CHEM 104
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WHAT IS CHEMISTRY AND WHY STUDY IT?

Introduction

The two questions I would like to address in this essay are: What is chemistry? and: Why should you be interested in studying it? I'll address the second question first because it forms the basis for the answer to the first question.

The one thing that we need to know about chemistry in order to address the second question is that it is a *science*. We'll come back to the relationship between chemistry and science, but we need to begin by discussing science in general. So, what is a science? There are many definitions of science, many of which depend on who is defining it. Definitions include aspects of rationality (there are logical connections between data and theory), empiricism (using the senses to collect the data or facts), and objectivity (minimizing the effect of one's personal biases on the interpretation of data). Each of these aspects can be taken to extremes. My definition is very broad, encompassing all of these aspects, but is based on a biblical foundation.

The Biblical Mandate for Science

The first chapters of Genesis describe both what science is and why humans should be interested in studying it. In Gen. 1:28 we read: "God blessed them and said to them, 'Be fruitful and increase in number; fill the earth and subdue it. Rule over the fish of the sea and the birds of the air and over every living creature that moves on the ground.'" Gen 2:15 says: "The Lord God took the man and put him in the Garden of Eden to work it and take care of it." And Gen 2:19-20 reads: "Now the Lord God had formed out of the ground all the beasts of the field and all the birds of the air. He brought them to the man to see what he would name them; and whatever the man called every living creature, that was its name. So the man gave names to all the livestock, the birds of the air and all the beasts of the field." God placed us in creation to care for it and gave us the authority to use it for God's glory (commonly called the *cultural mandate*).

God did not however, give us a manual that described how creation worked. We are to discover that for ourselves. Science is the means by which man works to understand the created order. In other words, the goal of science is to discover, by studying the creation, those laws which God uses to govern the universe. This is not limited to the "hard" sciences (physics, chemistry, biology), but includes any field that attempts to identify creational laws (i.e., math, psychology, economics, law, even theology).

To summarize, we do science because God commands us to do it and because our created nature (curiosity and dominion) compels us to do it.

Object, Method, and Tools

Science therefore studies all of creation. The word "study" suggests an empirical element to science. Scientists use their senses to look at the creation. However, trying to take on the whole creation at once is impossible for humans because of our limited abilities. So scientists abstract parts of creation for in-depth study; that is, they focus on a small part of the created order, studying it intently to identify the laws functioning in that small area. Within these smaller areas of study, the attempt to derive the laws of creation from observations describes the rational element of science. From observed patterns or regularities, we deduce laws and develop explanatory theories which often are predictive of other behavior. This collection of observations, theories, and laws are ideally a rational, logical unit. This abstraction has resulted in the formation of the various disciplines of academic study; i.e., math, chemistry, biology, sociology, art, literature, and theology. Chemistry is thus one of many disciplines that make up science. The exact nature of chemistry will be discussed later.

Science deals with the created order, but it is also a human activity. We bring to our scientific investigations our beliefs and predispositions about science and the world. This is the objective element. Our beliefs and opinions about the nature and function of creation skews our view of creation. In one sense this is good. Our abstraction of parts of creation is necessary, right down to what kinds of data we choose to collect. For example, you are not likely to record the outside temperature during an experiment if you know you are in an air-conditioned building. On the other hand, scientists sometimes attempt to use their data to prove a theory that they want to believe is true. A well known example is the case of "cold fusion" where a group of scientists believed they had caused two hydrogen atoms to react to form helium in a simple beaker (the same reaction which is used in the hydrogen bomb, a nuclear weapon). Many other labs attempted to reproduce this experiment, but none were successful and the original researchers were humiliated (to say the least).

A Neutral Science?

As a human activity, science is also a response to God and His commands. Thus it is not and cannot be "neutral". Science is often described as being religiously neutral, particularly in the natural sciences (math, physics, chemistry, and biology) because the object of study, the creation, is believed to be neutral. A non-Christian will see the world as a product of a long chain of natural, uncontrolled processes defined by a set of *natural laws* inherent to the universe. A Christian sees the world as the product of the creative acts of an omnipotent creator who continually upholds His creation (providence). Even so, when a non-Christian and a Christian study creation, they usually discover the same laws. Why is this the case, if science is not neutral?

The answer lies in the nature of God's relationship to his creation. When God created the world, he put in place a set of laws that define the created order. This set of laws cannot be broken (we cannot defy the law of gravity, for example), unlike the laws that govern the relationships between men and between man and God, which were broken when Adam sinned (although it is also possible to identify creational laws in these areas). Thus, because of this providential upholding of creation, all people see the same order, but they do not respond in the same way. Christians know of this relationship between God and creation, and thus have a good incentive to study, use, and care

for creation. On the other hand, the non-Christian either does not see God's hand in creation, or chooses to ignore or minimize it, and therefore his incentive is only one of personal curiosity and survival (conquering the natural elements). This difference in viewpoint is the same as the fundamental difference between Christians and non-Christians; that difference being whether God as the focus of one's life or the self as the focus of one's life.

Science and Truth

Science is often seen as a means of learning the "truth". While the scientist does attempt to find and understand the creational laws, it is impossible for any of the laws (or theories) that he defines to be described as "true" in an absolute sense. This is because it is impossible to prove that a theory based on empirical data (observations of the regularities in nature) is true because one cannot observe all of the empirical data. For example, in order for Newton's three laws of motion to be proven to be absolute, it would be necessary for us as humans to observe the motion of every body in the universe since the beginning of time to see if that motion fits within the bounds of Newtonian physics. Even one exception to Newton's laws would show that they are not absolutely true; and for Newton's laws, this is indeed the case, because they do not hold at speeds approaching the speed of light. So scientific laws can be shown to be non-absolute (that does not mean that they do not hold at all, but hold only under certain conditions), but they cannot be shown to be absolutely true.

As a result of this inability to prove the truthfulness of theory, the scientist who has no knowledge of God and his providence is left with no basis for absolute truth. His life becomes a meaningless fight for whatever values he might hold. The Christian can accept the tentativeness of the theories he proposes because he knows that he is a finite creature studying the work of an infinite creator, and thus knows that his work can only be an approximation of the creational laws instituted by God. His work then becomes that of critiquing the known theories to see if they fit in with the absolute laws of God that are known by the special revelation of the Bible and attempting to improve on these laws so that they may better approximate the creational laws.

For example, quantum mechanics, the theory underlying most of chemistry, has built into it a concept known as the uncertainty principle. This theory states that at the atomic level, it is impossible to know exactly the position and/or the velocity of the fundamental particles; the proton, neutron, and electron. In other words, when we look at an atom closely (assuming we could), the best we can do is to say that the electron will spend most of its time within a certain distance from the nucleus (center) of the atom. We can't know exactly where it is. The result of such reasoning if we extend it beyond chemistry is that all absolutes are abolished; that is, nothing can be absolute.

However, the Bible teaches, "even the hairs of your head are all numbered" (Luke 12:7). God knows everything, even the most inconsequential details. This is incompatible with the ideas of indeterminism and relativism that are discussed above. Thus even though quantum mechanics is currently the best theory available for understanding the workings of the atom, we must realize that the consequences of this theory may not be compatible with our faith. What we as Christians must then do is to study such theories as quantum mechanics and attempt to either explain the difference between the implications of the theory and our faith or redefine the theory in order to remove the anomaly.

For quantum mechanics, the resolution I use is to recognize that we are finite and God is infinite. In addition, we are constrained by creation, while God is not--he is only constrained by his own willful covenant to creation. Therefore, it is entirely reasonable to accept that we humans are constrained in our knowledge by the uncertainty principle while God is able to act freely even at the quantum level. At a different level, it is critical to remember that a theory such as quantum mechanics is limited in its scope. While it does apply to physical objects such as atoms, it is inappropriate to apply it to the workings of the human mind, which is governed by a different set of creational laws.

What is Chemistry?

Now let's return to the first question. What is chemistry? The text describes chemistry as being "about change…,[with] focus on the change of one pure substance…into another" (Kotz, Treichel, & Weaver, *Chemistry & Chemical Reactivity, 6rd. ed.*, pg. 5). Knowing now some of the bigger issues related to science we can give a somewhat different, but I believe more complete, definition:

> Chemistry is that field of study in which man, in response to the Word of God, attempts to understand the creational laws for the nature and composition of matter and the changes therein; and in doing so reflect the glory of the Lord Jesus Christ through whom all things hold together.

Through this we recognize that chemistry is only a small part of science; that it is done not for any selfish reasons, but rather as an aspect of our service to God; and that it is a fallible, human activity, in need of restoration and redemption.

The aspect of creation which chemistry addresses is the material, or physical, aspect. Chemists often use the term *substance* or *matter* to refer to the object of study. (More and more, the term molecule is used, but not all chemical substances are molecules, for example, salt. Compound is also used, but many elements are not compounds.) In the textbook definition given above, chemistry deals with the nature of substances, properties, structures, and reactions. In particular, they emphasize *change* in the form of the chemical reaction. It is these characteristics that form the *phenomena* of chemical science.

Chemical science explains these characteristics in terms of various theories. The periodic law describes the layout of the atoms in periodic table, and is based on quantum mechanics. Organic structural chemistry defines functional groups that explain the reactivity of substances such as carboxylic acids and alkenes. Equilibrium chemistry and thermodynamics explain the stability of some chemical substances relative to others.

There is clearly a rational structure to chemistry, to the point where some organic syntheses, a logical process, can be planned out by computational algorithms. The periodic table groups elements in a rational pattern based on reactivity and on

atomic properties. Quantum mechanics is a very rational and mathematical approach to understanding chemical structure.

Chemistry, as a typical science, does not leave creation for its concepts or explanations. Chemistry builds on the theories of quantum mechanics, thermodynamics, and statistical mechanics, all with their basis in physics. In fact, chemistry does not generally concern itself with the ultimate nature of matter (i.e. subatomic particles or cosmology), so chemistry does not generally touch on that collection of questions.

But it is not just the structure of matter that is of interest to chemical science, but also the ability to transform matter from one kind of substance to another. Probably more so than any of the other natural sciences, chemistry is characterized by the manipulation of matter to produce materials not yet found in creation. Nobel laureate Roald Hoffmann gives an elegant description:

> But so many more molecules of chemistry are made by us, in the laboratory. We're awfully prolific—a registry of known, well-characterized compounds now numbers over ten million. Ten million compounds that were not on earth before! It is true that their constitution follows underlying rules, and if chemist A had not made such-and-such a molecule on a certain day, then it is likely to have been synthesized a few days or decades later by chemist B. But the human being, a chemist, chooses the molecule to be made and a distinct way to make it. The situation is not all that different from the artist who, constrained by the physics of pigment and canvas, and shaped by his or her training, nevertheless creates the new. [*The Same and Not the Same*, pg 90]

Thus, while analysis of existing and new compounds is an important aspect of chemical science, chemists also work very hard at making new substances. It is through the chemical science of synthesis that the lines between "pure science", "applied science", and "technology" become blurred.

Chemistry has a long and lively history involving the manipulation of matter into useful products. Alchemists attempted to turn base metals into gold. Many chemists were trained as physicians, apothecaries, or pharmacists because of the use of chemistry (or alchemy) to treat disease. In the past two centuries, these practical activities have grown into a major industry. Nowadays, the U.S. chemical industry produced about $440 billion in products in 2000, accounting for about 10% of all U.S. manufacturing industries and about 27% of the global chemicals market. The industry employs about one million people.

General Chemistry textbooks include practical applications of chemistry, usually as illustrations of the principles described in a given section or chapter. More extensive discussions of these applications can be found in the more popular books such as those by Breslow and Hoffman (see bibliography). In each of these books there are two themes present. The first theme is that chemistry (as technology) is shown to be a necessary part of the development of our modern world. The development of aspirin, sulfa drugs, and antibiotics along with the growing understanding of the chemical structure and function of biological systems revolutionized medicine. The use of petroleum as starting materials for polymers (plastics) has created a whole range of materials useful in everything from beverage containers to clothing to cookware to structural materials. Photography (a personal interest) is an art, but photographic film is a complex photosensitive chemical system requiring chemical processing to create the actual photograph. The second theme is that these applications of chemistry come from the ability of chemists to synthesize new materials.

The significance of this discussion is that it leads to the conclusion that chemistry as a science and the chemistry as a technology are not far removed in character. That is, *chemistry* involves both science and technology, and therefore a complete description must address both aspects.

To summarize, chemistry is more than a pure science, it is concerned with more than understanding and predicting natural chemical phenomena. Inherent to chemistry is the notion of controlling matter, synthesizing it into desirable substances. Some of these new substances advance the science; others have useful functions outside of chemical science, as technological objects in human culture. As such, chemistry is a discipline that demonstrates a more thorough expression of the cultural mandate than is typically associated with scientific disciplines, which requires that humanity's efforts to understand creation be used to develop a God glorifying culture.

Putting Chemistry in Context

However, we cannot stop here in this analysis. I said earlier that science divides creation into smaller parts (abstracts) for easier study. Chemistry is one of those abstractions. Once we have some understanding of a particular field, we must step back and reintegrate our knowledge into the larger domain of science. The compartmentalized nature of most disciplines makes this difficult (what connection is there between chemistry and sociology), although it does occur between disciplines that are closely related (much of biology does depend on chemical principles), even if the disciplines have different fundamental principles (chemistry: matter and energy; biology: life). This is a point that is slowly changing in the disciplines as they realize there are benefits to cross-discipline communication.

So Why are You in This Class?

You may be wondering why you are studying chemistry if you are not a chemistry major. Chemistry is important in a number of fields. In biology and medicine, there is a trend towards focusing on the cell and intracellular activities (called cell biology, molecular biology, or biochemistry). Understanding both the structure of the cell and the events that happen inside the cell depend strongly (but not exclusively) on the chemistry of the cell, from the structural components that make up cell membranes and DNA, to the effect of fluid composition on the rate of various biochemical reactions. Engineering takes principles from physics and chemistry and applies them to practical problems. The chemical composition of steel determines its strength and ability to resist corrosion. The design of the internal combustion engine attempts to optimize the conversion of chemical energy contained in fuel

into mechanical energy that drives the wheels. The ability to design faster microprocessors for computers depends on the ability to fabricate smaller features on the chip, which involves the use of chemical processing. And of course you use chemicals every day, from the water you used for your shower this morning to the caffeine in the cola you drink to the ink or graphite in your pen or pencil you are using for notes. You might find that things you learn in chemistry help you to understand the nature and effects of some of these everyday chemicals.

Conclusion

To summarize, the Christian's motivation for doing science is two-fold. We do science because God has commanded us to do it (both explicitly in his commands in Genesis and implicitly through our curiosity) and because we need to act as agents of reconciliation for science, returning it to a God-glorifying activity rather than a man-centered one. We must also realize that this second reason will not come to completion until the second coming of Christ, thus we must be patient with our world as well.

Chemistry is but one of many sciences, all of which attempt to understand and/or apply the laws governing the creation. Chemistry focuses on that part concerned with the nature and composition of matter and the changes therein. That knowledge is also used, within chemistry, to control and manipulate the material aspect of creation to make useful technological products. Chemistry is not isolated, but interacts with the other sciences on many levels, each science contributing to our picture of creation.

Finally, our Christian understanding of science gives us a unique perspective regarding the care and use of the created order. We neither need to become radical environmentalists who hold nature as sacred and untouchable nor do we need to become uncaring exploiters of the resources we have available to us. As stewards of creation, we have the right to use the creation as we see fit; yet we must remember that all our actions are done in God's sight and we will be accountable to him if we abuse the privileges he has given us.

A Bibliography

Most of the ideas above do not originate with me. Here are a few books that you might find useful in expanding your understanding of the foundations of science. All are available in Dordt's Library.

Nancy R. Pearcey, Charles B. Thaxton. *The Soul of Science: Christian Faith and Natural Philosophy.* Wheaton, IL: Crossway. 1994. BL245 .P43 1994. This book is a good survey of the history of scientific thought. Along the way, you get a good picture of what modern philosophy of science looks like.

Del Ratzsch. *Philosophy of Science: The Natural Sciences in Christian Perspective.* Downers Grove, IL: Intervarsity. 1986. BL240.2 .R34 1986. A new edition published in 2000 is called *Science & Its Limits*. BL240.2 .R33 2000. This is one of the most readable and solid introductions to the philosophy of science I have ever seen. Strong connections to Reformed Christianity are also included. Take Philosophy 201 first, though.

Calvin B. DeWitt. *Caring for Creation: Responsible Stewardship of God's Handiwork.* Grand Rapids, MI: Baker. 1998. BT695 .D47 1998. This is a short discussion of environmental issues in light of a Reformed understanding of religion, science, and the environment.

Russell W. Maatman. *The Unity in Creation.* Sioux Center, IA: Dordt College Press. 1978. Q175 .M31 C.1. This is a very basic introduction to the principles upon which the physical sciences (astronomy, chemistry, and physics) are built.

Russell W. Maatman. *The Bible, Natural Science, and Evolution*. Sioux Center, IA: Dordt College Press. 1970. BL240.2.M3. This book is on a level similar to Del Ratzsch, but works out the nature and motives of science from biblical principles. The first half of the book outlines the philosophical basis; the second half applies this basis to the question of evolutionism.

Thomas S. Kuhn. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press. 1962. Q175 .K95. While rather technical, this book redefined our understanding of science and how it operates. The notion that science cannot be perfectly objective (not to be confused with religiously neutral) originates with this book.

A few other interesting books on chemistry and science:

Roald Hoffmann. *The Same and Not the Same*. New York: Columbia University Press. 1995. QD37.H612 1995. Written by a Nobel Laureate, this is a fascinating book describing the world of chemistry from a nontechnical perspective, with lots of interesting stories and analogies. It is a friendly way of getting a better understanding of what chemistry is about.

Walter R. Hearn. *Being a Christian in Science.* Downers Grove, IL: Intervarsity Press. 1997. BV4596 .S35 H43 1997. This is a nice book describing how one can be both a good scientist and a good Christian, without compromising principles in either area. It is also a good introduction as to what the life of a scientist is like, and what it takes to be a good scientist.

John C. Polkinghorne. *Belief in God in an Age of Science.* New Haven : Yale University Press. 1998. BL241 .P56 1998. This is one of several books by Polkinghorne, who has international reputations as both a Ph.D. physicist and Anglican priest. His writing is clear and succinct, while being thorough.

Ronald Breslow, *Chemistry Today and Tomorrow*. Washington, DC : American Chemical Society. 1997. QD 31.2.B75 1997. Breslow does a nice job of illustrating the practical and technological applications of chemistry.

Jeffrey A. Lee, *The Scientific Endeavor: A Primer on Scientific Principles and Practice*, San Fransisco, CA: Addison Wesley Longman. 2000. Q 162.L375 2000. This is a wonderfully concise discussion of the nature and practice of science.

National Research Council, *Beyond the Molecular Frontier: Challenges for Chemistry and Chemical Engineering*, Washington, DC: National Academies Press, 2003. TP 155.N38 2003. This is a forward-looking book outlining areas of future research in the chemical sciences and engineering.

All Scripture is quoted from the New International Version.
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Some Definitions of Science and Chemistry

A ***natural science*** is a theoretical explanatory discipline which objectively addresses natural phenomena within the general constraints that (1) its theories must be rationally connectable to generally specifiable empirical phenomena and that (2) it normally does not leave the natural realm for the concepts employed in its explanations.

Del Ratzsch, *Philosophy of Science*, pg 15
Del Ratzsch is a Reformed philosopher of science

Science is the acquisition of reliable but not infallible knowledge of the real world, including explanations of the phenomena.

Arthur Strahler, as quoted in
The Scientific Endeavor, pg 1.

Chemistry is the science that tries to understand the properties of substances and the changes that substances undergo. It is concerned with substances that occur naturally...and also with new substances created by humans. It is concerned with natural changes...and also with new transformations invented and created by chemists.

...

[C]hemists are involved in two different types of activity. Some chemists investigate the natural world and try to understand it, while other chemists create new substances and new ways to perform chemical changes that do not occur in nature.

Ronald Breslow, *Chemistry Today and Tomorrow*, pp 1-2
(QD 31.2.B75 1997)
Ronald Breslow is an award winning chemistry professor and past-president of the American Chemical Society

Chemistry is that field of study in which man, in response to the Word of God, attempts to understand the creational laws for the nature and composition of matter and the changes therein; and in doing so reflect the glory of the Lord Jesus Christ through whom all things hold together.

Carl Fictorie, "What is Chemistry and Why Study It?"