

Conceptual Change: Gods, Elements, and Water

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

On what does the meaning of the concept of water depend? I consider three possible answers: the physical world, theory, or both the physical world and theory. Each answer supports a particular history. If the history unique to an answer is confirmed by the actual history of the concept of water, then there is supporting evidence for that account of meaning.

I have documented the historical development of the concept of water, focusing on three periods: the ancient Greeks, the 18th and 19th centuries, and the 20th and 21st centuries. Conceptual change figures prominently in that history, and when enough historical data are available communication across theories is obvious.

Those features suggest that the meaning of the concept of water depends on the physical world and the theory in which it is embedded. The physical world explains cross theory communication; and theory accounts for the conceptual changes that I have documented.

The history of the concept of water suggests that Putnam (1975) is right: meaning depends on the physical world and the theory in which it is embedded. He's right, however, for the wrong reasons. Putnam relies on a thought experiment to demonstrate that the physical world contributes to meaning, but the history suggests that he built some chemically implausible assumptions into that thought experiment.

Acknowledgements

I am indebted to Paul Thagard. His guidance at every level of this thesis has been immensely helpful. I must also acknowledge Patricia Duern for her editorial suggestions. I have no doubt that she has played a key role in any success I may have, academic or otherwise.

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Finally I would like to thank my mother. Whatever she could do for me, she did do. And what she did do for me, made the difference. I immensely appreciate all she has done.

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Chapter 1

Introduction

A theory of meaning should answer the question: on what does the meaning of a concept depend? I shall not respond to that general question, but I shall try to answer a special one: on what does the meaning of the concept of water depend? I shall consider three possible answers:

M1: The meaning of a concept only depends on its relation to the physical world.

M2: The meaning of a concept only depends on the theory in which it is embedded.

M3: The meaning of a concept depends on both the physical world and the theory in which it is embedded.

Philosophers have different ideas about concepts. Here, Like Thagard (1992), I shall treat concepts as mental representations, which correspond to predicates. The concept of water corresponds to the predicate of the same name.

The world, in this context, is environment; however, it is the physical environment. The physical environment is distinguished from the social one, which Wittgenstein (1953) had thought determined the meaning of a concept.

Broadly, a theory is a system of concepts that are connected by the claims of the theory. The extreme of this view is that a theory or conceptual system determines the world within which one works, not the reverse (Kuhn, 1961).

I plan to evaluate M1, M2, and M3 using the historical analysis common in the historical philosophy of science. Each account of meaning makes historical predictions. Provided an account is correct, a set of historical predictions follows, which can be

evaluated against the actual history. If M1, M2, or M3's predicted history matches the actual one, then there is evidence for it; otherwise, there is evidence against it. The historical scenarios of M1, M2, and M3 are as follows:

H1: if M1 is right, then the history of the concept of water should be relatively stable, and, consequently, communication should be possible.

H2: if M2 is right, then one should expect dramatic conceptual shifts to mark the history of the concept of water, and, as a result, communication between people working within different theories should be near impossible.

H3: if M3 is right, the history of the concept of water should include stable and unstable features. Either the historical development of the concept of water is relatively stable and cross-theory communication is impossible, or the history of the concept of water is unstable, and cross-theory communication is possible.

H1 follows from M1 and one other assumption: the physical world is relatively stable with respect to its naturally occurring substances. If both assumptions are correct, we should expect the meaning of the concept of water to be relatively stable throughout history, which allows communication between people working within different theories.

H2 follows from M2 and one other assumption: the world changes with a theory change (Kuhn, 1996, p. 111). Provided both assumptions are right, dramatic conceptual shifts will characterize the historical development of the concept of water; consequently, cross-theory communication would be near impossible because speakers of different theories would intend different meanings but use the same word.

If the history supports H3, then the history will include stable elements and volatile ones. The stability is a result of the physical world, and the volatility is a consequence of theory changes.

Notice that the two salient features of the possible histories are conceptual change and cross-theory communication. The presence or absence of either of these two features from the history of the concept of water will decide which account of meaning best fits with the historical development of the concept of water. To make the comparison possible, I shall trace the changes in the concept of water, and evaluate communication between individuals working across different conceptual systems. For clarity, I shall designate concepts by small capitals (WATER), words with double quotation marks (“water”), and objects with plain text (water).

My research indicates that the actual history best fits with H3. Dramatic conceptual changes characterize the historical development of WATER, which Kuhn (1989; 1990) had anticipated; yet, when enough historical information is available the record suggests that communication happens across theories. Therefore the meaning of WATER has at least two factors: its relationship to other concepts in a theory, and its relationship to the physical world.

The physical world explains cross-theory communication. The physical world is relatively stable. And the dramatic conceptual changes are due to theory change. The fact that I have documented both cross-theory communication and dramatic conceptual changes in the history of the concept of water suggest that M3 is right. The meaning of WATER depends on the physical world and the theory in which it is embedded.

The historical analysis also shows that though Twin Earth's conclusion that the meaning of WATER depends on the physical world and the theory in which it is embedded is right, but it is right for the wrong reasons. Based on recent scientific investigation, specifically as it relates to mass variant water molecules, it is clear that at least one of Putnam's assumptions concerning the Twin Earth thought experiment is chemically implausible.

Putnam aside, Kuhn's thesis that communication is nearly impossible between speakers of different theories or conceptual systems does not fit the history either. Kuhn's argument about communication was a result of his historical work, but when enough historical information is available, it is clear that cross-theory communication happens.

The application of my research is limited for two reasons. First, I have only used it to suggest that there are *at least* two dimensions to meaning; however, it does not eliminate the possibility that, upon refinement, meaning is actually a dependent of three or more factors. Second, my research is only on WATER, and may only apply to the concepts of other natural entities.

The history I have developed relies on the distinction between belief revision and conceptual change. Belief revision is a process whereby a belief is either added or eliminated (Thagard, 1992, 1999). For instance, a solution might be thought acidic, yet upon chemical analysis, say a simple litmus test, the solution is determined neutral. The belief that the solution is acidic would be eliminated, and a new belief that the solution is neutral is added to one's beliefs. That kind of belief revision does not cause meaning

change. Thus, when the pH of a solution is determined to be neutral, the meaning of ‘acidity’ and ‘neutrality’ are not changed. These two kinds of belief revision are:

1. Adding a new instance, for example that liquid is water.
2. Deleting an instance, for example we believed that liquid was water, but our investigation tells us it is not.

Belief revision does not alter the meanings of concepts because it operates independently of considerations of conceptual structure, but more radical conceptual change alters a concepts structure (Thagard, 1992, 1999). These kinds of changes adjust the concept’s relationship to other concepts and the world (Thagard, 2003). Constructing the history of the concept of water, I have noticed five kinds of conceptual change:

1. Differentiation: introducing new distinctions into a concept. These distinctions divide one concept into two or more.
2. Coalescence: collapsing previous distinctions. This process eliminates the distinctions between two or more concepts.
3. Reclassification: moving a concept from one category in a conceptual system to another.
4. Reorganization: changing the organizational principle of the conceptual system.
5. Redescription: interpreting observations with a different conceptual system.

I have divided WATER’S history into three major periods: the Greeks, 18th and 19th century changes, and 20th and 21st century developments. Conceptual change occurs in and between each of the three periods. It is not clear if cross-theory communication happens at every stage of development, but there is enough historical information during the nineteenth and eighteenth centuries to conclude that communication across theories happens. I shall now describe the central changes that have taken place in the concept of

water, and when possible highlight cross-theory communication. Once that is complete I shall use that information to evaluate M1, M2, and M3.

Chapter 2

The Greeks

Introduction

In this chapter I shall investigate three historical developments of the concept of water with an eye toward the conceptual changes that characterize each shift. I shall begin with ancient Greek myth, and develop a fragment of that worldview as it relates to water. Next I shall elaborate on Thales' view, and explain the differences. I shall end with Aristotle's revisions to Thales' theory.

From the history I shall conclude: 1) the pre-scientific Greek concepts of water were based on water's visible properties; 2) Thales' shift to the second stage of development involved collapsing some of the prior distinctions that had been based on water's observable properties and the replacement of the organizing principle of the conceptual system; and 3) Aristotle's revision of Thales' view added four more substances.

Myth, Gods, and Concepts

The myths of literate ancient cultures have been recorded in poetry, plays, and prose. Expressions of these myths are found in sculpture, painting, and architecture. For many pre-scientific cultures myth set the context wherein observations were assimilated, conceptualized, and explained. Myth provides a pre-scientific conceptual system that categorizes, orders, and explains content.

Greek concepts prior to 620 BCE were understood in the context of myth. The poetry of Homer (900-800BCE) and Hesiod (700 BCE) are the principal sources of them, which were later recounted by Pseudo-Apollodorus (100 BCE). These stories reveal the Ancient Greek's conceptual system: their concepts, and their organization.

A Greek god is an artificial figure with human qualities, which is associated with an abstraction, or a natural entity (Webster, 1954, p. 10). Consequently, a god is a clue to the concepts in the pre-scientific Greek worldview—concepts for abstractions and for natural entities. Second, myth orders a god's relationship to another god (Sale, 1965, p. 668). By approximate substitution the relationship between the gods is a *rough* mapping of a relationship between concepts, given a god more-or-less is associated with a concept.

The most well known figures in Greek myth are the Olympians: Zeus, Hades, and Poseidon among them. Some of these gods personify natural entities: Zeus personifies the sky, and Poseidon the sea (Hesiod, trans. 1914, 453).¹ The first gods that come into existence, however, are not the Olympians, but rather, the Protogenoi. They are the figures of mythical cosmology (Hesoid, trans. 1914, 116-138).

In one influential account of the origin of the universe, Hesoid names three gods that come into existence from nothing: Chaos, Gaia, and Eros (Hesoid, trans. 1914, 116-120). They are the gods from which all the other gods descend. As first beings and parental figures, one might speculate that the concepts they are associated with are the most important.

The Protogenoi are supernatural entities that came into existence at the beginning of the universe (Hesiod, trans. 1914, 116). I concentrate on those Protogenoi that relate

¹ In this passage Hesoid does not refer to Poseidon by name but by “the loud crashing Earth-Shaker”, an associated concept. The concept and the name appear to be used interchangeably.

to water. And I shall outline two genealogical fragments of the Protogenoi that relate to it. The genealogy will serve as evidence for, and an elaboration of, the following two ideas: 1) a Greek god is associated with a loosely defined concept in the pre-scientific Greek worldview; and 2) a god's relationship to another suggests a hierarchical connection between the gods and their respective concepts.

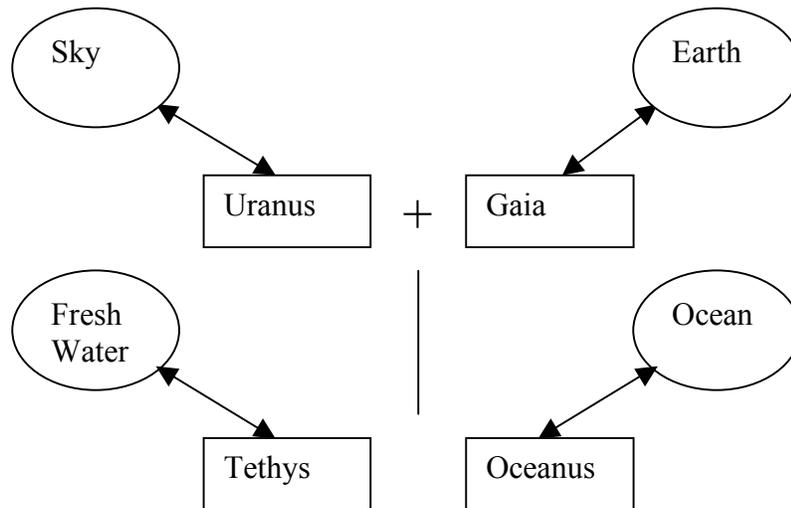


Figure 2.0 Fragment of the Greek Protogenoi Lineage (Hesiod, Trans. 1914, 116-138): circles represent concepts, squares represent gods, double arrows associations, and the addition sign represent procreation. Uranus and Gaia are the second and third beings to come into existence according to Hesoid. Tethys and Oceanus are water deities, and represent different kinds of water. Though Tethys and Oceanus have parents, the Theogony still groups them with the Protogenoi.

Notice that this genealogical fragment pairs a deity with a concept. Each god is a supernatural manifestation of his or her paired concept, modeled after human form, and given human psychology; consequently, a god is a personification of a concept. Much as our scientific understanding of the universe is encoded in the modern Periodic Table of The Elements, the Greek poetic and metaphorical interpretation of the universe manifests itself in their Pantheon of the gods.

This pairing immediately substantiates the first idea: a Greek god is a personified concept. That personification allows us to say that a Greek god *roughly* maps onto a concept. Through their mythical stories, the originators of these myths picked out the differences they thought important, and thereby built the concepts with which they viewed the world. The divine representatives are clues to the concepts in the pre-scientific Greek worldview.

The genealogical fragments also imply a familial hierarchy that organizes the gods. That familial hierarchy sets the relationships between the gods, and the concepts they personify. It shows how the pre-scientific Greeks viewed the organization of their concepts. Genealogy is only one part of the organization, however. Greek myth is also filled with stories of conflict between the gods. The outcomes of those stories also order, gods by relative power. Therefore both genealogy and social interaction organize the gods and their associated concepts.

For instance, Tethys is the god of fresh water, which suggests that the pre-scientific Greeks had a concept of fresh water. Tethys' divinity and role in Greek myth suggests that FRESH WATER is a differentiated concept in pre-scientific Greek conceptual system.

If I am right about myth's role in the organization of pre-scientific Greek concepts, then in many cases they look dramatically different than current ones. This is certainly the case for our concept of water. Greek myth suggests that pre-scientific Greeks had many concepts of water based on its different visible properties.

Considering only the Greek Protogenoi there are at least two separate concepts of water for the pre-scientific Greeks: FRESH WATER, and OCEAN WATER. Tethys, and

Oceanus represent these concepts (Hesiod, trans. 1914, 116-138). However, had I included the complete Greek Pantheon, then the number of concepts associated with water would multiple dramatically.

For instance, certain nymphs personified sea brine, foam, colour, and movement (see Hesiod, trans. 1914, 240, 349; Apollodorus, trans. 1921, 1.2). If the assignment of a deity to a thing picks that thing out as a differentiated concept, then Greek mythology suggests that the pre-scientific Greeks divided what we now classify as properties of water into separate concepts of water: SEA BRINE, SEA FOAM, SEA COLOUR, SEA MOVEMENT. All of these things are assigned divine representatives, suggesting that they are differentiated concepts within the pre-scientific conceptual system. The god hierarchy then organizes these concepts.

The Greek Pantheon is a clue to the conceptual system of the pre-scientific Greeks. That system, however, is not easily translated into our own. Below is a simplified and partly inaccurate attempt to translate the pre-scientific Greek view of water to a more familiar hierarchy.

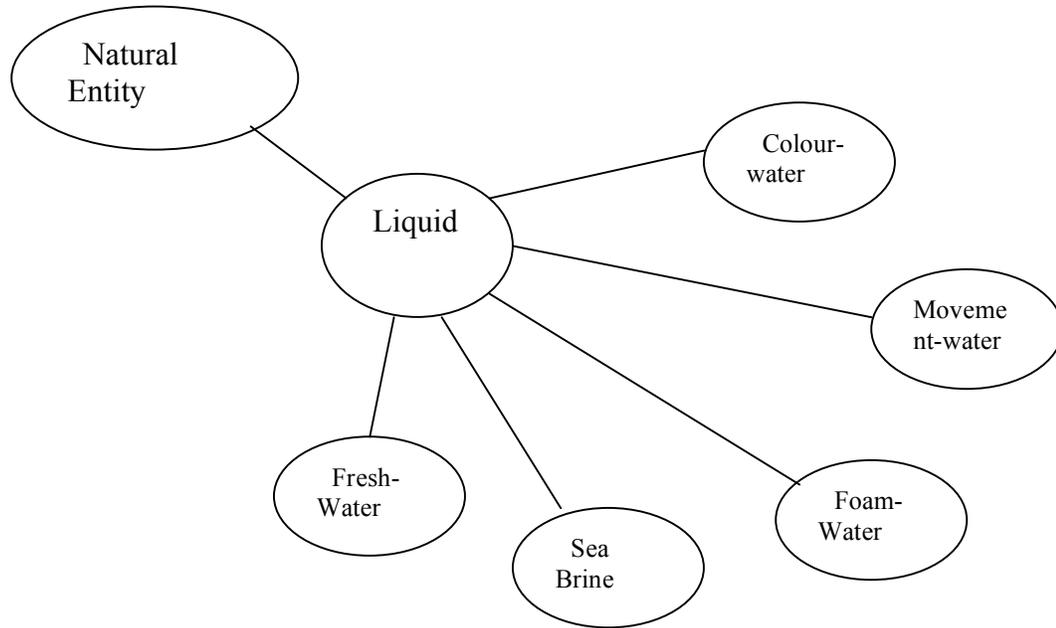


Figure 2.1 Fragment of one possible pre-scientific Greek representation of water's associated concepts. Straight lines represent kind relations. The concept of liquid might be substituted for the concept of water. I have also take liberty to disassociate the concepts from their paired deities.

From this survey of myths, we can see how pre-scientific Greeks, a seafaring group of island dwellers, differentiated their concepts of water by its various visible properties: fresh, salt, ocean, foam, brine, sea. And they ordered them using mythical stories of figures that personified them. This research is an incomplete survey of the Greek deities associated with the various properties of water, it is possible that a complete catalog would reveal more water deities, and, consequently, more concepts of water.

These divine figures are not only clues to the concepts of the pre-scientific Greeks, but are also invoked to explain the observations associated with the concept. These gods had the power to, among other things, alter waves and currents, influence the growth of sea flora and fauna, and cause droughts and floods. Apollodorus, for example, recounts two myths associated with drought and flood. The inhabitants of Rhodes, Apollodorus writes, declared that Rhodes belonged to Hera. In anger, Poseidon punished

the people of Rhodes by drying up all the bodies of fresh water, leaving the land completely waterless (Apollodorus, trans. 1921, 2.1.4). On another occasion an Ethiopian princess claimed that her beauty exceeded that of the Nereids, the personifications of different elements of the sea. Poseidon, sharing their anger, sent a flood to punish the people of Ethiopia (Apollodorus, trans. 1921, 2.4.3). Many similar examples are found in Odysseus's tortuous voyage home in Homer's *Odyssey*. Thus waves, currents, sea flora and fauna, droughts, and floods were often explained in pre-scientific Greek literature in terms of the gods who caused them.

Notice that our concept of water figures into the pre-scientific Greek worldview. FRESH WATER and OCEAN WATER are in our conceptual system, but on our current view they are not simples, but mixes; furthermore, we think those mixtures share a common constituent; however, on this interpretation the pre-scientific Greeks did not. Nowhere in the pre-scientific Greek worldview does anything resembling our concept of water exist.

Thales, Aristotle, and the Shift to Natural Entities

The mythical stage gave way to a qualitative one. At this stage natural entities, rather than supernatural ones, differentiated concepts and ordered them. Qualitative explanations of the observations associated with water probably began between 620 BCE and 546 BCE with Thales of Miletus. Because no primary documents exist, our best source for Thales' ideas about water is Aristotle who recounts them in *Metaphysics* and other places. Excerpts from *Metaphysics* show this much: 1) Thales thought that water was the basic material, and, therefore, collapsed the differences associated with the previous mythical conceptual system; 2) Thales reorganized these concepts based on their

relationship to water, the primary substance; and 3) Thales believed that water was the material cause of all things, and, thus, appealed to water to explained everything (Aristotle, *Metaphysics*, trans. 1953, sec. 983 b10, b25).

Thales thought that water was the basic material and the primary cause of all other things (Aristotle, *Metaphysics*, trans. 1953, sec. 983 b20). Viewing the world this way, all things were believed to be water in a different state; that is, all things were *modifications* of water, the primary substance. Before Thales the ancient Greeks thought that different occurrences of water were different kinds of things, and had different concepts for them. Thales collapsed those differences. He eliminated the distinctions between FRESH WATER, and SEA WATER, and the other concepts associated with the pre-scientific concept of water.

Today solid, liquid, and gas are considered physical states of matter. Thales believed that air, earth, and fire were physical state of water. It is not far fetched to say that Thales concept of water resembles our concept of matter.

Thales thought that water brought other things into existence, air, earth and fire (Aristotle, *Metaphysics*, trans. 1953, 983 b7-18). He supposed that as water changed states from liquid to gas, air and clouds were created. As water condensed and returned to the earth as a liquid it thickened into slime and mud, and eventually became earth and stone (Aristotle, *Metaphysics*, trans. 1953, 983 b22-28). Thus Thales ordered things in terms of their relationship to the primary substance water. There are things that water nourishes and things that water creates or becomes. Water nourishes living bodies and the sun, while it transforms into air, earth, and fire. In fact, Thales thought that water had the potential to transform into anything (Aristotle, *Metaphysics*, trans. 1953, 983 b22-28).

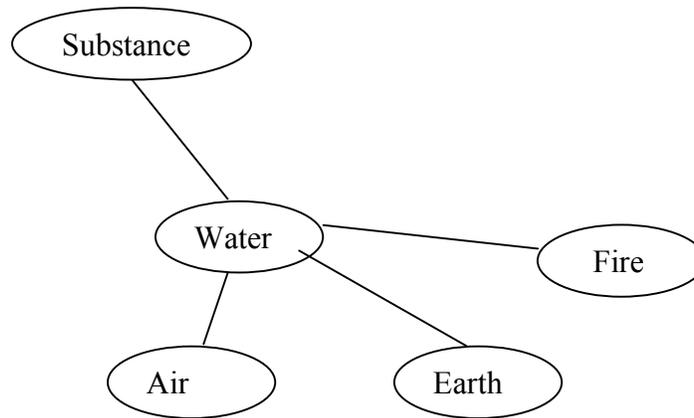


Figure 2.2. Fragment of Thales’s conceptual system interpreted from by Aristotle (Aristotle, *Metaphysics*, trans. 1922, sec. 983). Straight lines indicate kind-relations.

Given that Thales thought water was the most basic material, and that all other things were the result of its transformations, he organized concepts by their relationship to his concept of water. The Greeks before him used *myth* to understand their concepts, organizing them into a hierarchy of associated gods that personified concepts. Thales abandoned myth as an ordering principle in favor of the natural entities.

For instance, Thales explained cloud formation and air creation through the evaporation of water; he explained land formation—the build-up of silt on the banks of seas and rivers—as the condensation of water and its thickening. By another change of state water became fire. All things came into existence through water transforming into other states.

Aristotle thought that Thales’ theory could not account for the apparent opposition of earth and fire, and air and water (Aristotle, trans. 1930, sec. III). Given the apparent opposition, he reasoned that it was impossible to reduce one opposite to another (Aristotle, trans. 1930, Sec. III). For this reason Aristotle revised Thales’s conceptual system by classifying, air, earth, fire, and aether as substances along with water.

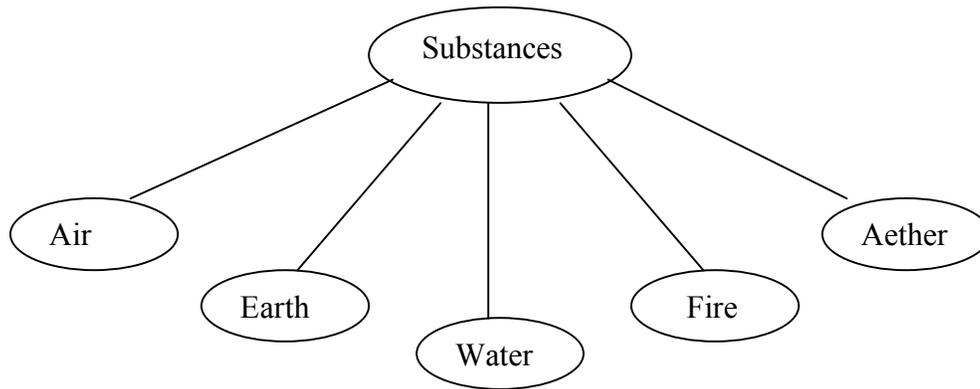


Figure 2.3. Fragment of Aristotle's conceptual system (Aristotle, *De Generatione et Corruptione*, trans. 1930, sec. III). Straight lines indicate kind relations.

Water remained classified as an elemental substance, though it no longer occupied that position alone. Aristotle classified air, earth, and fire as elemental substances, and added another, aether (a divine substance that makes up stars and planets). As a result water could not be the single cause of everything; and air, earth, and fire were not manifestations of it.

Conclusion

The pre-scientific Greeks differentiated WATER by the properties they thought were important. If I am right, and the Greek Pantheon roughly maps onto the pre-scientific Greek concepts, then each concept should be an elementary-simple akin to the elements of the Periodic Table. The pre-scientific Greeks differentiated their concepts related to water by macro-visible properties. It is not clear that they thought that they shared a common physical constituent, aside from noticing that they were all liquid.

We have examined, so far, two major shifts in the evolution of WATER: 1) a change from a mythical to a qualitative view entailed changing the organizing principle of the conceptual system from one based on the stories of myth to one based on natural entities. Thales collapsed the distinctions associated with the pre-scientific concepts of water, and concluded that water was the most primary substance, and, therefore, all things were a transformation of it; and 2) Aristotle revised Thales view by adding four other primary substances or elements.

Chapter 3

The 18th and 19th Century Natural Philosophers

Introduction

Aristotle's thoughts on natural philosophy exercised a powerful effect well into the Middle Ages, and its influence lingered into the 17th century. For that reason this chapter skips ahead, chronologically, almost two thousand years. My aims in this chapter are a continuation of the last. I shall examine two historical periods, with an eye on the conceptual changes that mark each shift. I shall begin with the Birmingham natural philosophers and their experiments on air; the isolation of the component parts of water; and the interpretation of those observations. I shall end with Lavoisier's reinterpretation of the same experimental observations.

From the history I shall conclude: 1) The shift from Aristotle to the Birmingham natural philosophers required a reclassification of water, from element to compound; and 2) The shift from the Birmingham philosophers understanding of water to Lavoisier's involved a reinterpretation of water's parts, though water continued to be classified as a compound.

The English Reclassification of Water From Element to Compound

Though Stahl had made important changes to Aristotle's conceptual system in the beginning of the 17th century, fragments of Aristotle's system survived almost seventy years after Stahl. Still, Stahl's reorganization of Aristotle's system continued to classify water as an element (Thagard, 1992, p. 41). That view, however, was abandoned in the

mid-18th century when Joseph Priestley and Henry Cavendish began a program that investigated air. Their results first suggested that there were many kinds of air, which ultimately implied that water is not elementary, but rather, the union of airs.

Priestley and Cavendish interpreted the results of their experiments on air within Stahl's conceptual system. Stahl divided the elementary into water and earths, and earths into three types: verifiable, liquefiable, and phlogiston (Stahl, trans. 1730, p. 36). Phlogiston, Stahl thought, was a kind of inflammable principle: a substance that could not be burned and had the potential to extinguish fire if present in abundance (Stahl, trans. 1730, p. 36).

The concept 'phlogiston' is vital here. The Birmingham natural philosophers working within Stahl's conceptual system believed that phlogiston was a natural entity. The concept of phlogiston was used to interpret their experimental observations.

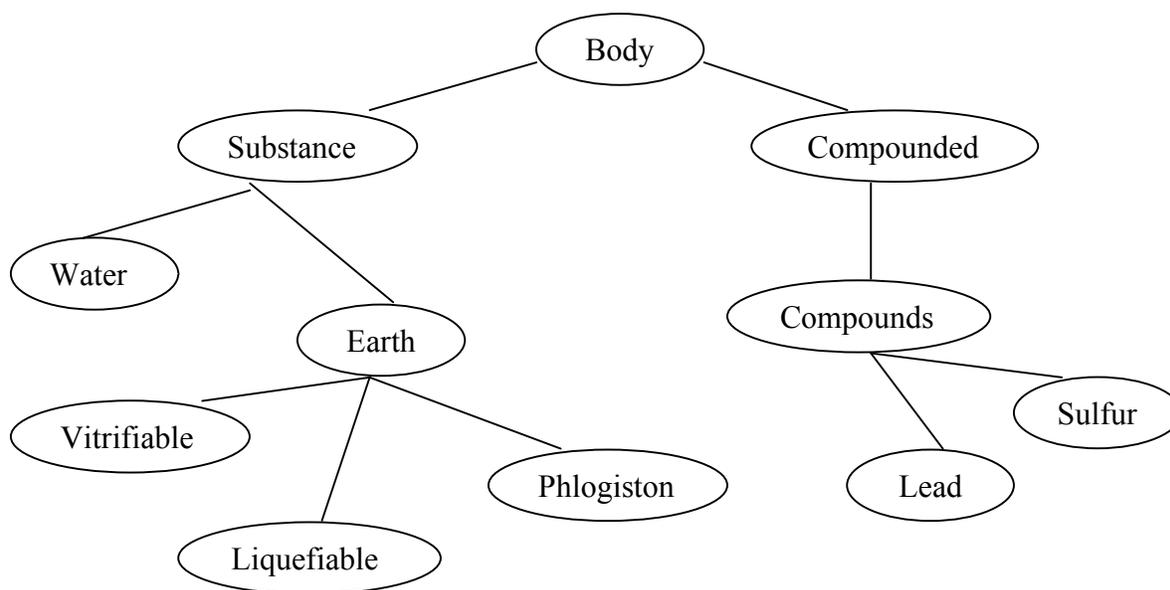
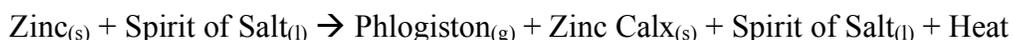


Figure 3.0. Fragment of Stahl's conceptual system in 1723 (Thagard 1992: 41). Straight lines indicate kind-relations. Taken from *Conceptual Revolutions*. This depiction is incomplete because I have only included enough to show the reorganization after Watt's interpretation of Priestley's and Cavendish's experiments.

With this conceptual system in the background, Henry Cavendish (1766) isolated inflammable air (hydrogen gas), and Joseph Priestly (1775) isolated ‘dephlogisticated’ air (oxygen gas). Though it is clear that Priestly did not immediately recognize that these airs were component parts of water, Cavendish’s thoughts are not nearly as obvious.

Cavendish isolated what he thought to be inflammable air or pure phlogiston. He produced this air by dissolving certain metals (namely, zinc, iron, and tin) in certain acids (namely, vitriolic acid, spirit of salt, or nitrous acid). He then captured the emitted air. Cavendish’s observations (Cavendish, 1766, p. 144-146) suggest the following reaction, which I have written as a modern chemical equation:

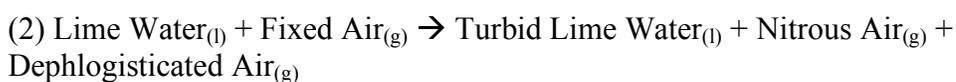
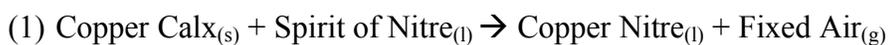


Equation 3.0. I have written the names of the chemical entities as Cavendish recorded them. I added subscripts that indicate the state of the entities: (g) indicates a gas, (l) indicates a liquid, and (s) indicates a solid.

Cavendish observed that the Zinc lost mass in the reaction while the Spirit of Salt lost volume. Phlogiston, Cavendish thought, was liberated from zinc by the acid. In the process, heat was released, and Zinc was reduced to its calx (Cavendish, 1766, p. 145-146).

Cavendish captured some of this air in a flask. Testing it, he noticed that the air extinguished a candle flame; indeed, no flame could survive in the presence of this air, hence its phlogistic interpretation. Cavendish presumed that this air was, in fact, phlogiston in a gaseous state (Cavendish, 1766).

Priestly isolated dephlogisticated air or air absent phlogiston by mixing the dried calx of certain metals², namely, gold, silver, and copper in nitrous acid. After the reaction Priestly collected and isolated many different kinds of air, one being dephlogisticated air. Priestly's observations (Priestly, 1977, p. 55-65) suggest the following reactions, which I have written as two modern chemical equations:



Equation 3.1. I have written the names of the chemical entities as Priestly recorded them. I added subscripts that indicate the state of the entities: (g) indicates a gas, (l) indicates a liquid, and (s) indicates a solid.

Priestly recovered the calx of copper by dissolving it in oil of vitriol. He dried the calx, mixed it with spirit of nitre and captured fixed air, then mixed the fixed air with lime water to recover and nitrous dephlogisticated air (Priestly, 1775; 1777, p. 60-61).

Having captured the air, he investigated its properties and observed that a flame in the presence of dephlogisticated air burns stronger and brighter than in the presence of common air. He had also designed experiments that suggested that respiration is best in the presence of dephlogisticated air (Priestly, 1775, p. 386-388).

Cavendish and Priestly isolated what are now known as hydrogen and oxygen gases—the constituent parts of water. Water's composition is now elementary knowledge, but this knowledge did not come easily. Despite experimenting with both gases, neither Priestly nor Cavendish immediately inferred water's composition. Priestly

² Though the state of the metal might seem a negligible difference, it's considerable. What 18th century scientists called the calx of the metal, was the metal oxidized. With that in mind, Priestly's observations should be unsurprising.

(1783; 1785) and Cavendish (1784) conducted experiments that involved both gases, which they had reported produced a dew, but water's composition still evaded them. Only after considerable thought did Cavendish and his friend James Watt begin to think that water could be the product of these two airs. Priestly, on the other hand, despite performing some of these experiments himself, remained skeptical. He was one of the last among his peers to accept that water consisted of inflammable and dephlogisticated airs, though his and Cavendish's experiments were the first step in this direction.

In Priestley's last volume of experiments, he discusses an anomaly, which Cavendish investigated (Cavendish, 1784, p. 126). He observed that a mixture of common and inflammable airs ignited by an electric spark resulted in a weight loss of the airs. He also noticed that the vessel wherein the reaction occurred, though dry prior to the reaction, had accumulated moisture on the wall of the vessel. Priestly initially explained this observation within Stahl's conceptual system concluding that the water was carried in the common air and liberated when that air was phlogisticated (Cavendish, 1784, p.126). Priestley's explanation kept Stahl's conceptual system intact.

Unsatisfied with Priestly's observations and conclusions, Cavendish replicated Priestley's experiments and recorded the following results:

Common Air	Inflammable Air	Weight Loss	Air Remaining	Test One	Standard
1	1.241	.682	1.555	.055	.0
1	1.055	.641	1.413	.063	.0
1	.705	.647	1.059	.066	.0
1	.423	.612	.811	.097	.03
1	.331	.476	.855	.339	.27
1	.206	.294	.912	.048	.58

Table 3.0. Taken from Cavendish's Experiments on Air 1784. Note that the final column represents the remaining 'inflammable air' after the explosion. The table shows that the more inflammable air is reacted with common air the higher the resultant weight loss of the airs. The measure of inflammable air is expressed in decimals of the common air.

Completing his experiments, Cavendish explained the anomaly differently. He notes that the “423 measures of inflammable air are nearly sufficient to completely phlogisticate 1000 of common air” (Cavendish, 1784, p. 128). He concluded that almost all the inflammable air, and about one-fifth of the common air, had condensed into dew when exploded.³ Refer to row four of the table above. Investigating this dew, Cavendish concluded it was pure water (Cavendish, 1784, p. 129).

Knowing that common air consisted of many airs, this experiment suggested another: Cavendish filled a glass globe with a mixture of inflammable and dephlogisticated airs, at an almost two-to-one ratio (Cavendish, 1784, p. 130).⁴ Then he exploded the airs with an electrical spark. Cavendish examined the dew produced from the explosion and, after some tests, concluded that it was acidic, as Priestly had reported.

However, when he changed the proportions to one part inflammable air to ten parts dephlogisticated air, Cavendish observed that the dew produced was pure water. In this case, he thought, the dephlogisticated air had been completely phlogisticated. Ultimately Cavendish concluded that “when a mixture of inflammable and dephlogisticated air is exploded in such proportion that the burnt air is not much phlogisticated, the condensed liquor contains a little acid, which is always of the nitrous kind, whatever substance the dephlogisticated air is procured from; but if the proportion be such that the burnt air is almost completely phlogisticated, the condensed liquor is not at all acid, but seems pure water, without any addition whatever” (Cavendish, 1784, p. 132).

³ This observation is consistent with the proportion of oxygen in atmospheric air as oxygen makes up approximately twenty percent of the earth’s atmosphere.

⁴ Though one might expect the first experiment to produce water because hydrogen and oxygen combine in a 2:1 ratio to form water, Cavendish did not see that result likely because his process/instruments used to produce the two gases allowed impurities.

The next step is tricky. The wording of Cavendish's explanation of his results makes it difficult to determine exactly what he thought. He wrote: "there seems to the utmost reason to think, that dephlogisticated air is only water deprived of its phlogiston, and that inflammable air is either phlogisticated water or else pure phlogiston; but in all probably the former" (Cavendish, 1784, p. 140). Cavendish's wording might mean: 1) that dephlogisticated air is essentially water missing an inconsequential part; or 2) that dephlogisticated air is water missing an essential part. If first interpretation is true, then Cavendish kept with Stahl's conceptual system. If the second interpretation is correct, then Cavendish suggested a change in Stahl's conceptual system—classifying water as a compound instead of an element.⁵ Whatever the case may be, there are instances of hesitation in Cavendish's publications to reclassify water as a compound, rather than as a simple substance.⁶

Watt was more explicit and less hesitant. Watt (1784) concluded and maintained from Priestley's and Cavendish's prior experiments, that water is a compound that consists of inflammable and dephlogisticated airs. While Watt generally worked within Stahl's conceptual system, his explanation of Priestley's and Cavendish's experiments requires a reclassification of water from element to compound.

Watt concluded that the experimental observations suggested the following reaction, written with modern technique:

⁵ Even if the second interpretation were right, Watt had already explained some of Priestley's results by reclassifying water from element to compound. Cavendish knew this because Watt had presented those ideas to the Royal Society (1784).

⁶ It is a matter of historical tension whether Cavendish knew of Watt's interpretation of Priestley's experiments prior to making his own conclusions. Therefore if the second reading of Cavendish is correct, then it might be said that Cavendish and Watt arrived at similar conclusions, independently.



Equation 3.2. I have written the names of the chemical entities as Watt originally conceived them. I added subscripts that indicate the state of the entities: (g) indicates a gas, (l) indicates a liquid, and (s) indicates a solid.

Watt maintained that the union of inflammable and dephlogisticated airs produces water, and, due to the state change, latent heat is released.⁷ The same year that Cavendish published *Experiments on Air*, Watt read a paper to the Royal Society suggesting that “phlogisticated air unites completely with about twice its bulk of the inflammable air from metals” (Watt, 1784, p. 349), which he had deduced from Priestly, and Cavendish’s experiments.

Watt’s explanation of the observations of Priestly and Cavendish came to be accepted, which instituted a change in Stahl’s conceptual system:

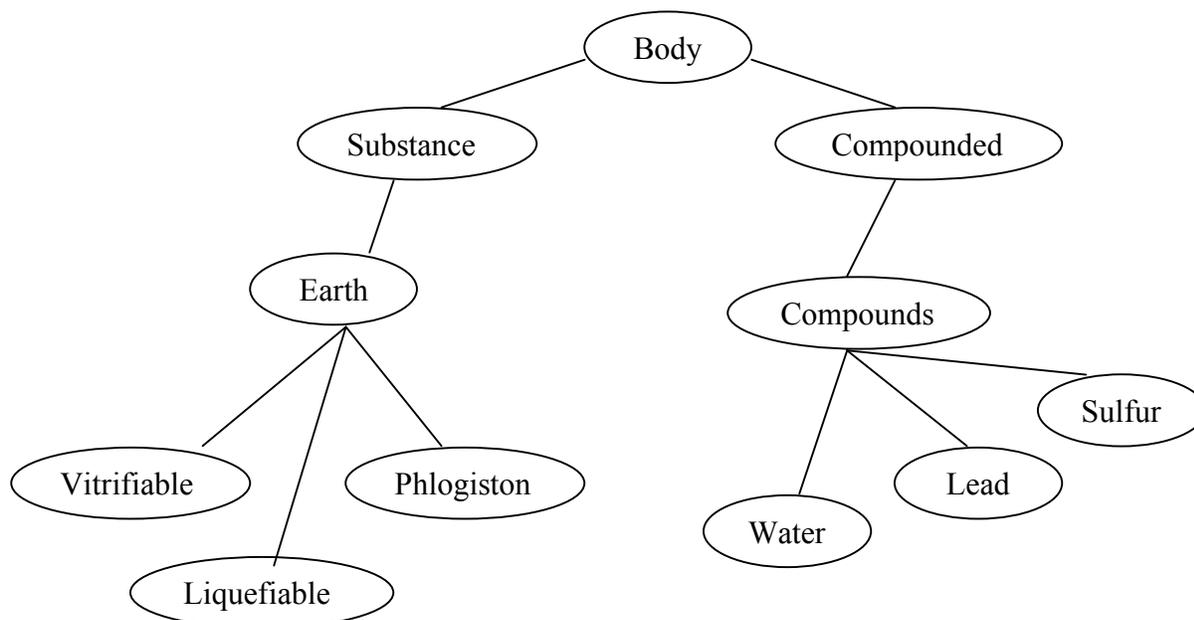


Figure 3.1. Fragment of the reorganization of Stahl’s conceptual theory given Watt’s reclassification of water to compound.

⁷ Cavendish acknowledges and distances himself from Watt’s position in *Experiments on Air*. Cavendish insists that the concept of ‘latent heat’ is fictitious (Cavendish, 1784).

Lavoisier's Reinterpretation of Water's Parts

Both Watt and Cavendish stress that Antoine Lavoisier, a scientist in France, was kept apprised of their experiments and conclusions. On a trip to France, Watt himself relayed some of Priestley's relevant experiments directly to Lavoisier (Blagden, (n.d), p. 70), and Cavendish mentions instances of his aides sharing his results with members of Lavoisier's circle, which Lavoisier then replicated on a larger scale (Cavendish, 1784, p. 134).

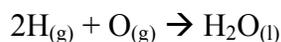
Repeating Cavendish's experiment while aware of Watt's and Cavendish's conclusions, Lavoisier arrived at the same conclusions, namely, that water is a compound of two substances (Lavoisier, trans. 1790, p. 83). However, he fit those observations with his conceptual system that had eliminated phlogiston, and, thereby, reclassified the constituents into oxygen and hydrogen (Lavoisier, trans. 1790, p. 88-90).⁸

Lavoisier's real contribution is this: where Watt and Cavendish saw the union of dephlogisticated and inflammable airs, Lavoisier saw the union of two different kinds of elements: oxygen and hydrogen. True, there are similarities: Lavoisier's conclusion and the conclusion of his English contemporaries both reclassified water from element to compound. But Lavoisier and his circle did not use Stahl's conceptual system to describe

⁸ Blagden wrote in a letter to Dr. Crell, which is not dated, "But those conclusions (Watt and Cavendish's) opened the way to Mr. Lavoisier's present theory, which perfectly agrees with that of Mr. Cavendish; only that Mr. Lavoisier accommodates it to his old theory, which banishes phlogiston. Mr. Monge's experiments, (of which Mr. Lavoisier speaks as if he made about the same time) were really not made until pretty long, I believe at least two months, later than Mr. Lavoisier's own, and were undertaken on receiving information of them. The course of all this history will clearly convince you that Mr. Lavoisier, (instead of being led to the discovery, by following up the experiments which he and Mr. Buequet had commenced in 1777) was induced to institute again such experiments, solely by the account he received from me, and out English experiments; and that he really discovered nothing, but what had before been pointed out to him to have been previously made out, and demonstrated in England" (Blagden, (n.d), p.73).

the constituents of water. Instead he devised a new one and conceived of the constituents in terms of that system.

Lavoisier's experiments on the composition of water had been prompted by experiments across the Channel; and Lavoisier had been aware of the conclusions drawn from them, but Lavoisier completely reformulated those conclusions without PHLOGISTON. Lavoisier (1789) described the following observations written with some modern technique:



Equation 3.3. H represents hydrogen, O oxygen. I added subscripts that indicate the state of the entities: (g) indicates a gas, (l) indicates a liquid, and (s) indicates a solid

Conclusion

This stage in historical development of the concept of water is marked by two major changes: 1) a reclassification of water from element to compound; and 2) a reinterpretation of water's component parts. The Birmingham natural philosophers unwittingly isolated water's parts, and noticed an anomalous dew formation when conducting experiments with those parts. Cavendish and Watt concluded that the dew was water and inferred that water is not an element, but rather, a compound. Cavendish and Watt described water's parts with phlogiston, an entity that proved nonexistent. Lavoisier then reinterpreted the components without phlogiston. We continue to use Lavoisier's description: H_2O .

Chapter 4

20th and 21st Century Developments

Introduction

The 20th and 21st century evolution of the concept of water has been relatively uneventful compared to the dramatic reorganization and reclassification that marked earlier periods. This chapter investigates the contemporary period, extending back to the early 20th century. I argue that it has been characterized by an ongoing project to isolate, observe, and understand mass variant H₂O molecules. Again, I shall emphasize the conceptual changes that separate this period from the last.

The scientific history of this period will demonstrate two things: 1) this period is marked by the differentiation of WATER; and 2) it is an open question as to whether mass variant water molecules are different types of water, or different kinds of molecules altogether.

Isotopes and Differentiating H₂O Molecules

Since Lavoisier, we have continued to describe water as two-parts hydrogen and one-part oxygen.⁹ Our understanding of chemistry, of course, has deepened, and our understanding of water has deepened, too. We are beginning to understand water's unusual properties, and have started to differentiate it from other liquids that share its

⁹ We have continued to describe water as two-parts hydrogen and one-part oxygen, but the meanings of the concepts HYDROGEN and OXYGEN have changed. Paul Needham (2002) noted that it was not until Dalton that these concepts were understood with an atomist model.

basic constituent parts (i.e. hydrogen and oxygen) but differ by mass and chemical properties.

In the early 20th century chemists speculated that the mass of an element was not homogenous across the board: that is, not all instances of that one atom had identical atomic masses. The initial research in this direction suggested the isotopic theory: an atom of one kind is a heterogeneous mixture of atoms with different physical intra-atomic structures, but homogenous chemical properties, aside for some properties that directly depend on atomic mass. Moreover, these mass variant atoms occupy the same position in the Periodic Table because their positive and negative charges coincide with that position (Soddy, 1913, p. 399-400). Fredrick Soddy framed this theory, and mass variant atoms of one kind were henceforth called isotopes, which is Greek for “at the same place.” The reasoning is simple: many physically distinguishable entities occupied the same space on the periodic table.

Fredrick Soddy’s theory of isotopes was a result of his research, which suggested that the radioactive atoms had isotopes (Soddy, 1922, p. 372). But the isotope theory remained simply a suggestion until Francis Aston’s work in mass spectroscopy validated it, and extended the isotopic atoms beyond the radioactive ones (Aston, 1920, p. 617). Aston measured the atomic masses of chemically homogenous atoms using a mass spectrometer, which indicated the presence of isotopes. He continued his research and by the time he had received the Nobel Prize with Soddy for his work, he had isolated 212 of them (Aston, 1922, p. 16).

The discovery of isotopes was a significant moment in the history of chemistry. In fact, chemists were generally relieved. Scientists had assigned hydrogen the atomic

mass one, and expected the masses of all other atoms to be whole number multiples. To their surprise, most of their observations yielded atomic masses with significant remainders. Soddy's and Aston's discoveries explained these observations: scientists had been measuring the mass of a heterogeneous mixture of isotopes, and each isotope had a different mass. The remainder had been explained as an average of atoms with the same number of protons and electrons but different masses.

Approximately twenty years later Harold Urey, then assistant professor of chemistry at Columbia University, began to wonder if the smallest atom—hydrogen—also had isotopes (Palmer, 1934, para. 7). Urey presumed that hydrogen's first isotope must be double its mass because hydrogen is assigned an atomic mass of one, and if the whole number hypothesis is right, then the next available mass is two (Urey, 1932, p. 4). And since there exists a relationship between atomic mass and volatility, Urey was able to predict that the heavier hydrogen would be less volatile, and he was therefore able to separate the two hydrogens by distillation (Urey, 1932, p. 6). The spectroscopic method was applied to the distilled hydrogen, which confirmed a mass doubling. Following the publication of this work in 1932, Urey was awarded the Nobel Prize.

Urey's discovery had immediate implications for our understanding of water, which professor W. Palmer (1934) recognized, and noted in his Nobel Prize ceremony speech. Palmer noticed two implications: 1) if the hydrogen atoms in a water molecule are replaced by hydrogen's first isotope, then the mass ratio is such that there is a greater proportion of hydrogen in the water molecule; and 2) the mass of the entire molecule will be heavier given the additional mass of the hydrogen molecules. His reasoning is quite simple:

The smallest particles of water, its molecules, are regarded as consisting of two atoms of hydrogen, with atomic weight 1, and one atom of oxygen, with atomic weight 16. As the whole molecule, taking the atomic weight of hydrogen as the unit, thus weights 18, water ought to consist of hydrogen to the extent of $\frac{2}{18}$ or $\frac{1}{9}$, i.e. to about 11%, the remainder being oxygen. If, however, the two hydrogen atoms are replaced by the atoms of the isotope, which are twice as heavy, the water will consist of four parts by weight of hydrogen and sixteen parts by weight of oxygen, i.e. will contain 20% of hydrogen. It should also be heavier, inasmuch as each particle is heavier in the proportion of 20 to 18. (Palmer, 1934, para. 10)

While Urey was working on isotopic hydrogen, James Chadwick had been investigating the effects of a certain type of radiation on atoms. The data he gathered was best explained with the existence of a new subatomic particle, the neutron, with a mass one and charge zero (Chadwick, 1932, p. 312). The existence of the neutron fit perfectly with the theory of isotopes. It explained the mass variance between atoms with the same number of protons and electrons.

Water's first mass variant was dubbed "heavy water", and given the chemical formula D_2O or 2H_2O . Its additional mass was accounted for by the addition of a neutron. The 'D' in D_2O stands for deuterium, a hydrogen atom with a proton and a neutron. The superscript "2", in the second notation, signifies the additional neutron on the hydrogen atom.

Mass and proportion were not the only differences, however. While scientists had not noticed any chemical differences of isotopic atoms, scientists at Berkeley reported many important different chemical properties in the mass variation of molecular water. Heavy water cannot support life in its pure state; heavy water's freezing point is almost four degrees higher than water's; its boiling point is one and a half degrees higher; and heavy water can dissolve less salts, and is more viscous (Lewis, 1933, p.3503-3504 Lewis, 1934, p. 151-153).

Quantum Effects Explain the Differences

Scientists are now beginning to understand the reasons for these observed chemical differences, and not surprisingly, the additional neutrons, they think, are the cause. The neutrons add mass to the nucleus of the molecule. Equations in quantum mechanics are used to determine bond energies and those equations partly depend on the mass of an atom's nucleus. Soper and Benmore (2008) used experimental techniques to show how the geometry of H₂O and D₂O differ. Geometrically, H₂O has a longer intramolecular OH bond than D₂O's corresponding OD bond (Soper & Benmore, 2008, p. 2); furthermore, the intermolecular bond is shorter in H₂O than D₂O. The intra and intermolecular bond lengths are not simply different from an H₂O molecule, but the length differences vary. These differences result in geometric variations between H₂O and D₂O (Soper & Benmore, 2008, p. 1). Without going into the specifics: H₂O has a broader structure than D₂O (Soper & Benmore, 2008, p. 1). In other words, H₂O takes up more space. The geometric difference is attributed to "the increased quantization of the proton compared to the deuteron [a proton and a neutron]" (Soper & Benmore, 2008, p. 4), and quantization depends mass.

Mass alters bond energies, which can be used to predict the behaviour of molecules. The greater the mass of a molecule the more classically it will behave; however, the smaller the mass the more quantum effects will be pronounced. The property differences between H₂O and D₂O have been attributed to the different masses, and, therefore, the strength of quantum effects.

D₂O is not the only mass variant water molecule. Scientists have identified another mass variant water molecule, T₂O, which resembles H₂O in appearance, but does

not have the same properties. The hydrogen atoms of the T_2O molecule each have two neutrons. These two neutron hydrogen atoms are denoted with a T. Not only does T_2O not share H_2O 's properties, but also in its pure state it is radioactive, corrosive, and carcinogenic (Doe Handbook, 1991, p.6-7; Yin et al., 2002).

The differences are not obvious because in any volume of naturally occurring H_2O there are only traces of D_2O and T_2O . In such a state, the properties of these isotopes do not manifest themselves. Only in higher relative concentrations do we notice the properties of these mass variant water molecules.

D_2O and T_2O are mass variant water molecules, but in these instances only the hydrogen is isotopic (2H and 3H , or deuterium and tritium). There are, however, naturally occurring mass variant water molecules whereby the oxygen atom is isotopic, not the hydrogen. Oxygen has three naturally occurring isotopes, but I shall only consider one, ^{18}O . $H_2^{18}O$ is of significant interest to meteorologists who have reported that it takes more energy to vaporize (Harmon, 1961, p. 1702). This difference has important implications for atmospheric models because it will allow for better predictions.

What Do The Differences Mean?

These discoveries mark a period of rapid differentiation of WATER. This period is, as I have mentioned, ongoing, and, therefore, the details of the changes are not yet clear. As far as I can tell there are two options: 1) divide WATER into different types; or 2) differentiate WATER into different kinds.

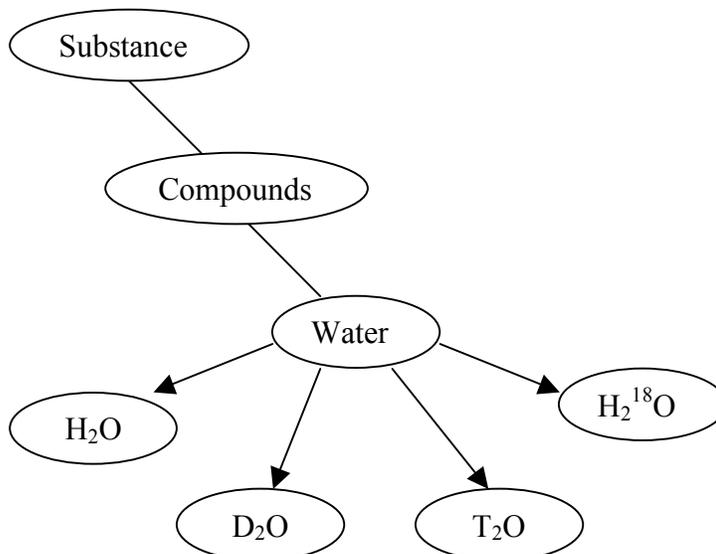


Figure 6.0. The figure represents one possible interpretation of the effects of the current work of scientists. In other words, we think of the mass variation of molecular water. Straight lines indicate kind-relations. Straight lines with arrowheads indicate types of water.

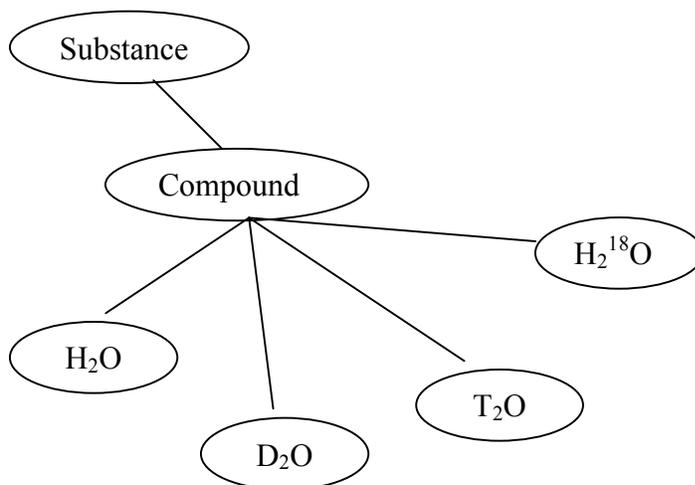


Figure 6.1. This figure represents another possible interpretation of the differentiation that is currently going on in chemistry. Each molecule is considered a separate compound different from each other, and different from water.

Currently, I think, scientists are learning toward the first model. However, there is some controversy, and the nomenclature appears to be a manifestation of it. The International Union of Pure and Applied Chemistry (IUPAC) prefers a nomenclature that signals an isotope as a type of its atom. IUPAC recommends that chemists write a number

superscript in front of the atom designating its number of neutrons. For instance, D_2O is written 2H_2O if the accepted nomenclature is followed.

Chemists and physicists seem to prefer D_2O , however. If protons and electrons make the differences, then it seems right to think of mass varied molecular water as types. Then again, if properties make the differences, it seems better to think of water's isotopes as kinds: each a different compound. The D_2O nomenclature makes sense if properties are what are important, but the 2H_2O nomenclature makes sense if protons and electrons turn out to be the only particles that matter.

Conclusion

Differentiation characterizes this period in the historical development of WATER— H_2O is different from D_2O , which is different from T_2O , which is different from $H_2^{18}O$. The number of neutrons differs, and, as a result, the mass of each molecule differs. Scientists think that the mass differentials are responsible for important property differences between the molecules. I have suggested that this process of differentiation means one of two things: 1) isotopes continue to fit the category built from protons and electrons; or 2) neutrons become a distinguishing feature, and as a result, isotopes are thought of as distinct atoms.

Chapter 5

On what does the Meaning of the Concept of Water Depend?

Introduction

Chapters two, three, and four told the history of the concept of water. Conceptual change is an important part of that narrative: differentiation, coalescence, reorganization, reclassification, and redescription. These conceptual changes signal different developments in the history of WATER, suggesting that theory plays an important role in the meaning of concepts. Despite these conceptual shifts when enough historical data are available, it is clear that communication happens across theories.

I shall now put the history to task and evaluate the expected histories associated with the three answers that I proposed to the question, on what does the meaning of the concept of water depend?

The first answer, recall, is that the physical world determines the meaning of the concept of water. I shall demonstrate the historical predictions associated with this view are inconsistent with the history of the concept of water, which is characterized by dramatic conceptual shifts.

The second answer I consider is that a theory determines the meaning of the concept of water. Kuhn's (1961) historical analysis of scientific development supports that view. I shall demonstrate that this answer is inconsistent with the history of the concept of water, and that Kuhn's historical analysis overlooked communication across theories in the history of science.

The third answer I shall evaluate is that the meaning of the concept of water depends on both the world and a theory. Of the three answers, the third best fits the history of the concept of water because part of the expected history associated with the first and second answers match the actual historical development of the concept of water. Given that elements of both M1 and M2 are consistent with the actual history, a better understanding of WATER'S history should include both the physical world and theory. The physical world explains cross theory communication because the physical world is relatively stable, and stability is required for communication. Theory explains the sharp conceptual shifts that characterize WATER'S history because it is relatively volatile.

Putnam's Twin Earth thought experiment is meant to show that the meaning of a term and its corresponding concept depends on the physical world and the theory in which it is embedded. That conclusion is right, but Putnam's thought experiment is not the reason it is right. The Twin Earth thought experiment includes at least one chemically improbable assumption, suggesting that the results of that experiment are not supported by the experiment itself. The history of the concept water does, however, support Putnam's conclusion.

Evaluation of the Historical Scenario One

The first historical scenario is tied to the idea that the physical world determines the meaning of WATER. M1 suggests a history whereby concepts are stable, and as a result, communication is possible.

That suggested history, however, is partly inconsistent with the history of WATER. WATER is not a stable concept. As seen in Chapter One, the pre-scientific Greeks had

many concepts associated with water. The pre-scientific Greeks had personified fresh water and ocean water with primordial gods, which means that the pre-scientific Greeks had concepts of fresh water and ocean water. If the other gods of the Greek Pantheon are included in the discussion, then the number of concepts connected to water multiplies dramatically.

Thales collapsed the pre-scientific water related concepts. He thought water was the material cause of all things, and that everything was a modification or transformation of it. In other words, water was every substance, material, or object. The concepts FIRE, AIR, and EARTH were differentiated from each other by their state. This meant that Thales had used a natural entity, not supernatural ones, to organize concepts in a hierarchical system. In this case, how they relate to water.

Aristotle revised Thales' conceptual system. Water, he thought, could not be the only elemental substance because it did not account for the apparent opposition of earth and fire, and water and air. If all things are modifications of water, he reasoned, we should not observe such opposition. Therefore he reclassified earth, fire, air, and aether as elementary substances whereas Thales thought water was the only substance, and earth, fire, air were different manifestations of water.

Skipping ahead nearly two thousand years, the Birmingham natural philosophers of the 18th century who had been working within Stahl's conceptual system had discovered water's parts. Priestly and Cavendish had been conducting experiments on air, both isolating many kinds. Unwittingly Priestly had isolated one part of H₂O, and Cavendish the other. Influenced by Stahl's conceptual system, they described these parts as dephlogisticated and inflammable air. Subsequent experimental observations

suggested to Watt and Cavendish that water was the product of these airs, and consequently, water was reclassified as a compound, not an element.

The current period in the evolution of WATER is a case of differentiation. Currently scientists have been investigating mass variations of molecular H₂O. The physical differences produce chemical differences observable at the macro level. How scientists classify these differences, however, seems an open question. Nonetheless this period is characterized by differentiation.

These conceptual changes are inconsistent with the seamless history expected from a concept that the physical world had fixed. The meaning of WATER was different at each point that I have documented. The meaning of WATER for the pre-scientific Greeks is probably closer to our concept LIQUID. Just as there are different kinds of liquids for us, the pre-scientific Greeks thought there were different kinds of water.¹⁰ For Thales, the concept of water resembled our concept MATTER; and Aristotle had classified water as an element.

The Birmingham natural philosophers reclassified water as a compound. They described water's parts with PHLOGISTON connecting WATER'S meaning with it too. Lavoisier accepted water's reclassification; however, he rejected its link to PHLOGISTON, and redescribed water's parts describing them with new concepts HYDROGEN and OXYGEN, altering its meaning again.

Recently, scientists began investigating the observable chemical differences between H₂O and mass variant water molecules. The results suggest that mass variant H₂O molecules have observably different chemical properties. What those differences

¹⁰ As far as I can tell there is no god in the Greek Pantheon that personifies water generally. All the Greek water deities are associated with observable properties of water or natural manifestations of it.

mean, however, is unsettled. One thing is clear, however, the meaning of WATER is now connected to the meaning of ISOTOPE because isotopic theory is used to understand the differences between mass variant water molecules. This new association adjusted the meaning of WATER again.

These conceptual shifts show the instability of the historical development of the concept of water. That instability is contrary to the relatively stable history predicted by M1, and, thereby, serves as evidence against that account of meaning.

Evaluation of the Second Historical Scenario

The second historical scenario follows from the claim that the meaning of a concept depends on a theory. Behind that claim is the view that theory determines the world because it shapes our observations, and, thereby, our concepts. If a theory determines the meaning of a concept in this way, then concepts should not be stable at all; instead, they should change with theory change. As a result, people working within different theories ought to be unable to communicate, given that the meanings of the concepts they would be using would differ (Kuhn, 1961, p.149).

The trouble with this view is that communication happens across theories. When enough historical data is available the record shows that cross-theory communication happens and it is beneficial. Given that communication takes place and is beneficial, a theory can only be part of the picture. If it were the entire picture, then cross-theory communication would not be part of the historical record. Though Kuhn had anticipated the historical inaccuracy of the conclusion of the Twin Earth thought experiment, he did not think that cross-theory communication would feature in the historical development of

WATER. Perhaps that is why he thought that WATER and other concepts like it were theory-dependent (Kuhn, 1989; 1990).¹¹

The Birmingham natural philosophers had made experimental observations that suggested that water was a compound. They described their observations using Stahl's conceptual system, and consequently, understood water's parts with PHLOGISTON. The historical evidence suggests that these experiments and the observations drawn from them had been relayed to Lavoisier. Lavoisier had replicated them and agreed that water should be reclassified as a compound; however he interpreted its parts without PHLOGISTON. Instead he thought the parts were hydrogen and oxygen.

Historical Critique of Kuhn's Non-Communicative Thesis

Historically speaking, the further one goes back the less historical data are available. Recent history, however, is better documented. For that reason, I want to focus on a relatively recent conceptual shift in the historical development of WATER to show that the historical record contradicts Kuhn's conjecture that cross-theory communication is impossible. The conjecture follows from the view that a concept's meaning depends only on the theory in which it is embedded, and, therefore, changes when a theory changes. I shall examine the conceptual shift between the Birmingham natural philosophers and Lavoisier.

¹¹ Kuhn argues that it was not until the Chemical Revolution that the "distinction between solids, liquids, and gases became physical, not a chemical" (Kuhn, 1989, 82). If Kuhn is right, then the different states of water (solid, liquid, gas) were differentiated chemically not physically prior to Lavoisier. This adds an additional level of conceptual change to the concept that refers to water. Paul Needham (2000) made a similar point in *What is Water?*

Recall from chapter three that the Birmingham natural philosophers had made experimental observations that suggested water was not elementary, but composed of parts. As a result the Birmingham natural philosophers reclassified water, grouping it with the compounds. Lavoisier was informed of these experiments, the observations, and Watt and Cavendish's conclusions. He replicated their experiments and agreed with the reclassification of water, but understood water's parts differently.

There are three historical facts that show that communication happens between people of different theoretical standpoints: 1) the Birmingham natural philosophers replayed their experiments to Lavoisier; 2) Lavoisier was privy to Cavendish's and Watt's experimental conclusions; and 3) the Birmingham natural philosophers complained that Lavoisier's 'discovery' amounted to nothing more than Cavendish's and Watt's idea repackaged without Stahl's conceptual system, especially phlogiston.

Lavoisier had been given an account of the experiments that Priestly and Cavendish had designed, which suggested that water was not an element, but a compound (Blagden, (n.d), p. 73). Lavoisier duplicated those experiments on a larger scale. The experiments are complicated, and duplication requires precision and accuracy. The experimental apparatus must be so, the exact substances must be used, and certain variables must be controlled. That requires a lot of communication, and a lot of understanding. If those specifics are not communicated well, then there is a good chance the experiment will not be successfully replicated. Remember, Lavoisier and the Birmingham natural philosophers were working within different theories, which differed on the issues at hand. But Lavoisier was still able to duplicate those experiments. That

duplication suggests that cross-theory communication occurred between the Birmingham natural philosophers and Lavoisier.

Lavoisier not only duplicated the English experiments, but he had also been kept apprised of conclusions that the English had drawn from the experimental observations; namely, water is a compound, not an element (Blagden, (n.d), p. 71-74). Not surprisingly, Lavoisier had drawn the same conclusion. The only difference between Lavoisier's conclusion, and Cavendish's and Watt's was the description of the parts. The fact that Lavoisier was aware of the conclusions of the English scientists, suggests that he understood them, and that they helped guide his own.

The historical evidence suggests that the experiments and conclusions of the English influenced Lavoisier. The English had even accused Lavoisier of stealing Watt's idea and simply expressing it without PHLOGISTON. Lavoisier's conclusion that water is composed of hydrogen and oxygen is, Watt's peers say, agreeable with his conclusion had Watt had not used phlogiston to interpret water's parts (Blagden, (n.d), p. 71-72). Blagden, a contemporary of Cavendish and Watt, claimed, "[Watt's conclusion] opened the way for Lavoisier's present theory, which perfectly agrees with Mr. Watt's, only that Lavoisier accommodates it to his old theory, which banishes phlogiston" (Blagden, (n.d), p. 73). The Birmingham natural philosophers and Lavoisier not only communicated, but the some English scientists thought that Watt's conclusion could be translated into Lavoisier's.

Evaluation of the Third Historical Scenario

The third historical scenario follows from the claim that meaning depends on the physical world and the theory in which it is embedded. For this scenario to be consistent

with the actual history of WATER'S historical development, parts of the prior two scenarios must be correct, but other parts incorrect. In other words, some of the historical expectations associated with M1 and M2 must be consistent with the actual history of WATER.

Recall, the historical scenario associated with M1 had two features: 1) historically stable concepts; and 2) cross-theory communication. And we expected the reverse from meaning account M2: 1) historically volatile concepts; and 2) the inability to communicate across theories.

The concept of water has undergone many dramatic conceptual shifts; however, there is historical evidence that communication between 18th and 19th century scientists who worked within different conceptual systems took place.

One feature of both M1 and M2 is consistent with the actual history of WATER, but one feature of each is inconsistent with WATER'S history, which suggests that M1 and M2 are both partly right, but also partly wrong. A better account of the actual historical development of the concept of water includes both factors, M3.

The world factor explains cross-theory communication because the objects that are being discussed do not change. Should the meaning of WATER include that stable factor, cross-theory communication should be possible. The concept of water in one theory and the concept of water in another will have different meanings, but part of their meanings should be shared, and that part is owed to the physical world. That shared element allows for communication. Cross-theory communication may be difficult, but it happens and is beneficial.

The theory factor explains the dramatic conceptual shifts that characterize the history of the concept of water. Conceptual systems change a lot. The categories that are made, and the connections that link one concept to the others alters depending on the theory or theories that help shape view of the world.

When theory pushes, the world pushes back. The history of WATER suggests that the meaning of the concept of water depends on the physical world and the theory in which it is embedded. The stability of the physical world explains the cross-theory communication associated with WATER'S history; and the tendency for theory to change explains the dramatic conceptual shifts.

A Chemical Critique of a Twin Earth Assumption

The history of the concept of water is evidence for M3 and Putnam's conclusion that the meaning depends on both the physical world and the theory in which it is embedded. Putnam's conclusion is right, but he reaches that conclusion for the wrong reason.

Putnam designed a thought experiment to show that two people can be in exactly the same brain state at the same time of an utterance, yet mean two different things. This is supposed to show that the meaning of a concept not only depends on the theory in which it is embedded but also the physical world.

Putnam's story goes like this: Suppose there exists another planet that is a near copy of this one, Twin Earth. Each person from Earth has a double on Twin Earth who has precisely the same physiology. And the world is a near exact copy, except for one difference, on Earth water, abbreviated water_E , is H_2O , but on Twin Earth water,

abbreviated water_{TE} , is a very long complicated formula abbreviated by XYZ. Water_{E} and water_{TE} are different things with different physical structures. Note: Putnam stipulates that H_2O and XYZ are indistinguishable at normal pressures and temperatures, and XYZ fills seas and oceans on Twin Earth in the same way H_2O does on this planet. In other words, H_2O and XYZ are visibly indistinguishable.

Now imagine somebody from Earth visited Twin Earth. On first blush, he would report that “water” has the same meaning on Twin Earth as it does on Earth. This report would be corrected, however, once it is learned that water_{E} is H_2O and water_{TE} is XYZ.

Here’s the crucial part: water_{E} and water_{TE} , have two different meanings. However by stipulation of the thought experiment, they share the same observable properties and occupy the same kinds of spaces on both worlds. In other words, water_{E} and water_{TE} are applied to the same set of things. Now remember, Earth and Twin Earth are identical except for the physical composition of water, and the speakers are in the exact same mental states. If you conclude that the meaning of water_{E} and water_{TE} differ between worlds, you must think that that difference is a consequence of the physical world, not a theory.

Putnam accounts for any addition or subtraction to the set of things denoted by “water” with what he calls the ‘ostensive definition’ of the term. Any ostensive definition of a term is accompanied by the following empirical presupposition: If we denote thing-X “water”, and we call thing-Y “water”, then we presume that thing-X stands in a kind of sameness relation to thing-Y. The sameness relation has two parts: 1) X and Y are both liquids; and 2) X and Y agree on the important physical properties. Putnam recognizes that ‘importance’ is an interest relative-notion, and is thereby

determined by the experts in a social context (Putnam, 1975, p. 238-239). If scientific investigation reveals that thing-Y is, in fact, not the same as thing-X, then we will alter our speech patterns to accommodate that finding, and come to accept that our previous speech was mistaken.

The upshot is this: scientific investigation changes our understanding of concepts; scientific investigation may reveal that we have been misapplying a term. That information will revise our manner of speaking. But those things do not mean that the meaning of the term has changed. What changed, says Putnam, is our knowledge (Putnam, 1975, p. 225-227).

The history of WATER suggests a manner to evaluate Putnam's thought experiment. Differentiation characterizes the evolution of WATER in the 20th and 21st centuries; scientists have begun distinguishing between mass variant water molecules. They noticed that mass variant water molecules have different observable chemical properties, and believe that those differences can be attributed to the mass differences. In particular, scientists believe that water's properties are due to its rather small molecular mass. As seen in Chapter Five, heavy water does not share those properties because the two additional neutrons modify the mass of the molecule to such an extent that it behaves more like a classical molecule. This information suggests two chemical reasons for the improbability that XYZ is chemically indistinguishable from H₂O, but physically different: 1) small physical differences make big chemical differences; and 2) chemical analysis suggests that it is improbable that any molecule with a mass less than 20u (20 atomic mass units) would be chemically distinguishable from H₂O.

The first lesson worth applying to Putnam's thought experiment is that small physical changes make noticeable chemical differences. The addition of two neutrons to the H₂O molecule dramatically changes its chemical properties. If the addition of two neutrons causes dramatic chemical effects, then why should we think that a molecule so large that abbreviation is required has all the same macro chemical properties of H₂O?

D₂O, T₂O and H₂¹⁸O are all chemically *distinguishable* from H₂O; furthermore, the chemical differences have even more dramatic consequences in large biological systems. As seen in Chapter Four, If either D₂O or T₂O replaced H₂O, life would end, except for some microbial organisms that do not require H₂O and are unaffected by D₂O or T₂O chemical properties. Pure D₂O is toxic and pure T₂O is corrosive and carcinogenic. If H₂¹⁸O replaced all atmospheric H₂O, then there would be noticeable atmospheric consequences because H₂¹⁸O requires more energy to vaporize (Harmon, 1961, p. 1702). Now if these small molecular changes have such pronounced effects, it is unreasonable to ask us to imagine a hypothetical scenario where XYZ shares H₂O's chemical properties but is dramatically physically different.

If that is not convincing, there is another reason to think that XYZ cannot be chemically indistinguishable from H₂O: if D₂O's properties are different from H₂O's properties because its molecular mass is too high, then we have a necessary condition for a molecule to share H₂O's properties.

The molecular mass of H₂O is approximately 18u, and the molecular mass of D₂O is approximately 20u. Given that D₂O's mass is sufficiently high that it does not share H₂O's properties, we are able to conclude that any molecule with a mass higher than 20u, cannot have H₂O's properties. After all, scientists attribute H₂O's properties to its small

molecular mass; and D_2O 's properties to its larger molecular mass. Therefore, 20u is the benchmark: if a molecule has a mass lower than 20u, it may share H_2O 's properties; but if not, then it should behave like a classical molecule with dramatically different chemical properties.

Now that we have a limit, we can perform some calculations. With a quick glance at the Periodic Table we know that there are eight elements that could form compounds whereby the resultant molecular mass is less than 20u: hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen, and oxygen. We cannot include fluorine because its atomic mass is 19u; therefore, any compound it forms cannot be less than 20u.

I rounded the molecular masses of these elements to the nearest whole number, and then wrote an algorithm to determine the number of mathematical molecular combinations with a mass less than 20u. Given that these molecules have a molecular mass less than 20u, they all meet the necessary condition for quantum effects, which are necessary for H_2O 's peculiar chemical properties.

The algorithm's results are all the possible mathematical combinations, not the chemically possible combinations. The set of mathematically possible combinations is larger than the set of chemically possible combinations, but each chemically possible combination is a member of the mathematical set. The result is 154 mathematically possible combinations.

Now of those 154 molecules we eliminate 77 off the bat. These molecules, in all likelihood, will not exist in nature because they contain helium. Helium's outermost valence shell has a complete octet; that is, it contains eight electrons. As a result it is

exceptionally unreactive, and incredibly unlikely to naturally form bonds with any other element. If we subtract those chemically impossible combinations, we are left with 77 chemical possibilities.

On inspection we can also eliminate all molecules that are entirely composed of hydrogen, except for H_2 because it naturally forms in a gaseous state. Hydrogen forms compounds with the highly electronegative halogens, and the less electronegative metals and metalloids; however, H_2 does not bond with itself to form chains of three or more hydrogens. Therefore, it is possible to eliminate all molecules that entirely consist of hydrogen, except H_2 . Since hydrogen has an atomic mass of approximately one, this eliminates a total of 17 molecules, bringing our total possibilities to 61.

Now the process of elimination becomes a bit more complicated. Mathematically speaking, a significant number of the remaining molecules would be ions: 56. An ion is an atom or molecule that has an unequal number of electrons and protons. Ions have special properties because of their charges; for that reason we should exclude them as candidates. They are unlikely to share the exact same properties as water. The remaining possibilities are five molecules. But since H_2O is itself part of this group, there are only four possibilities.

The possibilities are H_2 , CH_4 , BH_5 , and NH_3 . H_2 is a gas at normal pressures and temperatures so it is not a candidate. All boron-hydrogen compounds are toxic and highly flammable. CH_4 , colloquially known as methane, does not share H_2O 's properties either. Being the primary component of natural gas, it is highly flammable. NH_3 , otherwise known as ammonia, is a gas at normal pressures and temperatures, and hazardous.

From the perspective of modern chemistry, it is unreasonable to think that XYZ and H₂O share the same chemical properties but differ physically. Chemistry does not work that way. Small physical differences can make big chemical differences. H₂O owes its chemical properties to quantum behaviour, which requires a sufficiently small mass; therefore, we can eliminate a wide range of candidates for XYZ. And the ones we have left, we know, do not share H₂O's properties. For these reasons it is clear that Putnam has grossly misunderstood the chemistry, and built chemically impossible assumptions into the Twin Earth thought experiment. Therefore the Twin Earth thought experiment is seriously misleading.

Without the assumption that H₂O and XYZ are physically different but chemically indistinguishable it is impossible to say that H₂O and XYZ are applied to the same set of things. Therefore the difference in meaning might be attributed to the different application of the terms to things not its physical structure. Putnam's assumption had tried to block that possibility by stipulation, but that stipulation is chemically unrealistic.

Conclusion

The reason that M1 does not capture the complete meaning of WATER is because it suggests a seamless historical development of WATER, but conceptual change characterizes the actual historical development of WATER. The actual history contradicts the historical prediction of M1, and, therefore, suggests it is an inaccurate description of the meaning of WATER.

The historical scenario associated M2 is not entirely right either. One feature of that scenario is the impossibility of cross-theory communication. The actual history contradicts that expected historical scenario. That historical contradiction suggests that M2 does not accurately describe the historical development of WATER.

A much better understanding of the meaning of WATER includes both factors. Cross-theory communication was expected from M1, and conceptual shifts were expected from M2. For that reason the meaning of the concept of water depends on both the world and theory. The conclusion of the Twin Earth thought experiment is right for the same reasons. However the Twin Earth thought experiment does not support that conclusion. Recent history also suggested a manner to criticize the assumption that invisible physical changes may not have visible chemical consequences. That criticism suggests that Putnam had misunderstood the chemistry when he designed the Twin Earth thought experiment.

Conceptual changes are not limited to WATER. The meanings of Aristotle's five elements have all changed. Fire is not an element, but rather, the result of rapid oxidation in the chemical process of combustion. The visible part, the flame, consists of glowing hot gases. Air is a mixture that consists of seventeen gaseous atoms and molecules. It is mainly composed of nitrogen, oxygen, argon and carbon dioxide. Earth is also a mixture. If EARTH refers to the earth's crust, then at least 99% of the crust is a mixture of different oxides with SiO_2 , Al_2O_3 , CaO , and MgO as the major components of that mixture. Aether once thought to be the medium of space was eliminated when Einstein's theory of special relativity (1905) could make all the necessary predictions without aether.

Neither M1 nor M2 can wholly explain the history of the concept of water. Meaning as only dependent on the physical world cannot explain the conceptual shifts I have documented, and meaning as only theory-dependent cannot explain the cross-theory communication. The meaning of WATER is at least dependent on both theory and the physical world.

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