earth was a corrugated disk floating on water that, in turn, rested on a boundless expanse of water. His description reiterates the insight that everything rests upon or is produced from a boundless sea of water. Notice that the descriptions provided by both Thales and most creational myths are similar, in many respects, to the biblical account of creation in this chapter's opening quotation. According to the Bible, the Spirit of God (representing the creational deity) hovered over waters (representing the original chaos) that were distinct from the earthly waters that He later created. According to Thales, water was indeed the original substance of the universe, out of which everything is created and to which everything returns. Thales was perhaps the first to recognize water's unusual physical properties and its apparent universality, both as a solvent and as a "creational medium."

This perspective of water and its universal role was apparently not limited to ancient philosophies or religions from any particular region of the world. Mystics and philosophers in the Vedic and Taoist traditions recognized that water is both the substance and ultimate source of all things and of all existence.[3] In the Moslem religion, Allah is known to have created all living creatures from water. Such philosophic and religious views could be construed as additional examples of the ancient use of water as a metaphor for the Absolute.

According to some ancient philosophers, water was the original substance of the universe, out of which everything is created and to which everything returns. These philosophers were perhaps the first to recognize water's unusual physical properties and its apparent universality, both as a solvent and as a "creational medium."

AETHER AND THE FOUR ELEMENTS

During the fifth century B.C., Empedocles expanded on Thales' notion by proposing that all matter in the universe was composed of differing combinations of four original substances and two moving forces. Empedocles referred to these four substances as the Elements of fire, air, water, and earth, and he identified love and strife as the moving forces. The moving forces essentially energized the combining or dissociating of Elements, such that matter could not be created without love nor uncreated (destroyed) without its opposite moving force of strife. So stated, Empedocles' theory of the four Elements has stood as a fundamental understanding of Nature for an astonishing number of ancient cultures.

For example, the Huna religion of the ancient Hawaiians taught that the four Elements represented the descent of Spirit into matter and, as such, were not merely solid, liquid, heat and gaseous states of matter.[4] The Elements were known as *aumakua*, or guardian spirits, and represented the vehicle for transmitting *mana*, a Huna word for the universal etheric substance or energy. It was mana that imparted its divine spark to all of manifestation. Similarly, the American Indians believed that all life and all matter is a result of the interaction of the four Elements and that humans are responsible for acknowledging the Elements for their life-giving gifts. In particular, flowing water symbolized the shifting and changing of the Earth, from which all life was built.[5] In Pre-Christian Europe, the Element of water symbolized the Great Mother and had a special significance for birth and healing. Wells or springs were considered the womb of the Great Mother, in which babies were purified and the sick were healed.[6] Remnants of these ancient rituals are still evident in Christian traditions such as baptism.

In addition to the four Elements, there is a fifth substance that, according to Plato, was used by the Creator in manifesting the universe.[7] This mysterious fifth substance has been referred to throughout history as *aether*, a word coined by the Greeks to identify the substance filling all space beyond the Earth. The term "aether" was subsequently employed by the early physicists to explain the medium through which light waves and other forms of energy were transmitted in vacuums (e.g., outer space). Similar to the four Elements, this mysterious aether is an integral component of most ancient beliefs, where it is generally associated with a life energy or vital force. The aether or etheric substance/energy of the universe was considered to be sacred by Plato, who rarely spoke or allowed others to speak of it.

In Other Words

Apparently, the Greeks were not the first to recognize the four Elements and aether. Franz Bardon notes that the oldest oriental scriptures to identify and designate these primal components of the universe were those of the ancient Hindu, where they were collectively known by the name of *tattwas*.[8] The tattwas included *tejas* (fire), *apas* (water), *waju* (air), and *prithivi* (earth). The fifth and quintessential tattwa of the universe was known as *akasha* (aether), from which the other four tattwas originated and to which the mystics attribute memory or record keeping. According to some modern mystics, the memory or information applicable to everything in the universe is contained within the so-called *akashic records*. Hence, the Hindu equivalent of aether is now associated with stored information or memory.

The first Element born from the *akasha* was that that of fire, representing heat or expansion and depicted as the light of the universe. The second Element born of the *akasha* was the water, representing cold or contraction and depicted as darkness. Of course, all of the Elements had both an active (positive) and passive (negative) polarity that apparently described a dynamic balance between different aspects of the Elements, rather than a judgment about them. For instance, there would be no light without darkness because the contrast is what permits the recognition of both. Fire and water are the two *major* Elements, representing the electric and magnetic "fluids," respectively, that comprise the so-called electromagnetic spectrum.[9] From the interaction of these two Elements emerges everything in creation. Water's role appears to one of contracting or selecting the subset of akashic information that applies to specific aspects of creation.

The two *minor* Elements, air and earth, are also derived from the akasha. Air acts as the mediator between the fiery and watery principles and is represented by warmth (from the fire) and humidity (from the water). The earth Element is the last born from the *akasha* and represents the solidification or form-giving principle of the other three Elements. Notice the similarity between this definition of the earth Element and the Greek's original concept of Gaia as the form of living Spirit. Bardon notes that these Elements are not simply gross aspects of the manifested plane, but instead represent universal principles or intelligence (e.g., *akasha* represents the etheric principle).[10]

Elements and Elementals

Expanding on the theory of Empedocles, an alchemist and Hermetic philosopher named Paracelsus hypothesized that each of the four primary elements consisted of both a subtle principle and a gross corporeal substance.[11] In the case of water, the grosser dense fluid was a component of all earthly forms (e.g., animal, vegetable, and mineral), while the subtle or fluidic aspect constituted the element's spirit. According to Paracelsus, the spiritual essence of the four Elements worked in concert with a large group of Nature spirits called *elementals*, who were composed of the mysterious aether.[12] Because the elementals were etheric, rather than physical, Paracelsus theorized that they could neither be destroyed nor maintain an individual consciousness apart from their physical Element.

Among the elementals, a subgroup called the *undines* were composed of the "liquid" aether and were known to work exclusively with the Element of water because their respective vibratory rates were very similar.[13] The undines were considered to be female and to closely resemble, in both features and size, the human beings with whom they occasionally interacted. Some of the more famous stories of fairies or "little people" and their relation to sacred waters (e.g., lakes, pools, rivers) are those of the ancient Celtic tradition. The legendary *Menehune* of the pre-Polynesian Hawaiian Islands were also diminutive beings who were believed to have worked extensively with water. Some of the gods and goddesses comprising ancient pantheons may have actually represented these Nature spirits or elementals.

Looking back at the ancient's reverence for the Elements, it becomes clear that modern man is focused only on the physical form of the Elements and has completely forgotten about their essences or spirits. It is this spirit that animates the Elements and likely explains the ancient characterization of water as both living and sentient. Whether or not we modern humans are able to perceive the physical substance of water as living, many ancient and indigenous philosophies suggest that the etheric or subtle entities that energize water are alive. According to these ancient philosophies, water was not only perceived to impart life to other forms (e.g., biological organisms); water itself was considered to be living.

There was a pervasive ancient insight that everything was manifested from the Absolute (waters of chaos) using the four Elements and aether, which were often recognized as conscious and sentient. While aether is unseen, its influence on the material world was believed to be observable via its interaction with the Elements, particularly water.

ELEMENTS, SOLIDS & VIBRATIONS

In proposing that all things are composed of one or more of the four Elements, Empedocles also envisioned that these Elements were linked by the divine bonds of love or harmony. The Greeks theorized that this interconnectedness was revealed in the relationship of two numbers, which we refer to as a proportion or ratio. Hence, the ratios between two or more lengths, areas, volumes, angles, spirals, or tones supposedly represented a code by which creation is manifested from the Absolute. The study of these proportions, which are inherent in Nature, is generally referred to as *sacred geometry*. Although it is beyond the scope of this book to review sacred geometry, there are a few principles that are germane to the ancient view of water.

In the words of sacred geometer, Robert Lawlor, "geometry serves to make symbolically visible the orderly movement from the infinite formless to the endless array of interconnected forms through the mysterious passage from One to Two."[14] In creating or manifesting from the Absolute, the Creator was believed to have first distinguished Himself from the indefinable void by volumizing so that creation could begin. Lawlor notes that these essential volumetric solids were given the name "Platonic" because it is assumed that Plato had these forms in mind in the *Timaeus*, which presented a cosmology through the metaphor of geometry.[15] These essential solids and their inherent proportions were believed to interface between the higher and lower realms. As such, the connection between these solids and the Elements (including aether) was believed to shape the material world. Water is, of course, one of these Elements.

The Platonic Solids

The five regular platonic solids, along with their number of edges, vertices, faces and symmetry are given on Table 2A. A diagram of each of the solids is shown on Figure 2-1. The faces of a geometric solid are commonly known as its sides, while the edges are the straight lines that outline each of the faces. The vertices are points where two or more edges converge. The ratios or proportions among these edges, vertices, and faces are of considerable importance, as we will discover in the following sections. Let's consider each of the five Platonic solids in descending order from the most to least number of faces. The descriptions for each of the solids are provided by Robert Lawlor, unless otherwise noted.[16]

- The icosahedron is associated with the Element of water and is the obvious choice for the first form since all other forms arise naturally out of it. This solid is constructed from twenty triangles, symbolizing both the Trinity and the creative principle that links the etheric and manifested realms.
- The dodecahedron is associated with the mysterious aether and is constructed from twelve pentagons. The pentagon represents the integration of spiritual and physical realms. It is also the gateway to the *golden ratio*, or *phi*, which is associated with unconditional love and the numeric code used by the Creator to manifest the world (see Appendix A).
- The octahedron is associated with the Element of air and is constructed from eight triangles. The octahedron symbolizes crystallization, signifying the static perfection of matter as displayed in ice crystals.
- The cube, or hexahedron, is associated with the Element of earth and is constructed from six squares. The square represents materialization or the actual passage from the transcendent to the manifested realms.
- The tetrahedron is associated with the Element of fire and is constructed from four triangles. The tetrahedron is the most fundamental angular form in the universe and is believed to connect microcosm to macrocosm through geometry.[17] As will be presented in Chapter 5, the tetrahedron represents water's predominant molecular geometry.

It is not the static geometries, but rather their associated rotations or spins that generate the greatest mathematical interest in the Platonic solids.[18] These regular solids are to be understood in an extended sense, whereby spinning them about the center vertex creates a circumscribed sphere. Sacred geometry associates the sphere with the infinite and undifferentiated Spirit (the Creator or

Absolute) and, as such, the Platonic solids are the only angular three-dimensional geometries that form a perfect interface with the Absolute. It is through these geometries that our material world (as angular geometries) was believed to be connected to the Absolute (as a sphere). The tetrahedron, dodecahedron, and icosahedron have particular relevance to water and will be referenced throughout the book.

Figure 2-1. Representations of the five regular Platonic solids: (1) tetrahedron, (2) cube, (3) octahedron, (4) dodecahedron, and (5) icosahedron. [Adapted from R. Buckminster Fuller, *Synergetics*, 99.]

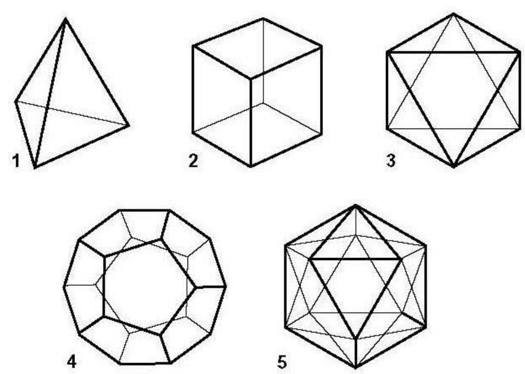

Table 2A. Number of edges, faces, and vertices associated with each of the five Platonic solids. Also listed is the number of axes of rotational symmetry, which simply refers to the number of axes around which the solid may spin while maintaining a mirror image of itself on either side of the axis. It was the spinning of these Platonic solids to create a sphere that symbolized the relationship between the corresponding Elements (including aether) and the Absolute.

	Tetrahedron	Cube	Octahedron	Dodecahedron	Icosahedron
Edges	6	12	12	30	30
Faces	4	6	8	12	20
Vertices	4	8	6	20	12
Symmetry	2, 3	2, 3, 4	2, 3, 4	2, 3, 5	2, 3, 5

Relationships Among the Solids

By aligning the vertices with the center of the faces, two pairs of the Platonic solids are reciprocal and the fifth (i.e., tetrahedron) is self-reciprocating. For example, the icosahedron is the exact inverse of the dodecahedron; hence, connecting the center points of each of the twelve faces of a dodecahedron yields the twelve vertices of an inscribed icosahedron. A similar relationship exists between the cube and octahedron. In the tradition of sacred geometry, the icosahedron and dodecahedron (related to the golden ratio) are considered to represent transcendent principles, while the octahedron and cube (related to the number 2 and its square root) operate at the level of the natural or manifested world.[7] The reciprocal geometric relationship between the icosahedron and dodecahedron was believed to have symbolized the intimate relationship between the corresponding Elements, water and aether.

In the material world, water essentially symbolized the perceptible counterpart and mediator of the imperceptible aether. Because matter or the material world (as represented by the cube) was supposedly manifested from the aether via the water, it follows that the icosahedron and dodecahedron are mathematically related to the cube according to the golden ratio (as ϕ and $1/\phi$, respectively). As explained in Appendix A, the golden ratio was believed by some ancient cultures to represent the numeric code by which the material world was manifested. An example of the intimate relationship between water and aether apparently also exists in the Huna tradition, whereby the word for water (*wai*) was commonly substituted for that of the etheric substance or energy (*mana*).[20]

According to most interpretations of the Huna religion, subtle energies of a person are divided among the lower self (emotional), middle self (reasoning) and high self (spiritual). The vital or etheric force (mana) of the lower self is often depicted as water, because it is generated via the person's consumption of food, sunshine, and air.[21] Clouds and mists symbolize the vital force of the high self; hence, rainfall is considered the returning of mana from the high self to the lower self. Here again, there is evidence that water (as a mist or airborne liquid) represents the vehicle by which the etheric force is presented to the manifested world. It is interesting to note that when there was a surcharge of mana in the lower self, it was returned to the higher self in the form of overflowing water.[22] This symbolism suggests that the linking of higher and lower realms may have actually consisted of exchanging water, through which the mana was created and altered by the various selves.

The five Platonic solids are 3-D geometric representations of the four Elements and aether. These geometries are inherent in all manifested forms and serve, via their rotations, as a connection to the Absolute. Specifically, the icosahedron and dodecahedron represent the intimate connection between water and aether.

A Vibrational World

While Plato and Empedocles provided important pieces in the understanding of the universe, it was the Greek philosopher and mathematician Pythagoras who tied together the fundamental concepts of number (ratios), form (geometry), and vibration (harmonics). So, how are the teachings of Pythagoras pertinent to our discussion of water? They are because vibration or rhythm is the most frequently cited mode by which water is able to mediate between the seen and unseen worlds. But how is it that vibration could create (manifest) or uncreate (destroy) the material world? To answer this question, we need to look at the Pythagorean tradition.

While the Creator was recognized as unmanifested, the Pythagoreans considered the orderly principles or laws of Nature that gave rise to the material world to be knowable. Everything manifest could ultimately be traced to a unique combination of individual vibrations or waves that is commonly referred to as a *natural frequency*. As such, the world was believed to have been created from waves (not particles) and the limit of material divisibility was considered to be a vibrational experience (not a material one) reached through consciously heightened perception rather than through the analysis of matter.[23] Essentially, our universe at its most fundamental level was understood by the Pythagoreans to be one of vibration

Vibration may be defined simply as an oscillation about a reference position (e.g., the motion of a swinging pendulum), such that each oscillation is considered to be a cycle. If the time of oscillation is relatively short (i.e., high frequency), we usually referred to a *vibration*; however, if the time of oscillation is longer (i.e., lower frequency) then we generally call it a *rhythm*. C*ycles* usually refer to oscillations with an extremely low frequency, although vibrations and rhythms are obviously cycles as well. The number of times that a system moves through this cycle per unit of time is referred to as its *frequency*. The time unit of one second is commonly used to quantify frequencies, which are expressed as cycles per second, or *hertz*. However, the choice of a time unit is arbitrary because, according to most ancient insights (e.g., Mayan), time itself is cyclic. Simply stated, vibrations are cycles and frequencies quantify vibrations by expressing a ratio between two cycles. Ancient philosophers, as well as modern naturalists and scientists, use vibration as an essential descriptor of water.

The ancient Mayan culture of Central America had an interesting view of a vibrational world. According to the controversial Mayan scholar, José Argüelles, the architect of the universe (*Hunab Ku*) not only created the material world and its laws from the celestial waters, but also communicates information to Earth (via our Sun) on a continuing basis.[24] The Maya apparently believed that solar energy interacts with the Earth's electric and magnetic fields, resulting in the downloaded information that is subsequently played out in the watery bodies of living organisms. The solar coding was believed to be in the form of harmonics (e.g., vibrational overtones) that are sorted and downloaded to the biosphere.[25] Moreover, the arrival of this coding was believed to be periodic in nature and dependent on interrelated cycles of the Earth, Sun, and stars (see Appendix B).

A BIBLICAL PERSPECTIVE

For those of us living in the Western world at the dawn of the twenty-first century, belief systems corresponding to the Bible and to science are arguably the two most influential. While science will be introduced in Chapter 4, we will take a look at the Bible's portrayal of water as the final section of this chapter. Water is frequently referenced in the Bible under a variety of contexts that are designed to communicate very different kinds of messages. In addition to water's obvious role in life processes, biblical scholars believe that the significance of water was heightened in an area (i.e., the Holy Land) where water was scarce and drought was a constant threat to life.[26] From a strictly practical viewpoint, water is an absolute necessity to sustain life in the desert and, as such, was considered to be a blessing from God and a symbol of His care for creation.

Beyond water's more practical considerations, the Bible portrays the spiritual aspects of water under three or four headings that are generally recognized by biblical scholars. Unless otherwise noted, these headings are described by the *Dictionary of Biblical Imagery* as follows.[27]

- *Cosmic water* serves as a primordial force that only God can control and govern. This aspect of water is integral to the biblical account of creation, the universal balance between chaos and order, and the Great Flood that destroyed the Earth. In this context, water is often viewed as the primordial Element of creation and as the chaos that God overcame to create the manifested world.
- *Cosmic sea* expresses the vast and unbounded nature of cosmic water and is routinely associated with both chaos and the seat of God's throne. The cosmic sea represents the undifferentiated realm from which God created heaven, Earth, and the seas (i.e., Earth's oceans). Heaven was perceived to be separate from Earth, just as water on the continents (freshwater) was considered to be distinct from that in the oceans (seawater).
- *Living water* symbolizes a source of life and a gift from God. It was considered to be distinct from ordinary water and, similar to the Sumerian tradition, was often used as a symbol of wisdom and knowledge. God is sometimes referred to as a "fountain" of living water, possessing the ability to produce a paradise on Earth.

- *Ceremonial water* symbolizes both the cleansing process and the passage between life and death. Water is portrayed as the primary agent for removing or dissolving impurities, for the ritual of baptism, and for the personal journey to and from the primordial chaos.

There are also biblical references to water associated with weather, water bodies (e.g., lakes, rivers, seas), afflictions (e.g., destructive waters) and various other phenomena; however, I will restrict my focus to the four categories outlined above.

Cosmic Water: Above or Below?

"Water(s)" is one of the first words presented in the Book of Genesis. In fact, the water or waters are already present as God begins to create.[28] The obvious paradox is that the manifested substance we call water (i.e., H_2O) could not have existed before God began to create because water is an aspect of creation. Perhaps the biblical references to water include one that is metaphoric and one that is literal. Similar to the Sumerian reference to "waters of chaos," the first mention of water(s) in the Bible may not refer literally to H_2O, but rather to the unbounded and unmanifested realm of the Absolute. If the biblical account of creation is consistent with that of earlier and subsequent myths, the Creator (God) manifests from the infinite possibilities of the Absolute. In other words, God creates from the metaphoric, rather than literal, waters of which He is one. Such an interpretation is consistent with the "Spirit of God hovering over the face of the waters" prior to the act of creation.

The next step is that God creates a so-called *firmament* in the midst of the water, thus dividing waters that are above from those that are beneath. The words "above" and "below" were often used in ancient writings to distinguish heavenly from worldly realms and have very little to do with the actual directions of up or down. As such, God's first act of creation had to be the division of the metaphoric waters. Again, if these pre-creational waters are truly a metaphor for the Absolute (which is an aspect of God), then this passage is consistent with the previously described creational myths. The confusion surrounding waters in the Book of Genesis seemingly arises from two sources. The first is an inability to distinguish between the metaphoric and literal uses of the word "water," while the second is an ambiguity surrounding the physical existence of a firmament(s) separating the waters.

"Firmament" is an English word that was actually created to translate the Hebrew word *raqia* and is usually interpreted as either an expanse separating the metaphoric waters of the Absolute from the literal waters of Earth (i.e., the manifested world) or some type of physical structure separating the literal waters of Earth (e.g., water located above and beneath the Earth's surface).[29] Confusion surrounding the physical existence and exact location of a firmament is evident from the many interpretations for it that have been provided over the years. The fact that an English word had to be coined to describe this physical and/or non-physical "thing" probably reflects the challenge faced by biblical translators. Some biblical scholars have even suggested that there are two firmaments, one (perhaps atmospheric) separating earthly waters from cosmic waters and the other (a more solid structure) separating Earth's surface waters from the so-called subterranean waters. Perhaps the most famous interpretation of a firmament was presented in the 1920s by Isaac Vail, who hypothesized that a water (liquid, vapor, or ice) *canopy* existed above the Earth.[30]

While biblical translators seem to have struggled with the physical and non-physical aspects of water, the post-Renaissance artists and naturalists, who were more focused on its nature than its definition, found a way to combine these aspects with relative grace and elegance.

The Canopy Above

Vail's canopy theory was based, not only on passages from the Book of Genesis, but also on the interpretation of myths from ancient cultures including Greek, Roman and Vedic. In most cases, these interpretations rested on the association between water and heaven(s), which was believed to be located above the Earth. As such, Vail was wrestling with the same ambiguities regarding the use of the word "waters" and the location of heaven that other biblical and ancient historians encountered. If, in fact, heaven refers to a non-material realm (rather than to the skies above), then designating an exact physical location is necessarily confusing. Heaven is both everywhere and nowhere. Heaven is sometimes referred to as the void between matter, denoting that it is not a physical location at all, but instead is a field of energy through which everything is created and through which everything returns. In fact, the often quoted passage from Genesis 1:6-8 indicates that "the expanse," which was later translated as the firmament, is actually heaven. Does this "heaven" refer to the skies above or to the non-place that is so often contrasted with Earth? Here is the passage:

> Then God said, 'Let there be an expanse in the midst of the waters, and let it separate waters from waters.' And God made the expanse, and separated the waters which were below the expanse from the waters which were above the expanse; and it was so. And God called the expanse heaven.[31]

Based upon the original Hebrew words from which the later translations were derived, as well as upon other passages in the Bible, there seem to be several points of agreement among biblical scholars. First, the waters referred to in this passage are liquid, rather than solid or vapor. At the end of the first day of creation, only a watery world existed (i.e., the material world had yet to be created).[32] One could convincingly argue that the physical substance of water (i.e., molecular H_2O) had not been created at this point. This first day was dedicated to separating the waters of the primordial ocean, such that there were waters both above and below the expanse. The use of the words "divide" and "midst" are generally interpreted to mean that the primordial waters (sea) were split into two halves or sections. As previously noted, the nature of a firmament or expanse is difficult to translate literally; however, it is associated with a "heaven" that separates the primordial sea. The expanse also separates God and the chaos in the waters "above" from the manifested order in the waters "below."

If literal water, as opposed to metaphoric water, was divided on the first day of creation, then biblical scholars are forced to explain how and where the liquid water was separated. This brings us full circle to Isaac Vail's canopy theory and any evidence there may be for such a physical structure. Supporting evidence for Vail's theory included ancient observations regarding Earth's climate, human life spans, the appearance of the sky, and the biblical Great Flood.[33] Interestingly, it was the scientific creationists following Vail who used this latter piece of evidence to tear down his canopy theory.

Alternatives to a Canopy

Simply stated, the volume of water required to supply worldwide torrential rains for forty days could not possibly be contained within a canopy above the Earth. Currently, only a tiny fraction of Earth's water is contained within the atmosphere (either as liquid water in clouds or as water vapor). Even if the water were contained as ice crystals in rings or shells, similar to those of planets in the outer reaches of the solar system, the volume of water required for the Great Flood is just too enormous.

In his technical review of water canopy theories, Joseph Dillow concluded that only a vapor canopy is physically possible and even a vapor canopy is not without problems.[34] In addition to insufficient water volumes, all canopy theories suffer from the problem associated with water's high *heat capacity*. Heat capacity is a physical property that is responsible for massive amounts of energy being consumed or released as water changes temperature or phases. In this case, canopy water (regardless of its original phase) would have to pass though a vapor phase before condensing into liquid water within the lower atmosphere, where it could subsequently rain down on the Earth's surface. This vapor-to-liquid phase change would have increased the planet's near-surface air temperature by more than 2000° Celsius, instantly killing all planetary life.

Besides the almost insurmountable temperature problem, scientific creationists have identified many other problems with the canopy theory. If an above-Earth canopy was not the source of water for the Great Flood, then what do creationists believe was the source? The answer to this question lies in the belief that the firmament (or one of two firmaments) is a physical structure that separates waters above and below the Earth's surface. It is these subterranean waters that were originally suggested by seventeenth and eighteenth century scientific creationists (e.g., Robert Hooke and Alexander Catcott) to be the source of water for the Great Flood. More recently, Walt Brown has expanded upon these earlier theories.[35] From a scriptural standpoint, he relies primarily on a passage from Genesis 7:11 that includes a reference to "all the fountains of the great deep" bursting open before the "floodgates of the sky" were opened. Moreover, the passage suggests that when the fountains of the deep and the floodgates of the sky were closed, the rain from the sky was restrained.[36]

Recently, two marine geologists from the Lamont-Doherty Earth Observatory provided another possible explanation for the biblical Great Flood.[37] Their research indicates that what is now the Black Sea used to be a much smaller freshwater lake, around which people settled and may have begun an early type of agriculture. Approximately 7500 years ago, the Earth was experiencing a short-term warming trend and, as a consequence, global sea levels were on the rise. Although this lake was fed by melting glaciers, it was hydraulically disconnected from the Mediterranean Sea by a natural geologic dam. Eventually, seawater began spilling over this geologic formation into what is now the Bosporus Straight. Because the sea level was higher than the lake surface, this freshwater lake was almost instantly transformed into the Black Sea. The scientists surmise that the resulting catastrophe was indeed the Great Flood (occurring about 5500 B.C.) and that people who fled this region carried with them the frightening story, which eventually appeared in the written history of many cultures throughout Eurasia.

Metaphoric vs. Literal Water

In order to manifest a material world, God divides the cosmic waters (often depicted as a battle between God and a sea) and uses the firmament to restrain the background threat of chaos. Destruction of the manifested world marks the breach of this firmament, permitting matter to return to its origin in the cosmic waters of chaos. If we assume that these original cosmic waters in the Bible (as in other ancient texts) are a metaphor for the Absolute, then we are faced with the question of why water seems to be such a favored metaphor. Perhaps water's fluidity and seemingly boundless nature (e.g., seas) best emulate the essence of what ancient writers understood as the Absolute. Or perhaps the ancient writers understood something about water, other than its appearance, that rendered it the most appropriate metaphor for the Absolute. Is it possible that there was an ancient understanding of water (i.e., molecular H_2O) that we in the modern world have forgotten or simply do not grasp?

In addition to the use of water as a metaphor, the Bible suggests (as do sacred texts from many other ancient traditions) that water served as both the source and the facilitator of the created world. The *Dictionary of Biblical Imagery* quotes 2 Peter 3:5-6, "by the word of God heavens existed long ago and earth was formed out of water and by means of water, through which the world of that time was deluged with water and perished."[38]

This biblical account of God's creating the world from "water(s)" corroborates Thales far-reaching observation that water is the original substance of the universe, out of which everything is created and through which everything returns. So stated, water is not only the original substance, but also serves as the means by which worldly forms come into existence, suggesting it plays a type of mediation role. In theory, we now have biblical classifications for both metaphoric water (the Absolute) and literal water (H_2O). In addition, the Bible distinguishes between two forms of literal water. The first form includes the ubiquitous H_2O that we routinely encounter in our environment, whereas the second is a special form of H_2O that is referred to as "living water."

Living and Ceremonial Water

Living water is sometimes referred to as the "water of life" (1 Enoch 17:4) and is often depicted as a fountain or spring from God. For example, God miraculously provides living water at the rock of Horeb, where Moses strikes the rock and taps into a spring.[39] The Old Testament prophets Ezeckiel and Zechariah speak of the Red Sea and the whole Earth being freshened as a result of living water reaching these destinations in the form of (or as a component of) rivers. Hence, there appears to be a connection between this special (living) form of H_2O and a spiritual essence or energy that imparts life. An obvious question relates to the physical or chemical differences, if any, between living and ordinary water. While possible answers to this question will be addressed later in the book, it should be reiterated that the designation of and quest for living water (or the water of life) is not unique to the Bible.

The Bible is clear that there is indeed a difference between living and ordinary water, such that the former not only satisfies thirst but also imparts life. Moreover, the production of living water or its transformation from ordinary water is not a trivial matter. Most of the water used for religious ceremonial purposes is not living water, but so-called "holy water" that serves as a surrogate for living water. Holy water is just ordinary water that is blessed by a priest or other religious figure so that it may be used as a cleansing or purification agent in ceremonies. As such, the Bible provides us with yet another distinction among waters—in this case, between two forms of ordinary water. Is ceremonial water merely a useful label for ordinary water, or is there a substantive difference between the two? Although the answer does not seem to be obvious (at least to me), we will explore this and similar questions in Chapter 8.

This brief look at the word "water" in the Bible suggests that while there may or may not be a difference between ordinary and ceremonial water, there is little doubt surrounding the difference between living and ordinary (including ceremonial) water. Similarly, there appears to be a consistent distinction between metaphoric and literal waters—if not by definition, certainly by description and usage. One could postulate that water not only serves as a symbol for the sacred chaos, but also as a literal representation of the physical substance that mediates between chaos (i.e., the Absolute) and order (i.e., the manifested world).

The Bible appears to reference water within two contexts. Cosmic water represented the undifferentiated realm from which God created heaven, Earth and the seas (i.e., Earth's oceans), whereas living water imparted life to the planet as a special form of liquid H_2O.

CHAPTER 3

MODERN NATURALISM
Adaptations of Ancient Wisdom

The journey from water the element to the H_2O molecule is just the prelude to water's mystery. It is a journey that is not about water alone, but about our whole concept of the material world.
Philip Ball, *H_2O*

Born of the Renaissance era were the naturalists and artists who realized, as did ancient peoples, that water is not ordinary at all. In fact, it is extraordinary in its movements and flowforms, in its vibrations, and in its apparent mediation between the seen and unseen worlds. While scientists set out in search of the physical basis for water's uniqueness, naturalists took a decidedly less aggressive tack that included observing and meditating upon water in its natural environments. As such, the naturalists' path (predominantly holistic) was more similar to that of ancient peoples' (predominantly experiential) than was the scientists' path (predominantly reductionist). Not surprisingly, naturalists began describing water in ways that were strikingly similar to ancient myths and insights. In many cases, the naturalists actually adopted ancient insights and expressed them in terms of today's primary language for describing the natural world, namely science. While not truly science by modern standards, naturalism holds a fascinating, if not precarious, position between ancient wisdom and contemporary science in proposing that physical mechanisms must underlie water's mystical attributes.

THE ART OF A VORTEX

Although it is difficult to arbitrarily draw a line between ancient and modern times, I have selected the Renaissance as the boundary between the two. Out of the Renaissance period were built some of the modern beliefs about the nature of water. While today's scientific theories had not yet taken hold as man's predominant understanding of the world, the Renaissance heralded an undeniably different way of looking at the world compared to that of previous epochs in human history. This chapter will explore not only the post-Renaissance beliefs (particularly those of naturalists), but also the modern revivals of ancient myths. The twentieth century was one in which naturalists, philosophers, and visionaries began to look to ancient insights as a foundation upon which they could build their own theories of the world. Hence, this chapter is not only about the emergence of man's new understandings, but also about his expressing ancient insights within a modern context.

If one studies water in its natural state (e.g., in oceans, rivers and lakes), it is difficult not to notice the variety of *flowforms* that constantly appear and disappear. In particular, the spiraling motion of eddies or whirlpools are among the most fascinating. Many ancient cultures placed considerable import on these motions and believed that they held great powers of both creation and destruction. Considering that the planet's most violent weather systems are vortical in nature (e.g., hurricanes and tornadoes), it is not difficult to understand how ancient people would have come to deeply respect such phenomena. A prevailing belief among ancient cultures seems to have been that forces lying within vortices were able to bridge the seen and unseen worlds in order to bring "things" into manifestation. In fact, many ancient cultures believed that life itself began in the water of the so-called "primeval vortex."[1]

Leonardo da Vinci

While the pre-Renaissance civilizations had a very mystical and sometimes foreboding view of spirals and vortices, it was the Renaissance sculptors, painters, and naturalists who provided the link between the Middle Ages and our current perceptions of vortical phenomenon. In particular, Leonardo da Vinci perceived the wave and vortex as manifestations of motion and power, respectively. This perception is believed to have inspired paintings and drawings that displayed an undeniable scientific mastery of the forms of motion. His portrayals of the human body were anatomically perfect and illustrated his understanding of the mathematical blueprint (e.g., golden section, Platonic solids, spirals, and other forms of sacred geometry) underlying both internal and external proportions.

Da Vinci correctly theorized that vortices inside the aortic valve of the heart are essential for the control and efficiency of this valve, even though it was not yet known that blood circulated through the body![2] The relationship between vortices and water or blood (as an expression of water) was fundamental to many ancient beliefs. Even today, the blood of saints is often associated with flowforms in holy waters, probably reflecting ancient beliefs (e.g., Celtic) that the waters themselves were an aspect of the saint.[3] The notion that vortices represent life-giving and world-bridging vehicles may be the most enduring perspective of water to have emerged from the Renaissance era.

While Leonardo da Vinci is best known for his paintings and sculptures, he was also a great student of water and its flowforms, including eddies, currents, and vortices. This great Renaissance artist compiled hundreds of sketches that illustrate the movement of water through both natural and man-made channels. He shows the spatial distribution and relative size of the vortices both at the surface and at depth in order to depict the three-dimensional movement of water masses. Based on his understanding of water flowforms, da Vinci laid out the design for many types of pumps and water conveyance systems that were developed into full-scale working models by others long after his death. Whether it was the blood in the body or water on the Earth's surface, da Vinci was convinced that the vortical motion of fluids was a key to understanding and utilizing the power of the universe. We will return to the concept of vorticity throughout the book; however, this introduction leads us to one of the most pervasive of insights regarding water, namely the power and magic of its flowforms.

The vortex was considered by many artists and naturalists to be the most powerful of water's flowforms, connecting macrocosmic to microcosmic events. The sacred journey of matter (order) to and from the Absolute (chaos) has often been attributed to vortical motions.

What Is a Vortex?

A *vortex* is the rotating motion of a multitude of material particles (usually referred to as a fluid) around a common center.[4] Vortices are often described as energy pathways that draw particles into them. An actual field, known as *vorticity*, is responsible for sustaining vortices. Vorticity is defined as the angular velocity of matter at a point in space-time, meaning that every vortical motion can be defined by mathematical parameters such as rotation and velocity at a given point in time and space. While this definition sounds daunting, it is actually similar to the description of a gravitational field that exists whether or not matter is present to actually "experience" gravity. The energy required to sustain a vortex is related to the viscosity of the fluid; hence, it requires one hundred times more energy to sustain a vortex in water than in air.

Vortices possessing a relatively large diameter compared to the axis appear as disks (e.g., galaxies), while those possessing a relatively small diameter compared to the axis appear as columns (e.g., tornadoes). The actual particles comprising a fluid may be entrained and then expelled by the vortex, such that the flowform itself is unchanging but the fluid is ever-changing. As a particle is drawn toward the axis of a vortex, it must drastically increase its angular and spin velocities in order to preserve its *momentum* or its impetus to keep moving.[5] A surprisingly small initial rotation within a fluid is sufficient to create a concentrated vortex. Although most are invisible, vortices are common in Nature and include phenomena such as whirlpools, eddies, hurricanes, tornadoes, galaxies and black holes. The diameters of common vortices range from a billionth of a centimeter for quantum-scale events to millions of light years for galaxies.

Interestingly, the first unified theory of physics is often credited to the fifth century atomist, Democritus, who assumed that the unordered motion of atoms is changed to an orderly one in response to the law of Nature, as represented by the vortex. [6]Atomists considered the world to be composed of tiny indivisible particles that were fundamental to all matter and energy. In both ancient myths and modern premises, vortices are commonly recognized as vehicles for connecting different worlds, whereby vastly different energies encountered in otherwise distinct realms are able to converge in the space-time phenomenon of a vortex. I will use the term "modern premise" to denote an understanding or hypothesis that is not generally recognized by contemporary mainstream science. It should be noted that many of these unconventional hypotheses actually represent adaptations of ancient insights or myths.

WATER'S FASCINATING FLOWFORMS

Two of the most diligent students of water flowforms in the twentieth century were the German naturalist Theodor Schwenk and the Austrian naturalist/inventor Viktor Schauberger. Both of these men were intensely focused on the macroscopic movement of water and were convinced that within water's vortices lie many of its secrets. Essentially, they expanded on the ancient understanding of and fascination with vortices in natural waters.

The Water "Wizard"

Borrowing an idea from Empedocles, Schauberger hypothesized that Nature shows two types of vortical motion.[7] The first is a *centripetal* or hyperbolic spiraling motion that moves inward and is associated with creation, development, and purification. This motion may be equated with Empedocles' moving force of love. The other is a *centrifugal* motion that moves objects outward in a straight line and is associated with destruction and dissolution. This motion represents the moving force of strife. Schauberger believed that while both motions occur in Nature, the centripetal spiral is used for development. By contrast, he maintained that all modern day technologies are designed to utilize the centrifugal spiral.

Schauberger believed that water motion is highly temperature-dependent and explained this dependence on changes in the binding of hydrogen to oxygen atoms in a water molecule.[8] While his exact descriptions do not relate to any mechanism recognized in modern physical chemistry, perhaps he was simply relating the insight that changes in the intermolecular chemical bonds that "hold water together" are significantly affected by temperature. If so, his observation does have something in common with modern scientific theories. Schauberger maintained that even minute temperature gradients in water (<0.1° Celsius) were sufficient to create vortices and that the pattern of vortices created as water moves through various conveyance structures was the single most important factor in determining its quality.[9] He maintained that water allowed to flow through natural meanders, thus producing its natural eddies and currents, was able to rid itself of pollutants more efficiently than that channeled through metal pipes or straight canals.

According to Schauberger, the vortex and its motion were responsible for the creation of forms. An alternation of vortical motion between centripetal and centrifugal modes was believed to represent the inhalation and exhalation, respectively, of creative energy. The former represents creation or an ordered movement from the Absolute, whereas the latter represents apparent destruction or a return to the Absolute. You may recognize this dichotomy as a reiteration of the ancient insight that all of creation originates from and eventually returns to the primordial waters of chaos through the substance of water. Schauberger's dichotomy also restates the biblical notion that God breathes life into and out of matter as a consequence of His balancing the universe between chaos and order. Further, his statement introduces us to the modern premise that vortices possess a rhythm, alternating between two opposite states or configurations that presumably permit vorticity fields to link the etheric and worldly realms.

A Naturalist's View

Like Schauberger, Schwenk was also fascinated with water's flowforms, particularly as they were reflected in rhythms. He intuited that water's relationship to time was inherent in its rhythmical movement that spanned cycles ranging from seconds to years.[10] He was convinced that wave patterns on a body of water were characterized by various harmonies and rhythms that could be described by distinct frequencies, overtones, and resonances, not unlike a musical instrument. Similar to Schauberger, Schwenk considered water as the ideal medium for form-creating processes. Wherever there are differences in water flow or at the boundary of surfaces (e.g., ocean currents, cell membranes), vortices are formed that he believed acted as delicate "sense organs" and allowed the rhythmic merging of the differences.[11] This is a major topic of his 1965 book, *Sensitive Chaos*.

It is important to realize that Schwenk's intuition and insights regarding water were not achieved via sophisticated laboratory experiments or complex computer models, but instead via long hours of observing and meditating upon the movement of water in Nature. Schwenk was not a modern scientist, but rather a naturalist in the spiritual tradition of Rudolf Steiner. Hence, his methods of experiencing the world essentially constituted a throwback to those of ancient and indigenous peoples; however, he possessed a twentieth century vocabulary with which to share his insights. He maintained that water vortices were a microcosmic model of the movements in the cosmos (e.g., orbiting planets, spinning stars, rotating galaxies) and that water is sufficiently sensitive to perceive everything in its immediate surroundings. It is probably this statement that most alienated him and his insights from the mainstream scientific community. He cites the effects of a solar eclipse on the water in plants and the bodily rhythms of fishes aligned to a specific positioning of the Sun and moon as support for his insights.[12]

Whether or not Schwenk's "examples" are considered valid science is, in some respects, a moot point. His real contribution is that, through his astute observations of water's flowforms, he re-introduced to the modern world an insight about water that corroborates the ancient experience of it as both a conscious and living entity. There are many brilliant scientists who are able to tell us more and more about why water is so unusual; however, we have far fewer teachers who are determined that we not push water's spiritual essence too far outside of our collective reality. The value of exploring ancient myths and modern premises of water is not to glean scientifically defensible mechanisms, but instead to ask unconventional questions and to temporarily adopt perceptions that are necessarily unfamiliar. Such unfamiliar places have been known to give rise to bizarre notions that were eventually distilled down into acceptable scientific hypotheses.

Vortices purportedly underlie the rhythmic flowforms used by water to interact with its environment and then to store or retrieve memory of those interactions. Some naturalists speculate that this rhythm permits water to function as a molecular-scale mediator.

LIVING WATER

Recall that the Bible claims that God is the source or fountain of living water and that living water is not just a liquid with which to bathe your body or to quench your thirst, but one that gives life itself. There is clearly a distinction between living water and the more commonplace water that is appropriate for most purposes. The terminology of living water is one that goes back to some of the earliest spiritual traditions. It not only appears repeatedly in the Bible, but also is present in non-Christian traditions as well.

One example is the Mandaeans, who are a small group of indigenous people that occupy a portion of southern Iraq. Apparently, they have resisted incorporation into the mainstream Arab-Moslem culture and instead have retained the language, religion, and traditions of their ancient Gnostic sect. In their religion, water provides the connection between the earthly world and the world of the "light."[13] Light is generally considered to be a metaphor for heavenly or etheric realms. It is water that mediates between the life-creating aspect of the light world and the earthly world; moreover, it is living water that is primarily responsible for the connection between the two realms. According to the Mandaeans, only one part in nine of water on the planet is considered living. The other eight parts in nine are referred to as black water and, while appropriate for more mundane uses, is not able to mediate between the two worlds. Only when black water is infused with living water can the mediation occur.

What Makes Water Living?

According to Schauberger, water is the Earth's blood and is, in and of itself, a living entity. He referred to "life" in water as the soul of the *First Substance*, whose boundaries and banks are the capillaries that guide it and in which it circulates.[14] Within his reference to the First Substance lies yet another designation of water as the primary or primordial substance from which everything is derived; the identification of water as a living entity; and an obvious analogy between the circulatory system of organisms and the hydrologic cycle of the Earth. Taking a page from ancient myths, Schauberger viewed living water as the accumulator and transformer of the energies originating from the Earth and the cosmos. Beyond just the chemical purity of water, he identified energies that apparently determine whether water may be categorized as living or dead. As was asked in the previous chapter, what exactly is the nature of those energies? We will examine this question both in this chapter and again in Chapter 9.

Schwenk defines living water as "that which contains not only the cosmic elements radiating life into the earth sphere, but that also has an inherent relationship to man as body, soul, and spirit."[15] Unfortunately, this definition adds no more specificity to the nature of or mechanisms governing living water than does Schauberger's. How might living water radiate cosmic elements into the Earth sphere? The answer seems to be through rhythm or vibration. Schwenk notes that the very word "rhythm" is derived from the Greek verb meaning "to flow," implying that it is the rhythm of life that is communicated through water.[16]

He believed that every activity of water takes place rhythmically. Others have referred to this rhythm as "water's song," which is described as sound-shapes or divine music in the ripples or waves of water bodies.[17] Schwenk maintained that water has the ability to recognize everything by its rhythm and, in a belief similar to that of many of ancient philosophers, that water was the Element of life itself.

The term "living water" has become quite a buzzword for entrepreneurs selling various aqueous concoctions at the dawn of the twenty-first century. Each of these concoctions contains a secret ingredient that transforms or structures the dead water (usually either polluted or distilled) via the addition of electrolytes, biomolecules, precious metals, colloidal suspensions, various polymers, or noble gases. The molecular structuring of water is also performed by exposing it to an array of electric, magnetic, and vorticity fields. The lure is that so-called structured or clustered water constitutes the optimal fluid for biological processes and, thus, retards aging and disease. What is there about each of these additives and/or treatments that supposedly brings dead or polluted water back to life? This modern technique is based on the ancient understanding that water is somehow able to retain or access a type of information (energy) that is colloquially referred to as "memory." This is a rather distasteful ancient understanding for science because the subject of water's memory has reared its head in the mainstream scientific literature during the late twentieth century.

As a sacred substance, naturalists often view water as the Element of life, such that all life forms simply represent water that is structured in a unique manner. Thus, the biosphere of Earth simply becomes an ordered (as opposed to chaotic) transformation of water by solar energy (fire).

Water's Memory

Recall that Thales believed that water underlies all the changes to everything that we see and feel. Throughout all the cycles of and transformations to the material world, something endures and simply changes form; that something is water.[18] Through his theory of water, Thales introduced a type of primary, or fundamental, matter (i.e., Schauberger's First Substance) whose permutations and rearrangements in space (i.e., Schwenks' rhythm) could account for all that we see. The ancient insight seems to be that the memory retained or accessed by water is fundamental to life and that it transcends both space-time constraints and untold changes to the substance itself. The Maori culture of New Zealand provided an example of this ancient insight, as was presented in Chapter 1.

Questions concerning water's memory have surfaced in modern times with regard to the mechanism underlying homeopathic remedies. The topic of homeopathy is very controversial from a scientific perspective because, as yet, there is no consensus on either a plausible molecular mechanism or an unequivocal method for demonstrating the phenomenon. A homeopathic remedy is one in which an active ingredient is added to water, forming an original aqueous solution. A long series of dilutions are then performed so that, at least mathematically, none of the active ingredient should be present in the final solution. Interestingly, the final solution purportedly affects living cells more strongly than does the original solution. Modern revivers of ancient wisdom have generally attributed the memory of water to the rearrangement or reorganization of water molecules in such a way as to store information obtained from non-water molecules.[19] In doing so, water molecules are believed to spontaneously transform themselves from a chaotic to an ordered state.

Another Austrian naturalist and inventor named Johann Grander attempted to solve the riddle of water's memory by suggesting, in a hypothesis similar to Schwenk's, that water is the bearer of vibrational information for all life on Earth.[20] Vibration is considered to be the one attribute of matter that uniquely characterizes everything manifest in the universe. According to Grander, "genetic information is contained within every seed and every cell, just as it is within water itself. It is the information in the water that activates the elemental information in the seed."[21] In other words, Grander explains the ancient belief that water is the substance from which all life springs to water's ability to somehow activate the information that is contained within the genetic code or blueprint. This is our first look at a modern premise that suggests water mediates, activates, or accesses memory (in this case, memory encoded by nucleic acids) rather than stores it. According to Grander, information that is activated by water may be distinguished by order, as opposed to chaos. Here again, the chaos-order dichotomy appears to be fundamental to the modern premise of water's memory.

Expanding upon another ancient insight (e.g., Mayan), Grander emphasized the importance of living water as a vehicle or antenna for attracting and storing life and creational energies that are received or downloaded in the form of vibrations from the Sun. Although much of Grander's work appears as interpretations by others, he apparently makes a distinction between the previously described genetic information and so-called "primeval" information. This primeval information is downloaded directly from or through the Sun, rather than activated from genetic codes. It is as if there were a type of cosmic coding, other than genetic codes, that is required to sustain life. Water acts as a mediator in translating the solar or cosmic codes and in activating the genetic codes that are specific to each biological species. As we shall see, the notion that some type of universal information is required to supplement genetic codes is also quite common among modern premises.

WATER, THE MEDIATOR

Theodor Schwenk proclaimed that no material change could actually ever occur in Nature without water.[22] Even if his proclamation is qualified to indicate that no changes in earthly life forms (rather than all of Nature) could occur without water, it still implies a monumental role for this substance. Perhaps it is this proposed role that accounts for the ancient recognition of water as the mediator between so-called higher or etheric energies and earthly forms. Schwenk is one of the few modern revivers of ancient insights to propose that information may also move in the opposite direction (i.e., from the water to the ethers). In other words, water mediates the vibrational transfer of energies in both directions. The insight that water acts as a mediator between the creative forces of the universe and the earthly realm is one that is as old as written history and has been repeatedly expressed through the writings of peoples from nearly every part of the world. In the twentieth century, it was definitely Schwenk who seemed to be most focused on water as a mediator, as is evident from in following two quotations from his writings:

> Thus, water occupies a median position between earth and the universe, and is the port of entry through which cosmic-peripheral forces pass into the earth realm. Is it not this wisdom itself which has created the element of water, a tool for its own activity?[23]

> The cosmic qualities and movements of water, which we have attempted to describe above, are images of the etheric stream and as such they are also its mediators in the material world. All the qualities of water are akin to this world of the etheric forces, and constantly express it. The laws of the etheric world are mirrored in the world of water and they carry on a constant creative dialogue.[24]

If the primordial "waters of chaos" were the source of the substance we refer to as water, then the final sentence of Schwenk's first quotation reiterates many ancient creational myths. In essence, the water (a metaphor for the Absolute) has created water (the molecular substance) as a tool for its own activity. Schwenk's references to "cosmic" definitely relate to the physical universe, as do those of almost all modern naturalists and scientists. In contrast, his references to "etheric" are based in the spiritual science of Rudolf Steiner, who described invisible and life-giving formative forces as being etheric in nature.

Steiner's description essentially reiterates an insight that is presented in many ancient myths (e.g., Greek, Egyptian) and that is echoed in the writings of the nineteenth century German zoologist Ernst Haeckel, who considered everything in Nature to possess a spirit that reflected both form and forces.

Table 3A. *Various designations and synonyms that are commonly used in mythological, philosophical and religious contexts to describe the Absolute, aether, and matter.*

	Realm	Energy	"Location"	Mediator
THE ABSOLUTE	Spiritual	Infinite	Primordial waters	None
AETHER	Etheric	Subtle	Heaven	Prana
MATTER	Worldly	Gross	Physical universe	Water

According to Schwenk's second quotation, all organic formation is based upon etheric forces, which in turn receive formative impulses from the spiritual world. These etheric forces utilize the medium of water, which vibrates in resonance with them and permits the passage of formative impulses to the material world. Notice that water acts as the mediator between the aether (i.e., etheric forces) and physical manifestation via the process of vibration. This is precisely the scenario outlined in many of the ancient traditions that were presented in the first two chapters (see Table 3A). Simply stated, water is believed to act as the observable counterpart of the unobservable etheric substance, or aether. The force that represents or mediates energy flow within this etheric realm is often designated as *prana*. According to some ancient philosophies, prana is the life force or subtle energy that is also referred to as *qi*.[25]

More Mediation

The final reviver of ancient insights, and specifically of water's mediation, that we will discuss in this chapter is the famous Russian philosopher and scientist Vladimir Vernadsky. Vernadsky believed that all organisms are special distributed forms of water and that animated water shapes the Earth's surface and its biosphere.[26] It was his view that the Earth's surface and its associated biosphere was an ordered transformation of the energies of the Sun. Within Vernadsky's worldview lie two of the most fundamental of all ancient insights regarding water. First, water acts as a mediator between cosmic forces and earthly life forms. In doing so, water is able to structure the biosphere using energies that are transmitted from the Sun. Second, the entire biosphere is nothing more and nothing less than water, which is then distributed or organized in such a way as to create the life forms on this planet. Furthermore, it is water's mediation of cosmic or solar energies in the form of a species-rich biosphere that has shaped the Earth's surface and atmosphere.[27]

Although highly controversial among geoscientists, Vernadsky's view of the biosphere seems to reflect a fundamental aspect of James Lovelock's Gaia hypothesis. The Gaia hypothesis elaborated on the notion that the Earth, which is composed of living (i.e., biosphere) and non-living (e.g., geosphere) components, has regulated its chemistry and climate through complex interactions and biological feedback loops.[28] A *feedback loop* is an iterative process whereby the factors that produce a result are themselves modified by that result (e.g., Earth's climate both affects and is affected by the biosphere). Rather than another revival of ancient insights, Lovelock's work is considered science (as opposed to naturalism or philosophy expressed in scientific terminology) from an unconventional perspective. According to the Gaia hypothesis, water has played a pivotal role in allowing Earth to regulate itself. The question then arises, what is the source of this planetary water? Ancient myths generally indicate that water was created as part of the Earth; however, more specific descriptions of water's origins seem to be rare.

In the following chapter, we will touch upon various theories addressing the source of water on this planet and within the universe. The source of planetary water is an important question from the perspective of its proposed mediation, particularly the mediation between cosmic forces and earthly forms. If most of the planet's water is of recent cosmic origin, then the possibility exists that water molecules are somehow altered or "programmed" in interstellar space and then imported to Earth. This notion is consistent with ancient and indigenous myths that claim water accumulates its memory from trekking through the cosmos. On the other hand, if most of the planet's water has been here since its formation, then there would seem to be a less direct mechanism by which cosmic forces influence the water that gives rise to earthly forms. Schwenk apparently considered this less direct mechanism to occur through the etheric realm. Etheric energy or information or memory is then mediated by water in order to influence the gross (as opposed to subtle) structure of worldly life forms.

Webster's New World Dictionary indicates that "cosmos" refers to the universe, exclusive of the Earth, as an orderly whole. Earthly forms are not considered to be part of the cosmos; hence, there might be a requirement for mediating between the two. Notice that the modern use of "cosmic" is very different from that of most ancient (e.g., biblical) traditions, in which "cosmic" refers to the "waters" of the Absolute rather than to an aspect of the physical universe. Unfortunately, the exact insights of ancient peoples may not be accurately captured by the definition of words in today's languages, particularly those words pertaining to modern science and spirituality.

Ancient myths and modern premises share several common beliefs about water, including its spiritual essence, its sentience, its primordial nature, its facilitation of life processes, its magical flowforms and rhythms, and its role as a universal mediator. In contrast, modern science has quite a different view of water's origins and its functions.

PART TWO

SCIENTIFIC THEORY

Physical concepts are free creations of the human mind and are not, however it may seem, uniquely determined by the external world.
Albert Einstein, *The Evolution of Physics*

The following four chapters explore a number of the modern scientific theories that address water. The primary focus of Part Two is on diverse interpretations of modern science, rather than on ancient insights and naturalism expressed in scientific terms.

CHAPTER 4

WATER'S ORIGINS
Cosmology to Hydrology

It has been here for billions of years, and will continue to be here for billions to come. . . In much the same way that every living organism has a life cycle, water has a water cycle: it circulates.
E.C. Pielou, *Fresh Water*

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The ancient and scientific versions of creation are vastly different in many ways; however, they do share a common belief that the process of vibration and the substance of water were instrumental to creation. Unlike the legendary "waters of chaos" that gave rise to heaven and earth in ancient myths, modern science hypothesizes that the hydrogen and oxygen atoms of water owe their existence to the Big Bang and to the stars, respectively. In fact, water is hypothesized to play a crucial role in the birthing of stars, which then give rise to most of the atoms in the universe (including the oxygen atom that comprises water). Once believed by science to be the substance that distinguished Earth from the rest of the universe, it is now understood that water is ubiquitous in the cosmos—not only as ice and vapor, but perhaps also as liquid. Within the hydrologic cycle of this planet, water acts as a mediator between solar energies and earthly *processes via its phase changes (i.e., ice, vapor, liquid). Hence, one of the simplest molecules in the cosmos performs some of the most diverse functions.*

HYDROGEN AND THE BIG BANG

Earth is sometimes referred to as the "water planet" because it appears from outer space to be composed predominantly of liquid water in the form of the great oceans. Water dominates not only the planet surface, but is also the predominant molecule in all living organisms and an integral component of many of the rocks that comprise the continents or dry land. Water is certainly not limited by the confines of this planet and is, in fact, one the most common molecules in the universe. The more that scientists look for water in the cosmos, the more places they seem to find it. Let's trace water's origins and, in doing so, see where scientists have found it lately.

What is water made of? This, of course, is a deceptively difficult and grammatically incorrect question. Let's start with water's most fundamental component. Hydrogen (abbreviated as "H") is both the simplest and the most abundant atom in the universe, representing about 75% of the atomic mass in the cosmos. The word "hydrogen" literally means "water-forming," which suggests that the most abundant atom in the cosmos has the task of making perhaps the most important molecule in the universe. In fact, the formal scientific name for water is *hydrogen oxide*. The reference to hydrogen's simplicity denotes that it is composed of a single *proton* and a single *electron*. A proton is an atomic particle that has an arbitrary mass of 1 and an electrical charge of +1. An electron is an atomic particle (or at least is presumed to be so) that has a negligible mass and an electrical charge of -1. Protons and electrons are drawn together by their opposite electrical charges, thus forming atoms.

An atom's nucleus consists of protons and, in all but hydrogen, *neutrons* (i.e., uncharged particles of the same mass as a proton). Electrons are distributed around the nucleus in various orbitals that are characterized by distinct energy levels. Although these orbitals were originally thought to be analogous to the planets' trek around the Sun, it is now understood that the electrons are distributed more like a cloud around the nucleus. It is primarily the atom's electrons that interact with other atoms and with various particles in the universe to facilitate chemical reactions. The nucleus comprises almost all of the atomic mass, while the electrons comprise almost all of the atomic volume. So you might ask, where do the atomic particles come from and how is it that they happen to find each other in the form of hydrogen?

In order to answer this question, we have to take a look at the scientific equivalent of Genesis, which occurred about 15 billion years ago as the so-called *Big Bang*. Reduced to a very simplistic interpretation, here are the major points of this hypothesis as they relate to the energies and particles that comprise water. There is some controversy as to whether the Big Bang represents the spontaneous creation of matter from energy or whether it corresponds to a *white hole*, through which the matter and energy that has fallen into a *black hole* of one universe is able to exit into another universe. A black hole is a star that has collapsed under the force of its own gravity to the point that everything around it is sucked in, with no possibility of escape. It has been theorized that this process converts all matter to energy, which is then shot out the other side through a corresponding white hole and, hence, is transported from one universe to another. For the purposes of our discussion, the important point is that at an instant in time (i.e., the Big Bang), an astronomical amount of energy was released, expanding and eventually forming what we now call our universe.

As the energy of this newborn universe began to disperse and cool, recognizable forms of matter and energy began to emerge. At this very early point in the enfoldment of our universe, the energy density was so high that it was dominated by extremely high-frequency *electromagnetic radiation*, *photons*, and a variety of *subatomic particles* that were constantly being created and destroyed.[1] Let's simply describe a few terms that appear in the preceding sentence.

- Electromagnetic (EM) radiation represents energy waves that differ in their length or frequency and constitute everything from radio waves to cosmic rays. Table 4A presents the electromagnetic spectrum, with the most familiar energies indicated within their respective frequency ranges.

- A photon is simply a quantum packet of EM radiation, or light energy, which may be described by a wave as well as by a particle.

- Subatomic particles are simply those particles (e.g., quarks) that comprise the atomic particles (e.g., protons), just as the atomic particles comprise atoms (e.g., oxygen).

Table 4A. Approximate frequency, wavelength, and energy ranges for electromagnetic, or EM, radiation as defined by common classifications of light and energy. Visible light represents a very small window situated between the infrared and ultraviolet ranges. Audible sound and other mechanical vibrations are characterized by frequencies less than those of EM radiation (i.e., $<10^5$ hertz).

NOTE: In scientific notation, the exponent that appears to the top right of the "10" refers to the number of zeros after the "1." For example, 10^2 equals 100, and 10^5 equal 100,000.

Property	Radio	Microwave	Infrared	Ultraviolet	X-rays	Gamma and Cosmic rays
FREQUENCY (hertz)	10^5-10^8	10^8-10^{11}	10^{11}-10^{14}	10^{14}-10^{16}	10^{16}-10^{18}	$>10^{19}$
WAVELENGTH (centimeters)	10^5-10^2	10^2-10^{-1}	10^{-1}-10^{-4}	10^{-4}-10^{-6}	10^{-6}-10^{-10}	$<10^{-10}$
ENERGY (relative)	minimal	low	moderate	high	very high	maximal

Returning to our tale of the Big Bang, cooling temperatures in the new universe resulted in the condensation of quarks. Quarks gave rise to the protons and neutrons that are bound together in the nucleus of an atom by the strong nuclear force. The universe had now cooled sufficiently to create atomic nuclei, around which the electrons began to be drawn.[2] This attraction of oppositely charged particles (i.e., protons and electrons) created the first and simplest atom, hydrogen. The universe was now predominantly composed of hydrogen atoms that coalesced into dense gas clouds, which would eventually form the stars and galaxies. In forming complex matter from hydrogen clouds, the universe had finally cooled to the point that interatomic forces began binding atoms together into simple molecules. As the first, simplest, and most abundant molecule in the cosmos, molecular hydrogen (H_2) was formed as the electrons of two hydrogen atoms interacted to create a chemical bond.

OXYGEN AND THE STARS

Oxygen is the third most abundant atom in the cosmos (behind hydrogen and helium) and is the most abundant atom on the surface of Earth. Due to the configuration of its electron cloud, helium is a very inert (non-reactive) atom; therefore, one could view the water molecule as an interaction between the two most abundant "reactive" atoms in the cosmos. The word "oxygen" means "acid-forming." This rather formidable attribute may be traced back to a mistaken belief by early scientists that all acids contain oxygen.

Unlike hydrogen, the origins of the oxygen atom are rooted in the stars rather than in the Big Bang. In order to trace the cosmic trek of oxygen, we need to briefly discuss how stars are created and how they die. If we return to our Big Bang story at the point where dense clouds of hydrogen began to coalesce under their own gravity, we find that this compression causes them to heat up. The collapse continues at a rate limited by the ability of the cloud to dissipate heat energy until, finally, the cloud reaches the ignition point of a nuclear reaction.[3] At this point, the new star lights up and expels the surrounding remnants of the cloud (i.e., those not ignited) into gravity-bound bodies that eventually become planets, asteroids, and comets. Upon ignition, the newborn star is said to be in the *Main Sequence*, whereby it burns hydrogen by nuclear fusion and produces almost constant stellar radiation for most of its life.[4] Actually, the energy in the center of a star is so intense that hydrogen atoms are torn apart into a soup of protons, electrons, and various subatomic particles that collectively comprise a phase of matter known as *plasma*.

Plasma is often considered by modern physics to be the fourth phase of matter, joining the three more familiar phases known as solid, liquid, and gaseous. If we return to the ancient concept of the Elements, plasma would be represented by fire and the other three phases would be represented by earth (solid), water (liquid), and air (gaseous). Although plasma is not a phase of matter that is easily observed using our five senses, a great deal of the energy in the cosmos (e.g., wave-wave and wave-particle interactions) is propagated through a plasma medium. Plasma is not only present in the interior of stars, but is also the major component of the *stellar* or *solar wind*. The solar wind consists of an electrified stream of charged particles (mostly protons and electrons) that are too energetic to be contained by the Sun's gravity and, hence, accelerate away into interplanetary space near the speed of light.

After most of the available hydrogen has been converted to helium, the star begins to expand and cool. This represents the initial process of the star's death and usually results in the envelopment of all the planets that have orbited the star for most of its existence. A star in this state is known as a *red giant*, which is both cooler and larger than a comparable star in the Main Sequence. As the last of the hydrogen is expended, the core of the star contracts and heats up as it begins to utilize helium as a source of nuclear fusion. Actually, a chain reaction is set off in these stars whereby helium nuclei react with other atoms in a stepwise fashion to produce progressively larger atomic nuclei. This is how the heavier atoms (at least those as heavy as iron), including oxygen, are born in stars. Atoms formed by the fusion of helium nuclei, including oxygen and carbon, are quite stable thermodynamically.[5]

As the most abundant of these heavier atoms, oxygen contains eight protons and eight neutrons in its nucleus, as well as eight electrons that maintain electrical neutrality. As mentioned earlier, oxygen is the third most abundant atom in the cosmos, while carbon occupies the fourth position. Oxygen, carbon, and hydrogen combine to form the most common icy molecules in the universe, including water ice and solid forms of methane and carbon monoxide. Unlike hydrogen, the molecular form of oxygen (O_2) is not commonly found in the universe, which is one of the reasons that the atmosphere of Earth is so distinctive.

Concluding our story of stellar death, red giant stars become more enriched in the heavier atoms, causing their gravitational energy to increase. This intense gravitational energy compresses the red giant into an extremely dense star that may actually explode during its final stages of compression, in which case it is known as a *supernova*.[6] As the outer layers of the star are released or exploded as part of a supernova, heavier atoms (including oxygen) contained within the aging star form interstellar clouds. If the aging star does not go supernova, it continues to be compressed by its own gravitational forces until it may eventually collapse into a black hole, bringing us back to the beginning of the scientific story of creation.

> *Water is ubiquitous in the universe as a result of the two most abundant "reactive" atoms combining to form the water molecule. The origin of hydrogen may be traced to the Big Bang, while oxygen continues to be born in exploding stars known as supernovae.*

Cations and Anions

Thus far we have discussed atoms in a state whereby their electrical charges are neutral as a result of their possessing an equal number of protons and electrons. Atoms that have an unequal number of protons and electrons possess a net electrical charge and are known as *ions*. Ions that carry a positive charge are referred to as *cations*, whereas those carrying a negative charge are known as *anions*. These terms are derived from the words "cathode" and "anode," referring to the negative and positive terminals of an electricity-producing cell such as a battery. Because the removal or addition of protons from atomic nuclei requires astronomical amounts of energy, ions generally result from increasing or decreasing the number of electrons in the surrounding cloud. Either particles or EM radiation may interact with sufficient energy to add to or delete from the number of electrons surrounding an atomic nucleus, in which case the particles or radiation are said to be *ionizing*.

Due to the simplicity of the hydrogen atom, there are only two ions of consequence in the cosmos. The hydrogen cation (H^+ or proton) is created by stripping away the atom's only electron and leaving behind a positively charged nucleus. The hydrogen anion or hydride ion, H^-, is more rare and consists of a proton with a two-electron cloud. In the cosmos, hydride ions are produced under high temperatures in the *photosphere*, or visible surface of stars.[7] Because of the complexity of the oxygen atom, it actually forms a variety of ionic species in both its atomic and its molecular forms (e.g., O_2^+, O_2^-, O^+). These ions often result from the reaction of oxygen with highly energetic particles (e.g., cosmic rays) or EM radiation to form short-lived intermediates in both interstellar realms and planetary atmospheres.

COSMIC WATER

The degree to which hydrogen and oxygen are ionized is related to temperature, permitting scientists to predict the state of these atoms in cosmic locations ranging from the interior of stars to interstellar space. When discussing temperatures, scientists usually refer to a scale named after the famous British physicist Lord Kelvin, who developed a measurement technique based on the relative internal motion of matter. At the bottom of his scale is *absolute zero*, or 0° K (-273° C), which is the temperature at which all internal motion ceases and, consequently, there is no "heat" or kinetic energy remaining.[8]

At temperatures exceeding 10,000° K, all matter exists as highly ionized plasma. As temperatures cool from 10,000° K to about 3000° K, the ionization of hydrogen decreases very rapidly so that it is present almost entirely in its pure atomic state (H).[9] Only at temperatures below 3000° K does molecular hydrogen (H_2) exist as the dominant species. Even though it is the most abundant molecule in the cosmos, molecular hydrogen is not a major component of the Earth's atmosphere because it and helium are too light to be retained by our planet's gravity. To put these otherwise arbitrary temperatures into some perspective, white dwarf stars sustain temperatures in excess of 10,000° K, whereas red giants are usually in the range of 2500° to 5000° K. Main Sequence stars vary widely in their temperatures, with our Sun sustaining surface temperatures of about 6000° K. In sharp contrast to stars, the temperature of interstellar space hovers near the frigid mark of about 10° K.

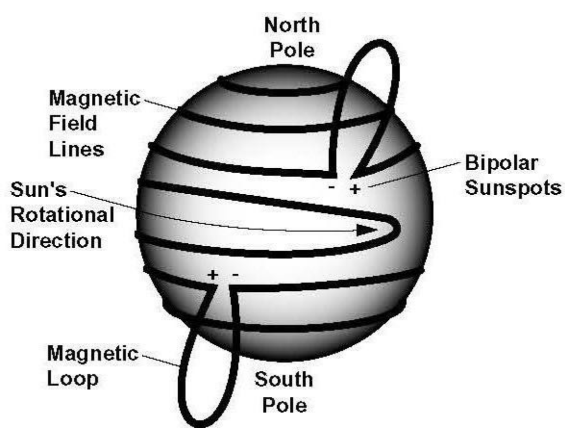
Similar to hydrogen, the various oxygen ions are a function of temperature and pressure. At very high stellar temperatures (near 10,000° K) the most prevalent form of oxygen is the cation (O^+), which decreases in abundance with cooling temperatures down to about 3000° K. At this temperature, the oxygen cation has completely reacted with an electron to form atomic oxygen (O), which is then available to combine with both hydrogen and carbon atoms to form water (H_2O) and carbon monoxide (CO), respectively.[10] In the frigid realms of interstellar space, oxygen exists primarily as an atomic component of water ice. Thus far, we have seen that water, comprised of two of the simplest and most abundant atoms in the universe, has the potential to be formed under a wide range of conditions and in many places. But just how prevalent is water? Only in the last decade has science begun to uncover how widely water is distributed.

Stars

Of all the places in the universe to find water, stars have to rate as one of the most unlikely. Actually, water is primarily found in so-called cool stars, such as red giants. Water has been identified in a surprisingly large number of stars, where it is the major player in determining the *radiative opacity* of the star.[11] Radiative opacity refers to the extent to which light and other EM radiation escapes from stars into interstellar space. Water impedes the outward flow of radiation from stars because it absorbs energy within certain wavelengths and, in doing so, renders the star more opaque that it would appear without the water. In essence, water acts to selectively filter the frequencies of stellar radiation that are released into the cosmos. According to the ancient insight, fire expands while water acts to contract or qualify the fire.

Recently, two of the brightest supergiants in the galaxy, Betelgeuse (in the Orion constellation) and Antares (in the Scorpio constellation), were discovered to actually have water in their photospheres.[12] As previously defined, a photosphere constitutes the visible portion of a star, where its gases transition from opaque to transparent. The structure of photospheres in cool stars is due primarily to the opacity of water, which is one of the most abundant molecules in such stars. The presence of photospheric water in these red supergiants confirms that it is located within the star itself and is not just a component of the dust and gas clouds surrounding stars. Aging supergiants have been observed to release massive amounts of water as they die, consuming their orbiting comets and planetoids. The exact source and role of this water is not yet known.

Figure 4-1. Twisting and warping of the solar magnetic field lines due to the faster rotation of the equator than the poles. Bipolar sunspots and magnetic loops are the source of the solar wind. The arrow indicates the rotational direction of the Sun. [Adapted from Kenneth Lang, *Sun, Earth and Sky*, 91.]



In addition to finding water in cool stars, scientists have now discovered water in the photosphere of a Main Sequence star, which just happens to be none other than our own Sun. Takeshi Oka notes that water is not supposed to exist on the surface of the Sun, where temperatures of 6000° K should dissociate the molecule into its component hydrogen and oxygen atoms.[13] The solution to this dilemma is that water exists only in the dark centers, or *umbra*, of sunspots, where temperatures are less than 3500° K. Sunspots are relatively calm solar regions where strong magnetic fields filter out the energy emanating from the intense interior, rendering them both the coolest and darkest regions of the Sun. As shown on Figure 4-1, pairs of sunspots form positive and negative poles of solar magnets, thus creating the magnetized loops that serve as active regions from which charged particles (e.g., the solar wind) and intense magnetic energy are released into the solar system.[14]

Another interesting aspect of sunspots (and of solar activity in general) is that their number and intensity vary periodically, progressing from a maximum to a minimum and back to a maximum in slightly more than eleven years. The source of the sunspot cycle may be traced to a so-called *dynamo effect*, whereby the solar interior converts the energy of the Sun's motion (rotation) into the energy of electric currents and magnetic fields. While the Sun has magnetic fields associated with its north and south poles (as does the Earth), it also has quadrapole magnetic fields associated with the equatorial region, because the equator rotates faster than do the poles. As shown in Figure 4-1, this difference in rotational speed causes the internal magnetic fields to be stretched and wrapped around the Sun's center like twisted ropes.[15] The loops on these twisted ropes (i.e., magnetic lines) get wound up and rise to the surface where they break through the photosphere and create bipolar sunspots. These sunspots serve as the major contributor to the solar wind inasmuch as each sunspot pair throws out protons and electrons, respectively.

Water-Birthing a Star?

The water discovered in the Sun and in various stars is understandably known as *hot water*, but it is unmistakably water, based on the wavelengths of infrared radiation that are absorbed. The question one might ask as this point is whether water plays a role in these stars. Well, water is believed to filter out certain frequencies of EM radiation that are given off by stars (i.e., the Sun). A clue to another role may be found in perhaps the strangest place to find water. As we have discussed, stars are being born and dying on an ongoing basis. Regions that birth stars generate 15% to 20% of the luminosity of a galaxy as dense gas and dust clouds are gravitationally compressed into newborn stars.[16] One of the most prolific star nurseries in our Milky Way galaxy is a region known as the *Orion Cloud Complex*. While this nursery in the Orion constellation is highly prolific, it is also full of water!

Recent data indicate that this cloud complex contains an extremely high concentration of water vapor, which has been estimated on the order of 1 part in 2000, or about 500 parts-per-million.[17] This is about twenty times greater than the water concentration in other interstellar gas clouds and represents enough water to fill the Earth's oceans ten million times! The super-abundance of water in stellar nurseries may permit the gas and dust to cool sufficiently so that condensation occurs and stars are formed. The vast majority of interstellar gas and dust clouds are not star nurseries, presumably because they do not contain enough water. Here is why water is indispensable in birthing a star. Hot winds are sent out in the form of shock waves during the stellar birthing process. The heated interstellar cloud, which is in the process of condensing into a star, is cooled predominantly by the ubiquitous molecular hydrogen (H_2). However, H_2 is no longer an effective "coolant" at temperatures less than 800° K, requiring water vapor and carbon monoxide to radiate the additional heat so that cloud condensation may proceed.[18] In other words, the condensing interstellar cloud must cool itself at the same time it is being heated by the shock waves.

A couple of aspects of this "water-assisted birthing" of stars are particularly fascinating. First, the actual formation of water vapor via the interstellar-cloud shocks results from atomic oxygen reacting explosively with molecular hydrogen. In other words, water molecules are actually created from their oxygen and hydrogen components, causing the water vapor concentration to increase substantially during the star-birthing process. This is not true of the other two molecular gases, hydrogen and carbon monoxide, involved in the process. Secondly, scientists have theorized one of two eventual fates for water created in the star-birthing process. One is that the intense heat of the fledgling star rapidly dissociates water (and other molecules) into its component atoms. The other is that the water is deposited on dust grains that later form the star's planetoids. If this latter theory applies to our solar system, then most of the water on Earth was originally used to birth our Sun.

Interstellar Space

Before I launch into a discussion of water in interstellar space, let's recall the ancient belief that water is fundamental to creation and the naturalists' contention that water mediates between cosmic energies and worldly forms. If water vapor concentrations are the major factor in determining whether interstellar gas and dust clouds condense sufficiently to birth new stars, then it may behave much as theorized. All worldly forms originate in the stars, and it appears that cosmic vibrations are, themselves, responsible for creating water. Water vapor is generated by shock waves (i.e., a form of vibrational energy) that cause the collision of oxygen atoms and hydrogen molecules, providing the mechanism for water formation in interstellar clouds. Water then mediates the birth of stars and humbly plays out its role in creation, as the two Elements of fire and water combine to manifest the stuff of the universe. When these stars die, they appear to go out in a flood of water as this Element plays out its less glamorous role of mediating the destruction or recycling of the universe's stuff.

In addition to water vapor, there is a tremendous amount of water ice in the cosmos, and particularly on the small interstellar particles comprising dust and gas clouds. Water is the primary molecular ice that is stuck to these particles, although methane, carbon monoxide, and hydrated ammonia (i.e., a water-ammonia mixture) may also be present depending on physical conditions in the gas clouds.[19] Water ice formed in the 10° K temperatures and vacuum conditions of interstellar space is what physical chemists refer to as *amorphous ice*, which is relatively unstructured compared to the highly crystalline ices that are formed at higher temperatures (e.g., those characteristic of Earth's surface and atmosphere). In fact, amorphous ice is so unstructured that it is actually able to flow, not unlike its liquid counterpart![20]

It appears that most interstellar ice requires ultraviolet radiation (e.g., sunlight or starlight) in order to acquire this bizarre amorphous structure. The molecular structure of natural ices will be covered in the next chapter; however, it is important to realize that amorphous ice undergoes an irreversible change in its structure as temperatures rise above approximately 150° K. During this irreversible change, which may result from the heat associated with gravitational compression or stellar radiation, amorphous ice acquires the rigid lattice and crystal surfaces that we commonly recognize as solid water. Hence, the ice is no longer amorphous, but instead is crystalline. A change from the amorphous to crystalline structure increases the ice's thermal conductivity, significantly enhancing its ability to radiate heat. The ability to radiate heat (also known as *thermal conductivity*) is extremely high in water, permitting it to act as a midwife in the birth of stars.

Comets

Comets are one of the few interstellar objects that are commonly associated with water, predominantly in the form of ice. Comets are composed primarily (~60%) of water ice that also incorporates many of the other simple molecules that have been identified in interstellar dust and gas clouds (e.g., carbon monoxide, methane, ammonia). Comets are believed to be among the most primitive components of the solar system, developing out of the interstellar dust and gas cloud that encircled a soon-to-be-born star about 4.5 billion years ago.

Comets are relatively small compared to most bodies in the solar system and are most easily recognized by their unmistakable tails, which can extend millions to hundreds of millions of kilometers behind the icy body of the comet. The tail consists of dust and ionized particles that are always transported away from the Sun by the solar wind. The ionization of water ices is the primary mechanism influencing the properties of a comet's tail, including the steam jets that release tons of water vapor per second from the comet. It is now believed that these steam jets are a result of solar-induced changes to ice's molecular geometry, transitioning from the amorphous to the crystalline form. In other words, comets owe much of their mysterious behavior to a transition in the molecular structure of water ice.

Creating the tail of a comet may represent just the tip of the proverbial iceberg when it comes to the magical repertoire of amorphous ice. A pair of NASA researchers, David Blake and Peter Jenniskens, suggests that the "flowing" structure of amorphous ice may have permitted the elements of carbon, oxygen, and nitrogen to join together and form the first organic molecules in the universe.[21] As amorphous ice is exposed to photons or charged particles (e.g., the solar wind), constituents such as carbon monoxide and ammonia are converted into *free radicals* that are able to migrate through the flowing ice and, hence, combine with other reactive components to produce organic compounds. Free radicals contain at least one unpaired electron, rendering them both unstable and highly reactive. Curiously, these interstellar-derived organic compounds may have reached Earth by stowing away in the water ice of comets.

Blake and Jenniskens suggest that as comets near the Sun, the amorphous ice is warmed—but not enough to crystallize all of it, which would necessarily destroy the organic compounds. Instead, a fraction of the amorphous ice holds on until almost 200° K, perhaps bringing it as close to the Sun as Earth's orbit before it finally transitions and dumps the organic compounds into the cometary tail. Once in Earth's orbit, these organic compounds may indeed find their way to the planet's surface and play out their role as biological life's precursors. Blake and Jenniskens note "water, it seems, was present at every step in the creation and processing of molecules necessary for life."[22]

No discussion of water and comets would be complete without a visit to the highly controversial hypothesis of physicist Louis Frank, who maintains that most, if not all, of the water on Earth is due to a constant barrage of small comets hitting the upper atmosphere.[23] Water that melts during a small comet's entry is re-frozen in the upper atmosphere and descends into the lower atmosphere, where it form clouds and eventually falls to Earth's surface as precipitation. Frank maintains that this process could account for all the water on Earth and for the anomalously high concentration of water in the uppermost layers of the atmosphere. Although the intricacies of the small comet controversy are beyond the scope of this book, suffice it to say that the primary scientific objection to Frank's theory is his interpretation of satellite data. Whether or not comets provide most of the water on Earth, there is no doubt that water and other chemical compounds transported by large comets (e.g., Hale-Bopp, Shoemaker-Levy) and small ones passing close to Earth do reach our planet's surface.

Planets and Moons

Most planet-sized bodies in our solar system and others are now known or suspected to contain water in some form. The combination of water ice and a few of the rare ices (e.g., methane, ammonia, carbon monoxide) compose more than half of the condensed material in the outer solar system.[24] Scientists now believe that water ice is present on the surface of Earth's moon, where water ice is mixed with lunar soil at the poles and in the bottom of craters. While the gaseous and solid phases of water are considerably more common in planetoids and stars than was previously believed, the occurrence of liquid water still appears to be very rare—or is it?

Based on precise radioactive dating techniques, the first liquid water in the Solar System was projected to have made its appearance on meteors just twenty million years after the Sun and its debris emerged from the interstellar dust and gas cloud.[25] Of course, water vapor was present during the Sun's birth. Although liquid water is rarely present on the surface of meteors today, the chemical interaction of water with primitive rocks produced carbonate minerals, indicating the chemical processes of water evaporation and condensation were among the earliest in the solar system. Recently, a small meteorite found in Texas contained actual liquid water that was contained within salt crystals formed from the original interstellar cloud that gave rise to the solar system.

Even more newsworthy is the success of NASA's Voyager and Pathfinder missions, which revealed a Martian landscape that almost certainly indicates the large-scale flow of liquid water. Not only do the surface features of Mars (e.g., flood plains, river beds, mud deposits) suggest the recent presence of liquid water, but also the mineralogy of Martian rocks could only have resulted from aqueous processes. The red planet may still contain water beneath its dry surface rock in the form of soil moisture (i.e., as liquid water and/or ice similar to that hypothesized for Earth's moon) or even flowing groundwater. Moreover, it has been hypothesized that Mars may have also once possessed surface oceans.

The Jovian moon, Europa, is another of the solar system planetoids that almost certainly contains liquid water, in this case located tens of kilometers beneath its icy surface. The liquid water underlying Europa's surface ice is believed to be an ocean containing saltwater that is similar in composition to the seawater of Earth's oceans. Unlike Earth, the heat required to maintain water in a liquid phase on Europa is believed to emanate from an internal source such as volcanic activity rather than from the heat of the Sun.

Cosmic water is present in all three phases (e.g., solid, liquid, vapor) and plays a major role in events ranging from the birthing of stars to the screening of solar radiation. The simple organic molecules required for biological life may have been created in a very unusual type of interstellar ice that is able to flow in a manner similar to liquid water.

Based on recently developed techniques for measuring a suite of stellar characteristics (e.g., orbital velocity, position, brightness), the search for planets has been extended beyond our solar system to other star systems in the galaxy.[26] Given the topic of this book, our next question has to be whether scientists have evidence that these extrasolar planets contain water. They do, at least indirect evidence. Various planets have been identified orbiting stars in the constellations of Leo, Pegasus, Virgo and Ursa Major that probably possess surface temperatures ranging from slightly less than 100° C down to almost -100° C.

While such a temperature range may not qualify these planets as potential human colonies, it does qualify them to contain water in solid, gaseous, and liquid phases. Hence, not only is it certain that other planets and/or moons in our solar system contain or have contained liquid water, it looks like this truism may be universal in scope.

EARTHLY WATER

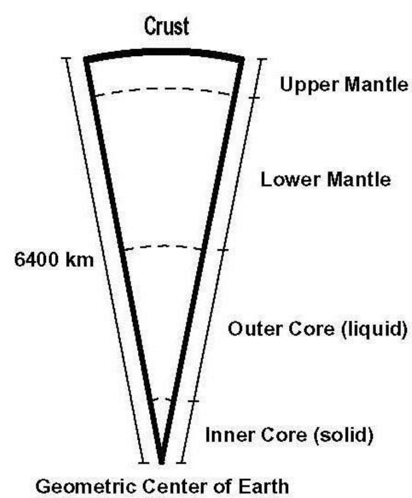
As previously noted, one of the most distinctive aspects of water on Earth is that it exists in all three of its phases. As an ocean-dominated planet, about 70% of the Earth's surface is currently covered in liquid water, with a substantially smaller percentage covered in water ice (i.e., near the North and South Poles). However, scientists believe that there was a long period before the appearance of the continents (approximately two billion years in length) when the planet was almost completely covered in oceans. This ancient superocean is now known as *Panthalassa*, while the ancient landmass that eventually appeared (and from which the present continents are hypothesized to have originated) is known as *Pangea*.

Today, slightly more than 97% of all the water molecules on Earth are contained in the oceans, whereas the polar ice caps and glaciers sequester only about 2%. All the other repositories of earthly water represent less than 1% of the total, with most of that remainder present in the form of groundwater.[27] Less than 0.02% of the total water molecules on Earth comprise the rivers, lakes, soils, and atmosphere combined! Finally, all of the life forms on the planet (e.g., humans, animals, plants, microorganisms) are composed of only 0.00005% of the water molecules. As we will see in Chapter 7, the oceans are the prime player in the planetary story of water, and they control most phenomena that occur on Earth's surface.

Earth's Innermost and Outermost Water

An unlikely place to find earthly water is at the planet's core, which formed early in Earth's history, when the cooling process created a solid inner core composed primarily of iron. The inner core lies at the center of a much larger, liquid outer core, as is shown in Figure 4-2. It has been known for some time that the composition of the outer core is not pure iron but is, instead, some type of alloy that is composed of about 90% iron and 10% other lighter elements. The identity of the main lighter element has been one of the great mysteries of geochemistry. Recently, planetary scientist Takuo Okuchi postulated that hydrogen was the most likely candidate for this lighter element.[28] This theory may explain not only the mystery of the iron alloy in the inner core, but the whereabouts of most of the hydrogen atoms that were present when the Earth was formed. While Okuchi's hypothesis is monumental in and of itself, here is the real kicker with regard to our discussion: the source of the hydrogen is believed to be water!

Figure 4-2. A geologic cross-section of the Earth showing its five major layers. The crust is the uppermost geologic layer of the planet (forming the continents and ocean floors), which is separated from the core by the mantle. The approximate distance from the crust to the geometric center of the Earth is 6400 kilometers. [Adapted from *The Handy Science Answer Book*, 73.]



Although water is generally not stable within the temperature range of 3500° to 5000° K that is believed to characterize the outer core, there is a way in which water could survive. Okuchi hypothesizes that the water is contained as a component of molten silica in an iron-water-silicate mixture.[29] An important prerequisite for his theory is that iron in the primordial Earth sunk slowly to the center of the planet, allowing sufficient time for the silicates and water to equilibrate and form the iron-water-silicate mixture. According to Okuchi, as the Earth cooled and chemically separated into the core, mantle, crust, and atmosphere, a portion of the planetary water found its way into the planet's iron-rich core. If his theory is correct, it pinpoints the location of up to 95% of Earth's hydrogen atoms and places water deep inside the planet in the form of a hydrated silicate.

A general rule of thumb is that water concentrations in the atmosphere decrease as a function of altitude. As such, Earth's middle atmosphere should be very dry. Yet recent satellite data indicates that this upper region is considerably wetter than scientists predicted on the basis of the upward movement of water vapor from near-surface air.[30] In fact, enough water occasionally accumulates to create *noctilucent* clouds, which can only be distinguished from ordinary clouds when seen against a dark sky as the Sun is setting. Concentrations of water vapor at these extreme altitudes display both a temporal and spatial variability that has caused some scientists to wonder whether most of this water is cosmic, rather than terrestrial, in origin. Whatever the origin, increased water vapor concentrations in Earth's middle atmosphere may be contributing to stratospheric ozone depletion due, in part, to water's role as a coolant. Ozone destruction is considered to be a highly temperature-dependent phenomenon.

Global-Scale Phase Changes

While the oceans have always contained most of the planetary water, the relative amount of water in the other "compartments" has varied over the history of Earth. One of the major contributors to water's redistribution appears to have been the Ice Ages, during which a portion of the liquid surface water (mostly seawater) was transformed into massive sheets of ice that extended farther and farther from the poles toward the equator. When the Ice Ages receded, planetary sea levels rose due to water's transition from solid to liquid (e.g., ice caps to oceans and glaciers to rivers).

While ice ages are responsible for a shift in the solid to liquid ratio of water on the Earth, modern man has engaged in activities that have affected the redistribution of liquid waters, particularly those on the surface of continents. For example, we have created reservoirs that have pooled ten trillion tons of water (mostly in the Northern Hemisphere), which has essentially shifted water from the oceans to the continents.[31] As a result of this redistribution, the Earth's spin has actually increased because of a reduction in mass around the equator and a corresponding increase the northern part of the globe. In a similar manner, human activities such as groundwater pumping and deforestation have redistributed water from the continents to the oceans, primarily by contributing to the evaporation of water that would have otherwise remained in the groundwater table or in vegetation.[32] The increased evaporation is then transferred to the oceans either directly as rainfall or indirectly as terrestrial runoff.

The ratio of liquid water to vapor on Earth is regulated by the same temperature fluctuations that have ushered the Ice Ages in and out throughout the planet's history. As the Earth's temperature increases, more liquid water evaporates. The tropical oceans absorb most of the solar radiation, some of which is stored and the rest of which is used in transitioning water from its liquid to gas phase. Oceans contribute most of the planet's evaporating water, which plays the dominant role in governing the energy balance that dictates Earth's climate. Because it is the most abundant and efficient of all the greenhouse gases, water vapor plays the key role in global warming or cooling. Clouds, which are composed of liquid water and ice (not water vapor), are second only to water vapor in balancing the planet's radiative budget. According to atmospheric and oceanic scientist Peter Webster, "In an increased CO_2-induced climate change, only water has the potential of enhancing or mitigating global warming."[33]

The interfaces separating the three different phases of earthly water regulate the interaction among global temperature, pressure, and chemical concentrations.[34] These interfaces include ocean-air, ocean-ice, air-cloud, and a variety of others where energy is exchanged between the atmosphere, hydrosphere, lithosphere, and biosphere via complex processes that are often characterized as chaotic. The modern scientific use of the word "chaos" differs from both the modern colloquial and ancient uses that have been discussed thus far. In science, chaos refers to the interrelationships among natural processes that are difficult or impossible to describe mathematically.[35] Essentially, water is the primary vehicle that redistributes the Sun's energy around the planet, thus acting as both a transducer and conveyor of energy. As ancient philosophers observed, not only may all earthly forms be described as different configurations of water, but the very energy by which these forms function appears to be dependent on water.

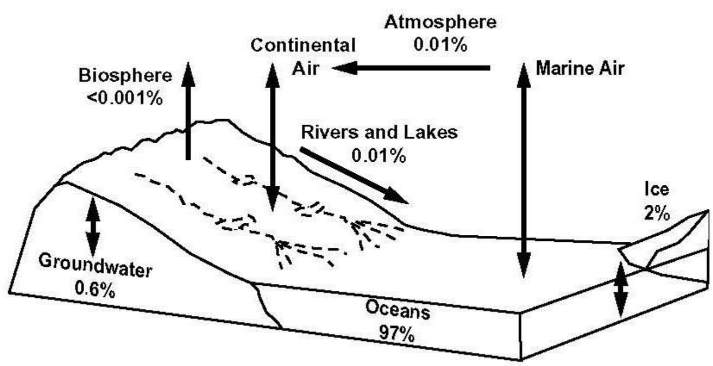
The solar energy reaching the Earth is made available for the planet's complex systems to do work largely through the phase changes of water. Water is the only molecule that is able to affect the planet's climate (e.g., global warming) on short timescales. These remarkable attributes may ultimately be traced to water's unique molecular structure and dynamics.

The Hydrologic Cycle

The circulation of planetary water, or the *hydrologic cycle*, represents the largest movement of a chemical substance on the Earth. Although Chapter 7 focuses on the role of water in Gaia's circulatory system, a brief introduction to the hydrologic cycle is presented here to contrast earthly water with cosmic water. It turns out that our old friend Thales of Miletus was one of the first bona-fide hydrologists. His ideas about how water cycled on Earth lead to subsequent theories (including those presented in Chapter 2) of water being produced in soils and deeper geologic strata, where it eventually finds its way to the surface and into the hydrologic cycle. This was the general understanding of the planetary water cycle until eighteenth and nineteenth century European scientists began to develop the modern hydrologic model.

The conventional concept of the hydrologic cycle maintains that it is essentially a *closed* system. In other words, a fixed volume of water is distributed around the planet and there have been no significant additions of "new" water or deletions of "old" water over the last four billion years or so. This has been and continues to be a point of disagreement among scientists holding unconventional views of earthly water, as will be explained shortly. As shown on Figure 4-3, the global hydrologic cycle classically consists of water's movement between various compartments (e.g., oceans, soils, atmosphere, biota) via the predominant processes of evaporation, precipitation, surface flow, and the release from biological organisms (mostly plants) known as *transpiration*. Through these processes, much of the solar radiation received by the Earth is transferred from the tropics to the poles in the form of heat energy.[36]

Figure 4-3. A simplified conceptual model of Earth's hydrologic cycle. The fraction of the planet's water comprising each compartment is shown as a percentage. The arrows indicate the major routes of water exchange among the various compartments (two-headed arrows indicate that water moves in both directions).



Under a closed system, the origin of water on Earth is related to our earlier story of planetary formation. Recall that planets were formed from the remnants of the interstellar cloud that remained after the Sun ignited. As the cooler material was pulled together by gravity to form the Earth, all water remained trapped until the initial crust solidified and released its gases through volcanic events. This primordial "burp" supposedly created an initial atmosphere comprised primarily of water vapor and simple molecules such as ammonia and carbon dioxide. As the Earth's temperature dropped, water condensed out of the atmosphere as rain that eroded the crustal minerals and, in doing so, formed the sediments and the oceans. In addition, geologists maintain that some of the water was brought to Earth by very large comets, which were believed to have been more prevalent during the initial 100 million years of Earth's history.

Closed vs. Open Systems

The concept of a predominantly closed hydrologic system is often disputed on two fronts. The first we have already covered in our discussion of Louis Frank's theory of the small comets. Not only does his theory suggest that most of Earth's water originally came from small comets, but also that these comets continue to pelt the upper atmosphere on a daily basis. As such, the comets are continually bringing "new" water to Earth's atmosphere at a rate rivaling that of surface evaporation. This theory argues for an *open* system simply because the hydrologic cycle is open to the almost infinite water supply of the cosmos.

The second front on which the closed hydrologic system is disputed relates to so-called *juvenile* water that is hypothesized to form within the Earth itself.[37] Not part of the hydrologic cycle, this juvenile, or primary, water is derived from *magmatic* rocks such as granites and basalts. These rocks cool and crystallize from the molten magma located deep within the Earth. It is theorized that water is an essential component of magmas (i.e., molten core material) and that the pressures and temperatures within the Earth are able to form massive amounts of steam, as is observed during the eruption of volcanoes. As such, the volume of Earth's juvenile water is limited to the tightly bound waters of mineral hydrates.

Juvenile water apparently differs from normal groundwater (e.g., that recharged via the hydrologic cycle) in both its temperature and chemistry. Unfortunately, juvenile water apparently makes its way to the ground surface though the same types of bedrock fractures that transmit conventional groundwater, making it difficult to separate the two on the basis of source locations alone.[38] The assertion that some crystalline rocks are hydrated (i.e., contain water as an integral component of their crystal structure) and that these rocks release tightly bound water as steam (water vapor) under extreme pressures and temperatures is not disputed. In fact, recent data suggest that water may be released more rapidly than previously imagined, pressurizing and eventually fracturing rocks that initiate some types of earthquakes.[39] The dispute focuses on how much water is produced by this mechanism and on whether it adds appreciably to water already present in the hydrologic cycle. In other words, the question is whether juvenile water has ever been a significant source of water for the planet's surface.

In considering the two theories of an open hydrologic system, here is an important distinction to bear in mind. Although the primary water theory demands an open hydrologic system, it does not demand an open planetary system. In other words, water may enter the hydrologic cycle through the groundwater; however, the amount of water on Earth is limited to that present during its formation. This is in sharp contrast to the small comet and other cosmic water theories, in which water enters the hydrologic cycle through the atmosphere and is essentially open to all extraplanetary sources.

Cosmic Forces and Earthly Forms

So, why do we care whether most of the planetary water was here from the time that Earth was formed or whether it is constantly exchanging with the cosmos? The answer lies in the interpretation of ancient and modern insights that claim water mediates between cosmic forces and earthly forms (as was discussed at the end of Chapter 3). Although the scientific controversy surrounding water's origin has not been fully resolved, the consensus is that the recent input of cosmic water to the Earth is minimal. As such, cosmic influences over earthly forms would be based predominantly on various fields, particles, and vibrations that affect water within the hydrologic cycle and not on an actual exchange of water molecules.

CHAPTER 5

THE DECEPTIVE MOLECULE
Ever-Changing Geometries

The element air is described by molecular kinetics and statistical physics. The "simple" substance fire is thermodynamically defined as heat or energy. Quantum mechanics, solid state physics and chemistry refer to matter rather than to earth. The problem child, however, is water, because so far no equation can thermodynamically describe its reaction and properties at the molecular level.
Egon Degens, *Perspectives on Biogeochemistry*

The first "deception" regarding water is related to its familiar chemical formula. Water is not simply H_2O, but rather is a complex network of interconnected water molecules, especially in the solid and liquid states. Moreover, this network is constantly shifting its connections (known as hydrogen bonds) among neighbors so that the resulting geometries are exchanged as many as a trillion times per second. The motionless appearance of water filling a stationary glass is nothing more than a macro-scale façade concealing its ultra-dynamic nature on the molecular scale. Many of water's most puzzling properties, as well as its ability to solvate or "include" an amazing variety of substances within its network, are a direct result of these molecular gymnastics and their associated geometries and vibrations. It is interesting to note that many ancient myths proclaim that water contains innumerable possibilities that are hidden beneath its seemingly boundless and fluid exterior.

AN UNUSUAL SUBSTANCE

Recall from Chapter 1 that Thales proclaimed water to be the most unusual substance if, for no other reason, it is the only one to exist on Earth in three different phases (i.e., solid, liquid, and gaseous) simultaneously. Since Thales made that observation, science has continually uncovered more and more unusual properties and behaviors of what seems to be a relatively simple molecule. While the individual molecule may be relatively simple, the substance in aggregate (including the interaction among molecules) certainly is not. Starting with Thales' observation, we encounter the first major anomaly regarding water, namely the extraordinarily large amount of energy required for a phase change. Water is said to have a large heat capacity, permitting it to store energy with less molecular agitation or rearrangement than just about any other substance. For example, molecules that are chemically similar to water exhibit markedly different freezing and boiling temperatures. Hence, water has gained the reputation of a universal "coolant."

In addition to its role as a coolant, water is also known as the universal solvent because of its unusually high *dielectric constant*. Water's high dielectric constant permits it to separate electrical charges and to dissolve a wide variety of solids (e.g., the major salts in seawater) and keep them in solution as ions. This property is related to the manner in which water molecules align themselves pole to pole, the way a collection of bar magnets does. Liquid water is also characterized by a very high *surface tension*, meaning that it has a strong tendency to "stick to itself" or cohere. In fact, it not only sticks to itself, it sticks to other substances, permitting it to wet most surfaces. If you have ever done a belly flop off the diving board of a swimming pool, you have experienced the effects of liquid water's surface tension. Finally, water not only acts as a universal solvent and coolant, it actually serves as a structural building block for rocks, plants, proteins, stars, and other substances than one rarely associates with water.

Water is characterized by a long list of physical and chemical properties that are considered by scientists to be either anomalous or unpredictable on the basis of properties that characterize seemingly similar substances. What is responsible for this unique and, from the perspective of biological life as we know it, important behavior? While science lacks a complete answer to this question, it is now apparent that many of water's properties arise from its complex molecular structure, which is based on a type of intermolecular link known as a *hydrogen bond*. As this chapter unfolds, we will see that water is not just a random collection of H_2O molecules that form a rigid solid and amorphous liquid. Instead, water molecules are hydrogen bonded to their nearest neighbors, permitting a surprisingly large-scale connectivity among the individual molecules.

It appears that many of water's anomalous properties (particularly the large energetic costs of melting ice and vaporizing liquid) are a direct result of water's resistance to breaking or altering this hydrogen bond network. It is actually the molecular geometries, which are created by this hydrogen bond network, that water seems to preserve to a greater degree than any other substance. We start our molecular journey into water with the chemical bond, much of which is based on the pioneering work of the American chemist and Nobel laureate Linus Pauling.

CHEMICAL BONDING

To fully appreciate the uniqueness of the hydrogen bonding structure in water, a little background on the nature of chemical bonds is in order. Basic chemistry proclaims that there are two major types of chemical bonds that create molecules by linking two or more atoms: *ionic* and *covalent* bonds. It is now recognized that these bonds actually represent more of an energy continuum than they do discrete bonding mechanisms inasmuch as some chemical bonds display both ionic and covalent properties. A typical ionic bond is found in table salt, sodium chloride (NaCl), whereby the molecule is held together by the electrostatic attraction between the positively charged sodium ion (Na^+) and the negatively charged chloride ion (Cl^-). Tremendous temperatures and pressures are required to break ionic bonds in the laboratory; however, water has the ability to separate these ions and keep them "in solution" for indefinite periods as a result of its dielectric constant.

Covalent bonds are simply those where one or more electrons are shared among the outer orbits of atoms comprising a molecule. As discussed in the previous chapter, it is not clear that electrons actually orbit the atomic nucleus in a conventional sense; instead, they are distributed around the nucleus as a cloud. The number of electrons occupying various energy states around the nucleus determines the covalent bonds than an atom can form with other atoms. An atom's bonding potential is referred to as its *valence*; hence, the name of this bond is co*valent*. The sharing of electrons among atoms affects the properties of the molecule to the extent that atoms possess similar or different affinities for the shared electrons. If two or more atoms have similar affinities for the shared electrons, then the electrons are positioned approximately equidistant among the atoms and the molecule is referred to as *nonpolar*. That is to say, there is no electrical charge separation within the molecule resulting from distinct positively and negatively charged regions.

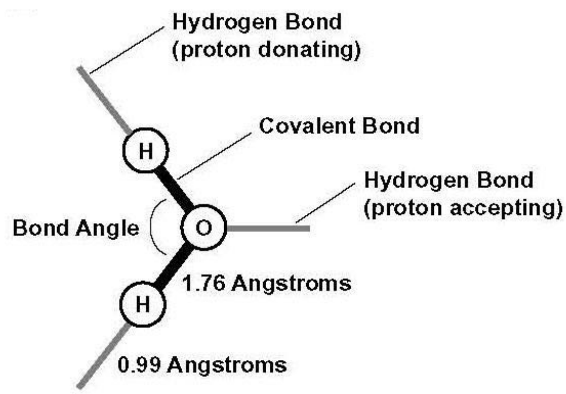
By contrast, atoms with different affinities for the shared electrons create a charge separation in the molecule due to electrons "spending most of their time" closer to the more *electronegative* atom. An electronegative atom is able draw the shared electrons away from the other atoms with which it bonds; hence, the resulting molecule is described as *polar* because distinct negative and positive poles are formed, similar to the North and South Poles of the Earth. Water is a common example of a polar molecule, because the shared electrons between two hydrogen atoms and an oxygen atom are drawn toward the electronegative oxygen, thus creating a charge separation (e.g., the oxygen region is more negative and the hydrogen region more positive). A so-called *dipole* force affects molecules possessing this type of charge separation, resulting in the positive region of one molecule being attracted to the negative region of a neighboring molecule. In essence, these oppositely charged poles of the molecules have a tendency to align themselves in a manner similar to the common bar magnets.

The Hydrogen Bond

The last major type of chemical bond is referred to as the *hydrogen bond*, or simply as the *H-bond*. Hydrogen bonds are formed between molecules that contain hydrogen and an electronegative atom (e.g., oxygen), which has at least one pair of unshared electrons in its outer orbit. The unpaired electrons of the electronegative atom on one molecule attract the partially positive hydrogen atom of another and, consequently, bridges molecules together. The hydrogen bond differs from a dipole force because there is an actual chemical connection formed between the molecules (i.e., the ends of the bar magnets actually touch each other). Each of the hydrogen atoms in water may form a covalent bond with one oxygen atom and a hydrogen bond with another, so that it sits between the two. This relationship is often expressed as *O-H·O*, with a dash representing the covalent or interatomic bonding and dots representing the hydrogen or intermolecular bonding. In addition to oxygen, the hydrogen bond may form with a number of other electronegative atoms, such as nitrogen or sulfur.

The energy associated with a hydrogen bond is less than that of either ionic or covalent bonds, but greater than that of *non-bonding intermolecular forces*. An example of a non-bonding intermolecular force is the dipole attractions among the oppositely charged regions of adjacent polar molecules. While the covalent bond may be thought of as the sharing of electrons among atoms, the hydrogen bond is sometimes considered the sharing of protons between molecules. A proton is simply a hydrogen atom without its electron (i.e., H^+). Most molecules that hydrogen bond act primarily as either a proton acceptor (i.e., containing electronegative atoms that attract the hydrogens of adjacent molecules) or a proton donor (i.e., containing hydrogens that are attracted by the electronegative atoms of adjacent molecules). However, the unique interaction between water's oxygen and hydrogen atoms permits it to act, simultaneously, as both a proton donor and proton acceptor (see Figure 5-1). Although there are a limited number of other molecules that exhibit this dual role, the pattern of hydrogen bonding in water is unmatched by any other known substance in the universe.

Figure 5-1. A planar schematic of the water molecule showing the relative positions of hydrogen and oxygen atoms, as well as the approximate length of the covalent and hydrogen bonds. Bond angles range from those of a perfect tetrahedron in ice to a distorted tetrahedron in liquid water. The distance between oxygen atoms of adjacent water molecules is about 2.75 angstroms, representing the sum of the covalent and hydrogen bond lengths.

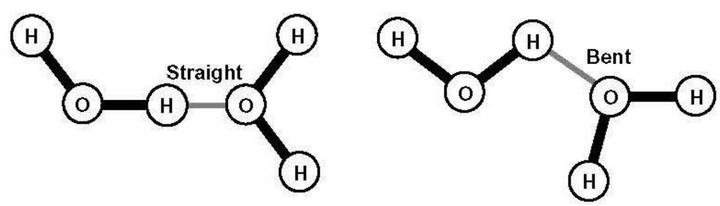


Water consists of H_2O molecules that are linked together by hydrogen bonds, creating an interconnected molecular network that appears to be unique among all known substances. The properties of these H-bonds determine, to a large extent, the behavior of the network.

Nuances of the H-Bond

In addition to linking molecules instead of atoms, the hydrogen bond displays two other characteristics that are distinctly different from those of either ionic or covalent bonds. First, the hydrogen bond has a directional component as a result of the positioning of the hydrogen atom between the oxygen atoms comprising an H-bond (see Figure 5-2). Depending on the relative orientation of two adjacent water molecules, the covalent O-H bond may lie either in a direct line with or at an angle to the acceptor oxygen. The former (straight) arrangement has been hypothesized to create a stronger H-bond than does the latter (bent) one. Physical chemist Jichen Li recently postulated that this difference in H-bond strength could explain which of the bonds in water are preferentially broken during heating and phase changes.[1] The critical temperature for changing strong to weak H-bonds is 37°C (i.e., the human body temperature). We'll discuss some potential implications for this temperature-dependent H-bond switching in biological organisms in Chapter 6.

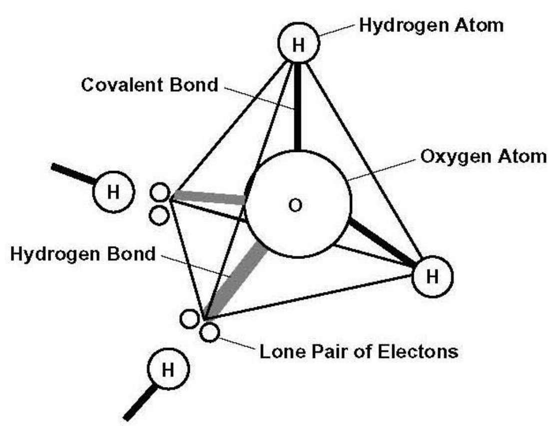
Figure 5-2. A schematic of the hydrogen bond's directionality, which includes the two positions that a hydrogen atom can assume between two oxygen atoms of neighboring water molecules. The oxygen atom of one molecule may lie along a straight or bent (angled) line with the oxygen atom of a neighboring water molecule. Directionality applies to all H-bonds; not just to those between adjacent water molecules. [Adapted from James Watson, *Molecular Biology of the Gene*, 95.]



It is worth noting that hydrogen bonds do not truly represent a distinct bonding mechanism, but instead show some covalent characteristics as well. Recent research into the H-bonds of water ice suggests that the two types of bonds (e.g., straight vs. bent) show differing degrees of this covalent character, perhaps distinguishing the strong from the weak.[2] Although the "strong vs. weak" designation for H-bonds is still being debated among physical chemists, the covalent character of H-bonds (originally predicted by Linus Pauling) is generally accepted. This covalent character implies that adjacent water molecules, not just adjacent atoms within a water molecule, are able to share electrons. As such, H-bonds provide a mechanism for two apparently separate molecules to share an intimate connection.

The second distinctive property of hydrogen bonds is their relative impermanence. Ionic and covalent bonds may endure for eons if temperatures and pressures do not fluctuate dramatically and if chemical reactions do not occur. By contrast, the hydrogen bonds of water (at least those characterizing most of the liquid phase) have a lifetime on the order of *picoseconds*. This means that hydrogen bonds in water are broken and formed as rapidly as a trillion (10^{12}) times every second. Chemists at the University of California, Berkeley have found that this rapid making and breaking of bonds is not a simple process that can be described by well-defined rate constants.[3] Stated in a slightly different manner, the breaking and forming of H-bonds is highly dependent on the spatial orientation of "nearest neighbor" water molecules and can be predicted only in terms of a probability function. This behavior is interesting because it implies that there are strong associations between neighboring water molecules; however, the complexity of such interactions lies beyond deterministic mathematical predictions.

Figure 5-3. The simplest tetrahedral unit (OH_4) of water's H-bonded network. The large oxygen atom serves as a center vertex, while the smaller hydrogen atoms serve as the four outer vertices, of a tetrahedron. Two of the hydrogen atoms are covalently bonded to the oxygen atom and the other two hydrogen atoms (each donated from a different neighbor) are H-bonded to the oxygen atom via its two lone pairs of electrons. (Adapted from Philip Ball, *H_2O: A Biography of Water*, 155.)



The solid form of water, or ice, does not exhibit this hydrogen bond switching at the same feverish pace as do the liquid and vapor states. The hydrogen bonds in ice have a lifetime on the order of minutes to hours, as opposed to picoseconds. Ice is relatively "frozen," with the oxygen and hydrogen atoms positioned so that the H-bonds form a perfect tetrahedron (see Figure 5-3). As ice melts into liquid water, a fraction of the hydrogen bonds are broken and the tetrahedron begins to bend. As the temperature of the water continues to increase, the bond breaking and geometry contorting increase slightly. One of the most unique characteristics of water is that its bulk liquid phase has an average of only 15% fewer H-bonds than does its solid phase. Most substances lose a substantially higher percentage of their bonds during phase transitions. This anomalous H-bond preservation plays a pivotal role in maintaining the molecular geometry of water through temperature and phase changes, as well as in giving rise to its unique physical properties.

Many of water's anomalous physical properties (e.g., density maximum, dielectric constant, specific heat) are associated with the preservation of its H-bonded network over a wide range of temperatures and the associated phase change. This preservation permits the liquid-phase network to display characteristics that are "ice-like."

WATER'S THREE PHASES

When we consider the hydrogen bonding of solid and liquid water, our conventional designation of the liquid or solid as "H_2O" becomes suspect. In effect, water almost never exists as a monomer (i.e., a solitary H_2O molecule) due to its propensity for hydrogen bonding with neighboring molecules. Therefore, a more functional description of water is the OH_4 unit, consisting of an oxygen atom that is linked tetrahedrally to four hydrogen atoms—two via covalent bonds and two via hydrogen bonds. Actually, each water molecule donates its two protons (hydrogens) to form H-bonds with two of its neighbors, and two other neighbors each donate one proton to H-bond with the oxygen atom's lone pairs of electrons.

A simple diagram of H-bonding in the water molecule is shown on Figure 5-3. A clever representation of H-bonding in water is presented in Philip Ball's recent book, *H_2O*, whereby he equates the covalent and hydrogen bonds of the tetrahedral OH_4 unit to the arms and legs of the oxygen atom.[4] Although the perfect bond angles of a tetrahedron (e.g., the spatial positioning of its arms and legs) are present only in ice, liquid water is able to retain bond angles that vary by only a few degrees from those in ice.

It should be noted that many substances besides water utilize a tetrahedral bonding geometry. For example, silicon dioxide (SiO_2), one of the Earth's most common minerals, displays tetrahedral bonding such that each silicon atom (Si) is linked to four oxygen atoms to create the SiO_4 subunit. Hence, the silicon and oxygen atoms in quartz are structural analogues of the oxygen and hydrogen atoms in water. Water is unique, not in its tetrahedral bonding geometry, but rather in the ceaseless manner in which its H-bonded network reforms the tetrahedra.

The Solid (Ice)

Water ice is characterized by varying geometries based on the temperatures and pressures under which it is formed. Scientists have created and described numerous forms of crystalline ice; however, only two forms are known to occur naturally.[5] The most common form of natural crystalline ice is known as *Ih*, which is an abbreviation for hexagonal ice. A more rare type of crystalline ice is formed at lower temperatures and pressures than are present on the surface of the Earth and is referred to as *Ic*. Ic is an abbreviation for cubic ice, which is formed at high altitudes in the atmosphere and in interplanetary space. While both forms of water ice from hexagonal rings, ice Ic transforms irreversibly to ice Ih at temperatures above approximately -100° C. The bond angles in ice Ic are exactly that of a tetrahedron, while those in ice Ih deviate slightly from a perfect tetrahedron.

All the other known structures of ice, except one, are formed at extremely high pressures in the laboratory and are characterized by a density greater than that of pure liquid water (i.e., 1 g/cc). The one exception is the previously described amorphous ice, which is formed in interstellar space at temperatures of approximately -260° C (10° K) and possesses less structure, a larger dispersion of bond angles, and weaker hydrogen bonds than do the Ic and Ih forms.[6] The general term *unstructured* refers to a non-crystalline arrangement where the water molecules do not form a perfect lattice, but instead occupy a range of conformations. Hence, amorphous ice more closely resembles its liquid cousin, which is able to flow thanks to the rapid breaking and forming of H-bonds that hold it together, than its crystalline siblings. It has been said that liquid water cradles life but solid crystalline water destroys it. Scientific research presented in Chapter 4 indicates that, perhaps, solid amorphous water cradles the precursors of life.

A review of Table 5A indicates that the Ic and Ih forms of ice differ very little in their structural dimensions and their physical properties. None of the differences between the Ic and Ih forms exceed 0.5%, whereas differences in the same structural and physical properties between the natural and artificially produced ices are on the order of 10% to 30%. This comparison suggests that the natural forms of ice are very similar in their structure and that no substantial changes, other than a slight difference in bond lengths and angles, are incurred in the transformation of Ic to Ih ice.

In addition to the fact that only the naturally occurring ices (i.e., Ic and Ih) possess a density less that that of liquid water, there is another significant difference between the natural ices and the "II+" forms created under high pressures in the laboratory. The Ic and Ih forms display what is known as *orientational disorder* over the entire temperature range within which they exist, whereas the II+ forms display both ordered and disordered arrangements. This orientational disorder makes it possible to determine only an average, rather than a specific, orientation for individual molecules.[7] Because there are two mutually exclusive positions that the hydrogen atom can occupy between adjacent oxygen atoms, a pair of H-bonded molecules assumes only one position at a time (i.e., either straight or bent). Depending on whether or not these positions are discernable, the water network is referred to as ordered or disordered, respectively.

Table 5A. A comparison of the physical and structural properties for water ices, including the naturally occurring Ih and Ic forms and the laboratory-derived II through VIII forms. Distance is presented in the units of angstroms, bond angles in the units of degrees, and density in the units of grams per cubic centimeter. Adapted from data presented by H.F.J. Savage.[8]

PROPERTY	**Ice Ih**	**Ice Ic**	**Ices II - VIII**
Distance between nearest neighbors (Å)	2.76	2.75	2.75 to 2.92
Orientational order	disordered	disordered	ordered/disordered
O~O~O angles (°)	109	109.5	81 to 144
Density (g/cc)	0.93	0.93	1.18 to 1.50

Notice that there is a difference between the terms "structure" and "order." The former refers to the overall geometry (e.g., degree of spatial distortion, extent of H-bonding), while the latter refers to the degree of rotational freedom (i.e., switching back and forth) as it affects the orientation of H-bonded molecules. This switching between molecular orientations has been described as the "flip-flopping" of H-bonds in a disordered system.[9] Strictly speaking, an H-bond's order also may be measured by the distance separating adjacent oxygen atoms, called its *translational order*. While the two measures of water's order (and their associated molecular motions) are not totally independent, one parameter may vary to a greater degree than the other. In an attempt to minimize the number of scientific terms, I will refer only to orientational order, which may include the closely related properties of translational order and directionality.

The Liquid

The conversion of water from a solid to a liquid requires the breaking of some of the H-bonds that comprise the nearly perfect tetrahedron of ice Ih. By retaining 80% to 90% of the H-bonds present in ice, liquid water essentially preserves a high degree of geometric consistency through the phase change. Any disruption to water's network requires energy to be added to the system. This energy is measured as the so-called *heat of fusion*, which is greater for water than for similar compounds due to water's unique H-bonding dynamics. By contrast, relatively weak (non-bonding) intermolecular forces, rather than hydrogen bonds, hold most liquids together. Consequently, water is substantially more cohesive than are most liquids.

As we all learned in school, water is very strange in that the melting of ice into liquid water initially produces a denser, rather than a less dense, phase. In other words, ice floats on liquid water—apparently because of the rather odd way in which water molecules choose to arrange themselves near the freezing point. Scientific research suggests that it is the tighter packing among distant neighboring molecules (i.e., those located further away than the four nearest neighbors with which a water molecule hydrogen bonds) that is responsible for the higher density of liquid water compared to ice.[10] As the temperature increases from 0° to 4° C, densely packed distant neighbors are created at the expense of loosely packed distant neighbors, even though the spacing between nearest neighbors remains fairly constant. Essentially, water molecules in the liquid are most tightly packed at a temperature of 4° C.

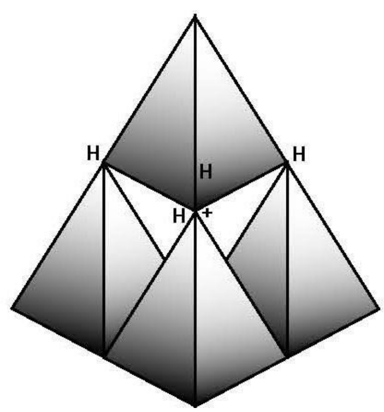
Similar to ice, most of water's liquid is characterized by orientational disorder. Unlike ice, liquid water is constantly and rapidly rearranging itself. The French chemist Paul Caro suggested that water might be thought of as one heavy and two lighter balls (i.e., the oxygen and hydrogen atoms, respectively) that are linked by flexible springs, thus forming a vibrating mechanical system.[11] He has identified three modes of normal vibration in the covalent (O-H) bond, which are layered upon an even greater number of vibrational modes in the hydrogen (O··H) bond. In other words, not only are the hydrogen and oxygen atoms moving in relation to each other, but also the molecules formed by these atoms are themselves moving in relation to one another. Add to this movement the varying rates at which H-bonds are switched and you get an inkling of water's dynamism. As we discuss the geometries of water, keep in mind that these are not static structures. In the words of Paul Caro:

> The strongest image that can be found for the 'structure' of water is provided by video simulations that represent the results of position calculations for each atom in each molecule for a total system lifetime that is just a few picoseconds (1 picosecond = 10^{-12} second). This technique reveals a world in motion, in which hydrogen bonds are constantly and rapidly being formed and broken, while the whole, continuously reconstructed network appears to pulse very slowly. Rapid rotations superimpose their rhythm on the slower background of translational motions.[12]

Liquid water classically has been described as a random, space-filling network of molecules that are connected by hydrogen bonds. The conceptual models for this network are generally placed into one of two categories. *Mixture models* characterize liquid water as a mix of structured clusters and unstructured bulk water. By contrast, *continuum models* characterize liquid water as a more homogeneous but distorted network of H-bonded molecules. While a definitive physical model for liquid water remains one of science's most elusive laurels, the combination of these two models predicts many of water's physical properties. *Bulk liquid* water simply denotes the fraction of water molecules that are not components of H-bonded molecular *clusters* or distinctly structured groupings. From the standpoint of mixture models, clusters are normally distinguished from bulk water in terms of their geometric structuring and their rate of H-bond switching. From the standpoint of continuum models, there is no such distinction.

Let's first consider water's bulk liquid, which is sometimes represented as a network of H-bonded molecules. The energy required to switch between H-bonds is a fraction of the bond energy itself, permitting each water molecule to readily interchange bonding arrangements with its nearest neighbors. In other words, water molecules switch H-bond connections among their neighbors in a never-ending game of partner exchange. In doing so, the OH_4 tetrahedral units form the individual building blocks for a so-called "supertetrahedron," which is composed of four water molecules and an associated proton (see Figure 5-4).[13] Each water molecule's oxygen atom is located at the center vertex of the four OH_4 tetrahedra that, in turn, comprise the outside vertices of the larger supertetrahedron. Notice that the supertetrahedron looks like four stacked pyramids, which have temporarily trapped an extra proton.

Figure 5-4. A representation of the supertetrahedron created by four adjacent water molecules. These four water molecules are able to trap a proton (H^+) in the center of the tetrahedral complex, which is continually breaking and reforming. Each of the four component (smaller) tetrahedra are characterized by one central oxygen atom, two hydrogen atoms, and two lone pairs of electrons. Hence, the supertetrahedron is also known as an $H_9O_4^+$ cation or hydrated proton. [Adapted from Egon Degens, *Perspectives on Biogeochemistry*, 244.]



Because water molecules have a tremendous affinity for the proton, H^+ nearly always occurs in water as a so-called *hydrated proton*. In fact, the supertetrahedron is best described as a $H_9O_4^+$ hydrated proton that traps an extra proton with one or more of its four water molecules. The supertetrahedral $H_9O_4^+$ hydrated proton is also known as the "Eigen cation" (named after the

German chemist and Nobel laureate Manfred Eigen), which has been characterized as the minimal molecular structure for water's trapping a proton.[14] Physical chemists sometimes describe the process of proton capture in terms of a single proton migrating along the H-bonds of the supertetrahedra such that it is successively shared between pairs of water molecules.[15]

In this manner, proton transfer through bulk water occurs via the formation of these transient structures (e.g., supertetrahedra), which exist only as ideal structures that are changing as fast as the H-bonds are broken and formed. In essence, the movement of the proton results from the continual reforming of water's molecular geometries that successively include a different set of neighbors. This sort of molecular sleight-of-hand is sometimes couched in the quantum mechanical term of *proton trapping*, denoting that the proton seems to be successively trapped and released by the transient structures. Because the water molecules are not actually moving around, proton transfer is really a function of the picosecond lifetimes of H-bonds. Proton transfer appears to be pivotal in the vast array of functions that liquid water performs, not least of which is its facilitating chemical reactions.

The H-bonds in bulk liquid water are shuffled or exchanged as fast as a trillion times per second, permitting water to flow with only minor disruptions to its H-bonded network. The molecules participating in the H-bonds assume specific orientations that give rise to one of water's most important properties, known simply as its order.

The Gas (Vapor)

As water is heated past 100° C, there is another phase change from a liquid to a gas. Actually, water boils and freezes over a range of temperatures depending on its exact structure and on environmental conditions such as pressure. Were it not for water's unique H-bonding dynamics, a substantially greater fraction of earthly water would exist in the vapor, rather than the liquid, phase. Water's transition from a liquid to a vapor phase involves the breaking of H-bonds that account for the cohesiveness of the former phase. Because the vaporization of water essentially destroys its molecular network, energy must be expended to break the weaker H-bonds that comprise liquid water at the phase change. This energy is measured as the so-called *heat of vaporization*, which is higher for water than for chemically similar molecular substances because H-bonds are stronger than non-bonding intermolecular forces.

Unlike the complex structures of liquid water and ice, the primary form of water vapor is the *dimer*. A dimer refers to two water molecules that are joined by a single hydrogen bond, thus forming a cluster that is often represented by the simplest of the aforementioned hydrated protons. Most vapor clusters consist of relatively few molecules that, unlike the vast networks of ice and liquid water, are disconnected from other clusters and from a bulk phase. Hence, the vapor displays a distinct lack of connectivity and, according to most current theories, behaves more like discrete or separate entities than like an integrated network.

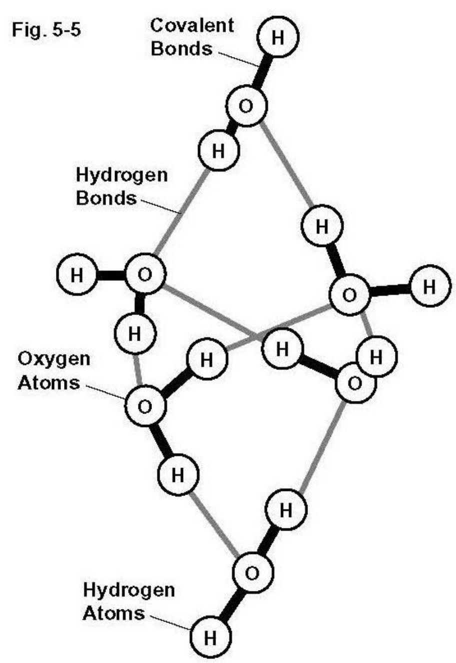
WATER CLUSTERS

Because the H-bonds in liquid water do not form a perfect tetrahedron (as they do in ice), the resulting macroscopic network has to be understood in terms of the connectivity and clustering that the H-bonds create.[16] Clusters may consist either of water-only assemblages or of water assemblages that contain *solutes*. Solutes represent any atom or molecule that is contained within the water network (i.e., dissolved). I will refer to water-only assemblages as clusters and to assemblages containing solutes as *hydration shells* or *clathrates*, depending on their size, geometry, and physical state. Moreover, the term "clusters" will be used to denote water assemblages that are H-bonded, as opposed to non-bonded associations that have been detected in water at extreme temperatures.

Cluster Geometry

As water molecules are added to the dimer, three-, four- and five-membered rings form triangular, rectangular and pentagonal shapes in two dimensions. The most stable form of six H-bonded water molecules, or *hexamer*, is not a two-dimensional ring, but rather a three-dimensional cage-like structure, as shown on Figure 5-5.[17] This cage-like structure is composed of six molecules that are held together by eight hydrogen bonds. A quick review of the Platonic solids described in Chapter 2 reveals the similarity between the geometries of the water hexamer and the octahedron, which is composed of six vertices and twelve (rather than eight) edges. In other words, the H-bonds connecting neighboring water molecules preserve the hexamer's octahedral geometry with only minor distortions.

Figure 5-5. A diagram of the water hexamer and its component atoms and bonds. The six clustered water molecules of the hexamer represent the simplest and one of the most prevalent of water's three-dimensional geometries. Each of the six oxygen atoms forms an outside vertex of an octahedron for this water-only cluster. [Adapted from K. Liu, et. al., *Nature,* 381 (1996): 501.]



Physical properties (e.g., H-bond lengths and energies) of small water clusters are reported by U.C. Berkeley chemists to be very similar to the average properties of bulk liquid water.[18] In addition, these small clusters exhibit H-bond rearrangement dynamics (i.e., exchange rates or rhythms) and dipole moments that indicate they are in constant flux. In contrast to small and highly transient clusters, the physical properties of larger water clusters are less similar to those of liquid water's bulk phase, especially with regard to their longevity and molecular rearrangement dynamics. Larger water-only clusters possessing the geometries of both a cube ($(H_2O)_8$) and a dodecahedron ($(H_2O)_{20}$) have been identified by physical chemists.[19]

It is interesting to note that clusters displaying the geometry of Platonic solids have the unique property of every molecule H-bonding with three others, which creates the most stable of all possible configurations. In fact, the dodecahedron was identified as the most stable geometry out of more than 30,000 possibilities for ($(H_2O)_{20}$). The dodecahedron possesses the so-called "magic numbers" for H-bonded clusters (e.g., 20 water molecules forming 12 pentagons that consist of 30 bonded and 10 non-bonded hydrogen atoms).[20] Recall that the dodecahedron consists of 20 vertices, 12 pentagonal faces, and 30 edges; therefore, the number of water molecules and H-bonds correspond to the number of vertices and edges, respectively.

Clathrates

Clathrates are a special group of water clusters that are formed around relatively small solutes, particularly biogenic gases (e.g., methane, carbon dioxide) and small nonpolar compounds. Clathrates are present as a solid phase, generally possessing between 75% and 80% of the hydrogen bonds that are present among water molecules in bulk ices.[21] Additionally, the switching of H-bonds in clathrates is orders-of-magnitude slower than that in bulk water. There are a couple aspects of water clathrates that should be noted. First is water's use of clathrates to cage a wide range of solutes and, thus, isolate them from the bulk network. Linus Pauling suggested that the clusters predicted by mixture models might actually consist of water-only clathrates, whereby the guest is simply another water molecule.

The second aspect of interest is the consistency with which water builds clathrates using the geometry of the dodecahedron. Dodecahedral clathrates are built by concatenating pentagons, which may provide the curvature required for water to rearrange itself around the surface of large solutes. Although not truly clathrates, many hydration shells appear to be "clathrate-like" inasmuch as their water molecules are more ordered than those of bulk water and they are constructed predominantly from pentagons. As the size of the guest increases, water concatenates polygons to form larger clathrates, typically consisting of modified dodecahedra.

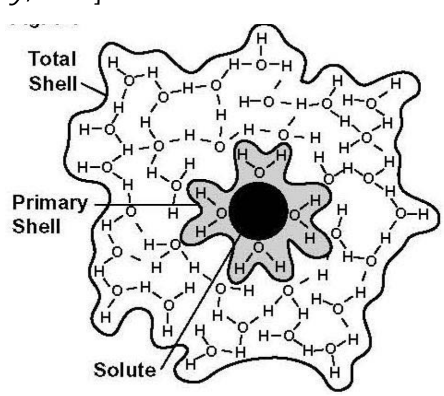
One of the most fascinating types of water clathrates is the *gas hydrates*. A gas hydrate simply refers to a water clathrate containing a guest such as methane, propane, or carbon dioxide. The only common gases that do not form clathrates are hydrogen and helium, the molecular diameters of which are too small to be contained within the cages. Recently, gas hydrates have made the front pages of newspapers as scientists have reported the ubiquitous presence of methane hydrates on the ocean floor along continental margins. Methane hydrates are a viable source of energy, and it has been estimated that the mass of organic carbon in methane hydrates exceeds that in all the coal, petroleum, and conventional natural gas deposits combined! In fact, scientists now estimate that more than half of the Earth's total organic carbon is in the form of methane hydrates. It is interesting to note that as seawater forms clathrates around methane, salts are excluded to the point that drilling through these hydrate formations actually yields freshwater from marine sediments.

Hydration Shells

As opposed to the clathrates that are formed around small nonpolar (hydrophobic) solutes, hydration shells are formed around larger nonpolar solutes, as well as around ionic (electrically charged) and polar (hydrophilic) solutes. Hydration shells also refer to the structured water that surrounds very large molecules such as proteins and nucleic acids. Water is unable to contain these huge macromolecules within even the largest clathrate, and instead concatenates polygons to form hydration shells containing an enormous number of water molecules. Similar to the clathrates, hydration shells generally possess a degree of structure and an H-bond lifetime that is intermediate between that of the bulk liquid and the ices.

When a typical ionic solute (e.g., table salt) is dissolved in water, the positively charged sodium and negatively charged chloride atoms are split apart and contained within the water lattice as ions. Water accommodates the ions by locally changing the hydrogen bond content of the bulk liquid, whereby the amount of required change is reflected as an increase in temperature of the aqueous solution. Structural changes in water due to the dissolution of ions are related to both a *primary* and a *total* hydration shell, as shown in Figure 5-6. In other words, the primary hydration shell consists of a population of water molecules that are aligned, via their dipoles, with the ion being solvated. This primary hydration shell is surrounded by and exchanges with a much larger population of water molecules in the outer shells, which are increasingly "bulk-like" because they are progressively less influenced by the hydrated ion and more influenced by the H-bonded network.[22]

Figure 5-6. The primary and total hydration shells surrounding a cationic (positively charged) solute. The negatively charged region (i.e., oxygen atom) of the water dipole is oriented toward the solute in the primary shell. Dipole effects on the H-bonded network diminish as a function of distance from the primary shell. [Adapted from Egon Degens, *Perspectives on Biogeochemistry*, 248.]



Scientists have traditionally explained the ion effects on the basis of their ability to affect the orientation of water molecules in the H-bonded network.[23] This rather simplistic explanation (correct or incorrect) asserts that small ions (mostly cations) with a dense charge tend to strengthen the H-bonded network and are known as *structure-makers*. Conversely, larger ions (particularly anions) with a more diffuse charge disrupt the H-bonded network and are known as *structure-breakers*. The disruptive effects of ions are more pronounced at higher temperatures where the H-bonded network is more strained even in pure water.

Polar, or hydrophilic, solutes include compounds such as ammonia and ethanol. Similar to the ionic structure-breakers, hydrophilic hydration tends to be less tetrahedral than the bulk water structure because of the strong interaction between the poles of the water and of the solute molecules.[24] These interactions have the effect of reorienting water molecules within the primary and, to a lesser degree, total hydration shell in order to dissipate electric field effects rather than to maximize H-bonding in the bulk network. Depending upon the size and separation of charges in the polar solute, hydrophilic hydration may be quite similar to the hydration of large ions with diffuse charges. In both cases, the local structure of water's bulk network is compromised.

Nonpolar, or hydrophobic, solutes include gases, hydrocarbons, and many other organic molecules. Traditionally, the dissolution of a hydrophobic solute has been attributed to the fact that the energy required by water to disrupt a portion of its H-bonded network in order to create a cavity for the nonpolar solute is offset by the apparent increased order or decreased randomness of water molecules. In other words, water molecules comprising the hydration shells of hydrophobic compounds are more ordered within their neatly structured clusters than are those comprising the bulk liquid. Water minimizes the disruptive effects of hydrophobic solutes on its H-bonded network by increasing the orientational order (i.e., decreasing the rotation) of individual water molecules in the hydration shell in addition to actually increasing the overall structure of the shell (i.e., reorganizing intermolecular positions).

Water molecules in the hydration shell are not only more ordered (i.e., possess less orientational freedom) than those in the bulk liquid, but they also rearrange or vibrate at a slower rate. Although hydrophobic hydration results in an increased percentage of broken H-bonds compared to that in the bulk network, the H-bonds that persist are likely to be stronger.[25] This theory of selective H-bond breaking and forming raises the possibility that water's network somehow balances the extent of H-bonding (including both weak and strong bonds) with the relative contribution of strong H-bonds. If true, the hypothesis that weak H-bonds are preferentially broken during various molecular reorganizational processes may be pertinent. Although science does not yet have the answer, this theory suggests that within water's orientational order lies the key to one of its most impressive tricks, namely dissolving hydrophobic solutes.

Scientists have recently postulated yet another pivotal role for the dissolution of hydrophobe solutes, particularly dissolved gases.[26] It seems that changes at the gas-water interface are linked to modifications in both the size and reactivity of water clusters. While the mechanism of this linking is still under investigation, current theory focuses on the role of dissolved gases in forming extremely small bubbles at the interface that, in turn, are capable of affecting cluster properties over relatively long periods. The "microbubble" theory also provides a possible mechanism for the apparent long-range interactions between hydrophobic solutes that cannot be attributed to relatively weak intermolecular forces. I will return to this theory in Chapter 8 as part of the discussion regarding water's response to electric and magnetic fields.

When substances are introduced to liquid water, structured groups of molecules known as hydration shells are formed around the solutes, thus minimizing the disruption to bulk water's tetrahedral network. Networks comprising the hydration shells are characterized by greater order and slower H-bond exchange rates than are those of bulk water.

ENIGMATIC SEAWATER

Our discussion of water thus far has dealt with either pure water or dilute aqueous solutions in which the solutes comprise only a very small fraction (e.g., less than 0.1%) of the total solution. By contrast, the salts or ions in seawater account for about 3.5% of the total solution. While the bulk of seawater (i.e., 96.5%) is just pure water, that other 3.5% has some profound effects on the bulk solvent. Seawater freezes at a slightly lower temperature and boils at a slightly higher temperature than does bulk water because of the effects of high salt concentrations on the molecular H-bonded network. Moreover, salts are absent from both the vapor and ice produced by heating and cooling seawater, respectively. Unlike pure water, seawater exists only as a liquid. Before launching into a discussion of the differences in molecular structure between pure water or dilute aqueous solutions and seawater, let's take a look at the gross chemical composition of the oceans.

Chemical Composition

As presented in an earlier section, seawater is composed of a long list of anions and cations that are hydrated or kept separate by water, which prevents them from forming ionic bonds and salting-out of solution. Chloride is the major ion and comprises about 55% of the solids in seawater. Ions are frequently described as dissolved solids such that the sum of all the anions and cations in water is referred to as the *total dissolved solids* or *salinity*. Besides chloride, two other anions and four cations collectively comprise more than 99% of the salinity and represent the only seawater constituents that exceed a concentration of 100 mg/L (milligrams per liter). The remainder of seawater's ionic constituents is considered to be present at trace concentrations (see Table 5B).

While the average salinity for the oceans is 3.5%, the concentration may vary from 3.2% to 3.8% depending on factors such as rainfall and evaporation, as well as localized biological activity and terrestrial inputs. Salinities are generally higher in tropical oceans due to the high evaporation rates, which remove pure water and leave behind the salts. Despite the wide range of climatic and geographic settings for the world's oceans, seawater's composition (in terms of the relative proportion of its major ions) is believed to have been constant for the last 500 million to 600 million years. In fact, the proportions or ratios among ions are so stable that the salinity of seawater may be accurately calculated by simply measuring the concentration of one its constituents (e.g., chloride). Why and how have these ion ratios remained so stable for so long? The answers are not known for certain.

Table 5B. A comparison of the concentrations and relative contribution of major dissolved solids in seawater. Also shown are the typical effects of these dissolved solids (ions) on the H-bonded molecular structure of bulk liquid water. Those ions that disrupt are often referred to as *structure-breakers*, while those that enhance are known as *structure-makers*.

Dissolved Solid	Concentration in Seawater (mg/L)	Composition of Seawater (%)	Typical Effect on the H-bonded Network of Bulk Liquid Water
Chloride	19,000	55	Minimally Disrupt
Sodium	10,600	31	Enhance
Sulfate	2560	7.4	Disrupt
Magnesium	1270	3.7	Enhance
Calcium	400	1.2	Enhance
Potassium	380	1.1	Disrupt
Bicarbonate	140	0.4	Disrupt
Bromide	65	0.2	N/A
Strontium	13	0.04	N/A
Boron	4.6	0.01	N/A
Silicate	2.9	<0.01	N/A

The standard scientific explanation for the stability of ion rations in seawater is that the water originated from condensation in the atmosphere during the initial planetary cooling. Some water was also released from the Earth's crust during solidification. The ions or solids were added, via surface runoff, to the water in ocean basins from the weathering of continental rocks. Eventually, a solution equilibrium was reached (i.e., enough salt had dissolved in water) and things have remained remarkably constant from that time on. This particular scientific dogma has been and continues to be challenged on the basis of the rock types (corals) laid down in the geologic record and of the cyclic activity of *thermal vents*.[27] Thermal vents occur on the seafloor along mid-oceanic ridges, where the planet's molten rock (magma) contacts seawater and introduces a variety of salts, metals, and gases directly into the oceans. You'll remember the mid-ocean ridges as a proposed source of subterranean water for the biblical Great Flood.

There are countless ways in which salts may be removed from and deposited into the oceans (e.g., biological uptake, thermal vents, sea spray, volcanoes, sedimentation, continental runoff). Moreover, the ongoing exchange of water between the Earth's crust and mantle may further maintain the ocean's salinity by assisting to regulate the volume of seawater.[28] The ocean's salinity must be maintained on an ongoing basis because the equilibrium achieved 600 million years ago could not have endured without some type of regulation. Whatever the proposed contributing mechanisms, science cannot fully explain either how the oceans' salinity has been consistently kept within such tight bounds (assuming that it has) or why such a precise chemical composition is required (assuming that it is).

Molecular Structure

Unlike the structure of pure water's bulk phases and clusters, the molecular structure of seawater is poorly described and remains somewhat enigmatic. Due its high concentration of dissolved solids, or "salts," seawater is very difficult to study using the techniques that physical chemists routinely employ to discern the structure of pure water or water containing relatively low ion concentrations. In addition to interfering with the investigative techniques, the relatively high concentration of ions in seawater has a significant effect on the structure of the water itself (see Figure 5-6). As the percentage of water molecules comprising hydration shells (i.e., those required to solvate the salts or ions) approaches that of the bulk water, the mixture and continuum models describing pure water or dilute aqueous solutions are invalidated. In very salty solutions (e.g., brine), the ions may begin interacting with each other and breaking down the hydration shells that protect the structure of bulk water. A salting-out effect may be observed at extremely high concentrations when the ion-water interactions become weakened to the point that ionic bonds re-form and create salt crystals.

The most pertinent changes that have been observed or hypothesized in transitioning from dilute aqueous solutions to a highly concentrated one, such as seawater, include the following:[29]

- Substantial ion-ion interactions in addition to water-ion interactions (as in dilute saline solutions) and water-water interactions (as in pure water);

- Overlapping hydration shells, such that a single water molecule may be involved in hydrating more than one solute at the same time;

- Varying orientational order in water molecules comprising the hydration shells, which is influenced by neighboring ions as well as by the ion that is actually being dissolved.

Although ion-ion interactions have been categorized, it is difficult to predict the exact structure of these shared or adjacent hydration shells.[30] Consequently, the solvation of an ion in seawater cannot be predicted with the same degree of certainty that it can in a dilute aqueous solution. Factors that control the mechanism of ion solvation in seawater include its physical properties (e.g., pH, temperature), as well as the concentration and identity of its inorganic and organic solutes.[31] Although simple ions such as sodium and chloride comprise the bulk of inorganic solutes in seawater, there are many dissolved gases (e.g., oxygen, methane, carbon dioxide) and small molecules (e.g., natural degradation products) that vary in concentration as a function of depth, temperature, latitude, and other factors. Given the variability in oceanic conditions, you can readily see why describing the molecular structure of seawater is such a daunting task.

Before we leave the subject of seawater's molecular structure, it is worth taking a slightly closer look at the anion that comprises more than half of the dissolved solids mass. Of the seven major ions that comprise seawater, chloride appears to be the least disruptive to water's bulk network, because the small chloride anion is more stable in aqueous solutions than are either the similar-sized cations (potassium, sodium, calcium, magnesium) or the larger anions (bicarbonate, sulfate). The distinctive behavior of chloride as a single ion solute is evident from number of physical observations regarding ion-water and ion-ion interactions.[32] For example, the distortion of H-bonds among water molecules is minimal in the hydration shells of chloride compared to those of the other major ions. Also, the time period required to reorient water molecules in the chloride hydration shell is very similar to that in bulk water. While the effect of chloride's unique behavior on the molecular structure of seawater is not known, seawater's most abundant ion may create the least disruption to the water network and its unique water-water interactions.

Seawater is perhaps the most enigmatic form of earthly water because of its mysterious molecular structure and its remarkably constant composition. Although life is presumed by some researchers to have originated in seawater, all of today's biological organisms depend on a less-saline type of water to sustain their physical forms.

WHERE'S THE ICOSAHEDRON?

In traversing this chapter, we have found that molecular water forms all the Platonic solids with the possible (or apparent) exception of an icosahedron, which just happens to be the ancient symbol of the water Element. Although there are a number of explanations as to the whereabouts of the icosahedron, I have selected those related specifically to water's H-bonding.

If the hydrogen bonding of water is represented topologically, the icosahedron is the most complex of the Platonic solids whose center may be simultaneously pierced by a tetrahedral set of directions.[33] The "tetrahedral set of directions" mathematically relates the undistorted H-bonding geometry of water to a larger and more inclusive topological map that includes the faces of an icosahedron. A topological map is essentially a geometric representation or projection of a data set. So, both the Element of water and its topological H-bonding map may be symbolized by the icosahedron, even though the most basic molecular geometry of water's H-bonded network is tetrahedral, not icosahedral. If we figuratively combine the tetrahedral and icosahedral attributes of water's H-bonded network with the corresponding fire and water Elements (consistent with the Platonic solids), we could surmise that there is a dynamic and ever-changing fire underlying the cool and often tranquil appearance of water.

More recently, professor and scientist Martin Chaplin has proposed that the most stable of water's large clusters assumes the three-dimensional geometry of an icosahedron. This icosahedral network of molecules is a component of the larger water network and is composed of individual tetrahedral units, representing the most basic molecular geometry of water. Specifically, fourteen tetrahedral units are packed into the icosahedral cluster, which is composed of 280 water molecules that form large internal cavities appropriate for storing solutes.[34] The edges of internal tetrahedra can alternate positions inside the larger icosahedron based on changes in hydrogen bonding, thus permitting the relatively stable icosahedral cluster to expand, contract, and connect to adjacent clusters. Is water's network tetrahedral on the scale of individual molecules and icosahedral on the scale of clusters?

CHAPTER 6

BIOLOGICAL MANIFESTATIONS

Earthly Life Forms

Biological functions may actually consist of the building and destruction of water structures, water being part and parcel of the living machinery and not merely its medium, the water structures and their interactions with electronic excitations being intimately connected with the very essence of the "living state.
Albert Szent-Györgyi, *Bioenergetics*

Based on the percentage of water versus carbon-containing compounds in biological organisms, there is little doubt that the biosphere is water-based rather than carbon-based. Not only does water constitute most of our mass, it is required in essentially every biological structure and process. It was formerly understood that water simply acted as the solvent or matrix within which the carbon-containing compounds (e.g., DNA, proteins) orchestrated the drama that creates and sustains biological life. It now appears as though water participates in directing the processes to an extent that was previously unimagined. Water's mediation of biological processes perhaps fulfills (at least in part) its role of "shaping worldly forms" that was suggested by many ancient insights. Not only is water a major component of biological structures and a major participant in biological processes, it is intimately involved in the energetics that power the biosphere.

BIOLOGY'S GEOMETRY

Water's necessity as a component of most known biological processes is undisputed. Water not only serves as the solvent within which all biochemical reactions take place, but it also aids in maintaining both structures and assemblies of macromolecules in the cell's *organelles*. Organelle is a term used by cell biologists to describe various specialized compartments (e.g., nucleus, mitochondria) that house cellular processes. If reductionist theory considers the cell to be the most fundamental unit of biological life, then there must be a synergy among the "non-living" organelles, biomolecules, and atoms that imparts life to a cell. In order to explore the link that science has uncovered between water and biological processes, we must first take a look at what makes biologically active molecules "tick."

The famous American physician William Mayo was apparently quoted as saying that "life is largely a matter of chemistry." If that is so, then recent developments in molecular biology have suggested that chemistry may be largely a matter of geometry. In the words of the Swedish chemist Anders Liljas, "function is structure."[1] Linus Pauling was one of the first scientists to fully appreciate the importance of molecular geometry in understanding chemical phenomena, as is beautifully illustrated in his 1964 book *The Architecture of Molecules*. His contributions to the understanding of atomic structure, chemical bonding, and molecular geometry are among the most monumental in the history of science. Pauling's concepts of molecular geometry and hydrogen bonding have provided the foundation for many of the scientific theories referred to in this book.

In 1968, the students, colleagues, and friends of Linus Pauling published a book titled *Structural Chemistry and Molecular Biology*, in which John Kendrew defines biological life as a continuous process of ever-repeating alternations between *information* and *conformation*, *genotype* and *phenotype*, and *DNA* and *protein*.[2] The first of these pairs denotes that information (energy) and form (geometry) operate in an iterative or feedback manner, such that a change in one always creates a change in the other. Genotype and phenotype are terms referring to the genetics and to the manifested characteristics (both genetically and environmentally derived) of an organism, respectively. DNA facilitates changes in genotypes, while proteins facilitate changes in phenotypes. The function of both DNA and proteins is inherent in their conformation, which is altered by information or energy in the environment.

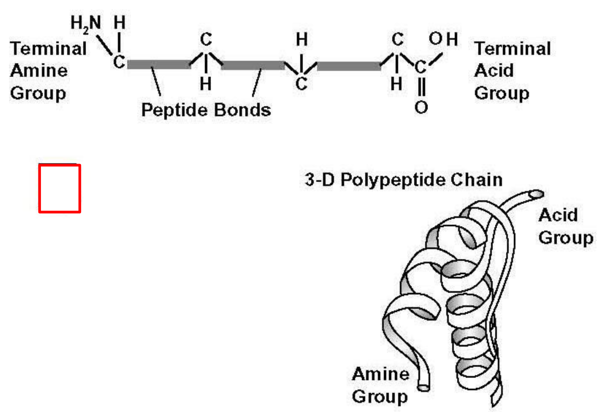
The Hungarian biochemist and Nobel laureate Albert Szent-Györgyi expressed some of the twentieth century's most innovative views on biological processes and energetics. One of his most famous theories was that of *submolecular biology*, which recognized that life is inherent not only in cells, but in the molecules and atoms of which they are composed.[3] As such, his views clash with reductionist theories in echoing the ancient insight that the macrocosm is just a scaled-up version of the microcosm. He also maintained that biological functions and energetics actually consist of the building and destruction of water structures, with water being part and parcel of the living machinery and not merely its medium. Another of Szent-Györgyi's major discoveries was ascorbic acid (i.e., Vitamin C) and its critical role in cell metabolism. You may recall that the immunological activities of Vitamin C were a major focus of Linus Pauling's research in his later years.

PROTEINS

Szent-Györgyi was known to refer humorously to proteins as nothing more than impurities in water.[4] While this concept of proteins may seem a bit odd, we will see that these biochemical building blocks of life both structure and are structured by water. Proteins function as biochemical catalysts, specialized carriers, receptors, hormones, and structural components for various biological systems. Proteins are highly specialized (e.g., a different one is required for each of the many functions performed) and all are composed of long chains of amino acids that are folded into a three-dimensional structure, serving as their bioactive form.

While it is well beyond the scope of this book to review the very complex details of protein structure, it is worthwhile to spend a little time looking at the basics of protein configuration and at the amino acids that comprise them. Although there are many amino acids in Nature, there are a total of twenty that comprise most proteins. All amino acids are characterized by the presence of an amine group (i.e., NH_2) and a carboxylic acid group (i.e., COOH); hence, the name *amino acid*. Figure 6-1 shows the configuration of a typical amino acid. Each one has an amine group, a carboxylic acid group, and a hydrogen atom covalently bonded to the central carbon atom. It is the unique fourth group that distinguishes one amino acid from another. The fourth group is referred to as the *functional group*. Amino acids are divided into three classes (i.e., ionic, polar, or nonpolar) based on the chemistry of this fourth group.

Figure 6-1. An imaginary protein and its three associated peptide bonds. All peptide chains are characterized by an amine group at one end, an acid group at the other end, and a distinctive functional group for each of its component amino acids. Long peptide chains form a three-dimensional structure that continues to fold upon itself in creating a protein crystal. [Adapted from Emil Smith, et. al., *Principles of Biochemistry*, 24, 28.]



The functional groups of the twenty amino acids are able to engage in a variety of interactions (both attractive and repulsive) that affect the three-dimensional structure of proteins. Deciphering the sequence of amino acids is, in practice, insufficient to predict either the structure or function of proteins. In other words, protein structure and function is not based solely on the sequence of amino acids, but instead is a function of the macromolecule's geometry.

Protein geometry is influenced by various environmental factors, not least of which is its interaction with water.

Water and Protein Geometry

To understand the importance of water in the structure of proteins, we may begin by looking at the amino acids that comprise them. Amino acids are able to engage in hydrogen bonding as a result of their carbonyl, amine, and other component groups that act as either donors or acceptors of protons (hydrogens). As a result, free amino acids are fully H-bonded to water, which is often referred to as "the solvent" because water is, in fact, the universal solvent for biochemistry. As the amino acids are assembled into proteins, they form H-bonds with other amino acids in the chain at the expense of H-bonds with water. Therefore, water gives up its H-bonds with amino acids, permitting the protein to fold into its three-dimensional structure. In addition to H-bonding, hydrophobic interactions among nonpolar functional groups and electrostatic interactions among oppositely charged ionic groups also affect protein folding.

There are so-called *orders* of protein structure that correspond to different ways of folding the long chain of amino acids (i.e., "peptide chain"). This folding process is similar to the way in which one might fold a sheet of paper many times so that each folding sequence results in a different set of creases that can be seen when the paper is unfolded. The *primary* structure of a protein is simply its amino acid sequence, while the *secondary* structure is related to the stretching or folding of adjacent amino acids into a recurring pattern. *Tertiary* and *quaternary* structures are created via the folding or winding of large three-dimensional subunits of proteins. Hydrogen bonds are involved in secondary through quaternary structures as a result of their building H-bonded bridges, or H-bridges, across the protein molecules.[5] Protein structure could be described as a three-dimensional network of H-bonds and other bridges (i.e., electrostatic and hydrophobic) in which water stabilizes the folded state.

Given the importance of H-bridges to the three-dimensional structure of proteins, it could be argued that the sequential dissociation of H-bonds between amino acids and water permits protein folding via H-bridges within the protein crystal. With respect to this view, there are two points that should be emphasized. First, the protein molecule always maintains a percentage of its original H-bonds with water via the functional groups that are not involved with folding. Secondly, protein folding is a spontaneous process that is dependent on the spatial and temporal patterns in which H-bonds between amino acids and water are broken, as well as on the pattern of H-bonding among protein components.[6] Water structure is crucial to the crystallization and stabilization of proteins, which contain somewhere between 20% and 70% water. This statistic suggests that Szent-Györgyi's offhanded comment about proteins being nothing more than water impurities is probably valid on more than one account.

Hydrating Proteins

It is curious that water prefers to act as a proton donor rather than a proton acceptor in H-bonding to proteins. It is believed that this H-bonding bias permits the greatest geometric flexibility for the protein.[7] Water molecules appear to be mobile among the protein structure and tend to occupy crevices on the surface and, often, in the interior of the protein, where they are referred to as being *bound*. I choose to use the term *integral*, rather than *bound*, because it more accurately describes both the structural and functional roles of water within proteins. By selectively breaking and then reforming H-bonds, water may either insert or remove itself as it alters the protein's secondary structure (e.g., bridging the gaps between functional groups). There are several mechanisms by which water inserts segments that alter a protein's secondary structure, some of which are facilitated exclusively by water.[8]

The water immediately surrounding the protein molecule is usually highly ordered (orientationally) as a result of its H-bonding with the protein's functional groups. Stated slightly differently, H-bonding to the protein essentially "locks in" the water molecules so that they cannot rotate freely and switch ceaselessly between straight and bent configurations. As such, "protein water" may be distinguished from bulk water by the degree of orientational order. From the small four- to six-membered ringed clusters, water builds large-scale hydrogen bonded networks within the primary hydration shell of a protein.[9] The difference in mass between one *mole* of water (18 grams) and of a typical protein crystal (ranging from 5000 to about 10 million grams) is substantial. Therefore, hundreds to millions of water molecules are required to hydrate a single protein crystal. One *mole* is a chemistry term that refers to a standard, albeit enormous, number of individual molecules ($\sim 10^{24}$).

It appears that the hydration networks with proteins consist of two types of water molecules.[10] The first are mobile hydration water molecules that constantly rearrange themselves, primarily affecting the shape and dimensions of the network. The second are relatively immobile hydration water molecules that bond to or otherwise interact with the integral water or the protein itself. The first group displays significantly less orientational order than does the second. Hence, even the primary hydration shell appears to be constructed from networks within networks of water molecules that decrease in orientational order as a function of distance from the hydrated protein surface to the bulk water. Considering its role within proteins, integral water appears to be less an extension of the primary hydration shell than it is a discrete component of the macromolecule itself.

Conformation and Information

Philip Ball suggests that the blind forces of physics and chemistry are sufficient to create and fold proteins in water; however, the same cannot be said for proteins dissolved in other solvents.[11] There simply are no other solvents than water for naturally occurring proteins. He further notes that, even after the protein is created, its ability to function in the cellular environment is dependent upon water. Scientists maintain that water plays several important roles with respect to proteins, including 1) stabilizing the overall three-dimensional structure, 2) folding segments together to create complex crystalline forms, 3) acting as an integral component, 4) forming a highly ordered hydration shell around the periphery of the molecule, and 5) transferring protons between the bulk solvent and the hydration shell(s). In this fifth role, water essentially supplies the protons that are required by proteins to fold and function.

Water's H-bonding with the functional groups of an amino acid both alters the geometry of and mediates proton transfer within specific segments of the protein.[12] Stated differently, proton transfer facilitates an energy exchange between the integral water and the protein, as well as among the integral water, hydration shells, and bulk water. Despite the absence of direct physical contact, proteins exchange energy with the bulk water network through proton transfer. Even conservative scientific perspectives on water-protein interactions acknowledge that water molecules are instrumental to some protein's "feeling" the shape of substrates that they bind.[13] What is actually being exchanged between the bulk water and the protein? There is an exchange of energy and, according to John Kendrew's hypothesis, there is also an exchange of information that is communicated by means of changes in the protein's conformation. So, do proteins structure the water or does water structure the proteins? It appears that both processes may be occurring, perhaps iteratively.

As an example of the exchange between water and proteins, let's take a look at *hemoglobin* (i.e., the protein responsible for carrying oxygen in our blood). Water mediates information transfer between subunits of hemoglobin primarily through destabilizing ordered water molecules in the hydration network.[14] This destabilization leads to an altered conformation of the protein subunits, thus accounting for the information transfer. A key to water's mediating information transfer is its ability to shift from one ordered arrangement of molecules to another one within the protein's hydration shell. Our next question might be whether these water networks (e.g., the primary hydration shell) mediate the transfer of energy and information only among protein subunits or whether they mediate such a transfer between different proteins as well. For at least some protein-protein interactions, the answer is that water does play a pivotal role in the required binding, recognition, and energetics.[15]

Biochemical Catalysts

In addition to the structural importance of water in protein molecules, the insertion and removal of water also has profound effects on the functioning of proteins. One of the most remarkable functions that proteins perform is that of a biochemical catalyst or *enzyme*, which permits chemical reactions to proceed at a rate millions of times faster than would occur under ambient conditions. Water appears to play at least four critical roles in the functioning of enzymes. First, its interaction with the protein's polar groups permits the structural flexibility required for the enzyme to achieve its active conformation. Second, the free energy used in binding the enzyme to its substrate is often provided by water molecules located at the interface. For example, water mediates the energetics of protein-substrate interactions for a common class of enzymes that degrade toxic chemicals.[16] Third, water is often excluded from the active site until the moment of catalysis, at which time it is permitted to enter the active site and reconfigure H-bonds. This permits the reaction to proceed. Fourth, the enzymes actually structure the water around them, thus enhancing the rate of catalysis.[17]

Because water is a major factor in the functioning of proteins, it stands to reason that it is also a major factor in the malfunctioning of proteins. Proteins no longer perform their assigned functions when their structure is compromised to the point that they are considered *denatured*. A study was performed on the nitrogen-containing waste product known as urea, which represents the major toxic constituent of mammalian urine.[18] The ability of urea to denature proteins has been known for a long time; however, the mechanism by which it does so has only recently been elucidated. Not surprisingly, the denaturation of proteins by urea is achieved by altering the structure of water's H-bonded network in the primary hydration shell. Specifically, the ratio of straight to bent H-bonds is altered such that water's heat capacity increases, permitting toxins to bind specific functional groups on the protein. Assuming that water functions as molecular-scale mediator for proteins, it is not surprising that water is able to facilitate the effects of toxic chemicals, either through hydration shells or integral water.

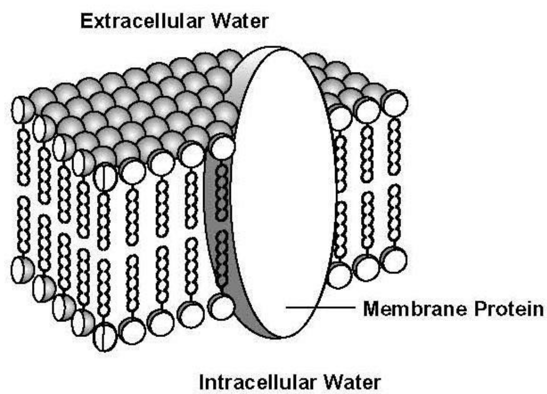
In addition to the effect of toxins on the H-bonded network of hydration water molecules, simply reducing the amount of hydrating water can also denature proteins by destroying their crystalline structure. Biomedical science recognizes that enzymes are one class of protein that must reduce water in its hydration shell in order to permit biochemical catalysis. So the question is, how does a protein dehydrate itself and still retain the three-dimensional crystalline structure that is required for its stability and function? The answer seems to be two-fold in nature.[19] First, the extent of dehydration required for enzyme activity is less than that which results in destruction of the protein's tertiary structure (i.e., denaturation). Secondly, only specific segments of the protein are dehydrated, such that crucial water bridges responsible for H-bonding various regions of the macromolecule together are not sacrificed. As such, enzymes might be thought of as proteins that must balance the potentially lethal "art of dehydration" between catalytic function and structural stability. A few enzymes function in non-aqueous solvents; however, the properties of non-aqueous catalysis are quite different from those of aqueous catalysis.

Biological Membranes

Of the countless structural functions that proteins serve, one of the most critical is that of biological membranes. Such membranes are a fundamental prerequisite for the existence of life (as biologically defined), providing a boundary between the living unit and its environment.[20] Membranes are predominantly composed of lipids and proteins. Lipids are often referred to as fats and contain both polar/ionic (i.e., hydrophilic) groups and nonpolar (i.e., hydrophobic) groups, allowing them to alter their structure and to either include or exclude water. The basic structure of a membrane is known as a *lipid bilayer*, which is composed of lipids and proteins, as shown on Figure 6-2. The hydrophilic ends of the molecules orient themselves so that they are in contact with the intracellular and intercellular water (fluids), while the hydrophobic ends form the middle of the membrane. This lipid bilayer permits the membrane to regulate its permeability to substances located both inside and outside the cell.

Just a thin layer of water appears to be adequate to affect the membrane's permeability to specific solutes.

Figure 6-2. A simple structural model of a cell membrane showing the locations of the lipid bilayer, an integral protein, and intracellular and extracellular waters. The lipid bilayer is arranged so that the membrane's surface is nonpolar, or hydrophobic, and its surface is polar, or hydrophilic. [Adapted from Emil Smith, et. al., *Principles of Biochemistry*, 273.]



A membrane's permeability seems to be controlled, to a large extent, by its electrostatic properties. Electrostatic properties of the membrane surface are, in turn, dependent on the arrangement and cooperation of adjacent water layers.[21] This dependence is specifically related to the correlation between water's orientational order and its pertinent physical properties (e.g., conductivity, dielectric constant). Once again, it appears that water's orientational order is a key to its biological mediation and, in this case, to a membrane's electrostatic properties and to its pores or channels. Water located inside the cell is known as *intracellular* and is apparently similar to freshwater in its lower salinity and greater capacity to maintain an electrostatic charge than is *extracellular* water. During the last fifty years, a number of researchers have noted that extracellular water is relatively unstructured, whereas intracellular and membrane-bound water is more structured.

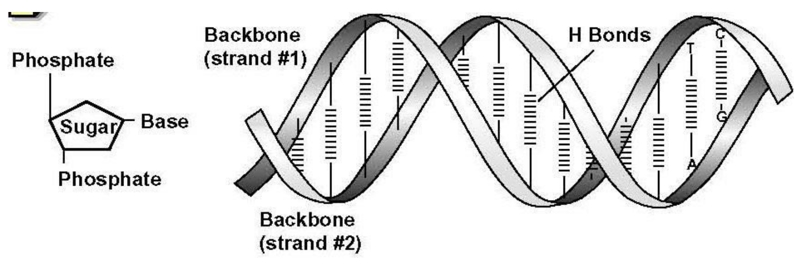
One of the more interesting membrane pores is known as a *water channel*, which refers to a high-permeability microtubule that is composed of specialized proteins imbedded in the lipid bilayer.[22] Water's ability to move through these extremely narrow channels may be facilitated by its molecules H-bonding to one another in a chain-like manner. Such water channels seem to be prevalent in tissues or organs that require relatively large amounts of water to be rapidly transported across membranes or that need to quickly secrete or absorb solutes (e.g., salts, sugars). Water channels are also found within the cell, suggesting that they function to route water among organelles or along intracellular corridors.[23] The reason that organs or cellular organelles require the ability to transport such large volumes of water on short notice is currently unknown to biomedical science.

NUCLEIC ACIDS

Nucleic acids are the biological macromolecules that contain and transmit genetic information, as well as synthesize proteins. At least, that is the prevailing scientific understanding at this time. If, according to Albert Szent-Györgyi, proteins are nothing more than impurities in water, then I propose that nucleic acids are simply the watery templates that code such impurities. Nucleic acids are immense, even when compared to such large biomolecules as proteins. In fact, the uncoiled DNA of humans is more than four centimeters in length, putting it nearly into the macroscopic world.

Nucleic acids have three major components including 1) four *bases* that pair up (one-to-one) to create the genetic code, 2) a *sugar* to which the bases are attached, and 3) a *phosphate* group that links the sugars together into what is commonly referred to as a *strand*. Figure 6-3 shows a portion of the DNA chain and its three major components. The phosphate groups link adjacent sugar molecules, which form long sugar chains that comprise the two strands of the DNA molecule. Attached to these strands are the paired bases, which form numerous connections between the two strands. The four DNA bases are split into two groups: the *pyrimidines* (represented by T and C) and the *purines* (represented by A and G). In all cases, the number of pyrimidine bases equals the number of purine bases as they link, on a one-to-one basis, and form the template of the DNA molecule. The DNA molecular structure is sometimes compared to a ladder, whereby the rails represent the phosphate-linked sugar molecules and the rungs represent the paired bases.

Figure 6-3. A simplified structural model of a segment of DNA. Hydrogen bonds between the base pairs act to bridge the two strands, as the helix winds around like a spiral staircase. The strands consist of sugar molecules that are "strung together" via phosphate linkages. Each base attaches to the part of the sugar molecule that is located farthest from the phosphate linkage. [Adapted from Emil Smith, et. al., *Principles of Biochemistry*, 137.]



The three-dimensional structure of DNA is referred to as a *double helix* because the two strands are bridged together in a twisting or turning manner (see Figure 6-3). Naturally occurring DNA represents a right-handed double helix with ten base pairs per turn of the helix. As was the case for the three-dimensional structure of proteins, the shape and structure of the DNA molecule is dependent on a number of interactions between its various components (particularly the H-bonding of base pairs). The interaction between DNA and proteins is fundamental to life because, in essence, the former holds the manifested blueprint of life forms and the latter represents the structural and functional components that permit the blueprint to be actualized and maintained.

Water and DNA Geometry

One of the more interesting studies in molecular biology was performed by a group of researchers at the University of Rochester, who found that replacing one of the four bases comprising the DNA code with a structural mimic resulted in the enzymes reading the DNA and replicating it accurately.[24] The mimic used by the researchers was a fluorocarbon, which is chemically quite distinct from the nucleic acid base, "T." Apparently, the enzymes that are charged with the task of reading and copying the DNA cue in on the geometry of DNA more than they do on the specific identity of its bases. This finding challenged the long-standing explanation for how DNA codes are read and instead suggested that geometry, rather than the individual base pairings, may be the critical factor.

Of the four bases that comprise the rungs of the DNA helical "ladder," C and G bond exclusively using a total of three H-bonds, while A and T bond exclusively using only two H-bonds. As a result of this difference in H-bonding, the A-T base pair is able to bind one more water molecule that is the C-G pair. These four bases form almost equally strong H-bonds with the oxygen and hydrogen atoms of water as they do with each other; hence, water must be removed from the fully hydrated bases in order for them to form the requisite number of H-bonds and build the DNA strands.[25] As the bases H-bond with other components of the DNA molecule, they form bridges that are similar to those described for proteins. It is worth mentioning at this point that the water bridges discussed in this chapter have straight and bent configurations, as do H-bonds, which corresponds to the twisting direction of DNA.[26] In other words, the type of H-bonds used to bridge DNA bases is related to the turning and overall structure of the macromolecule. Not surprisingly, the water participating in such H-bridges is highly ordered, thus "locking" the H-bonds into either a straight or bent configuration.

The critical role of water in stabilizing the helical structure of the DNA molecule has actually been surmised since the 1950s; however, only recently have crystallography techniques progressed to the point that the stabilizing structures could be identified. Water is fundamental in bridging phosphate groups to both sugars and bases, as well as bridging bases to sugars and to other bases. One the leaders in elucidating the role of water in biomolecules is the molecular biologist Eric Westhof, who writes that "these water molecules mediating structural bridges between atoms of the nucleic acid should be regarded as an integral constituent of the helical nucleic acids in aqueous solution and, consequently, be considered also as responsible for the fine-structural parameters."[27] Similar to the integral water of proteins, the structural water of nucleic acids is apparently best described as a bona-fide component of the macromolecule, rather than as simply an extension of the primary hydration shell.

A recent investigation into the base pairings of RNA has revealed that water may actually act as a mediator in linking the two bases.[28] In some instances, the bases do not H-bond with each other directly (as was described in the previous two paragraphs), but instead H-bond to intervening water molecules that complete the link through their assuming proton acceptor and donor roles, simultaneously. The reason that water occasionally plays this role with base pairs is currently unknown; however, it seems to function as both a conformational and informational mediator for the nucleic acid's bases. In an similar study, molecular biologists hypothesized that a switch in both bases at a particular pairing location on the DNA molecule could be accomplished without a resulting mutation if the switch preserved the H-bonding used by water to bridge strands across one turn of the helix.[29] In other words, the genetic information could be successfully preserved as long as the geometry of the water bridges was not compromised. These two studies suggest that the recognition of genetic codes sometimes requires water's mediating specific base pairings, in addition to its stabilizing the overall biomolecular conformation.

Hydrating DNA

In addition to its role as a structural component of DNA, water also hydrates DNA as it would any other solute in an aqueous solution. DNA has several layers of water that are arranged in shells around the molecule and are involved in a variety of bridging activities, either among base pairs or between bases and water. As noted for other aqueous solutes, it appears that water is most highly ordered adjacent to the DNA molecule and less ordered with each successive hydration shell. Water is also associated with the DNA strands, where an entire sphere of water molecules surrounds the phosphate groups and acts to stabilize the overall structure of the molecule.[30] As was the case for proteins, each subunit of the DNA seems to have its own water network that interacts with other networks and, through successive hydration shells, with bulk water. These networks interact with DNA and with each other via the processes of proton transfer and water molecule exchange. Even DNA's organization has been linked to changes in heat capacity that are due to the immobilization of water molecules within the double helix.[31]

The hydration structure, or envelope, that runs the entire length of the DNA molecule is apparently composed of two water layers. The first is occupied to varying degrees by ions such as sodium and magnesium that are apparently involved in the recognition of DNA sequences. The second layer, which does not interact with the DNA molecule itself, is geometrically similar to the first and acts as a model for the transmission of sequence information to the surrounding water.[32] It is generally believed that both the base sequence and the environment, which is necessarily an aqueous one, influence DNA conformation. These conformations then modulate the interactions of ions and other macromolecules such as proteins. Hence, water acts as mediator between DNA and its aqueous environment, permitting the flow of information in both directions (i.e., from DNA to its solvent and vice-versa).

It is reported that there are about thirty water molecules around each of the base pairs, thus comprising the primary hydration shell of DNA.[33] The geometry of this primary hydration shell is cluster-like and predominantly composed of pentagonal rings. If the geometry of the DNA molecule is contorted, the hydration shells and associated geometric clusters seem to be likewise affected. Similarly, the DNA molecule may contort in response to changes initiated by the water that hydrates it. In both cases, the reasons for twisting and folding include 1) stuffing it into chromosomes located within the cell nucleus, 2) unraveling it during transcription and replication, and 3) unzipping it during repair and modification procedures. Because water is fundamental to the bridging of base pairs, any changes to the helix necessarily requires the cooperation of water as both a structural component of and the solvent for DNA.

Vibrating DNA

It is well known in biophysics that electromagnetic (EM) radiation within the microwave frequencies induces changes to the DNA molecule. Biomolecules generally react to microwaves in the range of 10^9 to 10^{11} hertz, while water responds most strongly to frequencies within the lower portion of this same range. Researchers have actually been able to measure the speed of acoustic waves, or sound, through DNA and, in doing so, discovered that this speed (measured on the order of a few kilometers per second) was highly influenced by the presence of water.[34] Hydration shells actually interact with the DNA molecule at microwave frequencies, and the manner in which the macromolecule displays absorption and relaxation (corresponding to excitation by and recovery from the microwave radiation) phenomenon is coupled to the surrounding water.[35] As such, EM radiation is transmitted through DNA largely via its primary hydration shell, within which water is sufficiently ordered to function in concert with the macromolecule's components and to transmit relatively low-frequency EM radiation such as microwaves.

Besides microwave frequencies, the water-DNA complex also responds to a number of other EM frequency ranges, including a lower one at approximately 10^8 hertz. This is the frequency range of FM radios and is sometimes referred to as the upper radiofrequency range. The frequency of 10^8 hertz corresponds to a transition whereby water molecules within DNA's first hydration shell convert from an orientation that is ordered to one that is disordered.[36] String-like clusters of water molecules align themselves between DNA's strands as the helix transforms itself from a coiled shape into a bioactive crystal. This three-dimensional geometric transition of DNA again emphasizes the importance of water's orientational order in facilitating at least some vibrational processes within the macromolecule and in mediating many of the life-sustaining processes within biological organisms.

DNA also responds to very high-energy EM radiation that is present in the frequency range of 10^{15} hertz and greater. This so-called ionizing radiation includes everything from ultraviolet light to X-rays. As discussed in Chapter 4, "ionizing" simply means that the energy is sufficient to affect the atom's electron cloud and, thus, break chemical bonds. Biochemical research suggests that in aqueous solutions (representing the natural state of nucleic acids), DNA damage in the form of single-strand breakage is induced by both direct and indirect mechanisms. Specifically, DNA damage can result from the formation of water-derived radicals such as the hydroxy ($OH^{\cdot}$) radical that are induced by ionizing radiation.[37] Ionizing radiation essentially tears apart water molecules in the DNA hydration shells, not only creating free radicals but also affecting the macromolecule's H-bonded link to its primary shell. The damaging effects of other outside agents (e.g., many toxic chemicals) are also mediated through water-derived radicals.

The so-called building blocks and blueprints of life (i.e., proteins and nucleic acids, respectively) are three-dimensional crystals that are able to structure and to be structured by water. Many of the interactions within and between these critical biomolecules appear to be facilitated by or mediated through highly ordered forms of water.

BLOOD

Unlike protein and nucleic acid macromolecules, blood is an aqueous fluid that transports everything from gases to hormones to electrolytes through the bodies of animals. Of all the many biological fluids in the body, I have chosen to look at blood because ancient insights and modern premises often consider the movement and composition of blood in the body to be analogous to that of water on the Earth. While the latter is the subject of the next chapter, the former is the topic of this section. The relationship between blood, water, and heart (both the physical and etheric one) seems to be fertile ground for fringe, or *peripheral*, science; however, clues to interpreting natural phenomena sometimes lay buried within such unconventional perspectives. I use the word "peripheral," not in a disparaging manner, but instead to identify research and hypotheses that either are not addressed by or seemingly contradict mainstream scientific theories. Researchers who conduct and interpret these unconventional studies are sometimes described as working at the edges or periphery of conventional science.

One of Viktor Schauberger's major premises was that blood moved through the body due to the pulsation or peristalsis of arteries and capillaries, which act in response to temperature differences between the core and extremities of the body. He maintained that this pulsation creates opposite electrical charges in the arterial (positive) and venous (negative) blood, which triggers a muscular contraction as a method of achieving periodic equalization.[38] We commonly refer to this muscular contraction as a heartbeat, which has been known to create vortices in the blood (at least in the larger vessels) that are carried throughout the body. Schauberger noted that the creation and migration of vortices in blood was similar to that in many earthly waters (e.g., rivers and oceans).

Aqueous Chemistry

The aqueous component of the blood is known as the *plasma*, which is not to be confused with the fourth physical state of matter that we have previously discussed. Blood plasma consists of a pale yellow liquid that has an ionic or electrolytic composition very similar to that of seawater and solvates an enormous variety of organic and inorganic molecules. The whole blood consists of various cells and proteins that are suspended, rather than truly dissolved, in blood plasma as a result of their large size and surface charge. The most abundant solutes of the blood plasma are proteins such as hemoglobin. According to conventional biomedicine, the primary functions of the blood are to 1) circulate its dissolved and suspended components throughout the body, 2) deliver oxygen, nutrients, hormones, etc., to the tissues, and 3) remove waste products such as carbon dioxide. In addition, the blood plays a crucial role in maintaining the body's pH and temperature within acceptable limits as a result of water's buffering and heat capacities, respectively.

If we first turn to the composition of blood plasma, Table 6A indicates that sodium and chloride are the most abundant cation and anion, respectively. These two ions, when combined, create common table salt. Next in abundance are the bicarbonate and phosphate anions, as well as the potassium, calcium, and magnesium cations. You may recognize these cations as major players in biological processes as diverse as creating the electrical potential in nerve cells to building the skeletal system. You may also recognize the phosphate group as key components of the aforementioned DNA strands. The bicarbonate ion is probably less familiar to most people; however, it is of particular importance because it forms part of the *carbonate buffering system*. The carbonate system is the most common pH buffering mechanism in aqueous solutions, whether they are seawater, freshwater, or blood. Essentially, the carbonate system is an acid-base regulator, whereby carbonate and bicarbonate ions as well as carbonic acid and dissolved carbon dioxide gas are maintained in chemical equilibrium with each other. This system equilibrium is described as follows:

- $CO_2 + H_2O \Leftrightarrow H_2CO_3$ [carbon dioxide, water, and carbonic acid]
- $H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$ [carbonic acid, proton, and bicarbonate ion]
- $HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$ [bicarbonate ion, proton, and carbonate ion].

The two-headed arrow (⇔) indicates that the reaction may go either direction depending on what is added to the blood or the aqueous solution. Because the proton concentration defines the acidity of a solution, as protons are added to or taken from the water or plasma, the carbonate system must adjust accordingly. Furthermore, the blood is constantly picking up acidic and alkaline waste products from the cells and transporting them to the excretory organs. It is primarily the carbonate system that prevents the pH of the blood from fluctuating wildly as these and other processes are occurring. Maintaining a near-constant pH in the blood is as critical in maintaining the health of a human body as maintaining it in water is to that of a lake or river.

Table 6A. *A comparison of the relative contribution of the major inorganic constituents in seawater, in typical continental surface waters (e.g., rivers and lakes) and in human blood plasma. The two major ionic constituents of the respective solutions are shown in bold type. Approximately 70% of the solids found in human blood are suspended organics such as proteins, which were not considered in this comparison.*

Inorganic Constituent	Composition of Seawater (%)	Composition of Blood (%)	Composition of Typical Fresh Waters (%)
Chloride	**55**	**40**	5.8
Sodium	**31**	**36**	5.2
Sulfate	7.4	2.6	8.3
Magnesium	3.7	0.3	3.4
Calcium	1.2	1.1	13
Potassium	1.1	2.0	1.3
Bicarbonate	0.4	18	**52**
Bromide	0.2	<0.01	0.02
Strontium	0.04	<0.01	0.03
Boron	0.01	<0.01	0.01
Silicate	<0.01	<0.01	**11**

Returning to the comparison of blood and seawater composition, the data presented on Table 6A compare the concentrations of constituents in ocean and river water with those of the major blood constituents. The relative electrolyte concentrations are similar in seawater and blood, but considerably different in river water. If the seven major ions in seawater and blood are normalized (i.e., all other solutes are ignored), one can compare the ionic composition of the two fluids. Both solutions are primarily composed of sodium and chloride, which constitute 86% and 76% of the salinity in seawater and blood, respectively. Concentrations of the other three cations (i.e., potassium, calcium, and magnesium) represent less than 6% of the salinity in both fluids. There is a large difference in the relative contribution of bicarbonate, which is major component of the carbonate buffering system. Just as the total dissolved solids (TDS) concentration in seawater is orders-of-magnitude greater than that in freshwater (e.g., lakes, rivers, aquifers), the TDS concentration in blood is orders-of-magnitude greater than that in intracellular waters.

The Mysterious Component

In addition to the conventional blood components recognized by biomedical sciences, an occasionally referenced "mystery component" was first discovered by a nineteenth century French scientist named Antione Béchamp. Amongst the plasma proteins, Béchamp identified a class of nearly imperishable molecular granulations that he reported to be ubiquitous in blood and even in plant fluids.[39] He called these granulations, which persist even after the organism itself died, *microzymas* because he believed that they were "small ferments." From this discovery, Béchamp postulated that microzymas were actually precursors to the microbial pathogens (e.g., viruses, bacteria, fungi) that are now understood to invade the body from the outside. Essentially, Béchamp's microzymas are a distinct class of organisms that, under certain conditions in the host organism, decompose the oxygenated water and initiate anaerobic or fermentative processes.

The view that all diseases originate in the body of the host via these microzymas is known as *pleomorphism*, while the belief that diseases occur as a result of many distinct pathogens entering the body from the outside was known as *monomorphism*. Béchamp's main scientific rival in the pleomorphism versus monomorphism controversy was none other than his countryman, Louis Pasteur. While Pasteur captured the popular scientific thought on this controversy, Béchamp's ideas were not lost forever. During the twentieth century, the notion of pleomorphism was resurrected independently by a German zoologist named Guenther Enderlein and by a French-Canadian scientist and microscopist named Gaston Naessens. Although Enderlein and Naessens used different names for the granulations, these mysterious components of blood were viewed as a missing link between the living and the non-living in the sense of both an energy transducer and a nucleic acid precursor.[40]

Prior to writing this book, I had no idea that the existence of such granulations (i.e., microzymas or *somatids*) had ever been postulated. Following a lead given to me by a friend, I was introduced to the research of the British physician David Schweitzer, who suggested that there might be a relationship among blood, somatids, and water. Schweitzer (grandson of Albert Schweitzer) apparently became interested in the somatids when he discovered that they changed shapes and colors depending on the thoughts and feelings of the person from whom the blood was drawn.[41] He further hypothesized that water somehow acted as the intermediary or information carrier among somatids. The latter deduction was based on the somatids never having been observed in physical contact. While his hypotheses seem to be speculative, it would be fascinating to know exactly what these somatids represent and what their relationship is to water.

The idea that human thought and emotion are able to structure water through the geometry of somatids definitely falls into the category of peripheral science. In Chapter 8, we will revisit the controversial notion that thoughts, emotions, and subtle energies are able to structure water. However, it is worth noting here that a specialized class of proteins (i.e., *neuropeptides*) are found throughout the body and are believed by neuroscientist Candace Pert to be part of an integrated network that connects our minds to our bodies.[42] Considering the previously discussed energy and information exchange between water and proteins, is it possible that water plays some role in mediating such a mind-body connection? In other words, could water mediate the effects of thought or emotion on the body through conformational changes in proteins, somatids, or any other biological forms of matter?

Blood plasma is essentially water; it carries bodily information in the form of solutes and colloids. Water's physical and chemical properties, including its heat capacity and acid-base buffering capability, permit organisms to maintain their bodies within critical bounds.

BIOLOGICAL STRUCTURING OF WATER

As mentioned in Chapter 5, water's lowest specific heat occurs at a temperature of 37° C, which is a critical temperature for changing straight H-bonds into bent ones, and it corresponds to the human body temperature. Albert Szent-Györgyi suggested that Nature stabilized temperatures in higher organisms around 37° C in order to allow their cells to build crystalline water structures of their own choosing.[43] In other words, the body temperature of most warm-blooded animals permits the greatest flexibility in structuring and ordering water for specific purposes. In this respect, it is unlikely that structuring water outside of the organism eliminates the requirement for biomolecules, cells, and tissues to structure water for their specific purposes. Perhaps the "outside" structuring of water just increases the efficiency (e.g., reduces the internal energy requirement) of biological structuring. Generally, the structuring of water is believed to lower its entropy and thus increase the availability of free energy that may be used by biological systems.

Researchers have discovered countless ways to structure water (e.g., light, heat, sound, crystals, electromagnetic fields, colloids, solutes) and it is likely that all of them structure water differently. To say that water is structured implies only that it conforms to a geometry that is distinct from the apparent lack of geometry (or ceaseless changes in geometry) that characterizes the bulk liquid. In this way, observing whether water is structured or not is analogous to observing whether there are or are not words on a sheet of paper. Knowing that there are words on a sheet of paper does not necessarily identify which words are there or, more importantly, what information is conveyed by those words. The role of specific molecules and biological complexes in structuring water may be to select the exact words that appear on the paper and to sequence them in a manner that conveys information.

Is there evidence suggesting that water structured outside a biological system is either re-structured or modified in some way once it is inside the system? The answer to our inquiry is, obviously, "yes." This entire chapter is a testimonial to the structuring of water by biological molecules or surfaces and vice-versa. Regardless of which templates, fields, or EM frequencies are used to artificially structure water, these structures must be either modified (in the case of large clusters) or assembled (in the case of small clusters) inside the biological organism in order to be utilized. In the following section, we will look at three theories regarding *vicinal water* that have persisted for the past few decades. Vicinal water is a term applied to water that is present at the interface between biological molecules or between biological surfaces and bulk water.

Vicinal Water Theories

A number of theories have been developed over the last fifty years to account for the differences in water found in within the cell (e.g., adjacent to biomolecules such as DNA and biological surfaces such as membranes) compared to that found outside the cell. It is not my intent to explore these theories in detail, but rather to contrast their most basic assertions. The first vicinal water theory that I will consider is the *network model* as presented by James Clegg.[44] The network model suggests that only a portion of intracellular water is distinct from that of bulk water. In other words, some of the intracellular water is identical to the extracellular water. According to Clegg, vicinal water is created as a function of its proximity to membranes and nucleic acids; however, only these large-scale cellular components are able to structure the water. Smaller biomolecules do not structure water themselves (at least not on a cellular scale), but rather partition into vicinal water. As such, proteins and other small biomolecules are necessarily either membrane-bound or associated with nucleic acids.

In contrast to the network model, Gilbert Ling proposed a *polarized multilayer model* that suggests all of the intracellular water is physically and structurally distinct from extracelluar water.[45] According to his theory, intercellular proteins exist as a type of extended matrix, such that the number of water molecules between any two protein crystals is relatively small. Because the protein matrix restricts the motion or rotational freedom of the water molecules, intracellular water is both more ordered and exchanges H-bonds at a slower rhythm than does bulk or extracelluar water. The model suggests that these polarized molecules extend through many layers and are exchanged with the surrounding water in a dynamic fashion. One of the most interesting ramifications of this model is that it predicts certain solutes are excluded from intercellular water on the basis of their size and geometry. For example, common salts (ions) and small polar molecules are excluded from intercellular water simply because they are not "soluble." These same solutes are highly soluble in the water of extracelluar fluids.

Two of the unique properties of intracellular water are that it excludes most of the electrolytes found in extracellular water (e.g., blood) and, as a result of its structuring and orientational ordering, intracellular water has a different list of structure-makers and structure-breakers that does bulk water. The concept that membrane-bound and other intracellular waters are able to control their solutes without active transport mechanisms (i.e., those requiring cellular energy to pump solutes against a concentration gradient) is controversial. Nonetheless, a New Zealand scientist named Philippa Wiggins proposed a mechanism that arrives at a hypothesis similar to that of Ling's.[46] In her model, cellular energy is used to switch a membrane between an ordered and disordered configuration, whereby the former results in the adjacent water network being orientationally ordered and the latter in it being disordered. Wiggins' model is similar to Clegg's in proposing that all intracellular water need not be ordered and similar to Ling's model in that vicinal water includes and excludes solutes on the basis of their solubility.

All these vicinal models make certain predictions that are germane to our discussion. First, vicinal water is more ordered and exchanges H-bonds at a slower rate than does bulk water. Second, variations in the solubility of biomolecules and ions in vicinal, compared to bulk, water is responsible for wide range of biochemical processes. Third, the structuring of water in biological systems on the scale of the cell (either all intracellular water or that adjacent to biological structures) seems to be lumped into a single category. The term *structured* or *vicinal* denotes a broad class of water geometries, within which there are countless variations (e.g., vicinal water structured by a nuclear membrane compared to that structured by a DNA molecule). While the outside structuring of water may or may not reduce the cellular energy required to restructure vicinal water, the controversy has certainly not been resolved.

Water-Mediated Communication

The last aspect of structured water in biological systems that I will consider is that of biocommunication, whereby energy or information is exchanged through an aqueous medium. Szent-Györgyi believed that molecules send and receive messages through light in the form of photons that are emitted and absorbed.[47] Although the significance of this *ultraweak* biological light is highly controversial (as are many biocommunication theories), it appears there may be a relationship between such light and processes as diverse as DNA replication and cellular metabolism. Many theories of biological light, which date back to the early twentieth century, assume that light's *coherence*, rather than its intensity, is the critical factor in biocommunication. Coherence is related the cooperative manner in which different waves or vibrations may interact to reinforce one another, as will be discussed further in Chapter 8.

A trio of Slovenian biophysicists has identified water as the mediator through which ultraweak radiation is used to biocommunicate within cells.[48] This is a particularly intriguing hypothesis considering science's interest in the water network and its associated *nonlocal* phenomena. Nonlocal behavior suggests that individual water molecules act as part of a coherent whole, thus facilitating long-range interactions. Similar water mediation hypotheses identify the interaction between biologically structured water and cell membranes (particularly membrane proteins) as facilitating both cellular communication and membrane permeability. Recall that membrane permeability regulates the flow of substances in and out of cells. While water's mediation of cellular communication is controversial, its mediation of many crucial interactions within and between the proteins that comprise cellular components is not.

The communication between nucleic acids and proteins has been widely studied because of its role in transcribing genetic codes, repairing DNA, and countless other critical processes. Molecular research into this topic indicates that water molecules are often observed at the interface between nucleic acids and proteins, where water is involved in bridging the two via the formation of H-bonds.[49] Specifically, highly ordered water molecules present at the DNA-protein interface play a major role in determining the structural and thermodynamic properties of the DNA-protein complex. X-ray crystallography suggests that, at least in some instances, there is no DNA-protein contact and water mediates the interaction by communicating DNA sequences to proteins through specific H-bonded configurations in the hydration shell.[50] In this manner, appropriate DNA bases are paired with the functional groups of proteins via H-bonding with water. Stated differently, perhaps the most critical biochemical process occurring within earthly life forms can be mediated through water and its unique H-bonding capabilities.

While it might be a surprise that water is able to mediate the exchange between nucleic acids and proteins, it may be less surprising that vibration has been identified as a potential mechanism for doing so. A pair of Ukrainian scientists suggests that the embedded protein must match the longitudinal vibrations of the DNA helix in order to carry out the information transfer.[51] In other words, the protein must match the frequency of, or resonate with, the form of the genetic code in order to download the information (energy). Their hypothesis seems to originate from the edges of science, where modern premises maintain that the essential coding for all life forms is activated by and mediated through water. The extent to which water mediates exchanges between nucleic acids and proteins is currently unknown; however, this topic appears to be receiving considerable scientific attention.

Altering the structure and order of water inside biological organisms may be one of the processes that permit them to adapt to their environment. While the outside (e.g., artificial) structuring of water could reduce the energetic demands for structuring it within organisms, biological processes appear to require ultra-specific water.

WATER-BASED ENERGETICS?

Albert Szent-Györgyi's interest in ascorbic acid is actually quite pertinent to our present discussion of water and biology. He was focused on the ability of Vitamin C to increase the transfer of electrical charge between oxygen and hydrogen, which he believed constituted the basis of bioenergetics. He maintained that hydrogen is the fuel of biology and that its reaction with oxygen, as catalyzed by Vitamin C, brings life-giving light into living systems. This movement or transport of electrons from hydrogen (acting as the donor) to oxygen (acting as the acceptor) was considered by Szent-Györgyi to be fundamental to biological life. In his own words:

> Water not only plays an important role as part of the solid machinery, but also plays a central role in energetics. The driving force of life is the energy of solar radiation which is conserved by being used to separate the elements of water, H [hydrogen] and O [oxygen], or by taking a water molecule from between two phosphate molecules (Arnon's cyclic

> phosphorylation). The energy thus stored can later be utilized by reversing these processes and allowing the H and O to unite again (biological oxidation) or by putting the water molecule back between the phosphates (hydrolysis of ~P, the high energy phosphate bonds). In both processes water plays a central role. It is the hub of bioenergetics.[52]

This theory appears to simplify biological energetics to the basics, namely the splitting and forming of water. Szent-Györgyi suggests that shuttling protons and electrons around in such a way as to thermodynamically favor the breaking and forming of water may explain much of the chemistry associated with bioenergetics. In essence, one could envision this process as sort of an atomic "shell game" using the components of water (hydrogen and oxygen) in their many bioactive forms. A number of researchers (e.g., inventor Pat Flanagan) have echoed Szent-Györgyi's view in noting that the approximate one-volt potential difference between oxygen and hydrogen is the basis of energy production in the human body and that the end point of all metabolic biochemistry is the burning of hydrogen by oxygen to form water. Although a thorough treatment of bioenergetics is beyond the scope of this book, the processes of electron transport and water splitting/forming is so pertinent to understanding water's role in biological systems that I will endeavor to outline them as simply as possible.

Forming Water

Before rushing into biological energetics, let's take a look at how water is formed in non-biological systems. In the simplest sense, our cars are powered by the energy of water formation, which is facilitated by the reaction (burning) of hydrogen (as gasoline hydrocarbons) and oxygen (as air) in the engine. Because the reaction of hydrogen and oxygen liberates energy in forming water, there is an explosion in the cylinder that pushes the piston and ultimately powers the car.

But what really happens to provide this energy? Representing the combustion of gasoline according to the following simplified reaction provides a clue.

Gasoline Combustion: $C_5H_{12} + 8O_2 \Rightarrow 5CO_2 + 6H_2O + \text{energy}$

In this reaction, one mole of pentane (a common gasoline hydrocarbon) reacts with eight moles of atmospheric oxygen to yield five moles of carbon dioxide and six moles of water. What really is happening here is that electrons are being transferred among the participants of this reaction in accordance with process known as oxidation-reduction or *redox*. In a redox reaction, participants that donate or lose electrons are *oxidized*, while participants that accept or gain electrons are *reduced*. Because the shuffling of hydrogens is so closely coupled to the transport of electrons, it is often the case that the reduced participants gain hydrogens and the oxidized participants lose hydrogens.

In the car example, oxygen is reduced to water and the pentane is oxidized to carbon dioxide. This is why fossil-fuel burning contributes to atmospheric CO_2 levels and why there is so much written about the benefits of hydrogen gas, which produces only water when combusted, as a fuel. Pentane acts as the electron donor and gives up its hydrogens to oxygen, which acts as the electron acceptor. The reaction requires a requisite amount of heat (i.e., a spark) in order to permit the reaction to proceed. An H_2O molecule is thermodynamically preferred to the separate H and O atoms in a closed system; therefore, a lot of energy is liberated when water is formed, and an equal amount of energy is consumed when water is split.

Now let's see how this water formation plays out in the biological arena. The process responsible for the formation of water is known as *respiration* and, in a manner similar to all biochemical reactions, is initiated by an enzyme catalyst instead of a spark. In many other respects, aerobic respiration is analogous to the burning of gasoline in cars and is represented by the following simplified reaction:

Aerobic Respiration: $C_6H_{12}O_6 + 6O_2 \Rightarrow 6CO_2 + 6H_2O + \text{energy}$

In this reaction, glucose (a common sugar or carbohydrate) is analogous to the gasoline hydrocarbon in the example of the car. The glucose gives up hydrogens to oxygen in order to form water and, in the process, is itself oxidized to carbon dioxide. Stated in a slightly different way, oxygen is reduced to water as glucose is oxidized to carbon dioxide. Hydrogen (in the form of glucose) acts as the electron donor and oxygen acts as the electron acceptor. Unlike the car example, there are electron acceptors, other than oxygen, that may be used by various biological organisms to oxidize carbohydrates and form water. If compounds other than oxygen are used as the electron acceptor, the processes are known as *anaerobic*. Anaerobic electron acceptors include nitrate, sulfate, carbon dioxide, and various oxygenated forms of iron. Regardless of whether the electrons are transferred aerobically or anaerobically, the end result is the same. Namely, energy is produced as water is formed. Less energy is liberated from the reduction of anaerobic electron acceptors than from the reduction of oxygen; however, both serve as viable energy-producing mechanisms for earthly life forms.

Oxygen: A Mixed Blessing

The early history of Earth is one of anaerobic organisms and the absence of molecular oxygen, either in the atmosphere or dissolved in waters. However, once the first photosynthetic organisms developed the ability to garner their much-needed hydrogen (the so-called "fuel of life") by splitting the water molecule, oxygen became a major waste product. Oxygen was lethal to the early anaerobes, whether it was present in the atmosphere or dissolved in the oceans, because the anaerobes had no way of protecting their cells from its strong oxidizing effects. Organisms eventually evolved the ability to utilize oxygen as an electron acceptor without killing themselves in the process. Oxygen is a potent oxidizer and, even today, many organisms (mostly bacteria) use less reactive electron acceptors such as nitrate, sulfate, and iron. Aerobes enjoy the energetic advantage of using the most efficient "burner" of hydrogen—but not without paying a premium.

As the ultimate electron acceptor, oxygen is transformed within the mitochondria of biological cells to active oxygen species that are potent free radicals. These oxygen-derived radicals are capable of causing disease and aging predominantly through damage to DNA. An unfortunate attribute of the mitochondria (serving as the cell's powerhouses) is that they leak! Thus, free radicals escape the confines of this organelle and play havoc with other cellular components. One antidote to these oxygen-derived radicals is the ultimate electron donor, hydrogen, which may be present in a number of forms that are effective in scavenging the radicals.

Splitting Water

At this point, we might inquire as to the source of the reactants that combine to form water. In other words, what is the origin of the electron acceptors and electron donors? Well, we know that carbon dioxide is a product of many of the metabolic reactions forming water. The complex carbohydrates and oxygen are produced by a group of organisms know as *autotrophs*. Autotrophs are able to harness energy in the form of EM radiation from the Sun or in the form of heat from chemical reactions in order to split water and produce electron donors from carbon dioxide. The most common of all autotrophs are the photosynthetic plants that split water and use the resulting hydrogens in the reduction of carbon dioxide to carbohydrates. The oxygen liberated by splitting water is released either into the atmosphere as oxygen gas (O_2) or directly into oxygen-utilizing reactions.

The photosynthetic splitting of water and production of glucose occurs according to the following simplified reaction. Notice that this reaction is the exact reverse of aerobic respiration and requires solar energy to be captured via photosynthetic pigments such as chlorophyll.

Photosynthesis: $6CO_2 + 6H_2O + \text{energy} \Rightarrow C_6H_{12}O_6 + 6O_2$

Unlike the combustion of hydrocarbons in a car engine, biological organisms cannot have explosions going off in their cells and, hence, must have a way to store the energy of water formation in order to utilize it on demand. As such, the redox reactions shown thus far are mere simplifications showing the ratios of major reactants and products. The electrons and protons (hydrogens) are actually transported by a series of biomolecular complexes, which themselves are components of intricate biochemical cycles responsible for transferring the energy of water formation to the well-known ATP molecule. ATP is an abbreviation for *adenosinetriphosphate*, a compound composed of one of the nucleic acid's four bases, the sugar of RNA, and three phosphate groups that are connected via "high energy" covalent bonds.

ATP is actually formed by adding a phosphate group to ADP (*adenosinediphosphate*), which is identical to ATP except that it has one less phosphate group. Energy is stored in the bond that is created by adding a terminal phosphate group (i.e., ADP to ATP) and is released by breaking this same bond (i.e., ATP to ADP). Hence, the covalent bond that holds the phosphate groups together is formed by removing water and is broken by adding water. Although the covalent bond that connects the phosphate groups is often referred to as "high energy," what is actually meant is not the bond itself, but rather the *hydrolysis* of that bond. Hydrolysis simply denotes a reaction with water that, in this case, breaks the covalent bond connecting the terminal phosphate group and liberates energy as ATP is converted to ADP.

The aforementioned processes could be summarized in the following elementary manner. Photons in the form of sunlight strike an electron in photosynthetic pigments, requiring that water be split to replenish the electron-deficient pigments. Once water is split, the oxygen is released and the hydrogen is coupled to various biomolecular complexes. Simultaneously, ATP is formed from ADP by converting part of the excited electron's energy into one of its chemical bonds. The removal of water facilitates ATP formation. Because ATP is not appropriate for storing large quantities of energy in biological organisms, the energy contained within ATP's terminal bond is converted, by adding water, to carbohydrates via the reduction of carbon dioxide. The stored energy in carbohydrates is then available for both animals and plants that oxidize the carbohydrates back to carbon dioxide and, in doing so, form water. From this admittedly simplified perspective, bioenergetics is linked to and, in many respects, dependent upon the splitting and forming of water.

Water-Based Life Forms?

We commonly refer to living organisms on Earth as being carbon-based; however, the material presented in this chapter renders this designation suspect. In fact, even we humans contain about 70% water and less than 20% carbon-containing compounds, making us more water-based than carbon-based forms. Our fascination with carbon-based molecules is understandable given the long-standing belief among biologists that water simply acts as the universal solvent within which the "real" action is played out. Recent discoveries in many of the biological sciences suggest that, in some cases, water may be the real action at a molecular level and that carbon-containing molecules play more of a supporting role. It seems that earthly life forms are, both structurally and energetically, creatures of water.

Szent-Györgyi noted that life began in the ocean and could leave it only when organisms grew a skin and took the water with them.[53] Animals now carry seawater in the form of blood around with them; however, they are forever organisms of the water that serves as the matrix of life. In fact, marine as well as terrestrial animals carry around both saline and "fresher" water, each of which perform very different functions within their bodies. Szent-Györgyi believed the reason that biologists may have been unsuccessful in understanding living systems is that they focused only on particulate matter and routinely excluded the water matrix.

Theodor Schwenk went even further than Szent-Györgyi, hypothesizing that water is the mediator between living forms and the self-organizing energies of the universe. In this quotation, he updates the age-old question that asks whether it is living organisms that structure and animate water or whether it is water that structures and animates living organisms.

> The question however arises: Do the forms of the living organisms merely betray the character of the watery phase through which they have passed, or is it that the water itself, impressionable as it is, is subject to living, formative forces and creative ideas of which it is but the visible expression? If so, water as such would be the embodiment of a world of higher forces penetrating through it into the material world and using it to form the living organisms.[54]

Water is the fluid in which all biological structures are formed and all biochemical reactions take place. The designation of earthly life forms as carbon-based is probably a misnomer because they are composed predominantly of water, which is both a major component of their structures and an essential participant in the energetics that animates them.

CHAPTER 7

GAIA'S CIRCULATORY SYSTEM
Planetary Flowforms

The most dramatic cosmic influence upon terrestrial life, however, may result at the molecular level by changes in the structure of water. All life forms consist of a high percentage of water and thus may be touched at this level simultaneously . . . in the sense of a global regulation of system dynamics which would have a scope comparable to the self-regulation of the Gaia system.
Erich Jantsch, *The Self-Organizing Universe*

Similar to the circulation of blood in human beings, the circulation of water within the Earth is used to regulate overall body temperature, to exchange substances with other body parts, and to relay signals. Although a planetary body is immense compared to a human body, similar functions are required to maintain both. The temperature of the planet is controlled largely through the exchange of heat energy at the air-ocean interface. This exchange facilitates, or mediates, the planet's long- and short-term climate control system. The most highly publicized environmental crises of the twenty-first century (e.g., global warming, El Niño) are intimately related to water and its unique physical properties. While hormones in the human bloodstream act as messengers, it appears that subtle differences in seawater temperatures, which are transported by global-scale oceanic currents, perform a similar function for the Earth. Whether we focus on the human or the planetary body, water's unique properties are exploited for the purposes of regulation and communication.

GAIA'S OUTER BODY

As we learned in the first chapter, the original meaning of *Gaia* in the ancient Greek tradition was much broader than just the Earth. Gaia represented the entire physical universe, which was connected to Chaos (the Absolute) through the creative principle of Eros (the moving force of love). Eventually, the name Gaia came to be associated with the goddess of the Earth, representing the spirit or divine essence that inhabits our planet. More recently, scientists (originally James Lovelock) have revived the name "Gaia" to refer to a principle whereby the planet is perceived as a living organism. The planet's climate and surface environment are theoretically controlled, in large part, by the *biosphere* and in a manner that is best represented by a *superorganism*. "Biosphere" simply refers to all biological species inhabiting the very thin surface of the planet (e.g., plants and animals). "Superorganism" denotes that Gaia represents an organism by virtue of her being hierarchically composed of other organisms (i.e., the biosphere).

It is not the focus of this chapter to review the theories, counter-theories, and criticisms of the Gaia hypothesis, which was originally introduced by Lovelock in the early 1970s and has been modified and amended over the past thirty years. However, it is both necessary and helpful to review a few of this theory's basic concepts in order to understand how Gaia is able to utilize the copious amounts of water on her body (Earth) as a circulatory system for redistributing nutrients and energy. Gaian scientists maintain that the study of the Earth is not geology, but instead geophysiology, because it (or "she" as some Gaian theorists refer to Earth) is a living organism with body parts or systems similar to those of the human body.[1] One of the more interesting questions then becomes, what are the parts or systems of Gaia's body?

Tyler Volk, a biogeochemist at New York University, recently wrote a book that specifically addresses Gaia's body by employing Lovelock's theory in combination with his own focus on the molecular transformations between life and the global environment.[2] Unlike many Gaian scientists, Volk chooses not to look at the questions of whether our planet is alive or self-organizing, for which there are few agreed-upon criteria. More pertinent to our discussion is that Volk considers the air and water to be Gaia's *extraorganismal* fluids, which essentially means that the movement or circulation of these fluids is not under her control. Ancient insights regarding Gaia differ from modern theories insofar as she was known as a sentient being, rather than as simply a creation of her biosphere or of seemingly external forces such as those that circulate her fluids.

While identifying Gaia's fluids is really quite obvious, identifying her organs is much more nebulous. Volk decided to use cycles and *biochemical guilds* as the criteria for identifying her main compartments.[3] Essentially, these biochemical guilds are responsible for energy transformations on the planet and consist of a quartet that includes ocean, atmosphere, soil, and life. Life could also be substituted with *biosphere*, representing the very component from which the Gaia hypothesis was initially conceived. Soils result from the weathering of Earth's rocks and are considered by Volk to be the substance of planetary physiology. Air is a fluid that is very much the product of the biosphere because, without biological life, the composition of the atmosphere would be very different. Finally, the oceans represent the planet's major reservoir of water, acting to profoundly affect other three compartments. When paired one to one, these four compartments yield a total of six relations (air-ocean, ocean-soil, air-biosphere, etc.) such that the relation between any two defines fluxes of matter and energy.[4] The most extensive interface between any two compartments is that of the air-ocean.

Is the biosphere ultimately responsible for creating surface conditions on Earth? While modern science wrestles with this question, ancient insights usually attribute the planet's surface conditions to the Creator or to Gaia herself. An often-asked question is whether a sentient being (Gaia) could exert some degree of conscious control over her body (Earth) and, perhaps, utilize her available resources (e.g., solar energy, mineralogy, flora, and fauna) to create a planetary surface. Although ancient and indigenous peoples often viewed the Earth from a teleological perspective, scientists avoid this perspective because it violates the mechanistic tenets of science. In order to illustrate just how foreign the teleological view of Earth is to most of us postmodern Westerners, I have deliberately written this chapter from the perspective that Gaia consciously regulates her planetary body. Regardless of the arguments for or against such a viewpoint, notice how it changes the usual perception of global phenomena.

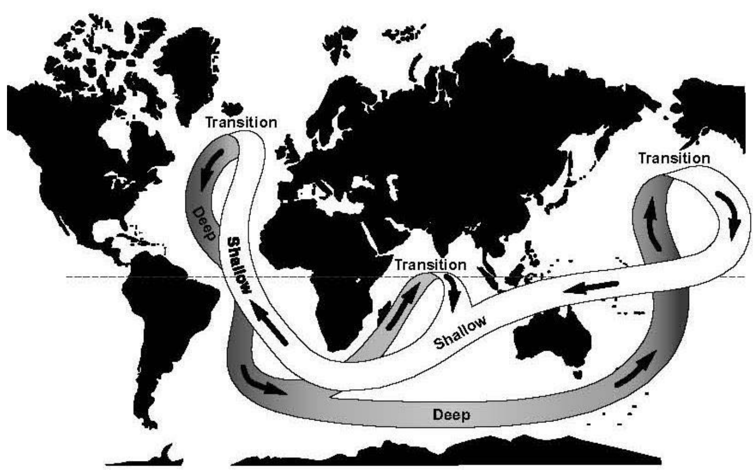
Gaia's Watery Fluid

As the surface fluids of Gaia's body, air and the water are sometimes referred to as her breath and her blood, respectively. Recall from the first three chapters that many ancient myths (as well as modern adaptations of them) taught that the movement of blood in humans was analogous to the movement of water throughout the Earth. Furthermore, the fundamental inorganic chemistry of blood is very similar to that of seawater, which comprises 97% of the water that circulates through Gaia's body. Blood circulation patterns in the body are fairly easy to map because they correspond to the networks of veins, arteries, and capillaries; however, the task of mapping water circulation patterns on the Earth is not quite so obvious.

In our cursory look at the global hydrologic cycle in Chapter 4, I noted that the movement of water represented the largest cycling of any substance on the planet. This cycling not only redistributes water throughout all Gaia's compartments, it also converts incoming solar energy into a useable form as a result of water's phase transitions. Water's *triple point* is where it is able to exist as a gas, liquid, and solid. It is this triple point and the associated nonlinear phase transitions that have made water instrumental in setting climatic regimes and in energetically driving many of the processes on Gaia's body.[5] If indeed she exerts some degree of conscious control over her body, the circulation of her primary surface fluids (i.e., air and water) would be expected to be paramount.

The planet's freshwater systems might be analogous to the intracellular or vicinal water of biological structures, as was presented in the previous chapter. Seawater and the major ocean currents, accounting for more than 90% of the global water circulation, might be analogous to the extracellular water of biological organisms (e.g., blood) that feed these smaller freshwater systems through major veins and arteries. The ocean and its associated currents are largely responsible for moving water from the locations where Gaia's "intracellular" fluids feed the major arteries (e.g., river mouths) to those where they are fed by the major arteries (e.g., the air-ocean interface).

Figure 7-1. An idealized map of the global thermohaline circulation, showing the transitional regions where water masses upwell and subduct. The "oceanic conveyor belt" and its vertical transitions between deeper and shallower depths are associated with temperature and salinity differences in seawater and with large-scale vortices, or gyres, within the world's ocean basins. [Adapted from John Steele, *Oceanus*, 32 (1989): 7.]



Oceanic Blood Flow

Large-scale ocean circulation is predominantly driven by differences in temperature and salinity (both of which affect the density of seawater) and by Earth's rotation. As shown schematically on Figure 7-1, cold water that sinks in the North Atlantic and the Southern Oceans is carried eastward as very deep currents that are eventually *upwelled* (i.e., rise to the surface) in the temperate Pacific and, to a lesser extent, the subtropical Indian Oceans.[6] In terms of geophysiology, the deep current could be considered Gaia's vena cava and the shallow current, returning seawater to the North Atlantic, her aorta. This large-scale circulation of ocean water is known as the *thermohaline circulation*, denoting that it is driven by temperature and salinity differences. The thermohaline circulation is sometimes depicted as a global conveyor belt, requiring about 10,000 years for water to travel the entire loop. This "round trip" is completed on the approximate timescale of Gaia's interglacial periods.[7]

Adhering to the analogy between blood and seawater, oceanic blood is not truly pumped. Instead, the thermohaline circulation might be more accurately pictured as a series of large vortices or circulation loops that exchange water at various depths, redirecting water to the next loop and linking the global conveyor belt. An admittedly oversimplified version of Gaia's blood flow could be described as follows:

- Cold, salty North Atlantic Deep Water (NADW) subducts (i.e., sinks) and moves southward through the deep Atlantic through a series of gyres to reach the Antarctic Circumpolar Current (ACC). The ACC is a giant swirling current that mixes the deep waters of the Atlantic Ocean and Southern Ocean.

- While most deep waters get off the ACC "merry-go-round" just east of Australia in the western South Pacific, a fraction of them get off early (just past the southern tip of Africa) and head north into the Indian Ocean.

- Once in the Indian Ocean, some deep waters are upwelled to intermediate depths and feed into a gyre that moves them westward around the tip of Africa. Other deep waters are moved by a series of gyres either northward into the western Pacific basin or southward back to the ACC.

- Pacific subtropical gyres feed intermediate waters into the equatorial thermocline, where eastward-moving currents upwell it to the surface in the eastern tropical Pacific. Shallow currents drive surface waters poleward and westward through the subtropical and temperate Pacific gyres.

- Intermediate water exits the Pacific Ocean along the eastern portion of the basin and around the tip of South America. Once in the western South Atlantic, this water moves northward toward the subtropical gyre and toward waters entering the Atlantic from the Indian Ocean.

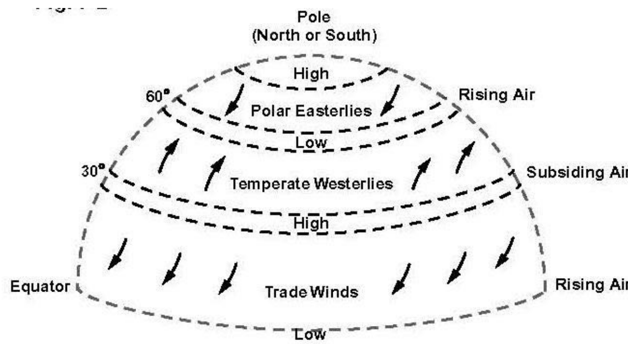
- As the intermediate water of the return thermohaline circulation reaches the North Atlantic, it loses some of its heat as evaporation, which decreases its temperature and increases its salinity. This change in salinity and temperature causes surface water to sink, forming NADW and starting the circulation anew.

In addition to comprising Gaia's major blood vessels, this global-scale circulation of oceanic waters is believed to transport climate signals from subpolar to subtropical waters in the form of long-term, but subtle, temperature changes.[8] That is to say, temperature signals are carried though Gaia's major blood vessels in a manner similar to way a hormone is carried by the human bloodstream to the appropriate target tissue. Although thermal changes in the oceanic conveyor belt can and do occur anywhere along its global trek, freshwater injected into the North Atlantic from melting ice sheets and continental runoff is the most likely candidate for the planetary "endocrine gland." In addition to transporting climate signals, the oceans are able to retain a history or "memory" of the planet's recent (i.e., tens to hundreds of years) climate using these encoded temperature changes. It is seawater's large heat capacity that allows the oceans to induce and then to record the Earth's climate regime.

Gaia's Airy Fluid

Let's switch now from Gaia's blood vessels to her lungs. The movement of Gaia's breath or air is influenced by a number of factors including her rotation, the Sun's energy, and processes that occur at the interfaces separating the atmospheric (air), oceanic (water), and continental (soils) compartments. Scientists have long recognized that the complex patterns of air circulation over the planet's surface are intimately connected to ocean dynamics and, by the same token, that oceanic circulation patterns are connected to atmospheric dynamics. For many years the issue of which of these compartments, if either, was actually directing the other was hotly debated in the scientific literature. Very recent discoveries and subsequent modeling data suggest that it is the oceans that are at the helm, primarily through temperature anomalies that characterize tropical sea surface temperatures.[9] Hence, Earth's long- and short-term climate appear to be largely a function of energy exchange at the tropical sea-air interface, although the exact mechanisms underlying changes in tropical sea surface temperatures have not been identified.

Figure 7-2. A hemispheric representation of global air circulation patterns. High and low barometric pressure zones at various latitudes are coupled to rising and subsiding air masses and to the prevailing winds in each of the two hemispheres [Adapted from Frederick Lutgens and Edward Tarbuck, *The Atmosphere*, 150.]



Similar to the oceans, the atmosphere is characterized by some well-defined circulation patterns that are responsible for everything from the direction of prevailing winds to the latitude of the Earth's deserts and rainforests. The combination of unequal heating of the Earth's surface and the planet's rotation sets up a predictable series of large-scale circulation cells that transport air around the globe. These idealized air circulation patterns are illustrated on Figure 7-2 and are commonly referred to as the *three-cell model* (i.e., polar, temperate, and tropical cells in each of the two hemispheres). The pattern of rising and sinking air masses sets up the common global winds, which are also shown on Figure 7-

2. There are some regions where the winds converge and air masses rise, and other regions where the winds diverge and air masses sink. The convergence of hemispheric trade winds near the equator creates low barometric pressures, rising air masses, and almost continuous thunderstorm activity. As will be discussed, equatorial regions figure prominently in oceanic-atmospheric events.

GAIA'S INNER BODY

To complete the perspective of planetary anatomy, Gaia also circulates an internal fluid in the form of molten rock, or magma, that comprises much of her core and lower mantle. The Earth's mantle comprises about 85% of the planet's volume and essentially acts as a regulator in permitting magma to reach the Earth's crust. Magma upwelling zones include volcanoes and the mid-oceanic ridges that are associated with the spreading of *tectonic plates*. Tectonic plates are massive chunks of the crust that move, relative to each other, upon the molten or fluid portion of the mantle. The continents and ocean floors make up the top portion of these tectonic plates and are transported extremely slowly around the globe. *Spreading zones* occur where new sections of plate are being formed and *subduction zones* occur where old sections are being recycled back into the mantle.

In addition to cycling rock between the crust and mantle, oceanic subduction and spreading zones are also believed to cycle water. Essentially, seawater entrained in the subducted portion of the tectonic plate is eventually incorporated into the rocks as a mineral hydrate—similar to the iron-silica hydrate discussed at the end of Chapter 4. The volume of water stored as mineral hydrates in the upper mantle is suspected to be many-fold greater than that filling the planet's oceans,[10] perhaps acting as a source of so-called juvenile water. The reservoir of water in the Earth's mantle is reclaimed when magma is forced upward to the crust, either as spreading zones or volcanoes, where water is freed from the rock's crystalline lattice and condenses as a liquid. In essence, the planet's surface water exchanges with its internal water through the oceans, where Gaia's inner fluid meets her watery outer fluid.

Vortices and Thermal Vents

One of the most unusual phenomena associated with the interaction of Gaia's magma and seawater relates to the vortices that are created above thermal vents. You may remember from Chapter 5 that thermal vents, which are chimney-like seafloor structures associated with volcanoes or magma-producing ridges, play an instrumental role in introducing minerals and gases to seawater. In addition, marine biologists now recognize that these vents contain a unique faunal assemblage that is found nowhere else on the planet. The combination of hot magma, cold seawater, and Earth's rotation spawn giant vortices or whirlpools that rise from the vents, owing to the difference in density between hot and cold seawater. In a recent article, Jon Copley cites the research of several physical and biological oceanographers in noting that these vortices break free from the vent area and carry with them heat, solutes, and larval animals.[11] Similar to Dorothy and Toto's trip to "Oz" aboard the infamous Kansas tornado, larval animals may be carried from vent to vent by these vortical water taxis.

Copley specifically cites the research of oceanographer Kevin Speer, who reportedly predicted that that these vortices span kilometers in diameter and migrate long distances through the abyssal waters instead of rising immediately to the surface or simply dissipating. Not only could these vortices assist in transporting mantle-derived minerals throughout the oceans, it is possible that massive thermal vents (as are suspected to have existed in Earth's early history) could have created gargantuan vortices that carried their heat all the way up to the ocean's surface. Although controversial, a significant rise in oceanic surface temperatures could have created storms of epic proportions. Was it the release of heat or of water that has led some creationists to identify seafloor fissures as the source of rainfall associated with the biblical Great Flood?

Biblical musings aside, let's take a look at vortices in terms of other ancient insights. Life supposedly originated in the water of the primeval vortex, which is believed to have existed in the ocean. Do the vortices associated with these thermal vents fill the prescription for the beginnings of biological life? Well, the water (seawater) and fire (magma) of the Mother (Earth) were mixed in the vortex, which contained the simple chemicals and energy required for building organic molecules. Is it the vortex that provided the organization or ordering of these simple chemicals (matter) as a result of its ability to link the observable and unobservable worlds through its mediator (water)? And was it the vortex that distributed life or life's precursors throughout the oceans? While there are no answers, it is interesting to ponder these far-reaching questions.

"Solidified" Internal Fluids

Before leaving Gaia's internal fluid, it is worth taking a quick look at the fate of this fluid when it solidifies. As mentioned previously, magma that is forced to the planet's surface and cooled eventually becomes the solid parts of Gaia's body. The cooled magma produces so-called *primary* minerals, most of which are silicates that structure themselves from a matrix, or framework, of silicon dioxide. This silicate framework then incorporates a number of other elements (e.g., calcium, potassium, sodium, magnesium, aluminum, and iron). The primary minerals or rocks on the Earth's surface are physically and chemically weathered over the eons, producing water-soluble ions and the miniscule grains that comprise the planet's soils and sediments. Eventually, surface and ground waters deliver these minerals to the planet's oceans.

The major physical and chemical agent for weathering primary rocks is water, which does so through its phase changes and its role in geochemical reactions. One could propose that water is the principle agent—with assistance from the Sun and carbon dioxide—in creating Gaia's soil compartment from her primary minerals. Once these soils and sediments are created and laid down (particularly in aqueous environments), they may be compacted and/or chemically reacted to form *secondary* minerals. Secondary minerals include rocks such as limestones and shales that owe their existence to chemical reactions involving water. In fact, water is incorporated into the crystalline matrix of many of these secondary minerals, not unlike water's integral role in the structure of biomolecules. Even if the soils and sediments are not compacted into secondary minerals, water plays a pivotal role in their ability to function as the fertile substance that supports the growth of terrestrial plants.

All soil grains are hydrated inasmuch as they are surrounded by a tightly bound layer of water than cannot be removed unless the soil is dried at high temperatures in an oven. Even desert soils possess this layer of water that mediates the exchange of protons, electrons, and various ions with the "mobile" water that infiltrates into or flows through soils. This mediation is critical in *sorption*, or the adherence of substances (e.g., natural organic matter and various pollutants) to soil grains, and in the reactivity of these sorbed substances. Natural organic matter refers to decomposed plants or animals. It should be noted that many environmental remediation technologies are designed to desorb pollutants by altering the network of water molecules surrounding soil grains—either directly or indirectly.

Finally, the sediments suspended in surface waters (e.g., lakes, rivers, oceans) are largely responsible for transporting substances that are otherwise relatively insoluble and immobile in water. Mineral sediments such as clays possess an electrical surface charge that attracts oppositely charged metals (e.g., lead, chromium), water-borne viruses, and certain electrically-charged subunits of natural organic matter. As long as the sediments remain suspended in the water column, these otherwise immobile substances are able to "hitch a ride." Moreover, the organic matter associated with fine clay sediments is able to act as a sorbing surface for organic contaminants (e.g., solvents, pesticides) and for microorganisms such as bacteria. Many substances are transported in earthly water not as solutes, but instead as hitchhikers on fine sediments or colloids that are suspended in the water column.

Whether the sorption mechanism is electrostatic or hydrophobic, it is mediated through the water layers surrounding both the mineral surface and the sorbed substance. Specific molecular-scale structures of water (some of which are related to the reduced number of H-bonds formed by molecules at the mineral interface) are responsible for proton transfer and other physical processes that ultimately result in sorption. Stated very simply, water acts as the glue that holds soils together and as the medium through which plants are able to access many the "ingredients" required for their production of terrestrial organic carbon. Whether on the bottom of a lake or in apparently dry soils, water hydrates mineral particles and acts out its role as a mediator in the processes that create and sustain much of the planet's "solid" surface.

About 97% of the water on Earth's surface is contained within the oceans, which act as the dominant planetary compartment for storing global heat, redistributing solar energy, and determining short- and long-term climate trends. The other compartments (e.g., soils, air, biota) cannot assume control primarily because of their lower heat capacity.

GAIA'S FLUCTUATING TEMPERATURE

Over a century ago, a Swedish chemist by the name of Svante Arrhenius hypothesized that the increased volume of carbon dioxide put into the air by human activities (mostly the burning of coal) could actually cause the temperature of the lower atmosphere to rise. He calculated that CO_2 and other gases that absorb infrared radiation given off by the Earth could trap the energy in their chemical bonds and retain the heat much like a greenhouse. Hence, the present-day designation of *greenhouse gases* and the highly controversial process of *global warming* has some relatively old roots, leading back to the supposition that human-related CO_2 production is the primary cause of an undesirable effect. Before launching into water's role in the global warming process, let's take a quick look at the process itself.

Reviewing the Basics

Here, in one paragraph, is an abbreviated version of the global warming theory. The Sun bathes the Earth in electromagnetic (EM) radiation. During this process, a fraction of the so-called *shortwave* solar radiation is absorbed, causing the daytime heating of the atmosphere. Solar radiation not absorbed by the atmosphere is either reflected back to interplanetary space or heats the Earth's surface. The Earth's surface heat is then radiated back to the atmosphere in the form of so-called *longwave* EM radiation, consisting of considerably lower frequencies (i.e., longer wavelengths) than those dominating the incoming solar radiation. Certain atmospheric gases are able to absorb the energy of Earth's outgoing radiation with varying degrees of efficiency, depending upon the ability of their molecular bonds to vibrate and stretch in response to specific infrared (IR) frequencies. The most common greenhouse gases include CO_2, methane (CH_4), and water vapor. As the concentration of greenhouse gases increases (assuming all other factors remain constant), so does the atmospheric heat retention. Due to its day-night cycle, global warming results more from warmer nighttime temperatures than from warmer daytime temperatures.

So, what is it that scientists believe they understand about Gaia's temperature? First, it appears that averaged global surface temperatures in the past twenty-five years have risen more dramatically than over any similar period for which scientists have comparable records. Second, Gaia's temperature fluctuates according to cycles ranging from millions of years to tens of years (e.g., the major Ice Ages as well as short-term warmings and coolings) and those cycles are nested within or superimposed upon one another. Third, it appears that the atmospheric concentration of certain greenhouse gases has risen sharply over approximately the same period that recent global temperatures have increased. Fourth, scientists infer from geologic and ice core records that similar changes in global temperature and greenhouse gas concentrations have occurred repeatedly in the past thirty-five million years or so. Some of these global temperature changes have been correlated with atmospheric CO_2 concentrations, while others have not.

What scientists don't know is exactly how these various factors are related and where the cause-and-effect relationships lay. In fact, the question of whether temperatures are warming, cooling or holding steady is based entirely on the timescale over which scientists discern the trends. For example, if we look at a timescale of a thousand years compared to that of a hundred years, it is difficult to tell whether Gaia is experiencing an increasing or decreasing trend in average global temperature. We also don't know why Gaia appears (or at least is perceived to be) powerless in reversing or even mitigating this warming trend, assuming (of course) that it deviates from the natural order of events. With what we now know about Gaia's body, here is the question that I will explore for the remainder of this chapter. Could water serve as Gaia's primary agent for regulating her temperature and other planetary phenomena? Let's begin by taking a look at her global thermostat.

A Watery Thermostat

As part of the discussion of earthly water in Chapter 4, I cited research indicating that water was the most important substance in climate regulation (generally) and in global warming (specifically). Scientists have also postulated that it is through the mechanism of water's phase transitions that much of this climate control is exerted. Let's see how Gaia may use water to regulate her surface temperature, just as a human might regulate his or her skin temperature. Humans cool themselves by perspiring, which places liquid water in contact with hot skin. Essentially, the skin's heat is used to break H-bonds, permitting liquid water to evaporate and to cool the skin. The Earth also uses water (i.e., her oceans rather than perspiration) as the primary substance to cool her body temperature; however, the process is a little different.

Heat absorbed by the oceans is both stored and used to evaporate water. As liquid water evaporates from oceans, it produces water vapor that quickly forms clouds, dropping rainfall back onto the oceans and onto the continents. Most of the evaporation of water from Gaia's skin occurs in the tropical and subtropical oceans, which is the primary source of the rainfall that falls on her body. During the recent period of global warming, warmer surface temperatures and higher rainfall have characterized the tropical oceans. As the evaporation above tropical oceans condenses and falls as rain, it transfers heat to the atmosphere and thus perpetuates global warming. The question of what has caused the temperature of the tropical oceans to rise and remain elevated since the early 1970s is a focus of many research projects.

Recall that temperature signals may be encoded in the deep-water currents of the global oceanic conveyor belt. In fact, a recent hypothesis suggests that both long- and short-term climate trends over the past 100,000 years may be due to alterations in this thermohaline circulation, resulting in the chaos that is characteristic of Earth's climate system.[12] One such alteration to the thermohaline circulation has been identified as a recent (past one hundred years) reduction in deep-water formation in the Southern Ocean.[13] In other words, the Antarctic has not been contributing its "fair share" of cold water to the global thermohaline circulation. This lack of deep-water formation seems to be correlated with the warming of local currents in the Southern Ocean and the concurrent destabilization of some of Antarctica's major ice sheets.

The amount of water that transitions from liquid to vapor at the air-sea interface is substantially influenced by the thickness and overall coverage of clouds. The relationship between clouds and the radiative budget of the planet is extremely complex and, even today, remains one of the great confounders of climate prediction. As nucleated forms of solid and liquid water, clouds represent a highly efficient mechanism by which Gaia regulates the radiative flux at her air-sea interface. Although clouds will be discussed in a subsequent section, suffice it to say that cloud formation is dependent on the concentration of atmospheric water vapor and of nucleating agents around which the water vapor condenses into a liquid or solid. The oceans serve as the primary controller of both water vapor and cloud nucleating agents. If water acts as the planet's thermostat, then it could be argued that the oceans control such a thermostat.

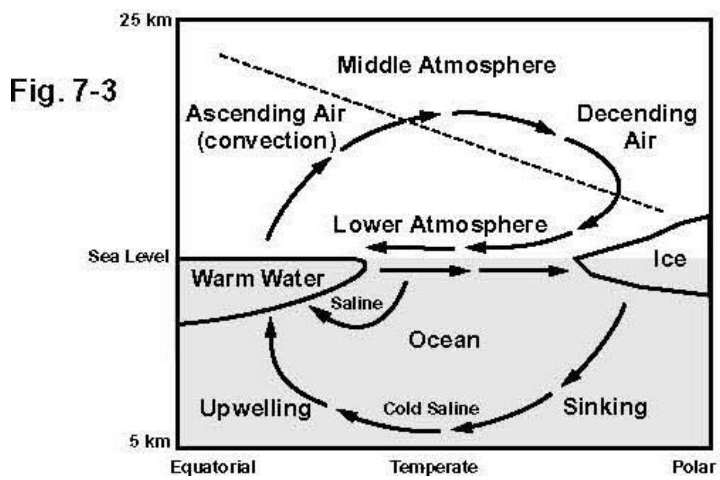
Sea Surface Temperatures

A substantial volume of data suggests that sea surface temperatures in the tropical Pacific are the cause of the escalated global warming that began in the early 1970s.[14] While global scale cause-and-effect relationships are very difficult to discern, it appears that the ocean is able to control the atmosphere because of its uncanny ability to store heat energy. Remember that water has a much higher heat capacity than does either air or soils, permitting it to store more solar energy with proportionally less temperature change. In fact, scientists have determined that a large portion of the world's ocean water lying at depths of 300 to 1000 meters has undergone a net warming in the last fifty years. The increase in heat content within these intermediate oceanic depths has apparently preceded the warming of sea surface temperatures.

Approximately 11% of the planetary oceans are characterized by surface temperatures of 28° C or greater, constituting an incredibly small 0.05% of the oceans' volume. Because warm water exists as a relatively thin sheet overlying the frigid abyssal waters, most of the seawater filling the world's oceanic basins hovers around the 4° C mark. The residence time for a molecule of water in the oceans is extremely long (i.e., thousands of years) compared to that in the atmosphere (i.e., weeks). With such a rapid turnover of atmospheric water and a slow turnover of oceanic water, how it is that the air-ocean interface could possibly control the climate of the Earth? The answer is that oceans mix vertically, permitting them to sequester heat and to vertically "shuffle" water layers so that the same water molecules do not endlessly exchange between the air and the ocean's surface layer. This mixing is maintained by everything from winds blowing across the sea surface to melting ice and falling rain.

It is the warm surface waters of the tropical oceans that drive the overlying air masses to higher altitudes and at greater velocities than anywhere else on the planet.[15] This so-called *convection* and the associated air circulation overlying tropical oceans dominate all other atmospheric circulation systems on Earth; hence, tropical sea surface temperatures are often implicated in driving the planet's climate patterns. Stated differently, Gaia may use her warm tropical oceans and the thermohaline "conveyor belt" to power the circulation of her blood (seawater) and her breath (air). Essentially, heat is circulated between the equator and the poles via the upward convection of warm air at the tropics and the downward convection of cold, saline water at the poles. An extremely simplified illustration of Earth's oceanic-atmospheric circulation is shown in Figure 7-3. The motion of oceanic surface water masses, acting to circulate heat from the tropics to the poles, converts potential energy to kinetic energy that then becomes available for earthly systems to do work.

Figure 7-3. A simple idealized schematic of the combined atmospheric-oceanic circulation patterns on the Earth. Air masses generally ascend in low-latitude and descend in high latitude regions, whereas oceanic water masses generally sink in polar and upwell in tropical oceans. Depth and altitude vary along the y-axis, while latitude varies along the x-axis. [Adapted from Peter Webster, *Reviews of Geophysics*, 32 (1994): 471.]



Not only do tropical sea surface temperatures (particularly those of the Pacific) influence atmospheric-oceanic circulation, but they also profoundly affect the amount of water vapor in the overlying air. The renowned geochemist Wallace Broecker has postulated that atmospheric water vapor may be the only molecule that is capable of warming and cooling the planet on short notice.[16] For this reason, water vapor (particularly water evaporated from tropical oceans) is sometimes referred to as the mediator of rapid global climate change. Because water vapor is the most potent of the greenhouse gases, even an atmospheric concentration change of 30% is adequate to alter average planetary surface temperatures by 5° to 6° Celsius. The intense global warming of the last thirty years has resulted in average global temperature changes that are considerably less than 5° to 6° Celsius.[17]

The oceans' global thermohaline circulation is hypothesized to transport signals that induce and then record climate shifts, in a process not unlike hormone circulation in the bloodstream of animals. This global oceanic circulation and its effect on sea surface temperatures are theorized to underlie phenomena ranging from species extinctions to the Ice Ages.

WATER'S GLOBAL GREENHOUSE

Thus far we have seen that Gaia's oceans are the primary controllers of the watery thermostat that serves to stabilize or destabilize her surface body temperature. It also appears that the oceans accomplish this monumental task by redistributing heat energy between equatorial and polar regions via large-scale oceanic and atmospheric circulation patterns. Both long- and short-term fluctuations in Earth's climate are related to tropical sea surface temperatures and quite possibly to spatial and temporal variations in the thermohaline circulation. Given this highly oversimplified scenario of global dynamics, how does the much-publicized greenhouse effect enter into the overall equation?

The answer to this question seems to be that Gaia utilizes certain of her atmospheric gases to absorb and retain heat energy over a relatively narrow band of the electromagnetic spectrum. Much of the emphasis on global warming has been placed on these atmospheric gases. In particular, a tremendous amount of scientific, social, and political energy has been directed toward the singular goal of reducing atmospheric concentrations of carbon dioxide. So, where exactly does water fit into this brouhaha? The answer is two-fold. First, we have seen that the Earth's climatic system is largely related to water in the form of the oceanic surface layers and atmospheric water vapor. Second, even if we focus in on the very narrow topic of greenhouse gases and its relationship to global temperatures, it appears that water plays a pivotal role in releasing these gases to the atmosphere. Through the regulation of greenhouse gases and the formation and distribution of clouds, Gaia appears to use her primary fluid (water) in regulating her surface conditions.

Table 7A. A comparison of the concentrations and relative contribution of major gases comprising atmospheric air on Earth. Concentrations of all gases, except water vapor, are expressed as a percentage of dry air. Actually, dry air does not exist because water vapor always comprises from one-tenth to a few percent of the total air, depending on temperature and global location.

Air Constituent	Greenhouse Gas	Composition of Dry Air (%)	Composition of Total Air (%)
Nitrogen (N_2)	no	78	----
Oxygen (O_2)	no	21	----
Argon (Ar)	no	0.93	----
Carbon dioxide (CO_2)	yes	0.032	----
Neon (Ne)	no	0.0018	----
Helium (He)	no	0.00052	----
Methane (CH_4)	yes	0.00015	----
Hydrogen (H_2)	no	0.00005	----
Nitrous oxide (N_2O)	yes	0.00003	----
Water vapor (H_2O)	yes	----	0.1 to 3.0

In order to understand how the atmosphere acts as a greenhouse for the planet, we need to look at the composition of air—at least that of today's air. Table 7A lists the relative percentages of the major air components along with their potential as a greenhouse gas. The two largest components of the atmosphere are nitrogen (N_2) and oxygen (O_2) gases, which together comprise about 99% of dry air. The minor components consist of noble gases (e.g., argon, neon, helium), hydrogen (H_2), and the common greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Because there is no such thing as dry air, we must also consider the water vapor content of the air. The water vapor concentration in Earth's lower atmosphere is a function of temperature, such that it may compose as much as 1% or more of the air in warm humid climates and as little as 0.1% or less of the air in dry cold climates.

The greenhouse effect results from the ability of atmospheric gases to trap IR, or longwave, radiation that is given off by the Earth. Water molecules are Gaia's most versatile absorbers of IR radiation, owing to their ability to capture energy over the entire range of wavelengths that she gives off. However, her outgoing radiation is not distributed evenly over the entire IR range, but instead is maximal at very specific wavelengths. Although methane and carbon dioxide do not have water vapor's absorptive versatility, they are actually more efficient at capturing the Earth's radiative energy within these specific peak wavelengths (e.g., CO_2 strongly captures IR at 12.5 to 18 microns). If all other greenhouse gases were removed from the atmosphere, the amount of IR radiation trapped by water vapor and clouds would increase many-fold. By supplementing water vapor with various other gases, Gaia appears to fine-tune the amount and wavelengths of IR radiation that she uses to create her planetary greenhouse.

Carbon Dioxide

If we return to the popular theory that *anthropogenic* CO_2 production is the primary cause of recent global warming, there is a curious finding that must be addressed. Only about half of the anthropogenic CO_2 released is actually accumulating in the atmosphere. "Anthropogenic" refers to the carbon dioxide introduced by human activities such as fossil fuel burning and deforestation. So, where is Gaia sequestering the other half of the anthropogenic carbon dioxide? If you answered "in the oceans," you are probably correct.

Is there evidence that the oceans are accumulating the excess CO_2? The answer to this question is "yes;" however, the challenge in assessing the effects of anthropogenic CO_2 on the oceans is at least two-fold. First, any carbon dioxide that is dissolved in seawater becomes part the carbonate buffering system. In this manner, much of the CO_2 is converted to bicarbonate ions, which tend to increase the dissolved inorganic carbon in seawater. Second, anthropogenic CO_2 production is estimated to account for a mere 0.05% of the dissolved inorganic carbon in seawater. Despite these challenges, inorganic chemical data suggest that the most of the carbon from atmospheric CO_2 is located in the deep-water masses of the oceans and, in particular, those of the Pacific Ocean.[18] It is interesting to note that there is some scientific speculation that increased levels of atmospheric CO_2 have actually affected the thermohaline circulation.

Here is the abbreviated scientific explanation for why this is so. Tiny, unicellular marine plants (phytoplankton) consume CO_2 in sunlit surface waters during the process of photosynthesis; thereby transforming the carbon in CO_2 to cell biomass (carbohydrates) and releasing oxygen. Some of this biomass sinks through the water column and is deposited on the ocean floor, creating what oceanographers refer to as the *biological pump*. Essentially, carbon is pumped out of the surface waters into deeper oceanic realms where marine bacteria and other microorganisms consume the carbohydrates and release CO_2. However, the CO_2 produced at depth in the oceans is largely sequestered below the surface waters and is not in contact with the atmosphere except in locations where these deeper waters are upwelled. Due to global circulation patterns, the Pacific collects the oldest organic matter of all the world's oceans.

In general, tropical oceans act as sources of atmospheric CO_2 due to the upwelling of deep CO_2-rich waters that are subsequently warmed, reducing the solubility of CO_2 and permitting it to be released to the atmosphere.[19] By contrast, temperate and polar oceans act as sinks for atmospheric CO_2. The tropical Pacific Ocean constitutes the largest oceanic CO_2 source region, contributing almost two-thirds of this greenhouse gas on a global basis! A major exception to this pattern occurs during El Niño events, when a thick layer of extremely warm surface water inhibits the upwelling of CO_2-rich waters from the deep equatorial Pacific. During El Niño years, the CO_2 flux from sea to air is diminished in the equatorial Pacific. Returning to our teleological view of planetary processes, might the more frequent and intense El Niño events be construed as a Gaian attempt to curtail the sea-to-air transfer of CO_2 from the planet's primary source area?

Carbon Sequestration

In addition to its role in balancing the natural atmospheric flux of carbon dioxide, seawater has been recently identified as the most practical "global dump" for anthropogenic emissions of this greenhouse gas. During the last decade, scientists explored the idea of using the biological pump to reduce atmospheric CO_2 concentrations by deliberately increasing the photosynthetic activity of phytoplankton in selected oceanic regions.[20] Essentially, the plan took advantage of the huge carbon sink in the oceans compared to that in the atmosphere and entailed fertilizing the oceans with a soluble form of iron, which tends to be a limiting nutrient for phytoplankton. Increased photosynthesis enhances the air to sea flux of CO_2 as this greenhouse gas is removed from surface waters during the production of biomass and oxygen. Theoretically, this biomass then sinks into the oceanic depths where it is sequestered away from the atmosphere.

Besides the difficulties of dispensing a soluble iron fertilizer, scientists became concerned about the efficacy and the ecological consequences of such a procedure. First of all, fertilizing the ocean would significantly alter the diversity of marine phytoplankton species. Second, such algal blooms could stimulate the proliferation of marine bacterial populations capable of rapidly consuming much of the biomass and respiring CO_2 back into the surface waters before it had an opportunity to sink. Third, if the augmented surface biomass did indeed reach the deeper oceanic water masses, it is possible that the increased oxidative demand could deplete the oxygen content of the seawater and, thus, locally alter the ocean's redox chemistry.

Scientists have begun testing a more direct method than oceanic fertilization for transporting CO_2 to the seabed and keeping it there for extended periods. Essentially, pure carbon dioxide liquid is pumped (via long hoses) to great oceanic depths, where it dissolves in seawater beneath the mixing zone. This method simply cuts out the photosynthetic and carbon sinking steps of iron fertilization. A more sophisticated offshoot of the pumping technique includes the formation of CO_2 gas hydrates (clathrates) as "ice-like" conglomerates that are transported to or formed within the oceanic depths. A potential difficulty with such technologies is their dependence on the long-term stability of deep oceanic waters, which is not exactly a sure bet. While these short-term fixes are well intentioned, are they wise? What is it that we are actually fixing, and on what timescale? How will this fix affect other processes? Beyond just the scientific ignorance associated with such fixes, ancient people might have questioned whether we are undermining a subtle response already implemented by Gaia.

Methane

While atmospheric concentrations of methane (CH_4) are about two hundred times less than those of carbon dioxide, this simplest of hydrocarbons has some rather unique properties that render it one of the most important of the greenhouse gases. While most of the excess carbon dioxide loading to the atmosphere is due to the combustion of fossil fuels, most of the methane that reaches the atmosphere is due to natural gas seeps or to the anaerobic biodegradation of organic matter (including plant material and fossil fuels) in aquatic environments.[21] Not only is atmospheric methane a potent greenhouse gas in and of itself, but it also reacts with common atmospheric constituents to produce other significant IR absorbers, such as carbon dioxide.

Methane is normally present within the pore spaces of oceanic sediments and as accumulations of gas hydrates (clathrates) on continental boundaries. Due to the limited conditions under which methane hydrates are formed, there are only a few planetary environments that are conducive to their formation. Most of Earth's gas hydrates are formed either beneath the ground in permafrost areas (e.g., Alaska, Siberia, Greenland) or in marine sediments lying at a depth of at least 500 meters beneath the ocean surface. Because the conditions for gas hydrate formation are met in almost all of the ocean basins, most of the global methane hydrates are present in marine environments. Once formed, the clathrate deposits are relatively stable if temperatures and pressures do not fluctuate. The prevalence of methane hydrates on continental margins and underlying large reef systems has raised some concern regarding their geologic stability as global atmospheric and oceanic temperatures continue to rise.

In addition to acting as a major regulator of atmospheric oxygen and a producer of other greenhouse gases, it appears that oceanic methane may have been responsible for some of the most radical climate changes in Earth's history. About fifty-five million years ago the temperature of the Earth rose rapidly (i.e., 1.5 to 2.0° C in less than 1000 years), killing countless numbers of marine species. After much searching for an explanation to this extraordinarily rapid and dramatic climate change, scientists have concluded that the release of trillions of tons of methane hydrates is the most plausible cause.[22] From the seafloor of the world's oceans came a massive rush of methane! While much of the methane was oxidized to carbon dioxide before reaching the sea surface, a fraction of it escaped into the atmosphere. The process of methane oxidation substantially lowered the dissolved oxygen content and redox potential of the oceans. Those species that could not adapt to highly anoxic conditions apparently faced a quick extinction.

The big question is, of course, what was it that caused the normally stable gas hydrates to burst and release this massive volume of methane. The answer seems to lie in the thermohaline circulation, whereby the global oceanic conveyor belt was affected by the already warming conditions on Earth in such a way that it permitted surface water, other than that from the North Atlantic and Southern Oceans, to sink. This disruption in Gaia's normal circulation permitted warmer waters to reach the seafloor and thus destabilize the methane hydrates. The stability of gas hydrates is extremely temperature-sensitive; hence, a miniscule increase was sufficient to initiate a worldwide change in climate. It appears that a similar incident may have occurred nearly 250 million years ago, when the Earth experienced another mass extinction of marine species that scientists generally attribute to CO_2 poisoning, or *anoxia* (i.e., lack of O_2). Could this incident also have resulted from the massive release of CH_4 from the normally stable gas hydrates underlying the Earth's oceans?

Water Vapor and Clouds

As has already been stated, water vapor is Gaia's most important greenhouse gas. Not only is water vapor present at higher concentrations and able to absorb IR radiation over a wider frequency range than are the other greenhouse gases, but also its atmospheric concentrations vary more rapidly and more radically than do those of the others. For example, atmospheric concentrations of CO_2 and CH_4 may rise a few percent over a decade, while water vapor concentrations can change several-fold on a seasonal and, occasionally, even on a daily basis.

Moreover, water vapor is transformed into clouds as condensation occurs on very fine particles. The initiation of water condensation into clouds is known as *nucleation*. Scientists now believe that the most common particles that nucleate clouds are aerosols (mostly derived from plants and cosmic ray interactions) and sulfuric acid derivatives (mostly from marine organisms). Another recent addition to this list of cloud nucleators is airborne bacteria, which possess an amazing adaptability to seemingly inhospitable environments. Clouds (particularly those overlying tropical oceans) play a major role in determining the radiative budget of the planet for several reasons, including the following:[23, 24]

- Clouds are able to both reflect the incoming shortwave radiation and absorb the Earth's longwave radiation. This is in sharp contrast to greenhouse gases that are able to efficiently absorb only the longwave radiation (e.g., oxygen is the only major atmospheric gas that absorbs shortwave solar radiation).

- Clouds are able to very quickly change both their thickness and overall coverage, permitting them to have either a net cooling (primarily blocking solar radiation) or net warming (primarily trapping IR radiation) effect on the planet's surface. There is some speculation that a rise in sea surface temperatures may initiate a change in the ratio of solar-blocking to IR-trapping types of clouds.

- Clouds may cover the Earth on scales of millions of square kilometers and can reach vertical heights of over 1000 kilometers in the tropics, where these immense clouds assist in stabilizing sea surface temperatures through the reflection of shortwave radiation.

- The spatial redistribution of cloudiness compensates for greenhouse effects caused by CO_2 and other atmospheric gases. This is because clouds have a more significant effect on the Earth's radiative budget than do all the greenhouse gases, except water vapor.

The role of clouds in the planet's radiative budget may be matched only by their role in global atmospheric electricity. It turns out that ice nucleation rates in the tops of clouds (a process also known as *electrofreezing*) affect the droplet distribution, amount of precipitation, and latent heat exchange between the atmosphere and the surface of the Earth.[25] Electrostatic charge accumulates on droplets at the cloud tops that interface with the overlying air, creating a potential difference between the ground surface and the *ionosphere* of about 250 kilovolts. The ionosphere, located from approximately 60 to 500 kilometers above the planet's surface, is composed of plasma that is ionized by the Sun's radiation. Although the air can sustain an electric field, it is a poor conductor of electricity. The air's electrical resistance sets up the aforementioned charge separation. According to Brian Tinsley, an atmospheric scientist at the University of Texas, the charge on the cloud droplets are not carried off by evaporation because water forms clathrates around the charged nuclei that render them too large to evaporate, thus concentrating electric charge at the cloud tops.[26]

While the aforementioned process is curious in and of itself, it has a couple of ramifications that are fascinating.[27] First, the rate of electrofreezing is related to the dynamics of the electrical connection between Earth's surface and her atmosphere. This electrical connection, in turn, appears to be governed by modulations in the solar wind and in the solar wind's effect on certain cloud nucleators. Second, electrofreezing seems to be related to global climate change.

In other words, it appears as though global climate changes are dictated by the Sun, at least to some degree through the mediator of water, which creates specific types of clouds. Let's take a closer look at this connection between solar activity, clouds, and climate change.

Correlations between global climate change and solar activity on scales ranging from days to millennia are well documented; however, plausible mechanisms to link the solar wind with such changes have been difficult to identify. Could the process of electrofreezing represent a key to such a link? The solar wind is able to affect the microphysics of water in the cloud tops by its apparent effect on the electrical parameters of Earth's atmosphere.[28] Nucleation rates and electrofreezing in the cloud tops have a substantial effect on the height, coverage, and dynamics of massive thunderhead clouds. These clouds, in turn, affect the planet's radiative budget.

Lightning in the Clouds

Water, is seems, plays the key role in yet another phenomenon that has been linked to clouds. A thin film of liquid water coats the ice crystals that are blown around and inevitably collide with each other in clouds, resulting in the electrification that gives rise to lightning. In addition to the lightning that electrically connects the ground surface to clouds, there is another type of lightning that connects the tops of thunderheads to the Earth's ionosphere! Thanks primarily to observations made from the space shuttle, scientists discovered the so-called *sprites* that connect the cloud tops to the upper atmosphere.[29] The most powerful form of cloud-to-ground lightning discharges a positive current that originates from the cloud tops and is associated with the sprites. Hence, sprite-accompanied lightning could be perceived as electrically connecting Gaia's surface to her upper atmosphere via thunderhead clouds.

Essentially, these sprites add an important electrical link to the Sun-Earth chain that includes the solar wind, upper atmosphere, lower atmosphere, and the planet's surface. Electrified water in the clouds plays a crucial mediation role in this chain. As previously noted, atmospheric air separates the opposite electrical charges of the ionosphere and the ground surface until lightning discharges them. In addition to facilitating an electrical connection between the cloud tops and Gaia's upper atmosphere, sprites (as well as cloud-to-ground lightning) may play a role in sustaining the so-called *global electric circuit* that surrounds the entire Earth.[30] It is this global electric circuit that connects the thunderstorm activity in one region of the world (e.g., tropical oceans) to fair-weather air masses in other regions. The electrical activity between Gaia's ground surface and her ionosphere also gives rise to one of the planet's most recognizable vibrations (see Appendix C).

Gaia appears to use water in controlling her planetary greenhouse. Water vapor and clouds are her most important regulators of surface temperatures, whereas the oceans influence the atmospheric concentrations of other greenhouse gases (e.g., methane and carbon dioxide).

GAIA'S HEARTBEAT: ENSO

The most powerful and globally pervasive climate event on Earth occurs at a frequency of about three to seven years and is known as the *El Niño*. In fact, it has been said that the changing of the four seasons is the only natural event that is more influential than El Niño on a worldwide basis. Essentially, the El Niño is an oceanic anomaly characterized by unusually warm surface waters in the eastern equatorial Pacific and, in particular, along the coasts of Ecuador and Peru. The name of this event was originally *la corriente del Niño*, which literally means "the current of the Christ child" in Spanish.[31] This name apparently refers to its occurrence during the Christmas season in South America. Subsequently, scientists discovered that this phenomenon represents more than just an ocean current; hence, it is now known simply as El Niño.

What is ENSO?

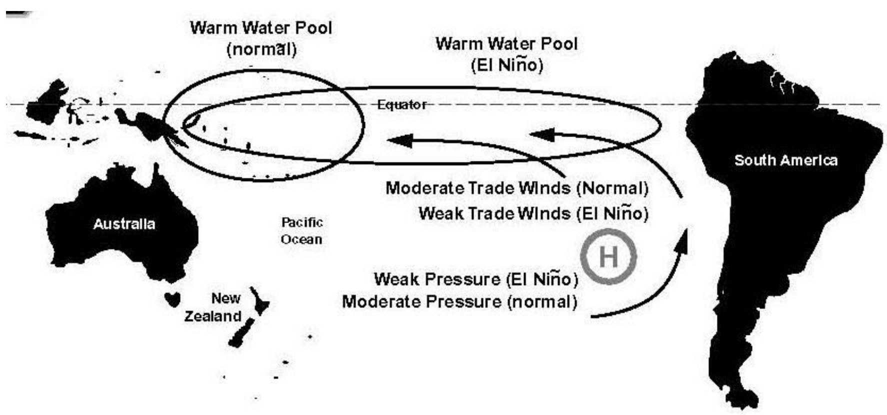
While the oceanic effects of El Niño are felt primarily along the west coast of the Americas, the associated atmospheric changes affect winds and precipitation patterns over the whole Earth. The atmospheric counterpart to El Niño is known as the *Southern Oscillation*, which simply refers to cyclic, interannual shifts in the relative barometric pressures between the western tropical Pacific (measured at Darwin, Australia) and the eastern tropical Pacific (measured at Papeete, Tahiti). Hence, scientists refer to the combined oceanic-atmospheric event as the El Niño/Southern Oscillation, or *ENSO*. Simply stated, the simultaneous reduction of oceanic temperature and atmospheric pressure gradients links the El Niño to the Southern Oscillation.

According to the logs of the Spanish explorer Francisco Pizarro, ENSO events were observed as early as 1525 A.D. and, according to the geologic records of the Earth, much earlier than that.[32] Probably no other topic in the earth sciences is currently being studied as intently as is ENSO. Scientists struggle to ascertain whether ENSO is an event that has occurred cyclically throughout Earth's history or whether it represents some kind of anomaly that is unique to the modern era. The timing of the recent severe ENSO conditions also begs the question of whether there is a cause-and-effect relationship between ENSO and the recent intense period of global warming. The possibility that increased concentrations of greenhouse gases and the associated global warming has intensified ENSO has been repeatedly raised.[33] On the other hand, the cause-and-effect relationship could work in the opposite direction, such that the recent ENSO events could have either exacerbated or ameliorated the global warming.

Although there are still many unanswered questions about ENSO, scientists believe that they understand a fair number of its attributes.[34] Normally, sea surface temperatures in the equatorial Pacific are distributed such that a gradient develops from cooler temperatures in the eastern region to warmer temperatures in the western region. The western equatorial seawater is sometimes referred to as the Pacific *warm water pool*. Normal and El Niño thermal gradients are shown on Figure 7-4. Reduced to its simplest terms, the El

Niño event either reduces or eliminates the gradient in sea surface temperatures, owing to the presence of unusually warm water in the eastern equatorial Pacific. So, what's the big deal? The big deal is that tropical sea surface temperatures act as an important controller of Earth's thermostat. Recall that even the atmosphere's greenhouse gases (e.g., water vapor and CO_2) are regulated, to a great extent, by upwelling dynamics and surface temperatures in the tropical Pacific Ocean.

Figure 7-4. A simple representation of the differences in atmospheric and oceanic conditions observed during normal years and El Niño events. During El Niño events, the Pacific warm water pool moves eastward, the trade winds diminish, and the barometric pressure lessens in the eastern tropical Pacific Ocean. In the last several decades, El Niño events have reoccurred on timescales of three to seven years.



Physical oceanographer David Enfield identifies several important feedback loops that work in concert to initiate and, eventually, to terminate the ENSO event.[35] With the lessening of trade winds (associated with the reduced barometric pressure gradient), not only is the surface temperature gradient lessened, but also the colder water that usually upwells in the eastern Pacific is trapped below a thicker-than-usual layer of warm water. This stratification predictably impacts the marine fisheries along the west coast of the Americas. Because thermocline depths increase in the eastern Pacific and decrease in the western Pacific, the warm sea surface tilts eastward and creates long-period waves that slowly slosh back and forth across the deep ocean basin. It is believed that the interaction of these long-period waves, as well as the smaller eddies and gyres that they spawn, are ultimately responsible for moving warm surface waters away from the eastern equatorial Pacific and bringing an end to the ENSO event.

ENSO's Effects

Scientific interest and funding for ENSO-related research has peaked because of the tremendous ramifications that it has on weather patterns all over the Earth. One theory suggests that ENSO is able to affect weather patterns around the globe by creating massive thunderheads over the eastern and central equatorial Pacific, thus redirecting high altitude winds known as the *jet stream*. The global positioning of the jet stream winds is, of course, a major factor in determining planetary weather patterns. Changes in the jet stream have also been linked to an increase in lightning activity that, in turn, corresponds to ENSO events.[36] Recall from the previous section that lightning activity electrically connects Gaia's surface with her lower atmosphere and, perhaps via sprites, with her upper atmosphere.

Scientists maintain that the global memory for a coupled oceanic-atmospheric system such as ENSO must reside in the thermal structure of the ocean's deep waters because anomalies in its surface layers, as well as those in the atmosphere, are too transitory to persist from one event to the next. As was the case for global warming, the tropical sea surface temperatures that control Earth's short- and long-term climate are actually initiated by temperature changes originating deeper within the ocean. Recent oceanographic research suggests that long-term shifts in the temperature structure of the deep tropical Pacific Ocean essentially "set the stage" for short-term changes in sea surface temperatures that characterize ENSO events.[37]

While ENSO marches forward on its three- to seven-year intervals, it now appears that the severity of the ENSO depends on where it falls within a number of longer cycles. For example, there is a so-called *interdecadal* oscillation that is responsible for warming and cooling the eastern tropical Pacific on timescales of ten to twenty years. Scientists now believe that they have uncovered a much longer ENSO cycle, which occurs on timescales of at least five thousand years. As such, ENSO appears to represent another example of a chaotic (nonlinear) phenomenon that is composed of endlessly repeating cycles within cycles. The magnitude of the ENSO event depends, to a great extent, on exactly how these cycles within cycles are synchronized to one another.

The length of ENSO's reign on the Earth is one of considerable scientific debate. If scientists restrict their investigation window to the last four centuries, the amplitude and frequency of ENSO events is projected to have been similar to those of the twentieth century. When they expand their window to millennial timescales, it is uncertain how long this phenomenon has been occurring. Based on analyses of shell fragments discovered as part of paleoecological research in northern Peru, Daniel Sandweiss has suggested that the present ENSO pattern dates back about 5000 years.[38] Other scientists claim that the fossil records indicate ENSO-type events have been occurring for at least the last 40,000 years.[39] In either case, there seems to have been a global shift in climate regimes, vegetation patterns, coastal morphology, and a host of other phenomena that occurred about five thousand years ago (see Appendix B).

A Heartbeat?

At this point we come full circle to the beginning of this chapter, when we asked the question about Gaia's body parts and her geophysiology. If her peripheral circulatory system consists of her surface and near-surface waters, then the thermohaline circulation could represent her major blood vessels. Due to its periodic or rhythmic effect on tropical sea surface temperatures and global climate, some scientists have referred to ENSO as the *heartbeat* of the Earth. According to Viktor Schauberger's analogy, we might expect Gaia's heartbeat to represent a rhythmic or periodic equalization for moving water around her planetary body. Like any healthy heartbeat, Gaia's (i.e., ENSO) is characterized by the mathematics of chaos; hence, an average "pulse" shows a lot of perceived randomness when viewed on short timescales. Physical control of Gaia's heartbeat seems to be centered in the low-latitude Pacific Ocean, which is the hub of planetary climate dynamics.

So, how might a global "heartbeat" function in concert with a planetary circulation system? Instead of viewing the thermohaline circulation as an inter-oceanic canal through which major water masses are pumped via a single organ, envision it as a series of vortices or large gyres that move water through the process of exchanging kinetic energy. The rhythmic pulsation of these oceanic vortices, which may be linked to a lower frequency cycle (vibration) such as ENSO, is one of the observations that prompted Theodor Schwenk to postulate that the cosmos were reflected in such vortical motions. Science has actually hypothesized a much more intimate connection between the cosmos (particularly the Sun) and ENSO than might have been imagined even at the time of Schwenk's death in 1987.

Planetary rhythms (e.g., ENSO, global climate shifts) have been correlated with solar rhythms (e.g., sunspot cycles), which result in the heating of Earth's surface and in changes to the global electric circuit. The latter effect may actually be mediated by water at the tops of thunderhead clouds that, in turn, respond to changes in Earth's upper atmosphere.

What is the source of these vortices that may serve as Gaia's "multiple hearts?" Well, there are actually a variety of sources. We have already discussed the thermal vents and the rotation of the Earth as sources of vortices. In fact, just about any process that creates a density difference and/or a swirling motion in water will create a vortex. Many small vortices may combine to form a single large one, or a single large vortex may split into many small vortices. Much of the seawater exchange between the Southern and Northern Hemispheres may be due to small *eddies* that are spun-off by gigantic oceanic gyres. Eddies are water vortices that normally run counter to a larger current. Large oceanic vortices may be tens to hundreds of kilometers in diameter and either remain fairly stationary or migrate (alone or in the company of other vortices) over entire ocean basins.

For example, the thermohaline phenomena that permit water masses to upwell and subduct have been implicated in the generation of oceanic eddies.[40]

THE SOLAR CONNECTION

The influence of solar and galactic cycles on planetary processes has been the subject of many ancient insights, most notably those of the Maya. Possible connections between the Sun and the recent intensity of both global warming trends and ENSO events is also a major focus of scientific research. For example, a Caltech scientist has recently postulated that ENSO may represent a mechanism for amplifying changes in solar cycles so that they are able to affect Earth's climate.[41] Long-term variations in solar output have been identified as ushering the Ice Ages in and out over the course of Earth's history, as well as creating ENSO itself. As you may have already guessed, many of the effects of solar variability on global-scale warming are facilitated by or mediated through water, at least to some extent. From a teleological perspective, could these effects represent a Gaian modification of solar energies?

Solar-Driven Oceans

The first and most obvious parameter examined in the Sun-Earth link was the intensity of the solar radiation itself. Solar intensity has gradually increased over the Earth's 2.5 billion-year history and, perhaps, has increased measurably over a decade! According to climatologist Richard Willson, the intensity of solar radiation increased by about 0.036% from 1986 to 1996 and is responsible for at least part of the increased surface temperatures that are normally attributed to greenhouse gases.[42] Besides simply heating the planet's surface and lower atmosphere, recall that any change in the intensity of solar radiation reaching the surface has major effects on the redistribution of water during the process of balancing Earth's radiative budget.

It appears that short-term fluctuations in solar irradiance are linked to the 11.5-year sunspot cycle. In addition to the 11- to 11.5-year cycle, scientists have identified a 40- to 100-year cycle over which sunspot activity has waxed and waned during the past millennium. While there are undoubtedly longer cycles, they are difficult to discern over timescales as short as the modern scientific era. It appears that increased solar irradiance cannot account for all of the recent warming; however, its effects are concentrated on subtropical oceans rather than distributed uniformly over the globe.[43] Subtropical oceans are pivotal both in regulating the atmospheric flux of greenhouse gases and in signaling climate changes. It is generally accepted that one of the ways that solar variability influences Earth's climate is through increased cloud cover, thus linking short-term changes in solar activity to planetary climate through water (both oceanic and atmospheric).

A review of any oceanography textbook reveals the scientific understanding that circulation patterns in the sea are driven by two primary forces. One is the rotation of the Earth and the other is the Sun's energy. Solar energy drives ocean circulation according to a couple of mechanisms, both of which we have briefly touched upon. The first mechanism is solar heating of the atmosphere that, combined with oceanic effects on the atmosphere, drives the winds that power surface waves and near-surface currents. The second mechanism is solar heating of the oceans, which affects heat flux and phase changes at the air-sea interface. These changes result in the density variations that allow seawater masses to subduct and to upwell.

Oceanographers have also found that the variability in ocean temperatures, as well as the interval and intensity of ENSO events, responds to solar signals.[44] While there is considerable debate as to how the observed variations in solar irradiance could account for ENSO and global warming, it appears that mediation occurs through heating of the oceans. The effects of solar cycles on the Earth are not limited to warming the planet's surface and lower atmosphere. For instance, solar cycles profoundly affect the upper atmosphere via changes in the solar wind. Recall that electrofreezing at the tops of massive thunderhead clouds apparently responds to changes in the solar wind, as do the closely related phenomena of lightning and global electricity.

While there may be countless processes by which solar changes affect Earth's climate, many of the processes identified thus far utilize water as a mediator.

Electric Oceans

Due to the relatively high electrical conductivity of seawater, there are two types of electromagnetic anomalies that are associated with the oceans.[45] *Primary* anomalies are induced directly by the interaction of ocean flow within the Earth's magnetic field, usually via fluctuations in the ionosphere itself. This interaction induces an electric field that meets with minimal resistance and penetrates the ocean depths, perhaps as deep as those characterizing the thermohaline circulation. *Secondary* anomalies are induced by actual electric current flow due to the motion of water (i.e., currents, gyres) in the ocean. Secondary, or motional, induction converts the kinetic energy of water flow into electromagnetic energy. In fact, the relationship between electric potential and global oceanic flow patterns is so predictable that scientists sometimes use computer models to calculate one of these variables from the other.[46]

Secondary induction is quite different than primary induction insofar as the latter is dependent upon the movement of a conductor (seawater) through a magnetic field as a source of electromagnetic energy. Secondary induction is created by the motion of surface waves and by oceanic boundaries, where dissimilar water types (i.e., those differing in salinity and/or temperature) contact one another and create an interface. Electrical conductivities on either side of the interface may be significantly different, even if the densities are minimally different.[47] Recall that Schwenk believed such interfaces, which separate water of different densities, permitted water to mediate between cosmic forces and Earthly forms. He believed that these interfaces (e.g., ocean currents, gyres, eddies) display a vortical rhythm that is unique to the pressure applied by their respective water masses. Curiously, Schwenk maintained that water vortices on Earth were linked to rhythms or vibrations of solar origin and, in particular, those of sunspot cycles. While science has not yet addressed the link between vortical rhythms and sunspot cycles, it has recognized that the Sun induces at least one vibration in the Earth (see Appendix C).

The frequency of motion-induced electric fields is higher than that of ionosphere-induced fields, while the intensity of ionosphere-induced fields is usually higher than that of motion-induced fields (except in locations where major ocean currents abut). Despite these differences, the ionosphere does affect the ocean's electric field. Global oceanic flow patterns are also reflected in the Earth's magnetosphere; however, such magnetic field effects are usually overwhelmed by routine ionospheric fluctuations. It is interesting to note that the one oceanic location where both primary and secondary anomalies display a predominantly vertical orientation is along the equator, serving as a key planetary location for both climate regulation and lightning activity.

Eddies, gyres, and other oceanic vortices both facilitate and are facilitated by the large-scale movement of ocean waters. These vortices transport substances globally and create interfacial electric fields, which some naturalists believe permit water to "sense" its environment.

Unconventional Views

The solar effects on the planet and, to a lesser extent, its inhabitants are currently a hot topic in scientific research. There are data indicating that solar events probably do affect human health. In particular, geomagnetic storms show a statistically significant correlation with the incidence of human heart attacks and strokes.[48] Scientists working in the field of *biogeomagnetics* have proposed that solar-induced changes to Earth's magnetic and electric fields may operate either directly on the cell components or indirectly on the cell's electrochemical properties such as membrane permeability. Recall that membrane permeability is very much related to the response of water (both as an intercellular fluid and as an integral component of membrane proteins) to electric fields.

Various researchers (e.g., Theodor Schwenk, Frank Brown) indicated that water is linked to cosmic forces in a way that lies beyond our current mechanistic understanding of the universe. Both of these men were particularly interested in rhythms, not only of the Sun and of water, but also of the life forms here on Earth that are believed to utilize water as a mediator of solar energies. Italian chemist Giorgio Piccardi also studied the physical chemistry of water in response to cyclic solar activity and the fields associated with EM radiation. He, too, suspected that many of the cosmic-induced changes are not recognizable using conventional methods for testing the chemistry or physics of water. In other words, science's routine descriptions of water are too crude to detect changes that are induced by solar and cosmic influences. Mainstream scientists generally object to such claims of subtle solar effects because the resulting changes to water cannot be reliably detected and because the mechanisms are unknown.

Let's now return to the question of whether Gaia uses water as the primary agent for control of her planetary body. Water seems to be involved in most, if not all, changes on a global basis. Whether it is vortices in the oceans, ice in the cloud tops, water vapor in the atmosphere, or phase changes within the hydrologic cycle, water appears to be an important mediator of change. While the Sun is the ultimate source of energy for Earth's compartments (e.g., atmosphere, biosphere, soils, and oceans), the conversion or transduction of this energy for use among and within the compartments is dependent on water. In essence, water serves as one of the essential mediators for global phenomena, which are underlain by countless interacting and interdependent cycles. Concluding our teleological view of Earth, to what extent might Gaia exert control over her planetary body by utilizing water within these cycles? And if you truly believed (as did many ancient peoples) that Gaia was a sentient being, might this belief affect the manner in which you perceive global phenomena?

PART THREE

THE CROSSROADS

It is the object of myth, as of science, to explain the world, to make its phenomena intelligible.
Pierre Grimal, *World Mythology*

The final three chapters explore the tenuous crossroads where ancient wisdom (and its modern adaptations) meets scientific theory. The primary focus of Part Three is on unconventional hypotheses and research, rather than on mainstream science.

CHAPTER 8

SURFING THE WAVES

Microcosm to Macrocosm

Water does not divide; it connects. With simplicity, it links all aspects of our existence. It is elemental to human perception even though chemistry has long told us how it can be broken down, but that's not to deny the mystery of that eddy and swirl.

David Rothenberg, *Writing on Water*

Does water serve as a mediator in transferring energy between macrocosmic and microcosmic realms? While the answer to this controversial question is not known, most modern premises implicate the processes of vibration and resonance in doing so. Ancient philosophers believed that the whole universe is nothing other than vibration or waves, which give rise to all matter and energy. Even today, water's mysterious vortices are often identified as the space-time facilitators of such energy transfers. Although most scientists reject this hypothesis, water's vortices represent enough of a stumbling block to keep the controversy alive. Molecular water possesses an enormous frequency range over which its bonds vibrate and exchange. While this range may or may not be sufficient to connect heaven and Earth, it is certainly sufficient to have captured the attention of many modern naturalists.

VIBRATION: ANCIENT AND MODERN VIEWS

According to many ancient texts, the Creator manifested the universe using "the Word." The Word is usually associated with the more general phenomenon that we call sound, which may be symbolic of the vibration that created everything in the universe. Unfortunately, the ancient texts are more focused on broad insights than they are on specific mechanisms or detailed physical descriptions. Even a modern scientific version of creation includes vibration and waves as major structuring forces of the universe. Very early in the history of our universe, light and charged particles are hypothesized to have formed a dense medium through which sound waves traveled until such time as the medium cooled and these waves began imparting their energy to what we know as matter.[1] Apparently, acoustic waves of only certain frequencies created the galactic matter because, like a guitar string, only certain harmonics were created in a universe of a given size and density.

Most ancient stories tell us that this universe was created from vibrations according to a purposeful intent. These vibrations collectively comprise all the aspects of matter and energy that we recognize—as well as the aspects that we do not. So, what does "the Word" and these universal-scale acoustic waves or vibrations have to do with the relatively tiny water molecule? Here is the answer. If water acts as a mediator between the etheric and worldly realms, both ancient myths and modern premises suggest that it probably does so through vibration.

Recall from Chapter 2 that *atomists*, such as Democritus, formulated perhaps the first unified theory of physics, whereby the accumulation of small, indivisible particles composed all matter in the universe. The relatively unordered motion of these indivisible particles, or "atoms," was believed by atomists to be ordered by means of vortices, thus creating matter. Moreover, Democritus has been credited with proposing that these indivisible particles were separated by a vacuum or void. This ancient hypothesis received considerable attention by nineteenth century scientists such as Hermann von Helmholtz and Lord Kelvin, who attempted to combine these indivisible particles (collectively forming a type of fluid) and vorticity fields into a unified physical theory. According to their theory, the properties of larger particles (e.g., today's atoms and molecules) were determined by the interaction of vibrating vortex rings. While Kelvin's unified physical theory was eventually abandoned by science, his vibrating vortex rings reemerged as vibrating strings in the late twentieth century thanks to a group of theoretical physicists pursing a totally different path to unify the forces of Nature into a single theory.

String Theory

The latest brainchild that theoretical physics has put forth to explain the nature of both matter and spacetime (and the only theory that unifies the four fundamental forces of modern physics) is known as *string theory*. String theory supposes that particles are represented by vibrating strings that are about 10^{20} (one hundred trillion trillion) times smaller than a proton; such that each subatomic particle is represented by a single string vibrating at a distinct frequency.[2] It is possible that these strings represent the ultimate particles that the ancient Greeks referred to as *atoms*, not as the particles defined by modern chemistry, but as identical and undividable constituents of the universe that are fundamental to all matter and forces. According to string theory, particles of the universe are not fundamental, but are simply the harmonies created by the tiny vibrating strings. In the words of theoretical physicist Michio Kaku, "the universe itself, composed of countless vibrating strings, would then be comparable to a symphony."[3]

According to Brian Greene, a Columbia University physicist, there are two aspects of string theory that have substantially changed the manner in which physics (or at least a subset of physics) views the world around us.[4] The first is that all particle masses and force charges result from resonant patterns of vibration in the fundamental strings, such that each particle (e.g., electron, quark, proton) simply represents different notes or tones played on the fundamental strings. The second is that there are extra dimensions of space that exist at scales smaller than the *Planck length*. The Planck length is named after the famous German physicist Max Planck and is currently recognized as the boundary of our familiar physical reality at about 10^{-33} centimeters or 10^{-25} angstroms. Because the patterns of string vibrations create the observable particles, the fundamental properties of the universe are a function of the geometrical size and shape of the extra dimensions.[5] Although the mathematics and quantum geometry of string theory are more sophisticated than anything proposed by Pythagoras, he was the first to have formally shared the insight that vibrating strings are fundamental to our world.

In essence, we live in a perceptible world that is composed of four dimensions (three space and one time); however, the mathematics of string theory suggests that this world must have split from a more complex ten-dimensional (nine of space and one of time) or even eleven-dimensional (including the spatial dimension of the string itself) universe almost immediately after the Big Bang. So, where are these extra six dimensions of space that we do not readily perceive in our world? The answer seems to be that they are folded or rolled-up into subatomic realms smaller than the Planck scale. The mathematics of string theory requires these higher spatial dimensions, which modern mystics and peripheral scientists often equate with the ancient concept of aether, to unify science's currently recognized forces. Unfortunately, there are no ancient insights regarding string theory. There is, however, an interesting numerical relationship between string theory's dimensions and the golden ratio (see Appendix A).

The Vacuum: Science's Non-Aether

There are probably few terms as repugnant to modern scientists as that of *aether*. Not only is it a remnant of the bygone language of early physics, it also carries the surrealistic and spiritual overtones of ancient philosophies. Modern physics has convincingly theorized that there is no etheric substance pervading the universe and that all phenomena can be explained by quantum mechanics and general relativity. Yet science writer Robert Matthews points out that the presence of transient particles, various force fields, and fluctuating energies in a vacuum is a little perplexing because, by definition, a vacuum should be void of all matter.[6] Moreover, force fields should not be emerging from nowhere and energy should not be present without a source. This "random" entrance and exit of matter and energy is, of course, relative to the four-dimensional spacetime that we recognize as our observable world.

Max Planck was one of the first scientists to note the peculiarities of a vacuum, whereby one of his equations contained a term for the energy of an object that was unrelated to its temperature. In other words, the object seemed to have a residual energy even at a temperature of absolute zero (i.e., 0° K). Matthews suggests that a vacuum or empty space may actually comprise a dynamic medium, serving as a permanent and nonzero source of universal energy. This is similar to the view of physicists who claim that a *zero point field* is responsible for the energy remaining when a vacuum is cooled to absolute zero. The so-called zero point field is one of tremendous electromagnetic energies that gives rise to particles; however, these energies or forces (i.e., many trillions of times greater than that of a proton) normally cancel each other and are rarely observed as tremendous.

While far from scientific dogma, the notion that fields (e.g., electric, magnetic, gravitational, vorticity) arise from different geometric distortions within the higher spatial dimensions is predicted by string theory. Theses higher spatial dimensions are, in turn, determined by vibrational patterns of the fundamental strings. According to ancient insights (most notably those shared by Plato), the universe is created through the aether; therefore, everything in creation is interconnected through the aether. If the aether is truly analogous to the extra spatial dimensions of string theory, then it differs from our observable world only in its vibrational frequencies and patterns. If we do indeed exchange energy with the etheric portion of the universe (as appears to be the case), we do not seem to be cognizant of our doing so. Hence, we are left to speculate about its properties, its geometry, and its very existence.

Connecting Microcosm to Macrocosm

From the Pythagorean viewpoint, the whole universe is linked by vibration through the yardstick of octaves. An interesting application of this viewpoint was put forth by the mystic and philosopher Georges Gurdjieff, who boldly postulated that every force in Nature is represented by an octave and that the octave serves as the underlying basis of seemingly unrelated "proportions" such as the golden ratio.[7] If every natural force is indeed represented by an octave, then it may not be surprising to learn that peripheral researchers have harmonically related the octave's tonal intervals to fundamental properties of matter, such as atomic weight and nuclear charge. Similar to Gurdjieff's theory, this universe is sometimes described as spanning hundreds or even thousands of octaves. The degree to which energy is translated up and down the octaves of a vibrational universe remains an unanswered question.

For example, how do the rhythms of a water vortex purportedly translate down to the much faster vibrations of water's molecular network? One frequently cited possibility is the overtones that were discussed in the early chapters; however, the intensity of harmonics generally decreases as a function of number (e.g., higher and higher overtones transfer less and less energy). In contrast to mainstream science, ancient myths and modern premises addressing harmonics suggest that the range over which overtones and undertones are able to transfer energy is essentially limitless. Might this controversial energy transfer relate to very specific ratios among waves (e.g., phi, octave)? From a modern scientific perspective, the answer is not known. From the perspective of ancient insights, we may infer the consequences of, but not the precise mechanisms underlying, a universe connected through vibration.

While operating on the molecular level, water is composed of atomic and subatomic particles that are, themselves, theoretically composed of vibrating strings. The energies associated with these progressively smaller units of matter are substantially greater than those associated with molecules because they lie closer and closer to the Planck scale. Water's molecular-scale dynamics would be expected to reflect the vibrations of the high-energy particles comprising the molecule, such that macrocosmic processes might be described as a scaled-up version of what is occurring at much more fundamental levels of physical existence. Because water is a molecule, the focus of this book is necessarily at the molecular scale; however, this chapter will begin to explore the more fundamental forces that interact with water. These fundamental forces, regardless of their scale, can be described in terms of vibration. A major challenge faced by modern researchers is identifying mechanisms that could permit vibrations of vastly different energies, or frequencies, to influence one another.

According to myth and to some scientists, the universe was created from vibrations or waves that are evident on scales as large as the cosmos and as small as the strings that compose its fundamental particles and energies. According to modern premises, water connects microcosm to macrocosm through vibration.

WAVES IN WATER

Besides its being wet, perhaps the most recognizable attribute of water is its ability to transmit waves. Generally, when we think of waves moving through water, we focus on surface waves that are generated by winds blowing over the air-sea interface and creating the perfect breakers that surfers ride. In addition to these very familiar waves, water is able to receive, transmit, and transduce a number of other waves that only an experienced surfer would even realize are available to be ridden. In this section, we'll take a look at how the principles of vibration and resonance play out at many different, yet purportedly connected, levels in water. This book has utilized (and will continue to do so) the terminology of vibration and geometry, rather than of waves, in describing water and its related processes because the jargon is more familiar to most readers. Nevertheless, the vibrational patterns of matter and energy are describable according to the science and terminology of waves.

When we talk about waves, there are several attributes that may be used to describe them. The most common description of a wave is its *length*, corresponding to the distance between the peaks of a common sine wave. Wavelength tells us something about the distance (i.e., angstroms to kilometers) over which the wave will interact with matter. Another common description of waves is *frequency*, which has already been discussed in detail. Finally, a wave may be described by its *energy*. A wave's energy is proportional to its frequency and inversely proportional to its wavelength. In other words, waves possessing the highest energies have the highest frequencies and shortest wavelengths. By contrast, waves with the lowest energies have the lowest frequencies and longest wavelengths.

Water's Vibrating Bonds

As was previously discussed, everything in the universe has a unique frequency at which it vibrates. Molecular vibration is dependent upon its component atoms oscillating at some given amplitude about a set of equilibrium positions. In working with the water *pentamer* (i.e., the pentagonal cluster serving as the basic building block for most large hydration shells), University of Chicago chemist Stuart Rice quantified vibrational states for the tetrahedral structure of water's liquid phase.[8] He observed that water's vibrational states are due to a combination of bending and stretching motions of the H-bonds. While water's covalent bonds stretch at or just below 10^{14} hertz, its H-bonds stretch within the lower frequency range of 10^{12} to 10^{13} hertz. Note that the frequencies of these bond vibrations are slightly greater than the maximal rate at which water exchanges H-bonds in its bulk liquid network (10^{12} hertz or less).

The process of bending and stretching chemical bonds is actually the mechanism underlying the previously described greenhouse effect. IR light first stretches the bond, which then contracts like a rubber band and creates a vibrational motion that is harmonic in nature. If you refer to the chart of EM spectrum (Chapter 4, Table 4A), you will notice that IR light is characterized by a lower energy and longer wavelength than is visible light. Energies involved in the bending and stretching of water's bonds fall within the radio or IR portion of the EM spectrum, while those associated with twisting and breaking bonds lie in the ultraviolet portion and beyond. It is interesting that many biocommunication theories identify the light transmitted through biological water as ultraviolet, which has a frequency greater than that of water's reported bond vibrations and rearrangement dynamics.

Vibrational spectroscopy methods have shown that the harmonics of water's O-H bonds differ depending on their length and position relative to neighboring molecules. Focusing only on differences between water's liquid and solid phase, the covalent bonds comprising the former are about 25% greater than those comprising the latter. Bond vibrations differ not only among the three phases of water, but also among different structural geometries within the same phase. For example, the bond vibrations are different for small transient clusters of bulk water than they are for larger clusters or hydration envelopes. Exactly which frequencies within the EM spectrum have the greatest impact on a particular molecular bond depends on a number of factors, including molecule's physical properties and the environment within which it is being acted upon.

Propagating Vibrations

As a wave travels through water, it imparts energy to the molecules that cause them to compress and then structurally relax along the pathway. As such, acoustic energy, or sound, in water may be defined as a periodic variation in pressure. Essentially, this process of energy absorption (disrupting equilibrium conditions) followed by structural relaxation (restoring equilibrium conditions) is how waves move through water. Simply stated, a pressure gradient arises from spatial differences in pressure among water molecules, resulting in the movement of energy along a path from greater to lesser pressures. This molecular process accounts for water's ability to conduct sound very efficiently.

While the propagation of mechanical vibrations (e.g., sound) has traditionally been attributed to the absorption/relaxation mechanism, scientists have generally considered this mechanism as being too slow to explain the lightning-fast process of *intermolecular excitation energy*. Intermolecular excitation energy is just a fancy term describing how an electronically excited molecule passes a portion of its energy to its neighbors and they, in turn, pass a portion to their neighbors.[9] Two Dutch physicists, Sander Woutersen and Hulb Bakker, have shown that the resonant transfer of this energy in water occurs on timescales of less than 0.1 picoseconds, which is more than an order-of-magnitude faster than the switching of H-bonds in bulk liquid water. The results of this study indicate that ultrafast vibrational energy in water cannot be localized long enough to affect most chemical reactions. Stated in another way, the energy of covalent (O-H) bond stretching in liquid water may be spread to many other water molecules before it is dissipated.[10]

Woutersen and Bakker suggest that the ultrafast vibrational energy transfer could play a crucial role in liquid water's transporting vibrational energy among certain solutes (e.g., proteins, DNA), as was discussed for water-mediated biocommunication. Because of its coupling to H-bonds, this newly discovered vibration could be instrumental in transferring information within water's local network, although this transference has not been demonstrated. The ultrafast energy transfer appears to be the fastest of water's vibrations, placing near the top of a vibrational range that spans more than sixty octaves (see Table 8A). Curiously, a significant experimental challenge faced by scientists in observing the collective motions of water's H-bonded network is that such motions are buried under water's many and varied vibrations.[11]

Table 8A. A comparison of the H-bond exchange frequencies for various physical states and locations of water. These H-bond rearrangements of water's molecular network span approximately sixty octaves and are compared to vibrational frequencies for water's covalent and hydrogen bonds (shown in italics at the top).

Physical State/Location of Water	Vibrational Frequency (hertz)
Covalent and Hydrogen Bonds	*10^{14} to 10^{12}*
Bulk Liquid Water	$<10^{12}$
Hydration Shells	10^{11} to 10^{6}
Structural Components of Biomolecules	10^{5} to10^{3}
Crystalline Ices	10^{-3} to 10^{-4}
Gas-Liquid Interfaces	$\sim10^{-5}$

A LIQUID WATER CRYSTAL?

One usually thinks of mechanical vibrations in terms of solids and, particularly, crystals. Is water a crystal? Well, water ice is definitely crystalline and water vapor is not. Liquid water does not fit the strict definition of a crystalline solid, although it is often referred to as "a crystal" in a colloquial context. One of the reasons for this colloquial designation is related to the extraordinary way in which water transfers protons through its liquid phase. This proton transfer is often considered similar to the way in which some solid crystals, when compressed in specific directions, develop electrical charges on their surface and conduct *piezoelectricity*. Piezoelectricity (sometimes colloquially dubbed as "proton electricity") is simply an electric polarization resulting from the deformation or strain of molecular bonds in the crystal lattice. While bulk liquid water is not a solid crystal, the bending and distortion of its bonds create molecular geometries that seemingly display both crystalline and amorphous characteristics. This behavior is certainly unusual, but does it qualify water as a "liquid crystal?"

In order to define a conventional liquid crystal (i.e., one of the workhorses of our digital age), we need to go back and consider the liquid and solid states of matter in terms of structure.[12] The solid state of matter represents a fairly rigid arrangement of molecules that maintain both a fixed location and a fixed orientation. On the other hand, the liquid state of matter contains molecules that occupy neither a fixed position nor a fixed orientation with respect to other molecules. A liquid crystal loses its structural (i.e., positional) order but retains some of its orientational order as it transitions from the solid to the liquid phase. The most common liquid crystals include nonpolar or weakly polar molecules such as elongated polymers and certain biomolecules that collectively exhibit long-range orientational order when exposed to an electric field.

Based on its physical properties discussed in Chapter 5, water does not conform to the strict definition of a conventional liquid crystal. While liquid water certainly does respond to electric fields, as will be discussed in the following section, it does so differently than do conventional liquid crystals. The colloquial reference to bulk water as a liquid crystal stems from its retaining a high percentage of the H-bonds, as well as the tetrahedral molecular geometry, that structure its ices. This geometry conservation is why liquid water is sometimes described as "ice-like." As an example, the biological structuring of water is sometimes described as creating organized liquid crystals that permit the water to act as a vital living fluid.[13] Although bulk liquid water is not a conventional liquid crystal, might there be other forms of liquid water that are better candidates?

Frequently cited candidates for liquid crystals include the so-called structured forms of water (e.g., large water-only clusters, clathrates, hydration shells), which display a greater orientational order but a similar degree of H-bonding compared to bulk water. Another is the enigmatic seawater. Although the molecular structure of seawater is a mystery, perhaps the relatively high percentage of water molecules that are involved in water-ion interactions permit dipole forces to play a substantial role in structuring (and restructuring) seawater. Could this account for the Maori's designation of the oceans as the planet's largest crystal? While the answer is not known, liquid water's response to various applied fields provides some clues to its legendary "crystal-like" behavior.

Liquid water is sometimes referred to a "crystal," suggesting that it retains a high percentage of the H-bonds that structure its ices and that it displays characteristics of both an amorphous liquid and a crystalline solid.

Field Effects

Whereas most conventional liquid crystals are nonpolar or slightly polar, we know that the water molecule is very polar. As such, water represents a permanent dipole, which is much stronger than the induced dipoles characterizing most liquid crystals. In order to polarize (i.e., alter the molecular orientations of) liquid water, an electric field must first overcome the water molecules' inherent polarity, permitting them to rotate and align with the field. Focusing exclusively on liquid water, the polarizability of water molecules in bulk water is greater than that in clusters or hydration envelopes. This difference in the polarizability is related to the greater rotational freedom and faster H-bond rearrangement dynamics of water molecules in the bulk network compared to those in clusters.

Is there a lasting effect associated with the exposure of water to fields? This question may be answered using the example of individual water molecules that form a cluster. When water molecules are released from the cluster, due either to the decomposition of the cluster or to the normal exchange of water molecules, they are free to orient in response to an applied electric field.[14] As the H-bonds exchange, the newly oriented water molecules are almost instantly incorporated into another cluster. This new cluster has a structure similar to that of the previous one; however, the dipoles are not necessarily arranged in the same direction as those in the original cluster. This change in dipoles affects the orientational order of the molecules comprising the cluster. Hence, electric field effects may or may not recognizably alter water's geometric structure but they almost certainly alter the orientation of its molecules.

In addition to electric fields, water molecules also respond to magnetic fields. Actually, magnetic and electric fields are related inasmuch as moving electrical charges produce magnetic fields. Water is usually categorized as *diamagnetic*, denoting that its molecules respond to magnetic fields by aligning themselves in a direction opposite to that of the field, regardless of temperature.

Water's Magnetic Personality

Various scientific researchers have observed that exposing water to magnetic fields induces structural changes that persist for some period of time after the field is removed. This so-called *magnetic memory* of water appears to be influenced by the length of exposure to and the intensity of the field, which combine to reorder H-bonds in the water network. Scientists from India's Banaras Hindu University report that water exposed to a magnet led to time-dependent structural changes that included distorted tetrahedral networks and so-called liquid crystalline (i.e., clustered) phases.[15] The researchers suggest that changes in orientational order resulting from the transition of bulk water to relatively long-lived water structures (e.g., dodecahedral clusters or clathrate-like frameworks) might be responsible for the observed magnetic memory. While highly speculative, this study attributes water's magnetic memory to relatively static molecular geometries (i.e., individual clusters or a chain of clusters).

A trio of researchers at Japan's Kyoto University looked more closely into the question of time-dependence as it relates to field effects on water.[16] These scientists found that the degree of magnetic effects increases with exposure to a field up to a certain time, when no further effects are observed, and that the magnetic effects diminish as a function of time after the field is removed. This diminished effect is accentuated by both temperature changes and by the addition of other chemicals to the water. Magnetic field effects were reportedly responsible for increasing the orientational order of water comprising the hydration shells of hydrophobic solutes. Here again, it appears that a key to water's response to fields (both electric and magnetic) is related to induced changes in its orientational order.

A pair of California-based researchers focused on the dynamics of gas-water interfaces and the associated microbubbles, providing yet another perspective on the magnetic memory of water.[17] Essentially, they postulated that magnetic and electromagnetic fields (e.g., AC and DC fields, permanent magnets, microwave radiation) induce changes at the gas-water interface that modify the size and reactivity of water clusters. Water molecules at the interface relax (i.e., return to their original state) quite slowly, thus accounting for the relatively long-term magnetic effects. Moreover, reactive compounds such as hydrogen peroxide are often produced during exposure of water to EM fields, affecting solutes (e.g., dissolved gases) at the interface. While these researchers acknowledge the speculative nature of their hypothesis, they make a couple of intriguing observations. First, changes at the gas-water interface are capable of affecting water in the bulk solvent as well as that in clusters. Second, the effects of magnetic fields on water are inhibited or terminated if the clathrate-forming gases are removed.

The interaction between electromagnetic fields and water is currently being tested on a practical basis to treat contaminated water and soils. Exposing water to a homogeneous magnetic field reportedly increased both the mass and rate of oxygen dissolution.[18] Concentrations of dissolved oxygen in aquatic environments are important because of their influence on the mobility and degradability of aqueous pollutants. Similarly, radiofrequency and microwave energy has been used to enhance pollutant removal from soils. Electric fields seem to affect pollutants in two ways. First, they increase the temperature of the water, thereby breaking and distorting H-bonds in the pollutant hydration shells. Second, they may induce so-called *athermal* effects that polarize both water molecules and solutes.[19] While controversial, this induced polarization may contribute to the free energy required for physical processes (e.g., desorption) and biochemical reactions (e.g., oxidation) to dislodge and degrade the pollutants.

The combination of vibrating and rearranging bonds creates a complex rhythm in water that spans about sixty octaves. Radiation and various fields are able to affect water, predominantly through changes in the vibrations and orientations of water molecules.

AS ABOVE, SO BELOW

From the periphery of science come reports that vorticity fields and *pranic* energy have been used to structure water. While science recognizes that electromagnetic energy can induce changes in water's molecular network, science does not even formally recognize the existence of pranic energy. Recall that prana (as one of many ancient designations for the etheric or life force energy) was often associated with water. Whether we explore ancient myths, religious rituals, modern premises, or peripheral research, the intimate relationship between water and prana (or aether) seems to be an unrelenting theme.

Pranic Energy

Biomedical researchers Glen Rein and Rollin McCraty report that, by entering psycho-physiological states normally associated with meditation or joy, people could actually alter the infrared (IR) spectra of water that they touched.[20] Recall that a change in the IR spectra normally indicates a physical shift in water's H-bonded molecular network. Can the energy associated with a simple touch or blessing (as was discussed in Chapter 2) actually transform water's molecular network? There appear to be some indications, albeit controversial, that a human touch can indeed transform water located outside the body. Unfortunately, potential mechanisms responsible for the correlation between human psycho-physiological states and the macro-scale structuring of water have not been demonstrated.

Cell biologist Norman Mikesell has reported the structuring of water by pranic energy associated with touch, as well as by EM energy associated with artificial and natural (Sun) light.[21] Subsequent to this structuring, he reportedly observes IR absorption spectra that are more characteristic of the H-bonds in ice than those in bulk water. It is interesting to note that he also reports the appearance of hydrogen peroxide, which has been identified as a component of the microbubble hypothesis. Could the modern premise that structuring water somehow enables or programs its memory relate to the gas-water interfaces that seemingly impact both clusters and bulk liquid water? Perhaps this question will be answerable in the near future.

Perhaps the most celebrated "demonstration" of subtle energies on water is illustrated in the recent book, *The Message from Water*.[22] Authored by a Japanese health practitioner, Masaru Emoto, this book contains spectacular photographs of ice crystals that are formed in the laboratory using liquid water collected from a wide variety of sources (e.g., lakes, rivers, sewage). In some cases, water from the same source is exposed to various forms of vibrational energy (e.g., words, music) and then frozen and photographed. The hexagonal ice crystals take on a very different appearance depending upon both the chemical quality of the source water and the energy to which it is subsequently exposed.

There are a couple of points to consider with regard to Emoto's popular work. First, his ice crystals are orders-of-magnitude larger than the molecular clusters that have been, and will continue to be, discussed at length in this book. There is speculation that a *fractal*-like relationship exists between Emoto's ice crystals and the type or degree of molecular structuring in the liquid water sample; however, the relationship between the two has not yet been demonstrated (at least to my knowledge). A fractal is an endlessly repeating geometric pattern that has exactly the same proportions but differs in overall size or scale. The Hermetic truism, "as above, so below," is often interpreted as an ancient reference to the fractal relationship that exists between macrocosm and microcosm. Scientists have recently looked into the question of whether Nature is fractal and have reported that it is fractal-like, if not fractal.[23]

Secondly, Theodor Schwenk's use of macro-scale water patterns as a means of testing water quality predates Emoto's photographs by fifty years. Schwenks's so-called *drop pictures*, created by photographing patterns that result from a drop of water falling onto a water surface, reveal small-scale vortices and other flowforms. Patterns observed in these drop pictures are similar, in many respects, to Emoto's photographs. The question of how differences in water quality (often reflecting molecular-scale phenomena) are evident in geometries created on a much larger scale has yet to be answered scientifically. To conclude, Emoto's "message from water" is essentially that water acts as mirror in asking us to take a look at ourselves (e.g., words, thoughts, emotions) and at our perception of the universe. He believes that *Hado*, which is yet another designation for prana or the universal etheric energy, underlies water's ability to act as a mirror. Hado supposedly originates in the vibrations of an atom's electron cloud, creating magnetic resonance patterns that are visible in the substantially larger ice crystals.[24]

Those Mysterious Vortices

A vortex is actually described by two different types of vibration. The first is related to the discrete units of matter comprising the stuff of the vortex (e.g., water molecules for whirlpools) and the second is the rhythm of the vortex itself. Pat Flanagan expanded on this rhythm by suggesting that a vortex's cadence arises from an alternation between a contracted diameter (extended length) and an expanded diameter (contracted length) in a periodic manner.[25] In essence, the mysterious vortices of water are sometimes explained in terms of the motion of a rhythmic "slinky." Flanagan notes that as the fluid particles (i.e., water molecules) approach the axis of the vortex, their velocity approaches infinity, permitting water's H-bonded network to be altered or imprinted. Whether attributed to its rhythms or to the rotational velocity of its fluid, the vortex is frequently identified by ancient myths and modern premises as facilitating the transmission of energy or information between macrocosm and microcosm.

In devising modern cascade systems for the flow of water, some researchers have assumed that natural spirals impart a rhythm to the flowing water that is translated all the way down to the molecular level as a result of vortical motion. That is to say, the large-scale motion of flowing water, cascading down a series of specially shaped basins that are constructed in accordance with specific numeric ratios, is presumed to influence the molecular-scale arrangements and vibrations of water. Engineer Dan Winter postulated that a harmonic series based on the golden ratio permits waves to converge without the interference patterns that would dissipate energy and, thus, limit the number of octaves over which various vibrational phenomena (e.g., global-scale vortices and molecular-scale changes in water) influence one another.[26] His proposed convergence among water "waves" is similar to the proposed coherence among light waves that facilitate biocommunication. In both cases, a very specific interaction among waves (i.e., a fractal or phase relationship) is attributed to the respective phenomena.

The reasons that these unconventional theories regarding water flowforms do not fade into oblivion are probably two-fold. First, water emerging from vortical water treatment devices and *phi*-based cascade systems seems to be physically and, in some cases, chemically altered to the extent that such systems are used for small-scale wastewater treatment. John Wilkes is one of the pioneers in using engineered cascade systems to emulate natural water flowforms (vortices) in the treatment of aquatic waste streams and drinking water. Second, the mechanisms underlying vortices and other turbulent phenomenon continue to represent one of the great unsolved mysteries of classical physics. In a recent article, physicist Sidney Perkowitz observed that physicists know more about the structure of subatomic particles than they do about the swirls and eddies of water.[27] Why have the mechanisms underlying water's vortices been so elusive? And why have vortices consistently been identified as the archetypal flowform that is responsible for, or serves as a symbol of, water's ability to act as the mediator between different realms? The unanswered questions about water's mysterious vortices persist.

The Edges of Science

The mystique of water's vortices, not unlike its highly controversial memory, seems to be perpetuated by a combination of ancient insights, modern mysticism, and peripheral research. What is it that prompts some researchers to push the limits of science beyond the point that most scientists recognize it as such? While there is probably no shortage of answers to this question, one theme seems to consistently surface. That theme is simply the search for the ultimate laws of Nature. Stated in terms of ancient wisdom, it is the age-old human quest to understand the universe as a coherent and unified whole, rather than as fragmented pieces. Essentially, the peripheral researchers could be considered a type of modern mythologist, who speak and write in terms of science (rather than in terms of shape-shifting monsters or holy grails) because it is the language appropriate for describing the natural world. Does their message represent science in the strictest sense? Often it does not. Is their message relevant to the way in which modern humans (including scientists) perceive the world? Quite possibly it is.

The reason that mainstream science is sometimes perceived as fragmented relates to the Hermetic truism, "as above, so below." In other words, if one truly knows the laws of Nature, understanding and describing the workings of a galaxy and a quark should be one and the same. That science is forced to employ a unique set of physical laws to explain the world on differing scales has been construed by some scientists as evidence that such laws are not truly fundamental. How can it be that physical laws are valid over some scales and either invalid or only partially valid over others? The contention is that modern science does not deal with the laws of Nature in an ultimate or fundamental sense. Instead, science deals with hypotheses for and statistical approximations of Natural laws over discrete scales of time and space. As a result, "new" approximations of those fundamental laws are required each time science moves beyond the scale within which its existing physical laws are valid.

At least some peripheral researchers attempt to tie worldly and otherworldly phenomena to a set of principles that they perceive more closely approximate Natural laws (e.g., those laws interpreted from ancient wisdom). Whether or not these researchers actually achieve their goal, water remains a favorite subject of such attempts. One of the many difficulties faced by peripheral researchers is that the phenomena they seek to understand (e.g., prana) can rarely be described or measured scientifically. Hence, prana and other "subtle" forces are often studied through their apparent effects on matter, particularly water, and human physiology. Water's legendary memory (i.e., accessing, storing, and retrieving information) is perhaps the best-known phenomenon that has attracted researchers who are positioned at the edges of science.

Peripheral research tends to focus on three of the most ancient of attributes bestowed upon water: its ability to mediate between aether and matter, its connecting microcosm to macrocosm via vortices, and its ability to retain or access information over time (i.e., memory).

WATER'S CONTROVERSIAL MEMORY

The idea that water somehow retains memory is, understandably, not a popular one among most scientists. Water's H-bonding patterns and its relatively long-lived molecular geometries (e.g., water-only clusters and hydration shells) are most frequently identified as the facilitator of memory. The scientific arguments against water's memory are that 1) its structures or geometries are not appropriate for storing information, 2) even if these structures do store information, they are too ephemeral to retain it for more than a few hours, and 3) even if information was passed among these temporary structures, it could not be accomplished without the inevitable occurrence of errors.[28] In addition to the problems associated with water's storing memory, most scientists have a problem with the mechanisms offered for water's retrieving or not retrieving memory. That is to say, if every substance that dissolves in water leaves behind a structural "impression" in the H-bonded network, how does water discriminate among its countless impressions when remembering? Why do some memories persist while others do not, and over what timescales are memories retrieved?

The mechanisms that have been presented for water's memory are not very satisfying from a mainstream scientific perspective. While it is theoretically possible for water's molecular geometries to code information (i.e., the conformation-information link), a major difficulty with the standard explanation of memory is that water represents a highly dynamic, as opposed to static, network. None of liquid water's H-bonds persist for more than a fraction of second, and even its relatively static structures (e.g., those comprising hydration shells or clathrates) are constantly exchanging water molecules with the bulk network. A dynamic network that stores static memories is a paradox. If water does retain information, it almost certainly does so in a dynamic fashion. How might information be stored in a dynamic, or ever-changing, system? The answer to this question again leads us to the edges of science.

In the mid-twentieth century, a group of mathematicians led by American Norbert Weiner coined the word *cybernetics*, which is derived from the Greek word *kybernetes* or "steersman," to describe a science whereby biological (particularly neural) and chemical systems are studied in terms of their controlling cycles or feedback loops. Recall from Chapter 3 that a feedback loop is an iterative process whereby the factors that produce a result are themselves modified by that result. The study of these complex and controlling cycles is now known as *systems theory*, which requires feedback loops to cyclically propagate changes through all the elements of a system. While the specifics of systems theory will be discussed in the next chapter, the significance of this theory is that it provides a holistic approach to describing natural phenomena. By contrast, modern empirical science is based predominantly on a reductionist approach to describing Nature. The purported relevance of systems theory to our present discussion is its potential to describe water's memory in a dynamic, rather than static, manner.

Another View of Memory

Gary Schwartz and Linda Russek, biomedical scientists at the University of Arizona, have recently authored a book, *The Living Energy Universe*, in which they suggest that the simple phenomenon of sympathetic vibration underlies a type of memory that is possessed by everything in the universe.[29] Essentially, their hypothesis rests on the mutual interaction between two or more objects experiencing sympathetic vibration in an iterative manner, such that the whole process may be described as a positive, or reinforcing, feedback loop. The authors have given this marriage of sympathetic vibration and positive feedback the name of *systemic memory*. Using a simple example of two objects, A and B, they explain the concept as follows.

If A is the object at rest and B is the object that is applying the forced or natural vibration, the repeated interaction may be viewed as a positive feedback whereby the behavior (amplitude) of A is augmented, and this "history" is interpreted by B. With each cycle, the A-B system is renewed and, due to the nature of positive feedback loops, the system's behavior grows over time. Not only does B interpret the behavior of A, but A also interprets the behavior of B. In essence, the system continually learns about itself and about its components in such way that holistic or systemic memories are created. Not surprisingly, this hypothesis has drawn considerable criticism from the mainstream scientific community, predominantly based on its inability to be experimentally disproven. Regardless of its provability, systemic memory seems to qualify as yet another modern revival of some now-familiar ancient insights.

The broader cosmological and spiritual ramifications notwithstanding, the systemic memory hypothesis has some obvious applications to water. The authors point out that the oxygen and hydrogen atoms of a water molecule may represent objects A and B. In addition, the objects could be represented by different water molecules or by a water molecule and a solute molecule or by two water clusters. The evolving complexity of such systems is hypothesized to lead to chaotic and self-organizing behaviors, which we will examine in the next chapter. The authors reach the conclusion that water is alive as a result of its ability to learn, adapt, evolve, and thus create a systemic memory.[30] Thus, water's memory and "life" are inextricably linked in the systemic memory hypothesis. I'll leave the issue of living water to the next chapter and focus here on water's memory.

What drives our ongoing fascination with water's memory? One answer may be our curiosity about ancient views of water. Another may be the apparent success of homeopathy and purported limitations of conventional water treatment techniques. Conventional water treatment processes, while removing chemical toxins and biological pathogens, are occasionally cited as producing water that continues to adversely affect human health in more subtle ways. The fact that modern science does not recognize these phenomena in no way denies their existence. By the same token, it is unlikely that phenomena such as water's memory will be "proven" using the very same models and experimental techniques that are employed by modern scientists. Hence, we are left with hypotheses—and lots of them.

Systemic Memory in Water

Schwartz and Russek suggest that when a substance is dissolved in water, it enters the dynamic network of water molecules and engages in a "continuous dynamic resonance." As previously explained, the resonance between solutes and water molecules is essentially an information or energy transfer mechanism that gives rise to the systemic memory of water as a whole. Let's see how the general theory of systemic memory may apply to information storage in water.

First, information and energy are considered to be one and the same; the former referring to pattern, form, or structure and the latter referring to force or the ability to do work.[31] Second, the solute information is transferred to the surrounding water molecules (e.g., those of the primary hydration shell) via a resonance between the water molecules and the solute. Third, water molecules in the hydration shell interact (e.g., via proton transfer) with those in the bulk liquid. As discussed in Chapter 6, information regarding the solute, or biomolecule, could be energetically transferred to the bulk water network. This last point differs from standard explanations of homeopathy, whereby the geometric structures of water (e.g., solute hydration shells) are required to persist over extended time periods in order for water to retain memory. Systemic memory theory suggests that information is stored in the water network as a whole; therefore, the longevity of hydration shells or clusters is important only insofar as sufficient time is allotted for transferring information to the bulk network.

Systemic memory explains the process of information retrieval according to the degree of resonance or sympathetic vibration between the information and the receptor. The authors use the example of a DNA molecule, which acts as an antenna or crystal receiver that "tunes in" very specific vibrational frequencies on the basis of its structure or form. Using this example, a DNA molecule is able to download selected information or energy from the bulk water network by way of its very specific geometry. This aspect of systemic memory is reminiscent of Johann Grander's modern premise that water activates or mediates the memory associated with genetic codes.

While the systemic memory hypothesis dispenses with the notion that distinct or recognizable clusters must persist in water for long periods, it introduces the new hurdle of explaining exactly how water's bulk network retains such information. It is this hurdle that complicates the application of simplistic vibrational models to water. Succinctly stated, the molecular network of bulk liquid water is so vast and complex (both geometrically and vibrationally) that scientists can neither directly observe nor precisely describe it. Most of what physical chemists infer about bulk water's network is based on necessarily oversimplified mathematics and models. Even peripheral researchers and water mystics avoid discussing bulk water, which is often portrayed as a chaotic menace that threatens biological life, in favor of discussing water clusters. It appears that science (mainstream, peripheral, or otherwise) is still a long way from answering the question of whether water stores memory within its bulk liquid network.

CHAPTER 9

LIVING WATER REVISITED
Self-Organizing Networks

The entire hydrologic cycle from atmosphere to ocean and back is a marathon line of nearly unabridged hydrogen bonds, a continual flow of awareness.
Craig Childs, *The Secret Knowledge of Water*

Although the Element of water was often considered "living" by ancient peoples, it is not considered living by reductionist science. When the water network is evaluated according to modern systems theory, it could satisfy the requirements of a self-organizing system that is capable of interacting with its environment. Individual water molecules act as system components, and the continuously exchanging hydrogen bonds act as system connections. According to autopoiesis*, a systems-based theory of defining life, water is probably not living at the level of individual water molecules and is difficult to assess at the level of water clusters. Clusters are created by the bonding of water molecules into distinct geometries that tend to persist longer than do associations among water molecules in the bulk phase. Modern techniques that purportedly transform polluted or distilled water into living water do so by creating specific types of molecular clusters. It is uncertain whether these clustered "living waters" are related, in any way, to the sacred "living waters" that were understood by ancient peoples to mediate between etheric and worldly realms.*

A QUESTION OF LIFE

There are few terms thrown around as freely as that of *living water*. If I had a dollar for every time I heard that expression—particularly when people discovered that I was writing a book about water—I could have probably published the book myself. In the first three chapters, we looked at living water from the perspective of ancient insights and the modern revivals of those insights. While this examination produced a few consistent attributes for living water (e.g., imparting life and mediating an etheric code), it did not provide a definition. Moreover, the actual mechanisms responsible for water's mediating etheric codes and transforming from a non-living to a living state were either ambiguous or predicated upon anecdotal observations. I believe that part of problem of providing a definition of living water surrounds the ambiguity of what it means (at least on a molecular basis) to be living.

We all have either an intuitive or intellectual concept of what we believe is and is not alive. Obviously, animals and plants are alive, but what about something like a virus? A virus certainly affects living systems, but is a packet of RNA wrapped in a protein coat really alive? Unlike a bacterium, or other organisms that are composed of one or more cells, the virus cannot feed, respire, metabolize, reproduce, or perform any "life-supporting" functions unless it commandeers the biological machinery of a host's living cell. In their inquiry to the definition of life, microbiologist Lynn Margulis and writer Dorion Sagan have concluded that a virus is not alive because it does not metabolize and it is not *autopoietic* (a term referring to self-making that will be further defined later in this section).[1] In fact, these authors conclude that the biological cell is the absolute smallest unit of life and that mental attributes or "mind" result from the interaction of these cells. However, anything smaller or so-called simpler than a cell is not considered to be alive. Stated more simply, the cell and everything composed of cells are the rare exceptions to a universe composed almost entirely of lifeless, inanimate objects.

This so-called *mechanistic* definition of life is simply a corollary of the reductionist viewpoint that anything is explainable according to its component parts or matter. By contrast, esoteric philosopher Helena Blavatsky's examination of ancient wisdom led to the understanding that life permeates everything in the universe (e.g., rocks, stars, atoms). She maintained that, as a result of the boundaries imposed by our modern reality, life becomes obvious to us only when organisms display purpose and self-regulation.[2] In other words, that which we call life is innate in everything, although we are able recognize it in only a few of its expressions. Recall from Chapter 2 that many ancient cultures considered the Elements (e.g., water) to be living and communicative entities. From the perspective of the modern mechanistic view of the world, the ancient view is considered to be *animistic*, or predicated upon an inner spirit (as an expression of consciousness or sentience) inhabiting the Elements.

Defining "Living"

An assumption contained within the mechanistic view of life is that consciousness or sentience or spirit, if they exist at all, are a consequence of life's biological processes. In fact, Margulis and Sagan maintain that a living being need not even be conscious to perceive, respire, metabolize or perform the other functions that characterize biological life.[3] The obvious paradox here is that the ancient animistic myths maintain that everything is conscious, whether or not it satisfies any particular criteria for biological life. By contrast, the modern mechanistic theory maintains that consciousness is not even a requirement of biological life.

Is this apparently divergent description of life one of perception or of semantics? I suspect that both perception and semantics contribute to the divergent descriptions. As discussed in Chapter 1, the accounts of myth and history that we read in modern English have been subject to numerous translations, which probably deviate from the original messages. Even the words we translate from modern-day indigenous peoples must be filtered through our postmodern lens for viewing the world. So, is there a way to functionally define life in postmodern terms so that we can distinguish between living and non-living entities? Although it is certainly not the focus of this book to present and critique the countless theories of life, we have already seen that water's nature continually points us in the direction of such philosophical puzzles.

The perusal of any biology textbook reveals that, although there is a lot of discussion about life, there is precious little discussion directed toward defining life. Even when some discussion of life is included, the focus is on characteristics or attributes of living systems (e.g., reproduction, growth, respiration, metabolism). Water does not possess these attributes and, therefore, the term "living water" is an oxymoron from a reductionist or mechanistic perspective. As discussed near the end of the previous chapter, there is another perspective (although controversial among modern scientists) from which to examine living water. Systems theory assesses life not from the standpoint of biological functions, but instead from the standpoint of connections among the various elements that comprise an entity. In this manner, systems theory represents a holistic, rather than a reductionist, perception of life.

This systems-base mode of inquiry raised the issue of whether there was a holistic definition of life and biological processes that remained essentially invisible to a mechanistic approach. Moreover, such systems approaches held the allure that mathematically derived principles (to the extent they actually exist), as opposed to mere expressions of those principles, could be used to define and describe life processes. Once this door was opened, other scientists seized the opportunity to question whether living entities were simply biochemical machines or whether there were other controlling factors that the mechanistic approach had overlooked. We will take a look at water from these unconventional viewpoints.

Unconventional Definitions

Although there are a number of authors who have taken stabs at defining the underlying principles of life over the latter half of the twentieth century, I have selected two lines of unconventional (and highly controversial) thinking that seem to be distinct in their approaches. The British biologist Rupert Sheldrake presents the first of these in his book *The New Science of Life*, which was first published in 1981. It is Sheldrake's view that the mechanistic view of life is incorrect. He has hypothesized that, in addition to the laws of classical science, structure and change in life can be traced to fields that control *morphogenesis*.[4] Morphogenesis is derived from two Greek words referring to the "origin of form." Sheldrake's theory suggests that *morphic fields* (i.e., those controlling morphogenesis) occur as a result of similar forms or structures that have existed in the past, and that subsequent forms or structures act as resonant attractors for the appropriate fields. His theory appears to be applicable to an evaluation of living water in the context of a substance that mediates between etheric and worldly realms.

Another attempt to define life was made in the 1970s by two Chilean biologists, Humberto Maturana and Francisco Varela, who coined the term *autopoiesis*.[5] Autopoiesis is yet another Greek word referring to the pattern of self-organization or "self-making" in living systems. Although the word *systems* may sound a little out of place when discussing life, it is applicable to a wide range of phenomena when defined as "an integrated whole whose essential properties arise from the relationships between its parts."[6] A number of postmodern theories have focused on describing or defining life according to systems theory and, especially, to autopoiesis. The autopoiesis theory appears applicable to an evaluation of living water in the context of a substance that is alive (i.e., a living entity).

In addition to autopoiesis and morphic resonance, I will briefly visit Stuart Kauffman's theory of order in living systems and speculate on the applicability of his principles to water's H-bonded network. My evaluating living water in the context of dynamic information networks is intended to address the common speculation that water's molecular network is responsible for the reported coherent and adaptive behaviors of water. The question of whether water's networks *could be* self-organizing obviously differs from the question of whether such networks *actually are* self-organizing.

What About Consciousness?

If ever there were a sticky wicket it is the subject of consciousness. Given the volumes of material that have been written about it and the myriad views surrounding its role in living entities, it is a bit foolhardy of me to even trespass on the subject. I am compelled to raise the question of consciousness (although I will not attempt to answer it) because many ancient insights and their modern revivals portray water as a conscious and sentient entity. Recall that animism views the entire universe as alive, representing a continuum of life and knowledge in everything manifest. If this worldview has any validity, what word might best describe the "life and knowledge" that is inherent in everything? Is it consciousness?

Although portrayed by ancient myths as a living and sentient being, water does not qualify as a biological life form and, hence, is not considered by modern science to be alive. According to less conventional definitions of life, water may or may not be alive. The question of water's sentience seems to lie beyond any agreed-upon criteria.

From mystical perspective, consciousness is often associated with a pure state of awareness, within which universal knowledge or memory (including the fundamental laws of Nature) is available to any aspect of creation that is capable of retrieving it. From a more analytical perspective, consciousness is often divided into four categories. These categories include *materialism* (consciousness is a consequence of matter), *idealism* (matter is an expression of consciousness), *dualism* (consciousness and matter coexist independently) and *panpsychism* (consciousness and matter coexist dependently).[7] I introduced both the materialistic and idealistic views of consciousness in the beginning of this chapter. Perhaps the simplest description of consciousness was provided by an inventor and visionary named Itzhak Bentov, who defined it as "the ability of a system to respond to stimuli."[8] According to his definition, an entity's consciousness is proportional to the frequency range over which energy is cognizantly exchanged between it and its environment. Bentov's definition is particularly compatible with our look at water from the perspective of the "living" state.

MORPHIC FIELDS AND RESONANCE

As briefly explained in the previous section, the foundation of Sheldrake's theory is that specific morphic fields are responsible for the characteristic form and organization of systems at all levels of complexity. He does not confine these "systems" to biological organisms, but expands them to include everything manifest at all levels (e.g., stars, rocks, molecules, quarks). Systems are organized the way they are because similar systems were organized that way in the past; therefore, forms and patterns of organization are repeated. While his theory in no way denies the role of DNA and genetic programs in the development of biological organisms, it does provide an explanation, albeit controversial, for phenomena that cannot be explained solely on a mechanistic basis. It should be noted that Shedrake's use of the word "morphogenesis" is different from that used by most developmental biologists.[9]

By definition, fields are non-material regions of influence, such as those associated with gravity and electromagnetism. In other words, fields are the medium of influence or action at a distance (i.e., nonlocal), permitting things to affect each other even though they are not in physical contact. Sheldrake suggests that morphic fields may be thought of as fields of information containing a built-in memory that is sustained by morphic *resonance*.[10] Resonance is a process whereby the natural frequencies or rhythm of any two objects (e.g., DNA and morphic fields) are sufficiently close so that they affect or, according to systemic memory, transfer information between each other. So, where exactly are these nonlocal morphic fields? Our attempting to pinpoint the location of a field is similar to ancient peoples trying to describe the location of heaven. The effects of fields may be observed (to greater or lesser degrees) everywhere, yet their very nature precludes a discernible locale.

Sheldrake suggests that one way in which morphic fields could be conceptualized is as another dimension or as a state of the mysterious aether.[11] Recall that early physicists also postulated fields to be an aspect of the universal etheric substance. Similar to the ancient concept of aether, fields structure matter but are not structured in matter—at least not in matter that we readily recognize. Is it possible that morphic fields represent distortions in string theory's rolled-up spatial dimensions? Could morphic fields be the source of an etheric code that is purportedly mediated by living water? Although Sheldrake's theory does not address water's mediation, it does predict that the degree of similarity among forms and morphic fields (as communicated through resonance) is proportional to the influence that a particular field exerts on the form. More recent and similar fields exert the greatest influence on a particular form; hence, Sheldrake postulates that the fields contain an inherent memory.[12] This aspect of morphic resonance is interesting in light of water's controversial memory, in which the most recent aqueous solutes reportedly exert the greatest influence.

Water and Fields

There are two points regarding Sheldrake's morphic fields that may be applicable to water. First, the spatial structure of morphic fields provides the ordering of change but not the energy for change. In other words, the energy required to alter physical forms (in accordance with the fields) must be supplied either by the form itself or by some energy mediator. The second point is that fields may provide an explanation for nonlocal behavior. Water reportedly exhibits long-range or nonlocal characteristics, even though short-range forces in the form of H-bonds link the nearest neighbor molecules. Scientists have noted that molecular interactions mediated through water extend far beyond the limits of hydration shells, although the questions of how far or by what mechanism are largely unanswered.[13] Is it possible that these long-range forces of water may be facilitated through morphic fields? This is quite an unconventional concept.

Because water is considered an inorganic system, the type of morphogenesis predicted by Sheldrake is *aggregative*, whereby previously separate morphic units come together into a so-called "higher level" morphic field that then becomes dominant for that form.[14] The morphic unit for small molecules such as water is the atoms comprising them; hence, water is created from morphic units represented by oxygen and hydrogen atoms. With respect to morphic fields, water represents a rather unique "form" for the following reason. Besides the single water molecule (monomer) and its characteristic clusters (water-only), water traces or mirrors the outermost geometry of every form, or solute, that it hydrates. Given water's role as a biochemical solvent, there are very few biological components that are not either dissolved in water or contain water as an integral part of their structure (form).

Is it conceivable that changes in the biological life forms on Earth are facilitated by water in response to an ever-changing mosaic of morphic fields? Could morphic fields represent the source of the mysterious etheric code (in contrast to the genetic code) that many naturalists speculate is activated through water? If so, could water actually play a role in altering the geometry of forms (other than its own) and, thus, mediating the transition of other physical forms from one set of fields to a slightly different set? And just how might water perform such a feat? Research described in Chapter 6 suggests that water often mediates the transfer of energy and information among biomolecules. Is it possible that water plays two mediation roles: one predicted by morphic resonance and the other by systemic memory? Perhaps the first relates to integral water's facilitating changes that are dictated by a biomolecule's morphic fields, whereas the second relates to the hydration shell's mediating an energy or information exchange between the biomolecule and the bulk water. We will explore these unorthodox and highly speculative notions later in the chapter.

AUTOPOIESIS

According to theory, all living systems are autopoietic; however, not all autopoietic systems are living. It is autopoiesis in physical space that characterizes living systems because living systems cannot undergo interactions that are not mediated through their components, and it is the components (e.g., molecules) that define the physical space. All autopoietic systems, living or not, adapt by undergoing structural change without loss of organization.[15] That is to say, an autopoietic system adapts by changing the arrangement of its particular components at a given point in space and time; however, it maintains the complex relationship among components and component-producing processes. What is it that permits these systems to change and adapt on one level and, at the same time, remain constant on another level?

The answer to this question apparently lies in the ability of a network to alter its connections in response to an environmental stimulus. Recall that the ability to respond to stimuli serves as Itzhak Bentov's simplest criterion for demonstrating consciousness. Francisco Varela and his co-workers have postulated a connectionist strategy in which simple components, when appropriately connected, express cognitive properties.[16] These cognitive properties emerge through a rule or rules for the change of connections starting from a fairly arbitrary initial state. These authors suggest that in such as system there is no need for a central processing unit (e.g., a brain) to guide the entire operation because the passage of local rules to global coherence is accomplished through *self-organization*. In other words, the learning, cognitive, and adaptive behaviors may be traced to a binary network that changes interconnections between components by some switching rule or rules.

Self-organization was first introduced by cyberneticists, who modeled the human nervous system as binary switching elements (i.e., neurons) coupled by ON-OFF nodes that are interconnected in such a way that the activity of each node is governed by the prior activity of other nodes according to some switching rule. When these models were run, ordered patterns spontaneously emerged. So, how are the switching rules determined? In man-made systems, the switching rules are programmed by people who are free to change the rules and then observe corresponding changes in system behavior. In Nature, the switching rules are difficult to decipher, presumably because the changing of interconnections among nodes is characterized by nonlinear dynamics.

Theoretical physicist Fritjof Capra notes that all models of self-organization are characterized by their 1) ability to create new structures, 2) operating as open systems far from equilibrium, and 3) nonlinear connectedness among the components.[17] Creating new structures is not restricted to the biological process of giving birth, but includes any process whereby materials imported from outside the system are assembled or disassembled into recognizable components of the system. An "open" system refers to one in which energy and matter flow in and out (e.g., water flowforms such as whirlpools), as opposed to a "closed" one where there is no input from or output to the outside (e.g., the redistribution of air molecules in a SCUBA tank). Autopoiesis emerges in open systems when a critical size is achieved, thus permitting the systems to establish an autonomous dynamic relationship with their environment. Nonlinear connectedness among system elements is of interest to our discussion because its applicability to previous descriptions of liquid water's H-bonded molecular network.

Water As a System

The first question for our consideration is whether water may be described as a system of binary switching elements. A *binary* system is simply one in which all components are represented by one of two possible states (e.g., ON or OFF, 0 or 1, connected or disconnected). As an example, binary networks constitute the basis of most modern computers. It appears that water may be described as a binary system if the H-bonded molecules are used to represent system elements. Depending on which H-bonds are ON and which are OFF, each molecule has a number of different ways that it can configure its H-bonds (see Table 9A). Which of these H-bond configurations exist at any instant depends on the molecule's previous configurations and on the present and previous H-bond configurations of neighboring molecules. The uncertainty associated with H-bond switching in water does not mean that "the rules" are haphazard, but only that our observational and mathematical techniques are currently inadequate to specify the rules that govern this complex process.

Table 9A. The manner in which the four potential hydrogen bonds of a water molecule may be configured. Except for the vapor (i.e., dimer), water rarely participates in only one H-bond. A schematic of the proton-donating and proton-accepting H-bonds for a water molecule are identified in Figure 5-1, Chapter 5.

Number of H-bonds	Proton Donating	Proton Accepting
FOUR	both **ON**	both **ON**
THREE	both **ON**	**ON/OFF**
	ON/OFF	both **ON**
TWO	both **ON**	both **OFF**
	both **OFF**	both **ON**
	ON/OFF	**ON/OFF**

Complex, nonlinear systems often display behaviors that are characterized as chaotic, meaning that changes occur throughout the network and are extremely sensitive to initial system conditions. By contrast, the changes associated with ordered behaviors tend to be more localized and less dependent on initial conditions. Systems theory maintains that the behaviors exhibited by a system are determined, to a great extent, by the attractor. Here we find a similarity between the theories of networks and morphic fields; namely that a particular form or attractor selects the appropriate fields or behaviors. In the following sections, we will examine two types of attractors that are commonly associated with the behaviors of binary systems.

The macroscopic behavior of complex systems is related not to static structures, but to dynamic interactions between components of the system (e.g., water molecules) and between the system and its environment (e.g., water and solutes/surfaces). These systems apparently must achieve a minimal size before self-organizing behaviors begin to emerge. Estimates for the minimal size of a self-organizing molecular system vary from as few as several million molecules ($\sim 10^6$) to as many as one mole ($\sim 10^{24}$), depending on other properties of the system. If these otherwise arbitrary numbers are applied to water, the liquid volume varies from several milliliters to a fraction of a *cubic micron*. A micron represents the approximate scale of individual biological cells and unicellular organisms such as bacteria. The question of how many water molecules are "sufficient" for self-organization (assuming that water's liquid network is self-organizing) is an intriguing one.

Water appears to form a binary network that may be capable of interacting with its environment, primarily through changes in the connections among individual water molecules (i.e., system elements).

LIFE'S COMPLEXITY

In his attempt to model a wide range of biological phenomenon using binary networks, biologist Stuart Kauffman found that complex, nonlinear systems containing hundreds to billions of elements produce order if only a few elements affect each one in the system.[18] Such systems are often referred to as "dynamic" in the sense that they are able to change over time as a result of the coupling among elements, while still maintaining their identifiable pattern. Kauffman notes that the emergence of order does not require that all the details of structure and logic be controlled precisely because the order arises from robust properties of the system. It is a bit confusing that the word "order" is used in systems theory to refer to both the organization and the behavior of systems. A system's organization may be thought of as its pattern, whereas a system's behavior describes changes within that pattern as a function of time and space.

Kauffman has identified attractors as limiting the almost infinite possibilities of the system by forcing the *trajectories* within a state space to converge over time.[19] "Trajectory" is a term from systems theory that refers to the movement of a system through space over time (sometimes represented by a succession of points plotted through what is known as a *space state*). "Space state" is a term that refers to the space of all possibilities that exist within a given system; hence, attractors are sometimes described as possibility limiters. That is to say, attractors limit the number of points through which a system successively moves and, in doing so, plots its trajectory.[20] If it were not for the attractors, systems would never settle into a behavior that we recognize as coherent. It is the trajectory of the system that we associate with its behavior (e.g., ordered or chaotic) in time and space.

The activity of each of the elements in a network is linked to the prior activities of a specific number of other elements. Kauffman found that if the number of other elements (designated by the letter *K*) equals two, order crystallizes in the system; however, if *K* is greater than two, the system behaves chaotically. He discovered that complex disordered systems may behave in a manner that is *ordered* or *chaotic*, depending upon the nature of the attractor.[21] In an ordered regime, many elements in the system freeze in fixed states of activity and form a large connected cluster, leaving behind isolated islands of unfrozen elements. In contrast, chaotic regimes yield predominantly unfrozen elements that percolate throughout the system, leaving behind isolated frozen islands.

Water's Complexity

While as many as five H-bonded neighbors (for transition states in the bulk liquid) and as few as one (in the dimer) have been identified, the number of connections associated with H-bonded networks in water is four. Thus, *K* equals four and, according to Kauffman's definition, water's H-bonded network represents a complex system that should behave chaotically. Is the previous description of a chaotic regime reasonable for what we know about the structure of water? It seems to be a good description for the unstructured form, but not necessarily for the more structured forms. In other words, one could describe bulk liquid water as predominantly unfrozen, surrounded by more isolated frozen elements in the form of clusters. On the other hand, the description of an ordered regime seems more applicable to structured water, whereby most of the elements in the system are frozen in the form of large connected clusters, leaving islands of bulk water between them.

Most systems possess more than one attractor, which permits them to display chaotic and ordered behaviors simultaneously.[22] Chaotic attractors are 1) relatively large, 2) display system-wide effects that influence most other elements in the network, and 3) permit the transformation of seemingly random data (quantitative information) into shapes or geometries (qualitative information). The latter two attributes are of interest in light of water's nonlocal behavior and its dynamic molecular-scale geometries. In contrast to the chaotic regime, attractors in the ordered regime are relatively small, limiting their influence on system behavior to localized regions of state space. Note the similarity of the ordered attractors to solutes, which act to rearrange water molecules into more structured hydration shells. Attractors of the ordered regime confine themselves to discrete regions, as do the clusters and hydration structures. Similar to biological systems, could the size and number of clusters serve to "fine-tune" water's network between order and chaos?

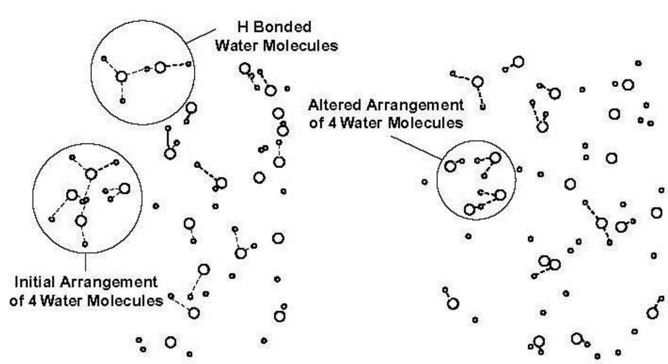
The fine-tuning of systems between order and chaos represents one of the primary objections voiced by critics of systems theory's explanation of life. Simply stated, the criticism is that open (dissipative) systems can explain the order, but not the complexity, required for life.[23] It is complexity, or the generation of sufficient information content in matter, that separates simple self-ordering systems (e.g., crystals and water) from living systems (e.g., those composed of biological cells). According to this viewpoint, a living entity must be composed of many different kinds of units, rather than many units of the same kind (as is water), in order to convey sufficient information. Despite the recent advances made in computing nonlinear dynamics, the question of whether an entity is alive by virtue of its achieving order through self-organization has not yet been resolved.

DOES WATER SELF-ORGANIZE?

Does the structure and patterning of water represent a viable network? A review of water's molecular structure strongly suggests a network in everything from bulk liquid water to crystalline ices and clusters. By definition, any network must be composed of elements or nodes that, in the case of water, are most commonly assigned to individual H_2O molecules. In the mid-1970s, American chemist Stuart Rice modeled liquid water as a space-filling random network connected by H-bonds among nearest neighbors.[24] His model was able to describe the network structure of liquid water by assuming that all potential H-bonds were either ON or OFF.

Approximately a decade later, an investigation into the connectivity of hydrogen bonds in liquid water was conducted to answer the question of how local interactions involving H-bonds led to global properties of water's macroscopic network.[25] Although this study was designed to model the connectivity of H-bonds at an instant in time, rather than as a dynamic system, the results indicated that water acted as a macroscopic space-filling network. While the H-bonded network is held together by short-range microscopic H-bonds between neighboring molecules, it may either behave as an extensive and distorted H-bonded network (i.e., the continuum model) or as individual smaller regions with local order (i.e., the mixture model). In other words, water's H-bonded network behaves as both a globally and a locally structured system.

Figure 9-1. A two-dimensional computer simulation of molecular motions in liquid water's network. The designated regions within the network illustrate changes in the spatial orientations and bonding patterns of water molecules over a time period of 1.1 picoseconds. These molecular transitions or rearrangement dynamics essentially map the network's trajectory. [Adapted from I. Ohmine and S. Saito, *Accounts of Chemical Research*, 32 (1999): 747.]



Depending on the nature of the attractors and switching rules, water may behave chaotically, orderly, or some combination of both. As a nonlinear system, water's network may have several attractors, because the state space is able to partition into distinct regions (each possessing its own attractor) and account for the network's spatial variability. Computer modeling of water's H-bonded network indicates that individual molecules sequentially pass through stages that are described as either more or less structured, thus accounting for the network's temporal variability.[26] The results of a computer simulation displaying the molecular motions associated with the transitions of a water network along its trajectory are shown on Figure 9-1.

Water's Attractors

If the H-bonded network of water is self-organizing, there must be, by definition, attractors that force the trajectories of the system into its various behaviors. The question then becomes, what serves as the attractors for the H-bonded network of water? To answer this question, let's recall what serves as an attractor (or its analogues) in other systems. The attractor for Kauffman's random binary networks is a set of points in state space, whereas the activator for Sheldrake's morphic field is the form itself. Are attractors or activators really different, or do they describe essentially the same thing? A clue to the answer may lie in the field of topology, which was briefly introduced in Chapter 5.

Topology is the study of those properties of geometric figures that remain unchanged even when the surfaces are distorted. The history of topology dates back to the middle of the nineteenth century when, even then, it was known that a relationship existed between a compound's topology and its measurable physical properties. Topologically, any molecular structure or shape may be represented by a series of points plotted in one- to three-dimensional space. For example, the water molecule has been represented as a 5000-point planar model and as a 12,500-point volumetric model.[27] Even the spatial correlations and H-bonding configurations of molecules in water's network may be represented and modeled topologically.

Attractors and activators may simply represent different ways to express geometry. What could serve as the "geometric" attractors for the H-bonded network of water? There are a number of possibilities. One is that the attractors consist of geometries that are always present in the water but somehow remain dormant or unrecognized until they are activated. If so, the question then arises of how, when, and why these geometries are activated. Another possibility is that the geometries are imparted to water by substances that are dissolved in, or are otherwise in contact with, the water. Might the activators correspond to water's solutes or to specific arrangements of the molecular network that are induced by importing energy (e.g., EM radiation) or additional water molecules? The possibility that solutes act as attractors for the behavior of water's H-bonded network is another twist on the modern premise that biomolecules act to download "information" that is mediated through water.

Another Water Network?

In our discussion of water's self-organizing molecular network, our focus has been on individual water molecules as system elements; however, there may be a second network that consists of water-only clusters as system elements. If water clusters represent the elements of another network, what serves as the connections between these elements? Hydrogen bonds are not a likely candidate because they connect molecules to molecules; however, it is possible for clusters to overlap and, thus, to share a common water molecule(s). Could the sharing of individual water molecules represent the connection among elements of a water cluster network? Overlapping clusters in a complex system have been described for so-called *quasicrystals*, whereby the assembly of such networks cannot proceed by adding one atom at a time, but instead must include global processes that permit the state of the pattern to be known at a considerable distance from the assembly point(s). The geometry of quasicrystals differs from that of ordinary crystals because the atoms arrange themselves into complex patterns (i.e., clusters) rather than into a regularly repeating pattern.

The study of quasicrystals has led to an interesting hypothesis for the nonlocal behavior and switching rules of complex nonlinear systems. Recent research indicates that the intricate patterns in quasicrystals are automatically formed when neighboring clusters share atoms.[28] In other words, the switching rules for quasicrystals are inherent in the sharing of atoms among neighboring clusters that, in turn, result in the observed global or nonlocal behavior. Could this "sharing principle" apply to a water molecule that comprises two adjacent water clusters? Is it possible that the sharing of water molecules among clusters describes a network that operates in conjunction with a more fundamental network of individual water molecules? Might there be other ways in which the water clusters comprise an interconnected network?

Let's return to the question that was asked in the beginning of the chapter. Namely, could water's H-bonded molecular network represent a self-organizing system? According to the systems-based theories presented in this chapter, liquid water appears to display the following attributes of a self-organizing system: 1) possesses components or elements in the form of H_2O molecules and interconnections among neighboring molecules via H-bonds; 2) adapts or responds to environmental stimuli by undergoing structural change (i.e., alterations in component connections) without loss of its organization or larger pattern; 3) maintains complex relationships among its components that are based on previous relationships among adjacent components; 4) exhibits molecular structures that may correspond to chaotic and ordered system behaviors; and 5) exchanges matter and energy with its environment, such that it acts as an open system.

While the solid and liquid water networks exhibit many attributes of a self-organization, the dimer and small isolated clusters comprising water vapor are represented by only a few H-bonded elements. As such, water vapor does not appear to fulfill the requirements of an extended network (self-organizing or not).

IS WATER ALIVE?

Our discussion in the previous sections leads us to the inevitable question of whether water, itself, is alive. As previously noted, the question of whether water is or is not alive depends solely upon our definition of life. Perhaps a more relevant question to ask is which of the modern definitions of "alive" (if any) best applies to the ancient insight regarding the Element of water. Our examination of systemic memory suggested that water is alive, as is everything else. Hence, systemic memory tells us nothing about the distinctive nature of living water in comparison to ordinary water. Let's take a look at the question of whether water is alive or living according the criteria presented in this chapter.

Is Water Autopoietic?

The first set of criteria I will use to assess whether water is living is that put forth by autopoiesis, which simply defines a living system as a self-organizing system that exists in physical space and whose components may be defined as physical. Water certainly seems to fulfill the requirement of occupying physical space, even though the size of that space can vary enormously. For example, an interconnected water network can occupy a space as small as the body of a single-celled bacterium to as large as the planet's oceans. Water is definitely physical, but is it autopoietic? Biologist Humberto Maturana states that a requirement of autopoietic systems is that they produce their own components. If water molecules are considered to be system components, then the system must produce additional water molecules.

The most straightforward example of H_2O production would be the importation of energy, oxygen atoms, and hydrogen atoms that, in turn, are assembled into water molecules. Although water does dissolve oxygen and hydrogen gases, a portion of which are eventually incorporated into "new" water molecules via biochemical reactions, the production of water molecules is not performed by the network alone. Water molecules are created during the star-birthing process; however, the involvement of a water network (i.e., an extended H-bonded phase) in this process is currently unknown. It seems that water molecules are primarily cycled through various compartments (e.g., lakes, oceans, clouds) rather than recreated within each one. At least on the molecular level, it does not appear that water's network routinely produces its own components from oxygen and hydrogen atoms; therefore, it does not satisfy the strict requirements of autopoiesis.

If the components of the system are considered to be the molecular clusters, rather than the water molecules themselves, then component-producing becomes the act of rearranging and H-bonding the molecules. The water network imports energy and water molecules that it uses to build the components (clusters) of the system and thereby could satisfy the component-producing requirement of autopoiesis. It is interesting to note that the structured or clustered forms, rather than the bulk form, of liquid water are colloquially designated as "living." In fact, many of the highly popularized water clustering techniques are specifically presumed to transform water into a living state. Is water living (according to autopoiesis) because of its ability to produce the clustered components? Does the sharing of water molecules among clusters qualify as a legitimate connection for system components according to autopoiesis? Are enough of the clusters connected to constitute a viable network?

Perhaps water's network functions on two scales, including one at the scale of individual molecules and another at the scale of clusters. The concept of tiered networks within water may be similar to that of self-organizing molecular systems (e.g., enzymatic) within cellular systems. The designation of "living" is reserved for biological cells that incorporate such enzymatic systems. Our current knowledge of the water network (or its network within a network) does not permit a definitive answer as to whether water is autopoietic or not. On a broader basis, does water's designation as autopoietic (or not) have any correlation to ancient insights regarding living water? While we do not know the answer, water's producing more water does not seem to be a focus of ancient insights. One major exception is the creation of water (i.e., the manifested substance) from the metaphoric "waters of chaos;" however, this exception does not apply here.

Does Water Exhibit Morphic Resonance?

Instead of addressing the question of whether water itself is alive, morphic resonance theory may be used to address the question of whether or how living water may act as a mediator between etheric codes and physical forms (at least biological ones). As such, we have to use a slightly different yardstick to evaluate water according to Sheldrake's theory than according to autopoiesis. It is the form of the attractor that determines which, and to what extent, morphic fields exert their influence. This concept of form appears to be compatible with the structures and geometries of water that have been discussed. If we assume that the blueprint for the H-bonded network in water is located within these morphic fields and that morphic resonance "activates" the blueprint, then the fields must be scaled-up or scaled-down to the form. Could this scaling be construed as a fractal-like relationship?

Recall that morphic resonance is a non-energetic process; hence, the field's memory must be implemented either by the form itself or by a mediator. By way of example, let's look at the building of a protein molecule. According to Sheldrake's theory, information for the sequencing and folding of proteins is contained within nucleic acids (e.g., DNA) and within appropriate morphic fields. As discussed in Chapter 6, at least some of the downloading of genetic information to proteins is mediated through water. Is it possible that information from morphic fields is downloaded to the protein via the same mediator? How might water access information from morphic fields belonging to a protein, particularly in view of the highly specific relationship between fields and forms? One suggestion is that primary hydration shells and integral water actually represent a component of the protein itself—both structurally and functionally. In other words, the water molecules that hydrate and structure proteins are as much a part of the macromolecule as are amino acids.

Perhaps water's relationship to morphic fields is two-fold. First, the bulk phases and the various water-only clusters exhibit morphogenesis in a manner similar to that of all other manifested forms. That is to say, water resonates with morphic fields that are exclusive to the various forms of the pure substance, H_2O. Second, water that is either integral to or hydrates other forms (via its primary shell) responds to the morphic field of that form. This notion seems to be consistent with Sheldrake's theory inasmuch as other molecular components of a protein (e.g., amino acids) respond to their own specific fields as well as to those of larger forms of which they are a component (e.g., proteins). From the perspective of morphic resonance, the uniqueness of water is not that it may respond to multiple fields, but that it may respond to nearly all fields influencing biological systems. Water might respond so universally because the components of almost all biological structures and macromolecules are hydrated at one time or another.

One of the ways that water has been hypothesized to interact with living systems is through morphic fields, which may guide the unfolding of biological structures via water's mediation. The highly speculative theories of morphic resonance and systemic memory invoke vibration as the phenomenon that transfers energy and information.

STRUCTURED VS. UNSTRUCTURED WATER

The highly structured arrangement of water molecules composing the natural ices (except amorphous ice) and primary hydration shells create predictable and definable geometries that are colloquially referred to as "structured." By analogy, the less-structured arrangement of molecules comprising the bulk liquid and amorphous solid collectively defines water that is "unstructured." Recall that *structure* refers to the spatial positioning or geometric arrangement among three or more water molecules, while *order* refers to the orientation of each H-bonded pair of oxygen atoms (e.g., O··H-O) comprising the arrangement. While changes in order are often associated with changes in structure, order cannot be predicted from structure alone. Apparently, some of the subtlest influences on water affect its orientational order without necessarily altering its structure.

During the final revision of this book, a study was published that investigated the relationship between water's order and its anomalous physical properties.[29] Using both measures of water's order (i.e., orientational and translational), the computer-modeling results suggested that physical anomalies constitute a cascade or a type of hierarchy that is ultimately related to the degree of molecular order. Structural anomalies occur over the broadest range of conditions, thus explaining why kinetic and thermodynamic anomalies, which occur over progressively narrower ranges, are usually attributed to structural change. Water's kinetic and thermodynamic anomalies are related to its physical properties, such as density and heat capacity. According to the Princeton University chemists who conducted the study, it is orientational order—not structure—that underlies water's renowned anomalous behavior.

Could water's orientational order tell us anything about water as a self-organizing network? It might; the question is "What?" Could water's orientational order or directionality reflect some of the system parameters, such as its switching rules? Could the water network employ another level of binary coding, perhaps at the scale of clusters rather than of molecules? For example, once a cluster arrangement is determined by the ON-OFF pattern of H-bonds among individual water molecules, might the behavior of the cluster network be coded according to the binary sequence of STRAIGHT-BENT bonds comprising it? Is it possible that water's H-bonded network operates as a *ternary* system (e.g., STRAIGHT-BENT-OFF) in lieu of a binary one? As asked by some peripheral researchers, is water primarily an information network that displays anomalous properties only as a consequence of its transmitting information? With respect to water's complex networks, there are many questions and few definitive answers.

The Clustering Craze

A brief perusal of the Internet will provide the experienced surfer with a litany of aqueous concoctions that are referred as "living" water. An entire book could be devoted to the various water-structuring methodologies and the observed effects on the people who drink the water. While such a lengthy examination will be deferred to other authors, let's take a brief look at the processes that purportedly transform ordinary water into living water.

- There is an emphasis on breaking down the bulk network (including the transient hydrated protons) and promoting the formation of more permanent clusters. The recommended size and geometry of the clusters varies considerably.

- Unlike homeopathic solutions, the preparation of living waters appears to focus on stabilizing water structures that best "match" those hydrating specific biological molecules and surfaces.

- The clusters do not necessarily replicate an entire hydration shell, but instead may replicate specific subunits of the shell. The solution is then exposed to EM radiation or various fields in an attempt to stabilize the otherwise ephemeral structures.

- The templates that are used to build the desired clusters are often proteins, polymers, or minerals that have been identified in the food or water of people who seem to be extremely healthy or long-lived.

After the water is structured, an overall increase in H-bonding is sometimes reported, suggesting that the structuring process either increases the number of potential bonds (i.e., reduces the percentage of broken bonds in the unstructured water) or increases the density of H-bonded clusters. Hence, the modern structuring craze is one of creating and, supposedly, preserving specific

H-bonded geometries in water. One could suggest possible mechanisms for the reported changes in water's physical properties (e.g., surface tension, pH, dielectric constant, proton transfer) as a result of structuring; however, let's turn to a broader issue regarding the practice.

While much emphasis has been placed on whether water is structured or unstructured (i.e., clustered or bulk), it is important to understand that this simplistic dichotomy defines a relatively gross parameter. Not only does it provide limited information on the molecular geometries of water, it provides no information on the orientational order that actually may be responsible for those geometries. What does artificially structuring water actually achieve? Well, the transition from bulk to clustered water presumably permits access to new, lower entropy arrangements. Because clusters possess a different geometry and lower vibrational frequency than does the bulk liquid, the characteristics of the water network have been altered. It has been suggested that the lower entropy arrangement of molecules permits biological organisms to more effectively utilize the water and to more efficiently restructure its molecular network. It has also been suggested that the artificial structuring of water assists in overriding recent information or "memory" associated with water's possible exposure to toxins.

Where is the information or memory for these new arrangements stored? Perhaps it is stored in the morphic fields, or in the bulk water network, or even in the energy that facilitates the structuring of the network. Regardless of where it is stored (if anywhere), perhaps a preoccupation with water's molecular structure has resulted in our looking past the orientational order that determines both its structure and its anomalous physical properties. Maybe today's most pertinent questions about water are which of its network connections (i.e., H-bonds) are straight, which ones are bent, and which ones ceaselessly switch between the two orientations. Unfortunately, our current empirical and computational abilities are not adequate to probe the intimate secrets of water's orientational order. In fact, describing the orientational order of H-bonds in water has been compared to watching a movie by stacking frames and looking through all of them at once.[30]

A Final Thought

I conclude by paraphrasing a question that I posed at the beginning of the chapter. Do the very different descriptions of water (and particularly of living water) used by most postmodern Westerners and many ancient/indigenous peoples relate to perception, semantics, or both? If indeed the different descriptions result from a combination of perception and semantics, then perhaps our expecting to find a link between the words used in modern languages and the words translated from ancient texts or myths is unrealistic. Instead of our attempting to match specific translations of ancient words with modern terms (particularly science's esoteric terms), perhaps it behooves us focus on broader insights that have been handed down to us. One of these broader insights includes water's role as a mediator.

In my view, there are several advantages to our pursing a greater understanding of water's mediation. First, water's mediation role has been widely acknowledged, including descriptions provided by myth, ancient philosophy, naturalism, peripheral research, and mainstream science. Second, the topic of water's mediation is broad enough to include many possible applications, processes, and mechanisms. That is to say, modern inquiries into water's mediation are less likely to become mired in disagreements over the meaning of specific words or the validity of a single proposed mechanism than are inquiries into water's memory and life. Third, water's mediation role may underlie its ancient and modern designation as *universal*. Water's universality has particular significance to our discussion when interpreted as both a ubiquitous presence and an unchanging nature through changing relations.

CHAPTER 10

A UNIVERSAL MEDIATOR

Summary

- *Renouncing any form of its own, it becomes the creative matrix for form in everything else.*
- *Renouncing any life of its own, it becomes the primal substance of all life.*
- *Renouncing material fixity, it becomes the implementer of material change.*
- *Renouncing any rhythm of its own, it becomes the progenitor of rhythm elsewhere.*

Theodor Schwenk, *Water: The Element of Life*

Is water a universal mediator? The short answer to this question is simply that we do not know. It is clear that water is instrumental in mediating many of the processes within biological organisms and the planet. In addition, science has recently postulated that water plays a critical role in manifesting certain types of cosmic matter and, perhaps, in creating the simple organic molecules that served as precursors to biological life on this planet. Maybe the ancient insight that the material world is manifested via the mediator of water is not quite as far-fetched as it once appeared. One of the difficulties in identifying the ways in which water acts as a molecular-scale mediator is that it performs these functions with such subtlety. Hence, we often underestimate the role of water in structuring and animating our world. Whether or not water's mediation role is truly universal, its role is definitely more extensive than is commonly recognized by our postmodern society. Perhaps such a restricted perspective has contributed, in part, to our escalating challenges with this most common of substances.

WATERS OF CHAOS

Does water represent a molecular-scale mediator? While the answer is "yes," the extent of water's mediation is open to question. Water is certainly an anomalous substance, but is it anomalous enough to act as a universal mediator? Of all the bizarre claims that have been made about water, perhaps the one that claims it is a universal mediator is the most bizarre. Could water serve as a universal mediator and yet do so in such a manner that its role has gone practically unnoticed, except by those who claim to know its essence or spirit? Let's take another look at water and its mythic roles as a mediator.

The first insight given to us by ancient cultures is that the "waters of chaos" or "primordial sea" existed prior to the creation of our observable world and of heaven. Chaos was an attribute of the waters (Absolute) from which everything (seen and unseen) was created. The power to permit or restrain the chaos, which profoundly impacted the manifested world, was solely that of the Creator or Source. While all of manifestation owes its existence to the chaos, the encroachment of that chaos into a world already manifested apparently brings change and even destruction. A delicate balance between chaos and order must be maintained in creating, maintaining, and destroying the manifested world within its never-ending cycles of change. Why are waters or seas so often used as an ancient metaphor for the unlimited expanse and chaotic nature of the Absolute? What insight were ancient texts sharing with regard to the watery nature of the Absolute?

As discussed in several early chapters, the use of waters or seas could be related to their apparent formless, fluid, unbounded and undifferentiated state. Are these the quintessential qualities of the Absolute? The waters of chaos were believed to possess a storehouse of unmanifested possibilities, such that they could give rise to forms from their very formlessness. The act of creating forms, or at least of mediating their creation, from a boundless sea of infinite potential is often used to describe the Creator's manifesting the physical world from the Absolute. Such an analogy could make sense from a functional perspective, assuming that "waters" served as a metaphor for that which, by definition, has no physical substance.

A more puzzling insight regards the ability of water (the physical substance) to mediate the transition of physical forms between the seen and unseen worlds. While physical chemists recognize that water's molecular network continually reconfigures itself into different geometries, this is a far cry from understanding that all (or even most) forms are manifested through water. Nevertheless, the insight that "all worldly forms emerge from the waters through water and eventually return to the waters through water" has been handed down to us (in one rendition or another) from a variety of ancient sources. Did ancient peoples actually observe forms (i.e., the material world) emerging from liquid water? It is highly unlikely that they did; therefore, such insights seem to be intuitive in origin. Furthermore, not all water was capable of mediating between the seen and unseen worlds. This magic was performed exclusively by living water.

Dividing the Waters

Almost all ancient texts refer to the initial step in creation as the division of the waters of chaos, or primordial sea. Where was this sea located? Well, there is some discrepancy among myths and stories; however, the two most frequently cited locations are *above* and *under* the world, respectively. As previously indicated, neither of these locations really brings much specificity to the question except to indicate that the primordial waters were apparently not observable from this world. But then, how might ancient people have described the location of something that does not exist in their observable world? Here again, we may be encountering the limitations of language as a vehicle for sharing insights that lie beyond the five senses.

What actually transpired during the division of the waters of chaos remains a mystery; however, most creational myths suggest that the following general steps were involved. First, the Creator had a thought or intention that broke the seamless tranquility of beingness, resulting in an apparent duality between the Creator and His thought. The nature of beingness is such that it cannot be divided; hence, the Thought facilitated a mirror for or a reflection of the Absolute that could be divided. Second, the Creator uttered "a word" in accordance with His thought or intention that gave rise to the manifested world. It is widely believed that this word represents a mechanical vibration (i.e., acoustic energy and the associated waves). Third, His creations included both the etheric and material realms. The material world continues to be manifested through living water, which acts as the mediator between the two realms.

If we express this sacred division in biblical terms, the primordial waters may have been divided into the waters above (a reflection of the sacred chaos), the waters below (the observable world) and the expanse (the firmament or heaven) that separated the two watery realms. Just for fun, let's see how this version of the sacred division might influence our interpretations of our reality. First, the three (or Trinity) was created from the One by dividing within Unity rather than by separating from Unity. Hence, the perception that we are somehow separate from the Absolute or the etheric realm (i.e., heaven) would seem to be illusory. It is only our inability to cognize the exchange of energy with this higher vibrational realm, which may be a function of our level of consciousness, that underlies our "illusion of separation." Second, heaven or aether was inherent in the undifferentiated waters of chaos, but it (along with the observable world) was not created until the original division occurred. Third, the symmetry breaking achieved by dividing the waters may have established both spatial fields and temporal rhythms, perhaps evident as various forces in *n*-dimensional space and vibrational patterns in the fundamental strings.

The Chaos of Water

The ancient insight that manifesting matter or energy from the Absolute is a process of moving from a chaotic source to an ordered creation seems to be a consistent one. All matter and energy originates from and, eventually, returns to the chaos. This transformation occurs either as a function of cyclic change or as an act of the Creator in alternately restraining and permitting the encroachment of chaos into the material world. What there is about water that is chaotic or renders it an appropriate symbol for chaos? More specifically, let's ask this question about freshwater because it seems to comprise or to be the primary component of a primordial sea, at least according to those myths that distinguish between freshwater and seawater.

Bulk water is normally characterized as the most chaotic of its liquid forms (e.g., as compared to clustered components of the mixture model), at least in terms of its orientational order and H-bond switching dynamics. Is bulk liquid water the most chaotic of substances with which ancient people would have been familiar? It is anybody's guess, because we have no idea how they might have discerned the relative chaos of a substance. If they truly believed that water was a crystal (very unlike other liquids), then it may have appeared to be chaotic compared to common solid crystals (e.g., ice, quartz, salt). Because of water's unique H-bonded network, its liquid represents an interesting compromise between the structure that characterizes solids and the lack of structure that characterizes liquids. Liquid water's "tightrope walk" between a typical solid and a typical liquid could be construed as a balance between order and chaos; however, the words "order" and "chaos" would need to be understood in a colloquial context.

If ancient people did consider liquid water to be a chaotic crystal, this could explain the Maori understanding that the oceans serve as the planet's largest one. Seawater does not fit the network models of pure bulk water (or even dilute aqueous solutions) because such a high percentage of its molecules are clustered into ion hydration shells. Might seawater's overlapping hydration shells be considered the most crystalline form of liquid water? Does seawater represent a less chaotic substance than does freshwater? Could this be the reason that ancient myths specifically refer to the "waters of chaos" as freshwater and not seawater? If so, the symbolic reference to a primordial chaotic sea relates to its unbounded and fluid nature rather than to its containing saltwater—as do Earth's seas.

It is interesting to note that all freshwater on Earth, including the living water that was considered to be so rare and sacred, was generally portrayed in ancient myths as the antithesis of chaos. The only association of freshwater with chaos seems to be related to the primordial sea or waters of chaos, further suggesting that water was used as a metaphor for the Absolute and that the physical substance (H_2O) did not exist before the act of creation.

Living Water

Living water apparently refers to the physical substance that serves as an etheric mediator, at least in the mythic sense of linking seen and unseen realms of the manifested world. As such, living water is distinct from the metaphoric "waters of chaos." Let's take a look at living water from the standpoint of the Absolute or spiritual realm. What is it about living water that warrants its designation as the physical carrier of spiritual energies? Well, it was Thales who in ancient times suggested that water's rearrangements or permutations permitted it to achieve a living state and it was Schwenk who in modern times indicated that water's living state was a result of its diverse rhythms. Given these two insights, is it possible that water's ability to rhythmically rearrange itself facilitates its bridging the worldly and etheric realms?

Water's designation as living apparently relates to its being alive, as well as to its bridging matter and aether. Is water alive? Water is definitely not alive according to a reductionist or mechanistic view of life. Water may be self-organizing, but not living (according to autopoiesis), when viewed as a network of elements that are represented by individual water molecules. Water's cluster networks might be autopoietic; however, we know too little about the connections within and dynamics of such networks to ascertain whether they even qualify as a functional system. Postmodern technologists who artificially structure water claim that water's living state is achieved via the transition of its bulk liquid to a highly clustered arrangement; however, the relationship between today's clustered water products and the ancient understanding of living water is ambiguous.

The transition of water's network from a chaotic bulk phase to a more ordered clustered phase is believed by some naturalists to breathe life into the manifested world. Recall that the Absolute is characterized by an infinitely high energy (vibration) and unlimited potential (all possibilities), yet it is described as being more chaotic than is the manifested world. As an analogy, the H-bonded network of bulk liquid water pulses at a higher vibratory frequency (e.g., higher energy), gives rise to all the highly ordered forms, and yet is more chaotic than the structured forms that it produces. In both cases, ordered forms are produced from chaotic sources. Contrary to popular (non-scientific) notions, liquid water's most profound magic may lie hidden within its vast, unobservable, and seemingly chaotic bulk network. Water's clusters may simply represent highly specific expressions of that magic.

A RECOGNIZED MEDIATOR

The hypothesis that water acts as a mediator for a variety of physical, chemical, and biological processes is generally undisputed. This includes water's mediation between two or more physical forms (e.g., matter-matter) or between electromagnetic vibrations and physical forms (i.e., energy-matter). In other words, the ancient truism that water serves a mediator in our world seems to be valid on both macrocosmic and microcosmic scales. Hence, the question I am exploring is not whether water serves as a mediator, but rather to what extent and with regard to what processes water serves as a mediator. Is water truly a universal mediator, or does it just mediate a handful of very specific processes? In other words, does water's mediation role in the physical world represent the exception or the rule?

Microcosmic Happenings

I have presented water's mediation role on the microcosmic scale primarily in terms of its H-bonded network. Because water is a molecule, the physical forms for which it mediates are of the molecular scale or larger. Although certainly identifiable in the atmosphere, hydrosphere, geosphere, and even in interstellar space, water's most recognizable mediation probably occurs in the biosphere. For example, water serves as a both a structural and functional component of proteins and nucleic acids, which act as the building blocks and physical blueprints of biological life forms, respectively. Water also serves as the medium through which biological structures (e.g., macromolecules, membranes, organelles) respond to environmental stimuli and, perhaps, communicate among one another.

In addition to water's role in the structuring and functioning of specific macromolecules, water is essential to the bioenergetics that permit biomolecular structures to be built and to sustain themselves. These well-established meditation roles alone might explain the ancient insight that all forms of life simply represent different conformations of water, depending on how broadly this insight is interpreted. Moreover, modern premises that maintain water "activates life-sustaining information" or "serves as the ideal medium for form-creating processes" could describe, albeit figuratively, the hypothesized roles of water in mediating life processes.

Bear in mind that ancient peoples and modern naturalists were not intentionally describing molecular-scale processes, but instead were relating an insight they had about the nature of water's role in earthly life forms. Are these non-technical insights less correct than modern scientific explanations? Well, non-technical insights lack the specificity of scientific explanations; however, the question of correctness is difficult to assess because of its dependence on interpretation. We are never certain that our interpretation of insights (at least ancient ones) is accurate, whereas scientific interpretations of the natural world are, by design, always evolving.

How do we interpret these often confusing ancient insights? Many postmodern philosophers (e.g., British physicist David Bohm) have suggested that interpretation is a fundamental aspect of our universe.[1] According to this worldview, we are actually changing Nature through our interpretations of it. Certainly, interpretation is a fundamental aspect of postmodern Western cultures; however, ancient insights seem to be based more on experiencing the world than on conceptualizing it. In other words, many postmodern peoples are focused on intellectually understanding water and its associated ancient insights, rather than simply experiencing that which is observed or described. This book serves as an example of just such an intellectual focus. While the ceaseless refinement of interpretations (both mythic and scientific) may eventually lead us to the laws of Nature, such a process may represent the proverbial "long road." Moreover, many spiritual traditions maintain that there are aspects of water (and of the universe) that we can never know exclusively on an intellectual or sensory-derived basis. If that is true, the proverbial road is more than just long—it is endless.

While water's mediation of processes involving biological structures seems to be the rule, the same cannot be said for non-biological processes and structures. For example, not all chemical reactions or their resulting products are mediated by water. Likewise, many of Earth's primary minerals do not incorporate water into their molecular or atomic structures. Once these chemical products or primary minerals are introduced to an aqueous medium or are weathered and become part of the planet's water-dominated environment, their reaction with or hydration by water is almost inevitable. But ancient myths and their modern revivals seem to be clear in proclaiming that the entire physical world, including all forms of matter (at the very least), is manifested through water. If water is being used as a metaphor for the Absolute (e.g., waters of chaos), this is simply a reiteration of what has already been discussed. However, if water is being used in a literal sense—as appears to be the case—there is no recognized scientific understanding that could apply to such a proclamation. Or is there?

Macrocosmic Events

Science does not fully understand the role of water in the birthing of stars. Although water is hypothesized to act as an "interstellar coolant," this role may represent only the most cursory that it performs in birthing stars. Remember that, until fairly recently, it was believed that water's only role in biological processes was that of a solvent. If water does play a more fundamental role in the coalescing of gas and dust clouds into stars, then it could live up to its ancient billing. All complex matter originates with atoms that are born in the stars; hence, the ancient truth that water gives rise to all worldly forms (i.e., at least on the molecular scale and larger) could be construed as valid, although in a more figurative sense than we postmodern Westerners usually infer from ancient myths. We are generally uncomfortable with non-literal interpretations, largely because interpretation is so fundamental to our intellectual worldview.

Stellar-borne atoms end up as components of interstellar clouds, where they combine to form gases that are occasionally encapsulated in amorphous ice. This unusual type of water ice permits the gases to interact and react, eventually forming the simple organic molecules that support biological life. At present, it is a challenge to understand exactly how science's recent discoveries jibe with the ancient insights about water (if at all); however, it is not a challenge to foresee that there are many surprises ahead of us with regard to water's roles in creating and sustaining the physical world.

Moving to the macrocosmic world here on Earth, science recognizes the fundamental role that water plays in structuring the planet itself and in mediating or regulating a wide range of dynamic processes. From global-scale phase changes to fluctuating sea surface temperatures to cloud microphysics, water appears to act as a critical mediator of change for this planet. It essentially occupies an intermediate position between the Sun and the various components of Gaia's body in combining the two major Elements (i.e., fire and water) that create and animate worldly forms. In addition to the Sun, the supporting role of fire is also played by Gaia's internal fluid or magma (heated by the radioactive decay of atoms born in stars), which may have combined with water to initiate biological life on this planet. The biosphere itself is sustained by water, not only as a mediator of countless processes on the microcosmic scale, but also by making solar energy available to earthly systems via its global-scale phase changes. The surprise regarding water's mediation role in macrocosmic events is not only that it is involved in so many seemingly unrelated processes (e.g., the dynamics of greenhouse gases, the signaling of climate change, and the global electric circuit), but also that it does so with such humility that its involvement in these processes is seldom acknowledged.

The key to the aforementioned interactions is cycles and, more specifically, the way in which many different cycles are synchronized with one another. Because we tend to think predominantly in terms of linear cause-and-effect relationships, it is challenging for us to perceive everything as nonlinear cycles. Such a perception may indeed be a requirement for understanding our macroscopic world. Of course, the perception of cycles may also be a requirement for understanding the microscopic world; however, cycles are generally shorter on diminishing scales and, thus, more easily recognized. Because rhythm is one of water's most obvious attributes (at least according to those who study its macroscopic behavior here on Earth), it has been identified as a critical link in the mediation of solar, earthly, and biological cycles.

It is likely that water's role as a mediator will receive increasing attention as science uncovers more ways in which seemingly independent cycles are synchronized to one another. Water seems to routinely show up as a facilitator in linking such cycles, whether in the stars or deep within the Earth. Water certainly seems to possess the vibrational repertoire for mediating the synchronization of at least some cycles. Unfortunately, the mechanisms by which water may perform this mediation are far less obvious. Water's vibrations are so numerous and complex that our simple vibrational models cannot even approach a simulation of what is actually occurring within its vast networks.

AN ETHERIC MEDIATOR

In addition to symbolizing the chaotic nature of the Absolute, water (the physical substance) has been repeatedly implicated by ancient philosophers and some modern naturalists as mediating between etheric and worldly realms. In fact, it appears that only living water is able to perform such a function. While scientific theories recognize water's ability to mediate among different forms of matter or between energy and matter, only ancient insights (and their modern counterparts) recognize water's mediating an exchange of energy or information between aether and the material world. Why were ancient texts so keen on describing the relationship between the etheric and worldly realms, and why have so many revivers of these ancient myths focused on this one insight?

Molecular-Scale Networks

Whether water is represented as its simplest network (e.g., individual H-bonded water molecules) or as a network within a network (e.g., clusters or groupings of clusters), water seems to possess many of the attributes of a binary system. Is this type of self-organizing system capable of interacting with its environment and exchanging information in the form of energy? Systems theory says that it is. In fact, it is generally accepted that information may be stored within the sequence of molecules, the spins of particles, or the vibrations of bonds. So, what is the difficulty when these mechanisms are applied to water? The difficulty arises when water is characterized as exchanging information (either conformational or vibrational) and mediating reactions between forms that either are not in physical proximity to each other or are no longer in contact with the water itself. The first of these predicaments is spatial in nature and is usually explained, although certainly not to the satisfaction of all, by one of several mechanisms postulated for nonlocal events.

According to systems theory, all that is required for self-organizing networks to display nonlocal coherence are system elements and their associated switching rules. Besides this systems-derived explanation, water's ultrafast vibration has been identified as a potential physical mechanism by which energy or "information" is almost instantly passed to surrounding molecules (e.g., between hydration structures and bulk water). Neither of these theories can explain how water purportedly retains conformational or vibrational information over an extended period of time (i.e., the temporal predicament). As we have seen, this ancient insight and its associated modern premises often lead us to explanations of water's memory that are provided by peripheral researchers.

Unfortunately, the ancient myths themselves are focused not on the mechanisms of water's memory, but rather on the consequences of such a memory.

We examined four lines of thought that have been applied to water's memory. First is the persistence of temperature anomalies in seawater that permit ocean currents to transport climate signals around the globe. This "ocean memory" ultimately results from changes in water's molecular dynamics and applies to timescales on the order of hundreds to thousands of years. The second line relates to EM radiation or fields altering the orientational order of water within clusters. This mechanism seems to restrict the length of water's memory to hours or, perhaps, days and is limited by the dynamics of gas-liquid interfaces and of so-called microbubbles. From a scientific perspective, this theory has only begun to be explored and there is no way to predict its applicability to water's memory over longer time periods.

The third line relates to systemic memory, which I took the liberty of applying to water and its H-bonded network. Instead of storing information within the geometries of water's clusters or hydration shells (as is commonly proposed), a hypothesized alternative is that information is stored within the complex vibrations comprising the bulk water. In this way, water's ephemeral clusters could be repeatedly produced from the bulk phase as a result of resonance between specific attractors and "latent" forms in the bulk water (e.g., those corresponding to particular system behaviors). From a scientific perspective, this hypothesis shares a shortcoming with its predecessor; namely, the lack of a currently testable mechanism.

The fourth line is based upon the assumption that water's memory is stored in morphic fields. According to my view of this theory, the unique role played by water is not about carrying universal memory, but instead about accessing such memory while it acts as an integral component of many different "forms" on this planet. The hypothesis of storing memory in morphic fields is interesting inasmuch as the most recent forms (e.g., proteins or pollutants) dissolved in water are predicted to produce the most pronounced effects. Similar to systemic memory, morphic resonance lacks a scientifically recognized mechanism.

Rhythmic Flowforms

Perhaps the greatest mystery of water's mediating between the etheric and earthly realms is related to its legendary flowforms. In particular, the vortex has been represented as the archetypal macrocosmic connection between the two realms; however, science has struggled with postulating a mechanism for this connection. While water is certainly not the only fluid that spawns vortices, it seems to be the fluid that has garnered most of the attention. The mechanism by which vortices may connect macrocosm to microcosm has not been identified; however, the preponderance of clues provided by modern premises point to the oscillation of the vortex itself and its effects on the spins of particles comprising the fluid. Many peripheral researchers presume that the ordering mechanism of a vortex is lies within its ability to produce vibrations or waveforms corresponding to very specific numeric ratios; however, this has not been demonstrated to the satisfaction of mainstream science.

The modern contention that vortices are responsible for connecting microcosm to macrocosm is one factor that sustains the modern premises regarding vortices. For example, it is difficult to ignore the apparent success in utilizing flowforms to alter the properties of aqueous solutions, whether or not a scientifically acceptable mechanism has been proposed. Within the vast water-related literature, there are many bizarre anecdotal references to vortices in both water and air, but these seem to be of limited value in revealing the magical workings of a vortex. Scientists will take a major step in better understanding the role of the oceans once they crack the scientific mystery of the vortex and other macroscopic flowforms. The oceans are home to the largest water vortices and most complex flowforms on the planet; however, we cannot seem to reconcile our scientific knowledge of these flowforms with observations made by contemporary naturalists. While such a reconciliation may not seem terribly important, the fact that it has not yet occurred suggests that our intuitional and intellectual "knowledge" of water's flowforms remain very far apart.

Judging from ancient myths, the oceans have always been the most enigmatic form of water on the planet. It appears that truism is still valid at the dawn of the twenty-first century. Ancient myths tell us that Earthly life forms may have actually made their debut in water's primeval vortex, which is perhaps better known as the ocean's thermal vents. While we know that seawater and its various currents, eddies, gyres, and interfaces essentially control (in response to solar cycles) the Earth's climate and global energy dynamics, we have very little understanding of whether or how the oceans may serve the planet on a solar or galactic scale. Is it possible that oceans function as a planetary-scale crystal in a manner that science has not yet considered? What might be the purpose of such a crystal within the context of what is known about the oceans?

The role of earthly water on a macroscopic scale will likely remain a mystery until we either intuit or understand the oceans on a more fundamental basis. Perhaps, as many naturalists have suggested, our scientific inquires have unintentionally overlooked the subtleties that are either responsible for or induced by water's flowforms. And perhaps, as so many non-technical insights suggest, the answer will arise not from our intellectual inquiry into water, but rather from our *experiencing* our connection to it. Science writer John Horgan suggests that the grand era of basic science has ended and that further empirical research will likely yield only incremental returns rather than revolutionary discoveries.[2] While his view is certainly not widely held, its very suggestion may signal a turning point in the human quest to unveil the mysteries of the universe. Are we shifting (or cycling) from a predominantly outward mode of inquiry to a more inward one? Our balancing among different modes of inquiry will certainly provide us with an altered perspective of water and Nature. Could an altered perspective of Nature lead us closer to knowing the "thoughts of God," as Albert Einstein observed? Is it this knowing, rather than any particular mode of inquiry, that motivates us?

A MILLENNIAL PERSPECTIVE

We modern humans face monumental decisions regarding water; therefore, any change in our perception or any glimpse of wisdom we may catch could prove to be invaluable to us. Beyond the anthropocentric questions of who owns and controls water resources is the larger realization that water is not owned at all, but is instead shared among all earthly life forms. Beyond the collective needs of the biosphere lies the realization that all planetary water originated with Gaia and the star from which she was birthed. Beyond its role within our solar system lies the realization that water performs innumerable roles in the physical universe. And beyond its role in birthing the stars lies water's mysterious connection with the etheric realms and, ultimately, with Spirit. Water will go wherever it is sent and do whatever is asked of it in performing its humble service. Water does not demand that we recognize it as sacred or as a mediator or as anything in particular. At the same time, our present and undeniably self-created challenges with this most common substance could well be a consequence of our inability or unwillingness to perceive it as more than commonplace.

We may never know water's essence in the same way as did our ancient ancestors, let alone perceive water as a conscious and sentient entity. It may be that our twenty-first century perception of water will include an amalgam of intellectual, spiritual, and experiential insights that is impossible to even fathom at present. Cosmologist Brian Swimme suggests that our transitioning into a new postmodern era might include acquiring an experience of the universe at the same time that we learn facts (or theories) about it.[3] Water certainly seems to be a favorite subject of so-called *new science*, which appears to be yet another of man's attempts to infuse an innate knowingness or spirituality into an intellectual view of the world. This attempt, while invaluable in its own right, is often referred to as "bad science" because it is not really science. In my view, the process of altering our perception of water will not include transforming mainstream science, but instead supplementing an intellectual or scientific view of Nature with intuition and wisdom (ancient or otherwise).

Science is as it must be. Science efficiently identifies and culls out hypotheses and research that do not correspond to its tenets, or rules. This discrimination ensures that other forms of inquiry into or accounts of the physical world (e.g., modern premises, peripheral research, mysticism, myth) are not mistaken for science. The designation of "unscientific" *does not* indicate that a hypothesis or perspective is invalid according to Nature's laws, but only that it violates science's rules. As a consequence of our closely associating the discovery of Nature's laws with the adherence to science's rules, many of us postmodern Westerners have looked exclusively to science to validate, or sanction, our perception of Nature. This practice is not only self-limiting (i.e., restricts our "knowing" water to a single modality), it places science in the awkward position of addressing topics (e.g., water's memory, Gaia's sentience) that exceed its capabilities or violate its rules. Moreover, our identifying science as the only legitimate view of Nature has, in my opinion, encouraged the mislabeling of many interesting, but clearly non-scientific, hypotheses and research studies. Our formulating a perception of water solely on the basis of knowledge acquired according to science's rules essentially denies the non-intellectual aspect of us (or at least some of us) that "knows" water.

The possibilities for an enhanced and expanded perspective of water in this new millennium are both exciting and limitless. Based on the lessons of the twentieth century, however, it is clear that we will not be able to regulate, legislate, or litigate our way into an ethical perception of water. We have also learned that our depending upon international organizations (e.g., UNESCO) to oversee the global "ethics of water" is not a solution. As I asked in the book's Introduction, do we expect to meet the challenges of water in the new millennium while holding essentially the same perception of water that gave rise to those challenges in the previous millennium? What seems to be required of us is a shift in our fundamental perception of water—and not simply a change in attitude (however sincere) or the adoption of more ethical practices (however permanent).

Do we in the postmodern industrialized world possess the ability to make such a profound shift in perception? Asked in another way, have people in postmodern industrialized societies simply forgotten or actually lost the ability to know water in an experiential or spiritual, as well as in an intellectual, sense? Perhaps this is less a question of ability than it is a question of desire and know-how. Do we even care whether we have forgotten our spiritual and/or experiential connection to water? This is a question that we will have to answer as individuals and in the collective. If we do care, then any reconnection will almost certainly require our use of direct experience and intuition, as well as the senses and intellect.

Is water a universal mediator? Although we cannot definitively answer this question at present, the combination of scientific theories, ancient insights, and naturalists' observations suggests that water is both more universal and more essential than we are able to comfortably fit into our postmodern reality. Will this "knowledge" simply add to our burgeoning storehouse of interesting data and provocative concepts, or might it actually motivate us to seek a different perspective? Any shift in our perception (of water or of anything else in our world) would necessarily affect our actions. Simply by having the desire to expand our perception of water, we will have taken the largest step toward actually doing so. As an inevitable consequence, our relationship to this remarkable substance will be forever changed.

APPENDIX A

The Mystique of *Phi*

Although *phi* (ϕ) was well known to ancient philosophers, artists, and architects, an Italian naturalist of the Renaissance era named Fibonacci was credited as the first to observe that branching in trees and the arrangement of leaves on plants followed a very specific numerical pattern that was described as follows: 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 81, 144, 233, 377, etc. This unusual numerical series has a couple of significant attributes. First, the addition of any two consecutive numbers in the sequence equals the next number in the sequence (e.g., 34 + 55 = 81). Secondly, the division of any two consecutive numbers in the sequence yields a quotient that is approximately 0.618 or 1.618, depending on whether one divides by the larger or smaller of the two consecutive numbers. Actually, as one moves further and further along the Fibonacci series (i.e., to higher and higher numbers), the quotients approach two irrational numbers known as ϕ (1.618 . . .) and $1/\phi$ (0.618 . . .). An irrational number is one that may never be defined exactly, but only approximated.

Moreover, if one divides two non-consecutive numbers in the sequence, the quotient is equal to an exponential power of ϕ. For example, when 377 is divided by 144 and 81, the resulting quotients approach ϕ^2 and ϕ^3, respectively. Another bizarre attribute about *phi* is that it may be created either through addition (i.e., adding one to successive powers of ϕ) or through multiplication by itself. In mathematical terms, $\phi^2 = 1 + \phi = 2.618$ and $\phi^3 = 1 + \phi^2 = 3.618$, the decimal portion of each value in the golden series is identical and only the integer located to the left of the decimal changes. This unique property of ϕ is the reason that the *phi* ratio is sometimes referred to as the only relationship in mathematics that both adds and multiplies. As is the case for all irrational numbers, *phi* is approximated by an infinite number of whole number ratios; however, its strict definition is $(1 + \sqrt{5}) / 2$.

Phi, or the *golden ratio*, was known to ancient mathematicians long before Fibonacci recognized it; however, it is his discovery that shed new light on its universal significance. *Phi* was known to ancient mathematicians in relation to the *golden proportion* and is represented by the analogy of a is to b as b is to a + b.[1] When applied to dividing up a line, ϕ represents the only geometric partitioning of Unity (i.e., the Absolute) and is known as the *golden section*. Here is how it works. One divides a line into two unequal segments so that the shorter one is equal to x and the longer one to 1 - x. The objective is to divide the line so that the ratio of the shorter segment to the longer segment is the same as the ratio of the longer segment to the original line, such that $x / (1 - x) = (1 - x) / 1$.[2] The solution to that quadratic equation is 0.618 . . . $(1 / \phi)$, indicating that the golden ratio is the only one that permits the mathematical relationship among all shorter and longer lines to be identical to that of the initial division.

In the more general case, the ancient truth states that the only way to create via the process of geometrical division (whether it be a line, volume, universe, or the waters of chaos) is according the golden ratio. Theoretically, all of manifestation is created through the process of dividing Unity or the Absolute, which is at the root of the occasionally quoted (and frequently misunderstood) statement that "God is number." The irresistibility of the golden ratio is believed to lie in its coding, which was considered transcendent inasmuch as it represents the only possible creative duality within Unity.[3] The oneness could not simply be divided in half because there would be no difference between the halves.

The proportion of the golden section was also used to create the aesthetically pleasing *golden rectangle*, which is the geometric basis for architectural masterpieces such as the Parthenon and for the easily recognizable logarithmic spiral that is inherent in all of Nature (e.g., a nautilus shell). If architects and Nature create via the golden ratio or Fibonacci Series, then it is not surprising that musicians do as well. Remember that music and geometry are based on some of the very same ratios. While Mozart is the composer who is best known for using the golden ratio in his music (probably because of his fascination with mathematics), the list also includes Beethoven, Chopin, Tschaikovsky, and others.[4] Perhaps not surprisingly, consecutive pairs comprising the first five integers of the Fibonacci Series may be used to create the musical ratios of the unison (1:1), the octave (2:1), the perfect fifth (3:2) and the major sixth (5:3).

Besides its applicability to music, the *phi* ratio has an interesting relationship to string theory's dimensions. The mathematics of string theory works out for a total of ten and twenty-six dimensions, exclusively.[5] In other words, a unified physical theory is not supported in an arbitrary number of dimensions. If twenty-six dimensions are divided by the golden ratio (ϕ), the resulting break in symmetry yields sixteen and ten dimensions. String theorists believe our universe was originally one of ten dimensions. If 10 is then divided by the golden ratio, it yields our reality of four perceptible and six rolled-up dimensions. Moreover, if one divides 26 and each of the resulting quotients by the golden ratio, the sequence created (when rounded to the nearest whole number) is 26, 16, 10, 6, and 4! All of these dimensional numbers, except perhaps 16, are specifically included in even the simplest explanations of string theory.

Most mainstream scientists and mathematicians do not share the ancient and mystical view of *phi*. In his recent book *The Golden Ratio and Fibonacci Numbers*, Richard Dunlap notes that while some of the attributes bestowed upon the golden ratio are mathematically supported, most of them are either highly speculative or absolutely ludicrous.[6] Interestingly, one of the areas where Dunlap does acknowledge the golden ratio as playing a prominent role is in the dimensions of all objects that have five-fold symmetry (see Table 2A, Chapter 2). The pentagon displays five-fold symmetry in two dimensions, whereas the dodecahedron and icosahedron display it in three dimensions. If the dodecahedron and icosahedron are constructed with an edge length of one, both their surface areas and volumes are related to the golden ratio.

APPENDIX B

Synchronized Cycles

A preoccupation with numbers and cycles may seem odd to us; however, there appears to have been a pervasive ancient understanding that all phenomena are cyclic. One of the ancient cultures that left behind the most detailed description of cycles (e.g., seasonal, lunar, solar, galactic) was the Maya. Their calendrics and understandings of how seemingly unrelated cycles are synchronized to one another is so precise that we have only recently been able to recognize their significance. Not only do their understandings call into question the notion of linear time, they suggest that the synchronization of cycles underlies the entire manifested world. Some people believe that the renowned Mayan calendar may actually foster a perception of our world as endlessly repeating and interconnected cycles.

Because everything may be traced back to synchronized cycles, the Maya apparently used the same harmonic module or numeric matrix to accurately predict and record both microcosmic and macrocosmic phenomena. There have been volumes written about this module, known as the *Tzol'kin*, and how it has been used to code everything from cycles of time (calendrics) to the movement of the stars. The Tzol'kin is a 260-unit matrix that is often depicted as a 13 x 20 rectangular grid, although it seems to have originally appeared as a radial matrix. According to the controversial Mayan scholar José Argüelles, the Tzol'kin is a "binary information matrix" that is communicated through sunspot cycles.[1] All information purportedly originates from the Hunab Ku (previously identified as the architect of the universe) and is qualified by the star of the receiving system (e.g., our Sun). Solar activity is cyclic in nature and often linked to the waxing and waning of sunspots. Let's take a closer look at the periodicity of sunspots.

In addition to the familiar 11.5-year sunspot cycle, there is an approximately 187-year cycle within which the sunspot cycle shows another distinct repetitive pattern.[2] This 187-year oscillation is considered to be one *Mayan Sunspot Cycle*, and a total of twenty of these cycles yield an even longer repeating pattern (i.e., cycle) that occurs on the order of 3740 years. All sunspot cycles, regardless of their duration, ultimately result from the twisting and looping of magnetic field lines created by the faster rotation of the Sun's polar field (~26 Earth days per revolution) than of its equatorial field (~37 Earth days per revolution). So, why were the Maya reportedly so keen on understanding and precisely describing these cycles of solar activity? According to many students of this ancient culture, the reason is that the Maya understood the profound affects that solar activity had on the planet and biosphere.

While the question of whether solar-induced effects on the Earth's fields affect water and the consciousness of earthly life forms is currently relegated to the periphery of science; there is some evidence that sunspot cycles correlate well with anthropological cycles. Perhaps the best-known example is represented by a correlation between periods of high sunspot activity and the rise of great civilizations and, conversely, a correlation between periods of low sunspot activity and the so-called Dark Ages.[3] These cultural or anthropological changes may result from direct effects on the biosphere (including humans) or to changes in global climate. It appears that variations in solar activity, which all seem to be governed by sunspot cycles, have significantly affected the Earth's climate during the current geologic epoch known as the *Holocene*. Scientists generally agree that Earth's climate has consistently chilled every 2600 years during the Holocene, which began about 11,600 years ago or around 9600 B.C.[4] This 2600-year cycle of climate change is one factor that complicates science's attributing global warming exclusively to recent trends in human activities.

The realization that the universe consisted of cycles was recognized as early as Babylonia, where the ~26,000-year cycle known as the Procession of the Equinoxes was recorded. The Procession of the Equinoxes is due to the so-called wobble of the Earth's axis of rotation, such that one complete cycle permits each of twelve stellar constellations (i.e., the Zodiac) to occupy a fixed position in the sky. As observed from Earth, the fixed position for each constellation lasts for a period of just over 2100 years. We are currently exiting the Piscean Age, which began just prior to the time of Christ, and entering the Aquarian Age, which will last well into the forty-second century A.D. One full procession of the equinoxes is composed of five Mayan Great Cycles, which are approximately 5125 years in length. The current Great Cycle is believed to have begun in August 3113 B.C. and to end in December 2012 A.D.

The current Great Cycle began during the mid-Holocene (~3000 B.C.), which may have marked the start or resumption of an ENSO pattern that has reached its pinnacle in the last two decades.[5] In addition to the climate and associated cultural shifts, the Earth and the entire solar system may have moved into the *Local Fluff* during approximately the same time period. The Local Fluff represents an interstellar cloud composed of material (mostly atomic hydrogen) ejected from supernovae located within this arm of the galaxy. Astronomers have estimated that the solar system moved into the Local Fluff between 2000 and 8000 years ago.[6] The midpoint of this estimated period is 5000 years before the present (i.e., 3000 B.C. ± 3000 years), perhaps paralleling the aforementioned climate and cultural changes on Earth. While the timing of many of these cosmic, solar, and earthly events is tentative, it is nonetheless interesting that the Maya apparently considered the initiation of a new Great Cycle to reflect distinct changes in the galaxy, solar system, Earth, and biosphere.

APPENDIX C

Earth's Vibrations

As discussed in Chapter 2, everything in the universe is characterized by a unique vibration or natural frequency. The natural frequency of the Earth is sometimes identified (correctly or incorrectly) with the so-called *Schumann resonance*, which has been measured at 7.8 to 8.0 hertz since its discovery by Nikola Tesla at the dawn of the twentieth century and later by W.O. Schumann in the mid-1950s. There seems to be some speculation that the frequency of this Schumann resonance has risen to as high as 11 hertz in the late 1990's; however, such a rise has apparently not been reported in the mainstream scientific literature. Designating the resonant frequency of Earth's surface-ionospheric, or Schumann, cavity as her natural frequency is complicated by the fact that it consists of a spectrum of discrete frequency modes (e.g., approximately 8, 14, 20 . . . hertz), with 7.8 to 8.0 hertz simply representing the lowest or most fundamental in the series.[1] While this resonance probably does not represent Gaia's natural frequency, it does represent a planetary vibration that is of central importance.

The Earth's Schumann resonance ultimately results from the difference in electrical potential between the surface of the planet and her ionosphere, which is able to conduct electricity and (along with the magnetosphere) propagate Gaia's global electric currents. Essentially, the atmosphere between the Earth's surface and the ionosphere acts as a wave guide for low-frequency vibrations. These low-frequency vibrations are primarily induced by electromagnetic emissions from lightning, which in turn, excites the global electric circuit. This phenomenon is heightened, as the Maya predicted, during the time of the spring and autumn equinoxes, when scientists know that geomagnetic storms in Earth's fields are more common. These storms not only increase the plasma concentration and electrical energy of the Earth's fields, they also repeatedly compress the magnetosphere and cause it to oscillate like a ringing bell.[2] In other words, the Sun induces a vibration in the Earth.

The same solar events that influence the global electric circuit (primarily via the microphysics of water at the tops of thunderhead clouds) also affect the height of the ionosphere, thus altering the dimensions of the resonance cavity. Not surprisingly, fluctuations in the Schumann resonance have been related to lightning flash rates, to the height of convention overlying tropical oceans, to sea surface temperatures, and even to ENSO. In fact, correlations between the surface-ionospheric cavity and near-surface patterns of heat redistribution are so predictable that the Schumann resonance may be used to predict tropical temperature anomalies.[3] Thus, it appears that changes in the Schumann resonance may be both coded by the Sun and mediated through water, which plays a pivotal role in all of the aforementioned global processes.

In addition to resonating at the Schumann resonance frequency, Gaia's body also has been discovered to vibrate at considerably lower frequencies. Several teams of Japanese researchers have noted that the Earth continuously oscillates in the frequency range of 0.002 to 0.007 hertz (i.e., 2 to 7 *milli*hertz), which is more than a thousand times lower than the fundamental Schumann resonance frequency.[4,5] In studying the frequency dependence and spectral amplitude of this vibration, the researchers concluded that small earthquakes could not be the cause, as was originally suspected. Instead, the most likely explanation for this low-frequency oscillation is atmospheric turbulence and, in particular, the winds that constantly blow over the surface of the planet. The energy for this low-frequency vibration is supplied directly by the Sun in the form of heat, which results in water's phase transitions (predominantly at the air-ocean interface) and drives the planet's large-scale atmospheric circulation. This atmospheric circulation generates a low-frequency "hum" that is distinct from all other known sources of planetary vibration.

Besides representing yet another planetary process that is facilitated largely through water's phase transitions, one of the most curious observations of the Earth's millihertz hum is that it consists of many individual notes that constantly appear and then drop out of the symphony.[6] This vibrational signature is much different from that of an earthquake or other seismic event, which creates a "chord" that is composed of many frequencies at once. The appearance and disappearance of notes comprising the Earth's hum suggests that the sequence of notes is composed over a time period longer than the events creating the notes. In other words, the hum is not created by simply playing the same note(s) indefinitely, but rather by varying the notes that are played over time. This description of Earth's hum is oddly reminiscent of the infamous "evolving songs" that are composed and sung by humpback whales inhabiting the planet's tropical and subtropical oceans. Coincidentally, the Earth's hum is loudest between December and February and again between June and August, when the humpbacks are singing in the Northern and Southern Hemisphere, respectively.

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CHAPTER 9

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2. Pamela Kent Demers, "What is life?—Toward a new paradigm," chapter nine in *Gaia's Hidden Life*, 111. This author presents various views on the origin and definition of life provided by a variety of scientists, naturalists, esoteric philosophers, mystics, and ancient peoples.

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GLOSSARY

Absolute, The. According to ancient insights, an infinite, unmanifested, and inseparable state from which everything is manifested. Also known as Source, Unity, pure consciousness, and many other terms.

Absolute zero (0° K). The temperature at which there is no heat or kinetic energy remaining.

Aether (akasha). The mysterious fifth substance (in addition to the four Elements) from which the world was created. Aether was once believed to fill all space beyond the Earth and to represent the medium through which energy is transmitted in vacuums.

Amino acids. Nitrogen-containing compounds that serve as the structural building blocks for proteins. Usually differentiated by their respective functional groups.

Amorphous ice. A form of water ice that exists in interstellar space and is relatively unstructured compared to the highly crystalline ices that exist at higher temperatures.

Ancient wisdom. Age-old tradition of "knowing;" usually associated with intuiting and experiencing the world, rather than (or in addition to) intellectualizing and conceptualizing it.

Angstrom (Å). Length used to measure distances at the scale of molecules; equal to one hundred-millionth of a centimeter (10^{-8} cm).

Animism. The doctrine that everything manifested possesses a spirit or sentience, usually as an expression of consciousness.

Anion. See “Ion.”

Antioxidant. Atom or molecule that donates an electron more readily than do biomolecules.

Atomists. Ancient philosophers who formulated a unified physical theory in which the accumulation of small, indivisible particles composed all matter in the universe.

Attractor. Acts to limit the number of points through which a system successively moves and, in doing so, plots its trajectory or determines its behavior in time and space.

Autopoiesis. Literally means “self-making” and refers to a hypothesis that many systems (living or not) adapt by changing the arrangement of their particular components at a given point in space and time while maintaining their complex relationships and processes.

Autotrophs. Organisms that produce organic carbon (i.e., reduce CO_2 to carbohydrates) by photosynthesis or chemosynthesis.

Bases. Specialized subunits of a nucleic acid that link to each other, on a one-to-one basis, forming the template and coding of DNA and RNA.

Binary system. One in which all components are represented by one of two possible states (e.g., ON or OFF, 0 or 1).

Biological pump. Process whereby organic carbon, which is produced by photosynthetic organisms in sunlit surface waters, then sinks into deeper oceanic realms.

Biosphere. Refers to all biological species inhabiting the very thin surface of the planet (e.g., macroscopic plants and animals, as well as microorganisms).

Bulk liquid. The fraction of water molecules that are not components of H-bonded molecular clusters (i.e., unstructured). Presumed to be the predominant form of liquid water and theorized to include transient hydrated protons.

Carbon sequestration. Practices designed to sequester carbon (either organic or inorganic) within oceanic depths as a remedy for rising CO_2 concentrations in the atmosphere.

Carbonate buffering system. The primary acid-base regulator for blood and natural waters; inorganic carbon species (e.g., bicarbonate ions, CO_2) are maintained in chemical equilibrium.

Cation. See "Ion."

Ceremonial (holy) water. A surrogate for living water; used for the purposes of cleansing, dissolving impurities, and acting out the passage between life and death.

Chaos. The formless matter and infinite space that existed before an ordered universe. Also used to describe the behavior of systems influenced by a chaotic (fractal) attractor. Colloquially, extreme confusion, disorder, and disarray.

Clathrates. A special group of solid-state water clusters that are formed around relatively small solutes (e.g., gases).

Cloud nucleators. Tiny particles around which water vapor condenses into a liquid or solid.

Compartments (guilds). Gaia's four primary parts or pools (e.g., ocean, atmosphere, soil, biosphere) that facilitate major energy transformations and exchanges on the planet.

Continuum model. A conceptual and mathematical representation of liquid water as a relatively homogeneous but distorted network of H-bonded molecules.

Convection. The relatively rapid movement of air masses to higher altitudes; usually in response to Earth's surface heating (e.g., overlying tropical oceans).

Covalent bond. Chemical link that holds atoms together via the sharing of electrons and, in doing so, creates molecules.

Creating. The process of manifesting matter, energy, or various fields from the Absolute.

Creator. The intelligence or knowledge that is associated with Absolute and that created the universe. Also known as God, Great Spirit, Source, and many other names.

Crust. The outer layer of rock that forms a thin skin over the Earth. The continents and ocean floors comprise the upper portion of this geologic layer (i.e., lithosphere).

Crystalline ices. Ices possessing a rigid lattice and the characteristic properties of a solid; natural ices include hexagonal (Ih) and cubic (Ic) forms.

Diamagnetic. Term describing molecules that respond to magnetic fields by aligning themselves in a direction opposite to that of the field, regardless of temperature.

Dielectric constant. Ability of a substance to separate electrical charges; water's high dielectric constant permits it to dissolve a wide variety of solutes.

Dimensions. The various divisions of space and time, which are normally distinguished by both scale and energy (e.g., those predicted by string theory).

Dipole force. Non-bonding intermolecular force resulting from the positive region of one polar molecule being attracted to the negative region of a neighboring molecule.

Directionality. Relative orientation of two adjacent water molecules sharing a hydrogen bond, either resulting in a straight or a bent configuration.

Disorder. Regarding H-bonds, an inability to distinguish between the two possible orientations of molecules sharing an H-bond. Also used to describe the organization of systems.

El Niño. A cyclic oceanic anomaly characterized by unusually warm surface waters in the eastern equatorial Pacific Ocean.

Electrofreezing. A term referring to ice nucleation in the tops of clouds; this process affects the latent heat exchange between Earth's atmosphere and surface.

Electromagnetic (EM) radiation. Vibrations propagated through space or matter that differ in their frequency (energy) and constitute everything from radio waves to cosmic rays.

Electron. An atomic particle (at least presumed to be so) that has a negligible mass and an electrical charge of -1. Electrons are hypothesized to distribute themselves among distinct energy levels surrounding the nucleus of an atom.

Electrostatic. Attraction between atoms or molecules based on their opposite electrical charges.

Entropy. A measure of the degree of disorder in a substance or system; entropy increases in a closed system and reduces the energy available to perform work.

Enzymes. Specialized proteins that function as biochemical catalysts.

Extracellular water. Water located outside the membrane of individual biological cells (e.g., bulk body fluids).

Feedback loop. A process whereby the factors that produce a result are themselves modified by that result. A change that propagates cyclically through all system elements.

Field. A collection of numbers that describe the direction and intensity of a force at every point in multidimensional space.

Flowforms. The various spatial and temporal patterns of movement that have been recognized in water (e.g., vortices). Also refers to specific types of engineered cascade systems.

Fractal. A repeating geometric pattern that has the same proportions but differs in overall size or scale. Sometimes associated with the ancient Hermetic truism (as above, so below) and with a chaotic attractor in systems theory.

Free radical. An unstable and reactive molecule (or atom) possessing at least one unpaired electron.

Functional group. Segment of an amino acid that distinguishes one from another and is often involved in folding the biomolecule into its crystalline form.

Gaia hypothesis. Theory that the planet's climate and surface environment are controlled, in large part, by the biosphere and in a manner that is best represented by a superorganism.

Golden ratio *(phi)*. A mathematical ratio that was believed by some ancient cultures to represent the code used to manifest the material world. Mathematically defined as or 1.618 . . . or $(1 + \sqrt{5}) / 2$.

Great Chain of Being. The ancient "knowledge" that Spirit both transcends and imbues all levels of the universal hierarchy (i.e., spirituality).

Greenhouse gases. Atmospheric gases that are able to absorb the Earth's outgoing radiation; their molecular bonds vibrate and stretch in response to specific infrared energies.

Guilds. See "Compartments."

Gyres. Large-scale oceanic vortices. Eddies usually refer to vortices that move against a current.

H-bond. See "Hydrogen bond."

H-bridges. See "Water bridges."

Harmonic. One of many vibrations created as overtones of a fundamental or base vibration.

Heat capacity. The ability of a substance to store heat energy; usually defined as the energy (in calories) required to raise the temperature of water by one degree Celsius.

Hertz. A standard scientific measurement of vibration; defined as cycles per second.

Hexagonal ice. Predominant geometry for the molecular lattice and macroscopic crystals of water ice at temperatures that characterize Earth.

Holy water. See "Ceremonial water."

Homeopathy. Process in which an active ingredient is added to water and then diluted to the point that none of the ingredient should be present in the solution. Often used to treat disease.

Hydrated proton. The temporary association of a proton with one or more water molecules in an H-bonded cluster or network.

Hydration shell. A population of clustered water molecules that envelop a solute, insulating it from water's bulk network. Primary hydration shells slowly exchange water molecules with a much larger population comprising the outer shells.

Hydrogen. The simplest and most abundant atom in the Universe, comprising most of the universe's atomic mass. The hydrogen atom is composed of one proton and one electron. Two covalently bonded hydrogen atoms form molecular hydrogen (H_2).

Hydrogen bond (H-bond). Chemical link between molecules containing a hydrogen and/or an electronegative atom, whereby unpaired electrons of the electronegative atom on one molecule attract the positively charged hydrogen atom of another.

Hydrologic cycle. The complex circulation of planetary water; represents the largest movement of a chemical substance on the Earth. Often associated with the hydrosphere.

Hydrolysis. A chemical reaction involving water in which another substance is altered or transformed (e.g., the breaking of a phosphate bond in ATP to form ADP).

Hydrophilic. Literally means "water-loving." Attraction between molecules based on their polar nature.

Hydrophobic. Literally means "water-fearing." Attraction between molecules based on their nonpolar nature.

Inorganic carbon. Usually refers to components of the carbonate buffering system (e.g., bicarbonate ion, carbonic acid, CO_2).

Integral water. Present in the interior of various biomolecules, where it serves as a structural and functional part of the biomolecule itself.

Interdecadal cycles. Cycles occurring on the timescale of tens of years; often associated with the temporal pattern of warming and cooling in the eastern tropical Pacific Ocean.

Interstellar water. Water not contained within a star system (e.g., planet, moon); water present in "outer space."

Intracellular water. Water located within individual biological cells.

Ion. Atom that possesses an unequal number of protons and electrons, creating a net electrical charge; either positively charged cations or negatively charged anions.

Ionic bond. Chemical link that holds atoms together via the electrostatic attraction between cations and anions and, in doing so, creates molecules.

Ionosphere. Portion of the upper atmosphere located from approximately 60 to 500 kilometers above the planet's surface; composed of solar-ionized plasma (protons and electrons).

Jet stream. Bands of high-velocity, high-altitude winds that blow from west to east and influence global weather patterns.

Juvenile water. Water that is hypothesized to form from primary or magmatic rocks within the Earth, i.e., not part of the classic hydrologic cycle.

Life forms. Specifically refers to the many forms of biological life on Earth (i.e., biosphere).

Lipid bilayer. The basic structure of a biological membrane, which is composed of lipids and proteins held together primarily as a result of hydrophobic interactions.

Liquid crystals. Weakly polar or nonpolar elongated molecules that collectively exhibit long-range orientational order when exposed to an electric field.

Living water. Cited in many ancient texts as the source of life; usually considered to be distinct from ordinary water. Water prepared by modern-day techniques of structuring or clustering.

Magmatic rocks. So-called primary minerals formed from the cooling and crystallization of molten material (magma) derived from Earth's mantle. Often contrasted with secondary minerals that are created via chemical reactions involving the primary minerals.

Magnetic memory. Structural changes in water that are induced by its exposure to a magnetic field and that have been observed to persist after the field is removed.

Magnetosphere. Outermost region of Earth's upper atmosphere where the planetary magnetic field dominates the interplanetary magnetic field; highly influenced by the solar wind.

Manifested. Something that exists in the physical world, whether or not we can perceive it with our five senses.

Mantle. A thick layer of rock that separates the planet's crust from its core; serves as the source of magma that comprises rocks on the Earth's surface.

Materialism. The doctrine that all phenomena in the universe (including consciousness and sentience) are ultimately explainable in terms of matter.

Mechanism (mechanistic). The doctrine that science's known physical laws are adequate to explain life. Also refers to the physical and chemical processes underlying natural phenomena.

Microbubbles. Extremely small bubbles formed by dissolved gases at the interface with liquid water that affect both water clusters and the bulk network.

Micron. Length used to measure distances at the scale of light waves and biological cells; equal to one ten-thousandth of a centimeter (10^{-4} cm).

Microzymas (somatids). Mysterious imperishable granulations that have been reportedly found in blood.

Mineral hydrates. Geologic materials that contain water within their crystalline structure.

Mixture model. A conceptual and mathematical representation of liquid water as a mix of structured clusters and unstructured bulk water.

Mole. A chemistry term referring to a standard number of individual molecules ($\sim 10^{24}$).

Morphic resonance. Controversial theory describing the manner in which physical forms are influenced, via resonance, by information contained within nonlocal fields.

Morphogenesis. Derived from two Greek words meaning "the origin of form." Refers to the ultimate source of form (i.e., morphic resonance theory) and to morphological changes over time (i.e., developmental biology).

Myth. A traditional story intended to explain natural phenomena, often for the purpose of bridging the perceptible and imperceptible worlds.

Naturalism. The doctrine that all truths in the universe may be derived from the natural world. Often related to the existence of or the search for Nature's fundamental laws.

Network. Large-scale hydrogen bonded assemblages of water molecules that function as a unit (e.g., hydration shells). In general, a system of interconnected or cooperating components.

Nonlinear. Complex mathematical relationships that cannot be described using simple equations with first-order terms.

Nonlocal. Behavior of a substance or system that suggests individual components act as part of a coherent whole, thus facilitating long-range interactions.

Nonpolar molecule. One in which there is no electrical-charge separation among molecular regions.

Nucleic acids. Biological macromolecules (e.g., DNA, RNA) that contain and transmit genetic information, as well as synthesize proteins.

Open systems. Ones that continuously import energy and matter from and export entropy to their environment. Systems reaching a certain minimal size have been hypothesized to maintain an autonomous dynamic relationship with their environment.

Order. Used to describe the organization of systems, as well as the behavior of systems influenced by an ordered (periodic) attractor. Colloquially, the antithesis of chaos.

Organelle. A term used to describe various specialized compartments within a biological cell (e.g., nucleus, mitochondria).

Organic carbon. Compounds that contain carbon derived from living sources (e.g., that produced by autotrophs).

Orientational order. The degree to which H-bonded pairs of water molecules may be described as assuming one of two possible positions. Inversely correlated with a water molecule's rotational freedom or its ability to switch positioning.

Oxygen. The third most abundant atom in the cosmos; containing eight protons and eight neutrons in its nucleus, as well as eight electrons that maintain electrical neutrality. Two covalently bonded oxygen atoms form molecular oxygen (O_2).

Pantheism. The doctrine that the Creator is not a personality, but rather the combined laws, forces, and manifestations of the universe; often expressed through polytheistic gods and goddesses.

Peripheral science. Research or hypothesis that either is not addressed by or seemingly contradicts mainstream scientific theories. Sometimes referred to as the fringes or edges of contemporary science.

Phase transitions. Water's switching among solid, liquid, and gaseous forms within the environment (e.g., from polar ice caps to oceans).

Photosphere. The visible portion of the Sun (or a star) where EM radiation transitions from opaque to transparent.

Picosecond. One-trillionth of a second.

Piezoelectricity. An electric polarization resulting from the deformation or strain of molecular bonds in the lattice of a solid crystal.

Planck length. The currently recognized boundary of our familiar four-dimensional physical universe at the scale of about 10^{-33} centimeters.

Plasma. Fourth physical state of matter (besides solid, liquid, and gaseous). Also, the aqueous component of blood.

Platonic solids. According to ancient knowledge, the essential volumetric solids comprising matter. The connection between these solids and the Elements (fire, air, water, earth) was believed to shape the material world.

Polar molecule. One in which there is an electrical charge separation resulting from distinct positively and negatively charged regions.

Polarization. The process of spatially reorienting a molecule, usually in response to another particle or an applied field.

Prana (mana). Vital or life force energy that is often associated with water and that was believed to be a part of the connecting link among spiritual, etheric, and worldly realms.

Primary anomaly. Electric property of the ocean resulting from the movement of a conductor (seawater) within the Earth's magnetic field.

Proteins. Biomolecules that function as catalysts, specialized carriers, receptors, hormones, and structural components; composed of long chains of amino acids.

Proton (H^+). An atomic particle that has an arbitrary mass of 1 and an electrical charge of +1. Also defined as a hydrogen atom without its electron.

Proton transfer. The migration of a proton as it is successively trapped and released by water molecules rapidly switching connections within the H-bonded network. Protons may also be transferred between water and other molecules.

Radiative budget. Balancing of the energy that Earth receives (i.e., solar) and then gives off.

Redox reaction. Chemical process in which participants (reactants) donate and accept electrons, allowing them to be transformed into products. Oxidized products lose electrons, while reduced products gain electrons. Redox potential measures the state of such reactions.

Reductionism. The doctrine that any system (living or not) is explainable through studying and understanding its component parts.

Resonance. Increasing the amplitude of an object's vibration by applying a forced vibration at that object's natural frequency. Colloquially, this term usually refers to sympathetic vibration.

Scientific theory. A formulation of the apparent underlying principles of observed phenomena in the natural world; usually supported by some empirical evidence.

Secondary anomaly. Actual electric current flow due to the motion of water masses relative to one another (i.e., oceanic currents and gyres).

Self-organizing. Open systems that adapt, evolve, create new structures, and retain an interconnected network of components without any "outside" orchestration.

Solar wind. An electrified stream of charged particles (mostly protons and electrons) that are released by the Sun into interplanetary space.

Somatids. See "Microzymas."

Sorption. The adherence of substances to soil grains, usually resulting from either an electrostatic or a hydrophobic interaction. Desorption refers to the reverse process.

Southern Oscillation. Cyclic atmospheric shifts in the relative barometric pressures between the western and eastern regions of the tropical Pacific Ocean.

Sprites. Lightning discharges that connect the cloud tops to the upper atmosphere. Usually accompanied by very powerful cloud-to-surface lightning discharges.

String theory. Physical theory that maintains all matter and forces in the universe may be traced to extremely tiny strings that vibrate at distinct frequencies.

Structured water. An arrangement of water molecules that creates predictable and definable geometries (e.g., clusters and crystalline ices).

Subatomic particles. Those particles (e.g., quarks) that comprise the atomic particles.

Subduction. The process of surface ocean water sinking to greater depths. Also, the recycling of the Eath's crust back into the mantle as a result of tectonic activity.

Submolecular biology. The theory that life is inherent not only in cells, but also in the molecules, atoms, and subatomic particles of which cells are composed.

Sunspots. Dark regions of the Sun that form the positive and negative poles of solar magnets, from which charged particles (e.g., the solar wind) are released.

Surface tension. The tendency of a liquid to “stick to itself” or cohere. Water has a relatively high surface tension due to its H-bonding.

Sympathetic vibration. The driving of a mechanical system at its resonant frequency by energy from an adjacent system vibrating at the same (or nearly the same) frequency.

System. An integrated whole whose essential properties arise from the relationships between its parts.

Systemic memory. Controversial hypothesis used to explain the phenomenon of memory in all manifested forms via the combination of sympathetic vibration and positive feedback.

Tectonic plates. Massive chunks of the Earth’s crust that move, relative to each other, upon the molten or fluid portion of the mantle.

Ternary system. One in which all components are represented by one of three possible states.

Tetrahedral bonding. Three-dimensional geometry resulting from an atom or molecule bonding with its four nearest neighbors, thus creating the four outside vertices (and the center vertex) of a tetrahedron.

Thermal conductivity. Ability of a substance to radiate heat (e.g., away from a surface).

Thermal vents. Location where the planet's molten rock (magma) contacts seawater and introduces solutes directly into the oceans. Often associated with mid-oceanic ridges.

Thermohaline circulation. Large-scale circulation of ocean water that is driven by temperature and salinity differences.

Topology. The study of those properties of geometric figures that remain unchanged even when the surfaces are distorted; geometric representations of a data set.

Total dissolved solids (TDS). Generally refers to the mass or concentration of ions dissolved in water (i.e., salinity).

Trajectory. A term referring to the movement of a system through space over time; a plot of the system's behavior.

Triple point. Temperature and pressure at which water is able to exist as a gas, liquid, and solid. The associated phase transitions have been instrumental in setting climatic regimes.

Ultrafast vibration. An intermolecular excitation energy in water, resulting in the passing of energy among molecules on timescales of less than 0.1 picoseconds.

Universal. Present everywhere or in everything; characterized by an unchanging nature through changing relations.

Unstructured water. An arrangement of water molecules that is seemingly less recognizable than that of clusters or crystalline ices (e.g., the bulk liquid and amorphous ice).

Upwelling. The process of driving deep oceanic waters toward the surface.

Vacuum. A completely empty space; a void that is totally lacking in recognizable matter.

Vibration. A simple oscillation about a reference position, such that each oscillation is considered a cycle. Vibrations are cycles, and frequencies quantify vibrations by expressing a ratio between two cycles.

Vicinal water. A term applied to water that is present at the interface between biological molecules or surfaces and the bulk liquid network.

Vortex. The rotating motion of a multitude of material particles (usually referred to as a fluid) around a common center. Vortices are sustained by a field (vorticity) and are often described as energy pathways that draw in particles.

Water bridges (H-bridges). Biomolecular subgroups that hydrogen bond to water and, in turn, to other subgroups as a method of achieving particular three-dimensional geometries.

Water clusters. H-bonded water assemblages that may either be water-only or contain solutes (e.g., hydration shells).

Waters of Chaos. The formless matter and infinite space that existed before the creation of a material universe. Also known as a primordial sea, a misty vapor, cosmic waters, and by many other names.

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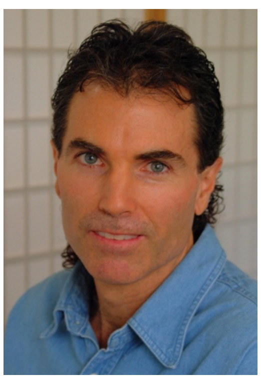
INNER OCEAN PUBLISHING

Ancient peoples generally understood water to be living and a symbol for the primordial "non-stuff" from which the known universe was manifested. By contrast, our modern world treats water as a mere commodity: to irrigate our crops, quench our thirst, or use as a solvent and coolant. Yet science has recently discovered that water is not only integral to the energetics that power our biosphere and to the mediation of biological processes, but is a critical ingredient for the birthing of stars from interstellar dust and gas clouds.

In the twenty-first century, we face monumental decisions about water that will affect not only the future quality of our lives, but that of all species on our planet. The author insists that we need a broader context from which to act regarding our threatening water crisis. Here he offers fascinating descriptions of ancient mythology, modern naturalism, and mainstream science to create an interesting perspective that will engage both the lay reader and scientist alike.



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