Great Ideas That Have Changed Our Worldview

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Although you can think of "Physics" as just a course that must be taken - or a body of knowledge that must be mastered at some level in order to proceed in some science or engineering or architecture curriculum, it is really about *ideas*. Its origins are in philosophy - or more specifically, *natural philosophy* - the quest to understand how the universe works. In that light, it is useful to see what some of those grand ideas are about and how they have changed the way humans view their universe. And even though some of those ideas are now familiar, they were not always so - and they certainly are not intuitive. These are indeed revolutions of human thought - triumphs of the human intellect.

The Copernican Revolution

We are all comfortable with the idea that the earth is one of nine planets orbiting our sun which is itself just one of the literally billions of similar stars in our Galaxy which is just one of billions of galaxies. But those ideas were slow in coming - and it was only with the publication of *On the Revolutions of the Heavenly Spheres* by Nicholas Copernicus in 1543 (on the day he died) that a model of the solar system with Earth as just one of the planets was formally presented. Nearly a century later, Galileo suffered greatly for espousing that idea and was forced to recant his belief in a sun-centered solar system during the Roman Inquisition - and spent the last eight years of his life under house arrest unable to publish his works.

Newton's Synthesis and the Universality of Physical Laws

Isaac Newton, who was born the year Galileo died one hundred years after the publication of Copernicus' *Revolutions*, developed the laws that govern the motion of the planets. In the process, he made an enormous intellectual leap in stating those laws apply equally well to *all* objects in the universe! That idea - that physical laws govern the universe and how it works - is a central idea in all of science. Newton articulated the relationship between forces and the changing motions of objects. But more than that, he expressed that forces are interactions between objects and determine how those objects behave. In that sense, Newton's laws are intimately related to the idea of *causality*. A consequence of Newton's synthesis is that the entire universe is a system of interacting objects - a mechanism that is governed by physical laws. The broad subject which includes those principles is called *classical mechanics*.

Energy and Entropy

These two ideas were developed over a period of about one hundred and fifty years - and can be thought of as describing the organizing principles that explain the macroscopic universe, from describing chemical processes - and hence life-processes - to describing the large scale behavior of galaxies and clusters of galaxies. The concept of *energy* is a central idea in all of science and engineering. And if the universe can be thought of as a mechanism, it can be said that energy is what drives that mechanism. And while energy can be both transferred between objects and transformed, it can always be accounted for. But even though energy is always conserved, it becomes less available for doing work - a principle expressed in the concept of *entropy*. That principle gives to natural processes a "direction" - that is, it assigns an order in time to natural processes. In that sense, the concepts of energy and entropy put limits on what can happen - and the order in which those events can occur.

The Conservation Laws

Expressing that energy can be either transferred or transformed - but can always be accounted for, is the equivalent of stating that it is a conserved quantity. The principle of energy conservation is just one of the conservation laws that are particularly useful in summarizing the laws of physics. When a quantity is invariant or unchanging, it becomes a very useful quantity to evaluate in the analysis of the behavior of objects or systems of objects. Newton himself first expressed the idea that certain quantities are conserved. He postulated, for example that mass is conserved in all processes in closed systems - ultimately, as we now know, because all matter is made up of constituent atoms - and they can always be accounted for. He also expressed the conservation of momentum in describing interacting objects or systems of objects. And energy conservation follows directly from his laws of motion. The conservation laws thus take on great importance in understanding the behavior of systems.

The Atomic Hypothesis

For well over two millenia, since the time of Democritus and Lucretius, the idea that everything is made of distinct atoms has been a part of natural philosophy, although neither understood nor even accepted even by many natural philosophers and scientists over much of the intervening time. Even as recently as the beginning of the twentieth century - within the lifetime of some humans - the existence of atoms as individual constituents of matter could not be verified without some doubt, and it had been assumed that any direct observation would be impossible. But the *atomic hypothesis* has become the *atomic fact* - and we now know that all materials are constructed of individual atoms that are distinguishable and distinct. Furthermore, the study of atoms in the first half of the last century has led to an understanding of the very structure of the atoms themselves and to the remarkable conclusion that we now know the characteristics of every type of atom that is even possible *in the entire universe* up to atomic number 110, or so, and the organizing principles for any that are heavier which are either discovered or manufactured - even in the core of some supernova in some distant unobservable galaxy. Even if the "modern physics" concepts of quantum mechanics and relativity - which changed our worldview from the classical physics of the previous centuries - are replaced by a "new" physics, it will not change what we know about the possible atoms that can exist. All that can be changed are the underlying descriptions - the mathematical formalism or interpretation that describes nature at the atomic level - but not the knowledge of the nature of the atoms themselves.

Relativity and Space-Time

Although it will not be a part of this course, the grand ideas surrounding Einstein's relativity have brought profound changes in the way the basic concepts of space and time are understood - and, in fact, have shown that Newton's laws are not strictly valid under all circumstances. (The conservation of mass, for example, is only approximately true since mass and energy are related through Einstein's famous equation $E=mc^2$ - but the conservation of mass and energy *together* is always true.) And as abstract (and even obscure) as the theory of relativity is, it is verifiable to a great degree of accuracy - and even plays a very important role in everyday life. The global positioning satellite technology that allows such precise determinations of positions of objects anywhere on the surface of the earth would not be possible in the absence of calculational corrections based on Einstein's general theory of relativity. And without that technology, even your cell phone - the operation of which depends on communication satellites - would not work properly.

Uncertainty and the Quantum Theory

The fundamental structure of the atom cannot be understood in terms of the classical physics of Isaac Newton. At the very core of our understanding of interactions between the constituent particles of all objects is the quantum theory - and that represents a fundamental change in our view of nature at the microscopic level. And inherent to that change in view is that nature behaves in probabilistic rather than deterministic ways. That idea - and the complex mathematics that goes with it when dealing with atomic and sub-atomic systems - calls into question the very ideas of causality. And although the quantum theory, when used to solve problems that can be experimentally tested, has never failed to achieve a high degree of accuracy, the interpretation of the theory is still developing - and could continue to evolve over a long period of time and could even be replaced by a more fundamental view of nature at the microscopic level.

Information Theory and Genetics

A fundamental change in the way we view, transfer, and store information occurred with the digital revolution. Information became data. Shannon's Law (articulated the same year the transistor was invented - a half-century ago) that information can be accurately transferred through noisy channels only if it is both digitized and redundant (thus allowing accuracy in encoding and decoding information) has led to the astonishing progress we have seen in both information technology and in molecular biology. Both computers and the replication of genes works on the same principle: Information can be faithfully reproduced if that information is in digital form and is sufficiently redundant, and mechanisms exist to decode the information - and that is the essence of molecular biology and the genetic code.