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Part I

Introduction

"The most beautiful experience we can have is the mysterious. It is the fundamental emotion that stands at the cradle of true art and true science." These words of Albert Einstein are evident throughout the history of science where we see great scientists, such as Archimedes, Copernicus, and Newton, search for the answers to the mysterious and develop the laws, models, and equations to explain how the natural world works. The contemporary understanding of science throughout history is as fluid as the Euler equations. This paper will answer how the contributions of the scientists studied in this course have changed and advanced the world in which we live. Four time periods and some of their significant members will be discussed. Ancient science progressed from oral tradition to recording keeping to theoretical-philosophical science of the Greeks. The Middle Ages brought an age of faith and an era where technology led science. The Renaissance experienced a rebirth of learning and a new challenge to the authority of the ancient scholars. The scientific revolution established the mechanical philosophy that enabled scientists to establish many of the significant laws that govern the physics of the universe. The history of science through the scientific revolution displays a human desire for an understanding of why nature is the way it is. Scientists, for centuries, worked to provide an explanation for the mysteries of the universe, which in turn provided the forces necessary to change the world for the better.

Ancient Science: Earliest Times to the Fall of Rome 476 AD

From the earliest times to the fall of Rome in 476 AD, science progressed through several different stages. From oral tradition, to record keeping and observational sciences by the

Egyptians and Babylonians beginning around 2000 BC, to the theoretical-philosophical science of Greek natural philosophers and the beginning of the Western intellectual tradition.

Before the invention of writing, oral traditions and myths allowed for the preservation of knowledge. The Egyptians and Babylonians advanced this into written text, allowing for further scientific development, as those in the field were able to reference old discoveries and find new ones. The Babylonians had collected much data regarding astronomical observations, but they did not generate a physical model of the universe. However, the Greeks recognized that from these astronomical data and observations they could create a model of the universe.

The Greek astronomers from the time of Pythagoras developed a two-sphere model of the universe, where the planets and outer sphere of stars orbit around a stationary earth. The search for a mathematical solution to the way the universe came together encouraged Plato to further the model of the universe. Plato supported the sphere that is the earth and the sphere of stars. He theorized, in his manuscript *Timaeus*, that the universe had a beginning and that all planetary orbits move in uniform circular motions. In his attempt to create this model, Plato designed each planet and moon as perfect spheres. This attempt not only worked to connect all of the observational data collected by astronomers, but also worked to support the Greek philosophy that the heavens were perfect and had a natural circular motion. For Plato, this model supported and in turn received reciprocal support from his geometrical atomism. Both argued the heavens were perfect and had circular motion. Plato accepted a philosophy of rationalism. Overall, Plato contributed to the advancement of science by promoting deduction and mathematics, believing that it would reveal the mathematical truths of the natural laws that stood eternal.

While Plato searched for mathematical truth, Aristotle believed deductive and inductive methods aided in the search for knowledge. Aristotle deduced that the universe had no beginning or end, and dozens of interrelated spheres made up the planets and their orbits around a stationary earth. Aristotle rejected the Platonic elements because they did not accurately describe the natural motions of the five elements. He observed the movement of the elements in nature and developed his own interpretation of their relation to one another that would remain standard for centuries. From his observations of animals, in *Historia animalium*, Aristotle adopted a discontinuous (division of animals into classes) and continuous (great chain of being) view of nature. He classified 500 animal species creating one of the earliest taxon. Aristotle strengthened science by advocating the establishment of the laws of nature from the observation of nature while still applying rational theory to what could not be observed.

No greater luminary of this Greek philosophy of rationalism existed than Archimedes. He patroned Plato's mathematical approach to solving the laws of nature with his calculation of the value of pi in 240 BC and with his derivation that the moment of force equals force multiplied by distance from the fulcrum. Archimedes also promoted Aristotle's inductive methods to obtaining knowledge with his development of the Archimedes' principle. Using the knowledge obtained from his experiments he deduced that density is equal to mass divided by volume. Archimedes' calculation of pi presented astronomers with a tool they could use to calculate values like the diameter of the Earth. His work with forces and density developed new branches of mathematics, statics and hydrostatics. Archimedes provided a series of equations and concepts that were so fundamental to science and mathematics that they are still used today.

While it is important to recognize the contributions of oral communication and early written text, it was the input of the logical, rational arguments made by the Greeks that advanced science in this period so far forward. It was the natural philosophy and theoretical intrigue of the Greeks that advanced scientific knowledge from simple observation to a quest to answer the "why" behind those observations. The Greeks accepted that natural laws governed the universe and they were capable of discovering these laws. This was the beginning of the Western intellectual tradition.

Science and its Application in the Middle Ages 400-1400

The Middle Ages began as an age of faith and little scientific incentive. By 1000 AD, Europeans began experiencing advances in cartography, magnetism, astronomy, and navigation, but in all cases, technology led science.

During the 500-year Dark Age, beginning in 476 AD, Europeans evoked little interest in natural philosophy as they focused on political and theological interests. After the closing of Plato's Academy in 529, the center of learning moved east to the Muslim Arab Empire until the Crusades in 1096. Muslim astronomers adopted a lunar calendar that remains in use today. They also perfected the astrolabe, which enabled navigators to determine latitude. Muslim sailors constructed a mariner's compass using a magnetic lodestone that guided English sailors in the 1100s and Italian sailors in the 1200s. In 1269, Peregrinus explained how the compass worked by determining the law of attraction and repulsion for magnets. These advances in navigation compounded well with advances in cartography. At the same time, Muslim scientist Alhazen performed optical studies that would not be surpassed until the 1500s.

Roger Bacon carried out his own optical studies in Europe in the 13th century. He believed that mathematics and the experimental method would be important to his investigations on mirrors, convex and concave lenses. Bacon also established the first theory that the Earth could be circumnavigated. The Magellan expedition from 1519-21 successfully proved this theory. As a religious man, Bacon sought to follow in the steps of Augustine and establish scientific knowledge to put into the service of the church. He never sought to disprove the existence of God, only expand the understanding of the world God created.

The existing geocentric model of the universe created by Ptolemy remained virtually unchallenged. Ptolemy first projected lines of longitude and latitude from a globe to a conical projection around 129 AD and adopted a north orientation. Gerardus Mercator devised a method to project a globe onto a flat surface in 1569. This created a true scale near the equator but distorted the scale increasingly the closer to the poles the projection got. Nevertheless, Mercator's projections allowed for maps to be easily read and understood. The Mercator projection is still used today by major street mapping services like Google Maps.

Another Medieval scientist proposed concepts that would remain in use beyond the 1400s. Nicholas Oresme gave the first graphical representation of velocity: velocity against distance. This graph introduced the idea of uniform and difform motion, but could not be thoroughly explained until Newton's invention of Calculus. In the 1350s, Oresme proposed that the Earth rotated daily from west to east on its axis and this accounted for day and night. This objection to the Aristotelian belief of a stationary earth would be largely ignored until Copernicus' heliocentric theory. Oresme also proposed the universe is infinite in size, a theory that has been expanded on in recent years and is being tested and proven today. Nicholas of

Cusa, a German cardinal, supported Oresme's theories in 1440 with his *Doctra Ignoratia* that discussed the daily rotation of the Earth on its axis and life on other planets. As members of the church, both men sought to follow the footsteps of Roger Bacon and put scientific knowledge in the service of the church.

The Middle Ages experienced a lesser desire for scientific knowledge because many Europeans believed faith would help them survive the Plague and rise victorious in the Crusades. Craftsmen often made technological breakthroughs, such as the water wheel, windmill, printing press and iron manufacturing, without understanding the science behind it. Scholars performed scientific research in service of the church but, along with craftsman, understood and practiced a new method of inquiry and experimentation that contributed to the intellectual transformation that began in Europe after 1000.

Science in the Renaissance 1400-1600

A reverence for the past, a scholarly challenge to the scientific authority of ancient scholars, and a denial of progress made during the Middle Ages defined the renewal of learning that was the Renaissance.

When it comes to the Renaissance, no man was better known than Leonardo Da Vinci, the Renaissance man. In the late 15th century and early 16th century, he made contributions to art, medicine, science and engineering. Da Vinci held an ontological and epistemological philosophy on science. He appreciated the adaptability and dynamic movement of nature while not accepting the authority of ancient scholars, instead relying on experimentation. Much of Da Vinci's work involved observation of the natural world and a desire to obtain knowledge. His major contribution to science being his differentiation of potential and kinetic energy from his studies on falling water. This laid the foundation for mechanics. Da Vinci performed extensive scientific studies but made little effort to publically challenge existing standards of knowledge.

Nicolas Copernicus wrote *Commentariolus* between 1502 and 1510. In this manuscript, Copernicus directly challenged the authority of ancient scholars with his heliocentric model of the universe. He argued that placing the sun at the center of the universe was not only a simpler model, but it also explained the retrograde motion of the exterior planets. He further argued that the planets held a regular orbit order with the sun at the center of the universe but not with the Earth at the center. The Copernican model challenged earlier astrologers and their macro-micro cosmic link by removing Earth from the central position in the universe, and it even questioned the outer sphere of fixed stars and its legitimacy. Other scientists developed similar challenges to the works of the ancient scholars.

In 1543, Andreas Vesalius published *De Humani Corporis Fabrica*. In this publication, Vesalius introduced the anatomical terms for muscles, bones, brains, and abdominal parts. This medical book challenged the existing, and highly supported, concepts of Galen that had stood the test of time. Vesalius argued that Galen established his anatomical conclusions without dissecting humans and therefore failed to provide an accurate anatomy of the human body. He promoted demonstrations, experiments, and comparative anatomy. He believed in a hands on approach and that physicians should look to nature for answers on the body, not Aristotle or Galen. Many Renaissance scientists held similar beliefs leading to the end of ancient science.

Paracelsus challenged the four humor theory of Hippocrates and Galen and the popular beliefs in signatures and remedies, and he emphasized, with iatrochemistry, the shift in alchemy from transmutation of metal to preparation of medicines from plants and metals. Alchemy flourished, but Renaissance metallurgists focused on their efficiency at extracting metals from their ores. The increased mining and smelting caused increased pollution and the first attempts of communities to control pollution.

The long dominant Aristotelian-Ptolemaic-Galenist science struggled to remain relevant after the challenges presented by the likes of Vesalius and Copernicus. This marked the beginning of the new mechanical philosophy of nature, and for the next century natural philosophers sought to discover the laws that accounted for the motions within nature.

Scientific Revolution 16th and 17th Centuries

The study of matter in motion, or mechanical philosophy, characterized the scientific revolution of the 16th and 17th centuries. Mechanical philosophers sought to discover and quantify with mathematical equations the laws that governed the motions of matter. The scientific revolution witnessed an increase in experimentation and the invention of new instruments, all to help define the mechanical philosophy.

The scientific revolution began with a strong promotion of experimental science. Francis Bacon argued that no scientists should blindly accept the authority of others without testing it themselves. He promoted the inductive method that would be used by Galileo.

Galileo spent his life quantifying science. He believed that mathematics provided the key to understanding the universe. Extending 60 years, Galileo's contributions to science included the first person to demonstrate the isochronicity of a swinging object in 1583, give an explanation for uniformly accelerated motion and its effects on falling bodies in 1602-05, establish relative motion, define horizontal and vertical forces in 1608-09, provide evidence that the moon was not a perfect sphere and that Jupiter did not leave its moons behind so it is likely the moon orbits the earth in 1609, point out the phases of Venus and seasonal variation of sunspots' paths in 1613, provide proof of the law of fall in a vacuum, the principle of independence of forces, and the theory of parabolic ballistics in 1638. Galileo argued that mathematics provides humanity with the certainty about nature it seeks and stressed the importance of quantitative experiments and hypothetical deductive reasoning. Galileo's work gave support to the Copernican model of the universe as well as established the most detailed understanding of mechanics at that time.

Galileo was not the only scientist to make great strides during the scientific revolution. New methods of mathematical calculation such as logarithms, analytical geometry, and calculus provided new kinds of measurements and quantification that allowed for experimental observations to be converted to mathematical equations. New instruments such as the vacuum pump, telescope, barometer, and microscope, enabled scientists to investigate the natural world in areas that had eluded them before. This led to the defining of scientific laws, like Boyle's law, Snell's law, Galileo's laws of motion, Kepler's laws, Hooke's law, and Newton's three laws and law of universal gravitation.

If Copernicus began the scientific revolution with his challenge the Aristotelian universe, Newton completed that revolution with the establishment of his three laws of motion and universal gravitation. Newton invented calculus because he did not have the math to explain how the Earth attracted the Moon. With the laws of planetary motion established by Kepler and Hooke's law, Newton derived his law of universal gravitation for any two bodies attracting one another. He published this and his three laws of motion in the *Principia* in 1687. Though

Newtonian mechanics did not dominate physics until 1750, he established the most significant laws of physics.

The study of matter in motion provided a foundation for the works of Galileo and Newton. Combined with new instruments and new mathematics, the mechanical philosophy became the dominant view of the world and defined the scientific revolution. This revolution saw the discovery of many significant laws of science, the speed of light, the discovery of circulation, and how the greater universe works.

Conclusion

Through centuries of scientific study, scientists established and challenged understandings of the universe to provide the human mind with a sense of certainty as to why things are as they are. The work of Greek theoretical-philosophical scientists transformed humanity from an observational species to one that made attempts to understand their existence as well as the world around them. Middle Age scientists may not have made the same strides as the Greeks before them, but they still made additions to their understanding of the world around them from the technologies they created to make their daily lives easier. The Renaissance scientists challenged the long standing concepts of the universe and where Earth and humans stood in that universe. The scientific revolution saw the rise of the laws that would define mechanics, culminating in Newton’s laws that would not be challenged until the discovery of subatomic particles. The quest to understand the mystery of the universe drove scientists for centuries and is still a quest that scientists are attempting to complete today.

Part II

Introduction

“ If you can't explain it simply, you don't understand it well enough.” This quote from Einstein explains the motivation of scientists from the eighteenth and twentieth century. In the eighteenth century, both the physical and life sciences sought to classify the visible elements of their respective sciences, although the physical sciences worked to understand the composition and behavior of these elements. As the nineteenth century developed, the life sciences experienced new theories of evolution to explain how life came to be as it is today, while the physical sciences experienced new mathematical evidence and laws that provided an electrodynamic worldview to accompany the already held mechanical worldview. The twentieth century began a new age of discovery and understanding for the life sciences with the development of genetics. Meanwhile, the second scientific revolution uprooted classical physical science and replaced it with new laws and theories that provided greater understanding to how the world works.

Physical and life sciences in the eighteenth century:

The eighteenth century enlightenment saw the study of composition and the classification of matter, theories of heat, and the electrical behavior of matter directed the physical sciences, classification by the naturalists and the impact of science and mechanics on society.

Physical and life sciences both worked on identification and classification. A new phase of matter, gas, became increasingly important as it was studied along with solids and liquids. Scientists like Boyle and Helmont studied gas’ properties to begin identifying and classifying them. Boyle also contributed to the classification of substances by studying acids and bases.

These studies of matter developed and understanding of composition, combustion, and imponderables (fluids) present in matter. Much of this early work did not emphasize quantification. Hales, Black, Cavendish and Lavoisier focused on this idea of quantification.

A French empirical chemist, Antoine Lavoisier (1743-1794) emphasized using quantitative measurements. An example of this approach is his 101-day pelican experiment to disprove the conversion of water to earth. From 1772-74, Lavoisier's combustion studies displayed that each resulting product(oxide) had gained something from the air(oxygen) and left a partial vacuum in the container because the product always weighed more than the reactant(element). Such that: $S(s) + O_2(g) \rightarrow SO_2(g) + H_2O(l) \rightarrow H_2SO_3(l)$. Upon Priestley's visitation of Paris in 1774, Lavoisier proposed that dephlogisticated air (oxygen) was the air component that was responsible for combustion. With this discovery at hand, Lavoisier deduced the composition of red mercury calx, water and human respiration. He summed up his experimental research in *Elements of Chemistry* in 1789. Between 1768-72, Lavoisier developed the experimental proof to prove the third conservation law of science; that in a chemical reaction, the mass of the reactants is equal to the mass of the products. In the 1787 publication of *Méthode de Nomenclature Chimique*, Lavoisier proposed the caloric as the element of heat, where heat was a fluid of particles that were self-repulsive but attracted to matter, and adding or removing caloric accounted for the expansion/contraction of substances and for the phases of matter.

While much of the scientific community accepted the caloric theory, Count Rumford (Benjamin Thompson, 1753-1814) believed that mechanical motion produced heat. He reached this conclusion by boring a cannon. Rumford noticed that the boring process generated heat as long as mechanical motion persisted and the heat was inexhaustible. He questioned how a metal could contain so much caloric to generate a never ending supply of heat and not melt, while remaining cool to the touch upon the ending of the mechanical motion. Rumford provided the means to calculate the mathematical value for the relation between heat and motion, known as the mechanical equivalent of heat. James Joule (1818-1889) would calculate this value to be 31.92 Btu generated by 1 Hp in 1843 using Rumford's measurements in 1843. Rumford's research also led him to discover that water has a greater density at 4℃ than at 0℃.

The studies on heat led to the development of steam power and steam engines. While in the field of electrical studies advancements were made, including Franklin's one-fluid theory of static electricity, the Volta's first battery, and the production of current electricity. Ray and Linnaeus developed both natural and artificial systems of classifying plants and animals. Linnaeus perfected the binomial system of classification still in use today. During this Enlightenment era, scientists adopted the empiricism and sensationalism of John Locke. The scientific breakthroughs, especially in heat studies, led to the invention of the steam engine, by James Watt, and the industrial revolution in Europe.

Darwin's century:

During Darwin's century, geology and natural history transitioned from classification (record keeping) to theories and laws. Mendel solved Darwin's problem of inheritance with his new science of genetics.

The late eighteenth and early nineteenth centuries saw the end of a classification based natural science, and witnessed the development of theories about the origin of species, evolution, and the age of the Earth. Using the strata of the Earth, Cuvier, Buffon, Hutton and Lyell calculated various ages of the Earth ranging from a few thousand years old to 300 million. With the development of radioactive dating in 1905, scientists could then develop a more accurate age of 4.6 billion years old. Two theories were developed by naturalists to account for change or evolution within species: the Buffon- Erasmus Darwin- Lamarck influence of environment-use and disuse theory and Darwin's theory of natural selection. Darwin's theory allowed for it to be tested, unlike the alternative.

Englishman, Charles Darwin (1809-1892), began his natural studies on his voyage on the *Beagle* after he graduated from college in 1831. In 1835 the vessel visited the Galapagos Islands, where he studied the 13 visibly-related types of birds across the islands. Darwin noticed that the birds all looked the same except for the different beaks that are required from their different sources of food. Darwin had recognized that these different species were the 13 best finch species to adapt to survive in their respective environments. This agreed with Lamarck's remark that Giraffes did not just stretch their necks, the ones born with longer necks survived better than the shorter necks. In 1858, Darwin published his manuscript on the theory of natural selection in the *Proceedings of the Linnaean Society*. His theory contained five elements: common ancestry; descent with modification; gradualism and change by small, incremental steps; multiplication of species by splitting of lineages; and natural selection acting on random variations. The next year, Darwin published *The Origin of Species*. This work only dealt with plants and animals, and it did not give real examples of evolutionary change which made it controversial to individuals like Richard Owen, Rudolf Kolliker and Claude Bernard as well as many religious communities.

Gregor Mendel (1822-1884) provided the evidence for Darwin's theory of evolution in 1866 with his paper, "Experiments with Plant Hybrids." Mendel, an Augustinian priest, is known as the founder of genetics. He studied physics and statistics at the University of Vienna. Mendel used statistics and quantification plant studies to discover and demonstrate the mathematical relation in his plant breeding experiments. From 1856-63, Mendel studied the inheritance of elemente (genes) in 28,000 pea plants. He chose the pea plant because he could grow large numbers and they could easily be manipulated, cross-pollinated and self-pollinated. His experiment allowed him to see how characteristics, such as size and color, passed from generation to generation. Mendel developed 3 laws of genetics: the law of segregation states that in breeding a specific gene determines each of the different characteristics of the parents and their offspring; the law of independent assortment of characteristics states that an inherited gene does not affect any other inherited gene; the third law showed that each organism has 2 sets of genes, one from each parent, and one gene from the pair always predominates over the other gene. Mendel's work was ignored because Biologists did not use mathematics in their work. At the turn of the century, Mendel's paper was rediscovered and would be used by Reginald Punnett to develop the Punnett Square, the most basic interpretation of genetic inheritance.

Darwin's theory developed strong resistance that persists until this day because it did not leave a place for God within our world. This pushed many theologians and Americans away from accepting the theory. Today, many of the large religious institutions accept some form of evolution with God's influence, but fundamentalist religious believers continue to deny the evolution of species and the age of the Earth.

Molecular biology and the double helix:

Built on previous advances and the move of physical scientists and their instruments to the field, a new field of study emerged in the life sciences. Molecular biology emerged from the investigations of cells, proteins, chromosomes and genes.

Johann Friedrich Miescher (1844-1895) discovered the nucleic acids deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) in 1869. Miescher studied white-blood cells because of their small amount of cytoplasm and their nucleus housing the nucleic acid made it easier to obtain. After extracting the nuclein by washing the cells with sodium sulfate solution, he analyzed the remaining material. He recorded that it contained 14% nitrogen, 2% sulfur (in protein), considerable phosphorous (3%), an acid (DNA or RNA), and a basic protein component or histone. The nuclein had a molecular formula of $C_{29}H_{49}O_{22}N_9P_3$. Miescher later found nuclein in yeast, kidney, liver, and sperm cells.

The second half of the nineteenth century and the first half of twentieth century experienced a new scientific understanding from the unit of life, the carrier of hereditary characteristics, chromosomes, to the sequence of DNA bases that make up all life. None of this would have been possible had it not been for the infusion of physical scientists into the field. They brought with them their instruments, such as electron microscopes, chromatography, radioactive tracers, and x-ray diffraction. These tools would play a huge role in photographing, understanding and solving DNA's molecular structure.

The two men who solved the molecular structure of DNA were James Watson (b.1928), an American biologist-geneticist, and Francis Crick (1916-2004), an English physicist. Using x-ray diffraction images of crystalline DNA created by Maurice Wilkins (1916-2004) and Rosalind Franklin (1920-1958) in 1952, the keto structure (ketone, HC=O) of the bases guanine and thymine proposed by Jerry Donohue (1920-1985), and equal amounts of adenine-thymine bases and guanine-cytosine bases displayed by Chargaff's Rule , $\frac{A}{T} = 1$ and $\frac{C}{G} = 1$, Watson and Crick developed a double helix model for the structure of DNA in 1953. The pair predicted that the two helixes unwound and replicated the original DNA helix to duplicate the exact sequence of base pairs and genetic information. This structure and process would be confirmed in a 1957 observation of *E. coli* reproduction by Matthew Meselson (b. 1930) and Franklin Stahl (b.1929). Watson, Crick and Wilkins received the 1962 Nobel Prize in medicine for their discovery.

Molecular biology continued to have breakthroughs after Watson and Crick's work. Nirenberg Khorana solved the genetic code in 1961. The Human Genome Project completed the mapping and sequencing of the human genome in 2001. The study of introns has enlightened scientists to why humans have a similar genome but different physical appearances. Cloning and stem cell research have been successful but controversial, often with those who resist to accept Darwin's theory of evolution.

Physical sciences in the nineteenth century:

In the nineteenth century, the electrodynamic worldview complemented the existing mechanical worldview, while classical physics and determinism dominated the physical sciences but began to collapse at the century's end.

Thomas Young's revival of wave theory of light in the early 1800s renewed scientific acceptance of a space-filling luminiferous ether. Albert Michelson perfected a terrestrial method to calculate the speed of light. The later decades of the nineteenth century completed the scientific revolution of the previous centuries with the establishment of an electromagnetic interpretation of the universe with laws arising from the studies of Faraday and Maxwell.

As a great English experimental physicist, Michael Faraday's (1791-1867) experiments established important relations including the motor principle, transformer and generator principle, and electromagnetic induction. The motor principle, established by Faraday in 1821, showed that an electric motor converts electrical energy to mechanical motion. 10 years later, Faraday discovered the motion of a magnet in a coil connected to a galvanometer created an alternating current in the coil. This was the first demonstration of the electrical generator and the principle of electromagnetic conduction. That same year, 1831, he established that, depending on the winding in a coil, a transformer could increase or decrease the voltage of an electrical circuit. Later that year he constructed the first direct current generator. In 1846, Faraday displayed the presence of lines of forces in a magnet by scattering iron filings on paper placed over a magnet. In an earlier study of electrolytic reactions in 1832-33, Faraday established two laws of electrolysis, q=it and m=zit. Faraday also introduced words such as cathode, anode, cation, anion, electrolyte, and electrolysis in 1833 to describe an electrolytic cell.

James Clerk Maxwell (1831-1879), of Scotland, provided the mathematical theory for Faraday's experimental research. Maxwell's equations, $\nabla * E = \frac{\rho}{\varepsilon_0}$, $\nabla * B = 0$, $\nabla x E = -\frac{\partial B}{\partial t}$, and $\nabla x B = \mu_0 (J + \varepsilon_0 \frac{\partial E}{\partial t})$, accounted for the generation of electrical and magnetic fields and provided the foundation of classical electrodynamics. Maxwell's equation E=cB led him to conclude that light comes from the motion of an electric charge. Maxwell had mathematically proved the correctness of Faraday's electromagnetic experiments and conclusions. He believed that the ether transmitted electromagnetic radiation and that the transmission of radiation occurred mechanically along the lines of force or throughout the magnetic field. The work of Maxwell, Faraday, and others like Ohm and Gauss established a new electrodynamic worldview.

The nineteenth century also saw the development of the laws of thermodynamics. Joule established the first law in 1847 from experiments where he converted potential energy to kinetic energy to thermal energy. He recognized that heat energy always balance the loss of another form of energy, proving the conservation of energy, $\Delta E_{in}=\Delta E_{out}$. Rudolf Clausius (1822-1888) experimentally established in 1850 that the entropy of the universe strives to a maximum and heat always flow from higher temperature to lower temperature. Clausius defined entropy as the energy unavailable to do useful work with the mathematical derivation $\Delta S= \frac{\Delta H}{T}$. Walther Nernst (1864-1941) established the third law of thermodynamics which states that the entropy of a perfect crystal is zero at absolute zero. Nernst, in 1906, introduced the heat theorem that said in any reaction involving solids and liquids the change in entropy approached zero at the temperature approaches zero.

Nineteenth century science sought new deterministic laws and principles for its advancement and the better understand the physical and life sciences.

Twentieth-century physical science:

In the second Scientific Revolution in the twentieth century, theoretical science, quantum theory, special and general theories of relativity, quantum mechanics replaced classical physics and determinism as the foundation of physical science.

From 1890-1935, a series of significant breakthroughs challenged the accepted doctrines of the physical sciences and ended classical science. This second scientific revolution was led by the rejection of determinism, the transformation of classical physics, and the acceptance of quantum theory. Scientists made breakthroughs in x-rays, radioactivity, the electron, quantum theory, relativity, and quantum mechanics. The modern pillars of physics and physical sciences were established by the Germans Max Planck (1858-1947) and Albert Einstein (1879-1955).

In 1900, Planck established that matter emitted radiant energy in quanta according to the formula E=hv. Plank treated the internal energy of a black body as a function of entropy. By interpolating Wien's distribution equation, $E(\lambda_{max}T) \propto \lambda^{-5}T$, that held at high frequencies and low temperatures and the Rayleigh-Jeans equation, $E(\lambda T) \propto \lambda^{-4}T$, that held at low frequencies and high temperatures, he derived a new radiation law. Planck found a theoretical explanation for his equation by applying Boltzmann's probabilistic interpretation of entropy, and by making the assumption that a black body emitted its energy in discrete frequency values not in a continuum. This explained his equation that the energy radiated or absorbed is equal to Planck's constant multiplied by the frequency of the energy radiated or absorbed. Planck received the Nobel Prize for physics in 1909.

The work of Planck and his concept of quanta would be used by Erwin Schrodinger and Werner Heisenberg to independently propose new quantum mechanical models of the atom. In 1905, Albert Einstein used Planck's equation to prove the photoelectric effect.

Albert Einstein was the most recognized scientists of the 20th century. By his looks and his intellect, he became the ultimate example of a scientist. His genius began to be publicly known in March, 1905 with his quantum theory of light to solve the photoelectric effect, where Einstein showed that a photon's energy depends on frequency not intensity and at a high enough energy can create an electric field upon sticking a metallic surface. This theory would become the law of the photoelectric effect, it earned Einstein the 1921 Nobel Prize in physics, and it confirmed Planck's equation, $E=hv$. In May 1905, Einstein provided a mathematical explanation, $D= \frac{RT}{6\pi N v r}$, to explain the Brownian movement or the random motion of small particles immersed in a liquid, such as pollen in water. In June, Einstein developed his special theory of relativity. The theory of special relativity explains how space and time are linked for objects that are moving at a consistent speed in a straight line. One of its most famous aspects concerns objects moving at the speed of light, where as an object approaches the speed of light, its mass becomes infinite and it is unable to go any faster than light travels. This theory required 4 dimensions to define a body's location in space, x-y-z and time. To support his theory, Einstein established 3 relativistic equations: one for length, $l=l_0\sqrt{1-\frac{v^2}{c^2}}$; one for mass, $m=\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$; one for time, $t=\frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$. In September, Einstein derived the mass-energy equivalency by determining that the amount of energy released in a reaction resulted from the reactant's loss of mass. The mass of a body, Einstein concluded, provided a measure of its energy content, such that if the energy changed by an amount L, then the mass would change according to $\Delta m=\frac{L}{c^2}$. In 1907, he published his equation relating energy, mass, and the speed of light $E=mc^2$. In 1915-16, Einstein developed his alternative to Newtonian gravity with his theory of general relativity, $G_{ab}=\kappa T_{ab}$. This theory described gravity as the influence of one body on the geometric space-time in which a second body is moving. Einstein died in 1955 and was studied extensively, even after death.

As the 20th century continued more discoveries were made in particle physics with the discovery of neutrons, neutrinos, meson, quarks, and the fundamental forces of particles. The desire to end World War II introduced the world to atomic energy in the 1940s and changed the role of science in society.

Conclusion

Science from the eighteenth century to the twentieth century evolved from a study of classification in both the physical and life sciences to evolutionary theories in the lifes sciences of the nineteenth century and a new electrodynamic worldview to complement the existing mechanical worldview in the physical sciences. In the twentieth century, a second scientific revolution occurred in the life sciences with the emergence of genetics and in the physical sciences with the two new foundations of physics, general relativity and quantum mechanics. Through these centuries scientists continued to search for a simple explanation to understand how life and the universe work.

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