1.2: Atomic Realities and Scientific Theories

We assume that you have lots of ideas about atoms but did you ever stop to think how we came to accept this information as reasonable or what the reality of atoms implies about how the world we perceive behaves? Atoms are incredibly and unimaginably small. A gold atom with its full complement of electrons is less than a nanometer (1×10^{-9} meters) in diameter and its nucleus, which contains 79 protons and generally around 116 neutrons, has a radius of $\sim 1.5 \times 10^{-14}$ meters. While these sizes are actually unimaginable, there are a number of web-based activities that can help you come to terms with the scales of atoms.[1] There is no way you could see an atom with your eye or with a light microscope, although there are now techniques that allow us to view computer representations of individual atoms using various types of electron and force-probe microscopes. The smallest particle of matter that you can see with your naked eye contains more atoms than there are people in the world. Every cell in your body contains a huge number of atoms. Obviously, whatever we know about atoms is based on indirect evidence; we do not directly experience atoms.

The full story of how we know what we know about the existence and structure of atoms is fascinating, complex, and perhaps fortunately for you, too long to go into in detail. What we do want to do is to consider a number of key points that illustrate how our ideas of atoms arose and have changed over time. We will present the evidence that has made accepting the atomic theory unavoidable if you want to explain and manipulate chemical reactions and the behavior of matter.

Atomic theory is an example of a scientific theory that began as speculation and, through the constraints provided by careful observation, experimentation, and logical consistency, evolved over time into a detailed set of ideas that make accurate predictions and are able to explain an increasing number of diverse, and often previously unknown, phenomena. As scientists made new observations, atomic theory was adapted to accommodate and organize these observations.

A key feature of scientific ideas, as opposed to other types of ideas, is not whether they are right or wrong but whether they are logically coherent and make unambiguous, observable, and generally quantitative predictions. They tell us what to look for and predict what we will find if we look at or measure it. When we look, we may find the world acts as predicted or that something different occurs. If the world is different from what our scientific ideas suggest then we assume we are missing something important: either our ideas need altering or perhaps we are not looking at the world in the right way. As we will see, the types of observations and experimental evidence about matter have become increasingly accurate, complex, and often abstract, that is, not part of our immediate experience. Some of these observations can be quite difficult to understand, because matter behaves quite differently on the atomic and sub-atomic scale than it does in the normal, macroscopic world. It is the macroscopic world that evolutionary processes have adapted us to understand, or at least cope with, and with which we are familiar. Yet, if we are to be scientific, we have to go where the data lead us. If we obtain results that are not consistent with our intuitions and current theories, we have to revise those theories rather than ignore the data.

However, scientists tend to be conservative when it comes to revising well-established theories because new data can sometimes be misleading. This is one reason there is so much emphasis placed on reproducibility. A single report, no matter how careful it appears, can be wrong or misinterpreted and the ability of other scientists to reproduce the observation or experiment is key to its acceptance. This is why there are no miracles in science. Even so, the meaning of an observation is not always obvious or unambiguous; more often than not an observation that at first appears to be revolutionary turns out to have a simple and even boring explanation. Truly revolutionary observations are few and far between. This is one reason that the Carl Sagan (1934-1996) quote, "*Extraordinary claims require extraordinary evidence*" is so often quoted by scientists. In most cases where revolutionary data is reported, subsequent studies reveal that the results were due to poor experimental design, sloppiness, or some irrelevant factor. The fact that we do not all have cold fusion energy plants driving perpetual motion refrigerators in our homes is evidence that adopting a skeptical approach that waits for experimental confirmation is wise.

A common misconception about scientific theories is that they are simply ideas that someone came up with on the spur of the moment. In everyday use, the word theory may well mean an idea or even a guess, a hypothesis, or a working assumption, but in science the word theory is reserved for explanations that encompass and explain a broad range of observations. More than just an explanation, a theory must be well tested and make clear predictions relating to new observations or experiments. For example, the theory of evolution predicted that the fossil record would show evidence for animals that share many of the features of modern humans. This was a prediction made before any such fossils were found; many fossils of human-like organisms have since been and continue to be discovered. Based on these discoveries, and on comparative analyses of the structure of organisms, it is possible to propose plausible family trees, known as phylogenies, connecting different types of organisms. Modern molecular genetics methods, particularly genome (DNA) sequencing, have confirmed these predictions and produced strong experimental support for the current view that all organisms now living on Earth are part of the same family–that is, they share a common ancestor that lived billions of years ago. The theory of evolution also predicts that the older the rocks, the more different the fossilized organisms found will be from modern organisms. In rocks dated to ~ 410 million years ago, we find fossils of various types of fish but not the fish that exist today. We do not find evidence of humans from that period; there are, in fact, no mammals, no reptiles, no insects, and no birds.

A scientific theory is also said to be falsifiable, which doesn't mean that it is false but rather that it may be proven false by experimentation or observation. For example, it would be difficult to reconcile the current theory of evolution with the discovery of fossil rabbits from rocks older than 300 million years. Similarly, the atomic theory would require some serious revision if someone discovered an element that did not fit into the periodic table; the laws of thermodynamics would have to be reconsidered if someone developed a successful perpetual motion machine. A theory that can be too easily adapted to any new evidence has no real scientific value.

A second foundational premise of science is that all theories are restricted to natural phenomena; that is, phenomena that can be observed and measured, either directly or indirectly. Explanations that invoke the supernatural or the totally subjective are by definition not scientific, because there is no imaginable experiment that could be done that might provide evidence one way or another for their validity. In an important sense, it does not matter whether these supernatural explanations are true or not; they remain unscientific. Imagine an instrument that could detect the presence of angels. If such an instrument could be built, angels could be studied scientifically; their numbers and movements could be tracked and their structure and behaviors analyzed; it might even be possible to predict or control their behavior. Thus, they would cease to be supernatural and would become just another part of the natural world. Given these admitted arbitrary limitations on science as a discipline and an enterprise, it is rather surprising how well science works in explaining (and enabling us to manipulate) the world around us. At the same time, science has essentially nothing to say about the meaning of the world around us, although it is often difficult not to speculate on meaning based on current scientific ideas. Given that all theories are tentative, and may be revised or abandoned, perhaps it is wise not to use scientific ideas to decide what is good or bad, in any moral sense.

As we will see, the history of atomic theory is rife with examples of one theory being found to be inadequate, at which point it must be revised, extended, and occasionally totally replaced by a newer theory that provides testable explanations for both old and new experimental evidence. This does not mean that the original theory was necessarily completely false but rather that it was unable to fully capture the observable universe or to accurately predict newer observations. Older theories are generally subsumed as newer ones emerge; in fact, the newer theory must explain everything explained by the older one and more.

? Questions

Questions to Answer: Scientific Questions and Theories:

- How would you decide whether a particular question was answerable scientifically?
- How would you decide whether an answer to a question was scientific?
- What is the difference between a scientific and a non-scientific question? Provide an example of each.

Questions to Ponder

- What things have atoms in them? Air, gold, cells, heat, light?
- How do you know atoms exist?