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Dancing with Falsification: The Dynamic of Chemistry Atomistic Theories Across Centuries

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Abstract

This research aimed to explore the contribution of the falsification process to the progress of science in the field of atomic theory. The analysis focused on the history of atomic development and how this theory underwent a process of falsification. This research was qualitative research using a literature study with a narrative review method. The results showed that the development of a theory, including the theory of atoms, has undergone many improvements. Falsification is an essential aspect of scientific progress, especially in atomic theory, involving testing the theory through experimentation and observation to determine accuracy. In the development of atomic theory, falsification played a key role, as in Dalton's atomic theory. Although revolutionary, subsequent experiments revealed subatomic particles, resulting in the falsification of Dalton's ideas and the emergence of a more complex understanding of atomic structure. The evolution of atomic theory shows that scientific knowledge is dynamic, continuing to develop through falsification. New evidence continues to refine ideas, ensuring scientific knowledge accurately reflects the natural world. The scientific method emphasizes openness to falsification, stating that theories must be testable and can be replaced when significant evidence refutes the theory. This openness is the basis for scientific progress and a deeper understanding of the universe.

Keywords: atomic theory; chemistry; falsification

Abstrak

Penelitian ini bertujuan untuk mengeksplorasi kontribusi proses falsifikasi terhadap kemajuan ilmu pengetahuan di bidang teori atom. Analisis berfokus pada sejarah perkembangan teori atom dan bagaimana teori tersebut menjalani proses falsifikasi sehingga ditemukan teori yang mapan yang digunakan oleh komunitas ilmiah sains sekarang ini. Penelitian ini adalah penelitian kulitatif menggunakan studi literatur, menggunakan metode narrative review. Hasil analisis menunjukkan bahwa perkembangan sebuah teori termasuk teori mengenai atom telah berkali-kali mengalami perbaikan. Falsifikasi adalah aspek penting kemajuan ilmiah, terutama dalam teori atom, melibatkan pengujian teori melalui eksperimen dan observasi untuk menentukan akurasi. Pada perkembangan teori atom, falsifikasi memainkan peran kunci, seperti dalam teori atom Dalton. Meskipun revolusioner, eksperimen selanjutnya mengungkap partikel subatom, mengakibatkan falsifikasi ide Dalton dan munculnya pemahaman yang lebih kompleks tentang struktur atom. Evolusi teori atom menunjukkan pengetahuan ilmiah bersifat dinamis, terus berkembang melalui falsifikasi. Bukti baru terus menyempurnakan teori, memastikan pengetahuan ilmiah mencerminkan dunia alam dengan akurat. Metode ilmiah menekankan keterbukaan terhadap falsifikasi, menyatakan bahwa teori harus dapat diuji dan dapat diganti ketika bukti signifikan mematahkan teori tersebut. Keterbukaan ini menjadi dasar bagi kemajuan ilmiah dan pemahaman yang lebih mendalam tentang alam semesta.

Keywords*:* falsifikasi; kimia; teori atom

Introduction

Scientific and philosophical theories that appear to be based on statements that are clearly true may turn out to be wrong or questionable. Even some propositions of deductive logic, previously thought to be true, are now considered to be reasonably doubtful (Couvalis, 1997). Karl Popper, a philosopher who developed the concept of falsification, stated that the scientific knowledge of science is found when within the theory itself there is openness to evaluation and the possibility of being refuted. Second, from his analysis, the main characteristics of science are falsifiable, can be refuted, can be shown to be wrong (Wibowo, 2022). Falsification was interpreted by Popper (1963) as a criterion used to determine the scientific status of a theory.

A theory that states that a statement or system of statements must be able to contradict possible or conceivable observations to be considered scientific(Popper, 1963). In other words, a scientific theory must be able to be tested and refuted through observation or experimentation. If a theory cannot be disproved by a conceivable event then the theory is considered non-scientific. Falsification is an attempt to prove that a theory is wrong and every valid test of a theory is an attempt to disprove it.

For example, Newton's theory of gravity predicts certain behavior of celestial bodies that can be observed and measured, but if these observations do not match the predictions then the theory can be refuted. In the case of astrology there are no clear and specific predictions that can be tested and refuted in the same way, so astrology does not meet the criteria for falsification proposed by Karl Popper as a standard for legitimate science. According to Karl Popper's view, because order is not found, but we suspect that order exists.

The rationality of science is maintained, because sometimes we can falsify conjectures by confronting them with basic statements that are inconsistent with them (Couvalis, 1997). The development of science can occur due to distrust of scientists, science can be formed because it is built or filled with a collection of several theories.

This implies that there is a process of scientific development that is ongoing and can lead to the creation of new, more precise theories (Ulya & Abid, 2015). Then what about atoms? Can this be considered scientific or non-scientific knowledge? On the other hand, the development of atomic theory is an important thing to teach students (Park & Light, 2009).

Integrating historical and philosophical perspectives into chemistry education can enrich students' understanding by providing context, encouraging critical thinking, and addressing misunderstandings, thereby leading to a more comprehensive and accurate understanding of basic scientific concepts (Lemma & Belachew, 2022). Therefore, it is important to know how the falsification process contributes to scientific progress in the field of atomic theory.

Method

The analysis focused on the history of the development of atomic theory and how this theory underwent a process of falsification so that it was found to be an established theory that is used by the scientific community today. This research was qualitative research using literature study. Narrative review was used in this study. Narrative review is a way of reviewing literature that tries to summarize or synthesize what has been written about a particular topic, but does not intend to generalize (Green et al., 2006; Sylvester et al., 2013). Technically, this study was carried out in the following steps: (a) collecting references that were appropriate to the topic raised, namely related to the falsification process that occurred in the theory of atoms; (b) write references and organize the important points that will be discussed.

Result and Discussion

The development of atomic theory has been a complex and long journey from hundreds of years until now (Kozlov, 2021). Humans have tried to understand the structure and basic properties of matter and its constituents (Fritzsche et al., 2021). Scientists have developed various theories that reflect their views on atomic structure (Yerokhin et al., 2021a).

The beginning of the long journey of atomic theory began with the figure of Democritus who was a philosopher from the city of Abdera in Northern Greece who lived around 460 BC-370 BC. Democritus taught that there are things called atoms, and from these atoms objects are formed. The existing atoms referred to by Democitus are atoms in the philosophical sense, not yet something empirical. Democritos himself was in line with his predecessors who stated that nature does not change by itself but is caused by something.

If viewed from philosophy, philosophy is an activity of endless search and adventure regarding the meaning of truth and wisdom, whether it is about God, the existence of the reality of the universe or the purpose of human life itself (Krisna Pradana, 2018). Democritus agreed with his predecessors that nature could not change completely, therefore he assumed that everything was made of blocks that could not be seen by the eye, each of which was eternal. Therefore, it is impossible for something that exists to arise from nothing.

Democritus named these small units atoms or in Greek, Atomos (a = no) and tomos means cut into pieces, which means invisible.

Atomist philosophers, at that time Democritus was one of the leading atomists, believed that there were two realities that make up the physical world, namely atoms and nothingness (Marsiti, 2018). The void in space where atoms move and collide with each other when these atoms collide with each other they may repel each other or they may connect to each other forming bonds on the surface of the atoms and coming together to form something new.

Democritus believed that nature consisted of atoms that could not be the same and were infinite in number. With his atomic model, he was able to explain that the matter in the universe, which is around us, consists of smaller parts or building blocks which were then referred to as atoms, but this democritus model lacked strong experimental evidence and only in 1800 -an experimental evidence of this emerged.

Democritus continued to search and adventure endlessly in formulating atomic theory so that he was known as a materialist(Marsiti, 2018). Democritus himself was a student of Leukipos, the founder of the atomist school. Democritus developed ideas about atoms so that he was known as a philosopher who wrote about natural science. The theory expressed by Democritus was falsified by Aristotle. Aristotle said that a substance is composed of air, fire, water and earth. Aristotle's opinion has been believed for centuries and Aristotle argued that matter is continuous, which means it cannot be divided continuously to infinity. This is of course contrary to what was stated by Democritus (Krisna Pradana, 2018).

In the 8th century in Europe the development of science experienced obstacles (Sujito et al., 2019). This was an era when atomic ontology became a potential core of philosophical and religious debate. The debate is also driven by religious concerns about immortality and creation. This extends to the issue of whether atoms exist as a reality or not. These events continued to occur until the 12th century, and continued into the 14th century. Because their sole emphasis was on maintaining God's divinity, both Christian theologians and Islamic atomists denied the real existence of causality, including atoms, in the created world (Lemma & Belachew, 2022)

This was because at that time the thinking of scientists was confined by dogmatic religious teachings which bound freedom of thought about nature. Thoughts that are considered contrary to religious teachings are considered a sin that must be atoned for by physical punishment or even life. The Aristotelian paradigm is still recognized because it is considered not to conflict with religious teachings. Not only does the atomic concept receive justification from religious teachings, other ideas include the geocentric concept and the rejection of the concept of empty space. While Europe was experiencing darkness, the Middle East was experiencing rapid progress in science and technology. One of the scientists who touched on the problem of atoms was Abul Hasan Al Asy'ari, who linked atoms with events in the universe. He believes that the universe exists because of the atoms that make it up and these atoms have their own properties and are not densely developed and cannot influence each other, so according to him the atoms that make up the universe cannot disappear.

Based on his belief in Allah SWT, Abul Hasan Al Asy'ari believes that "entering" means being created by God and "going out" means being eliminated by God, so according to him, atoms must always be created by Allah subhanahu wa ta'ala at any time to replace the atoms. -atoms that have been abolished by Allah subhanahu wa ta'ala. This view is almost in accordance with Leukipos and Democritus who acknowledged the discontinuous nature of matter, but Abul Hasan Al Asy'ari rejected the notion that changes in the universe are caused by definite natural laws and are subject to the law of cause and effect inherent in the behavior of atoms (Mustofa, 2017). Linier with this opnion Dainton (2023) discusses the philosophical position known as panpsychism, which states that consciousness is a fundamental aspect of the physical world, even in the simplest or smallest entities. Until 1808 John Dalton revealed his atomic theory.

Dalton's work marked the beginning of the modern era in chemistry. Hypotheses about the nature of matter were the basis of atomic theory. Dalton's atomic concept is much more specific than the concept of Democritus. Dalton's initial hypothesis states that atoms of one element are different from atoms of other elements. Dalton never tried to describe the structure or arrangement of atoms. Actually, Dalton had no idea what an atom actually looked like. but he realized that the differences in properties exhibited by elements such as oxygen and hydrogen could be described by assuming that the hydrogen atom was not the same as the oxygen atom. Dalton's second atomic hypothesis states that to form a compound it is not enough to need only atoms of 1 element, but a specific amount of each of these atoms is also needed.

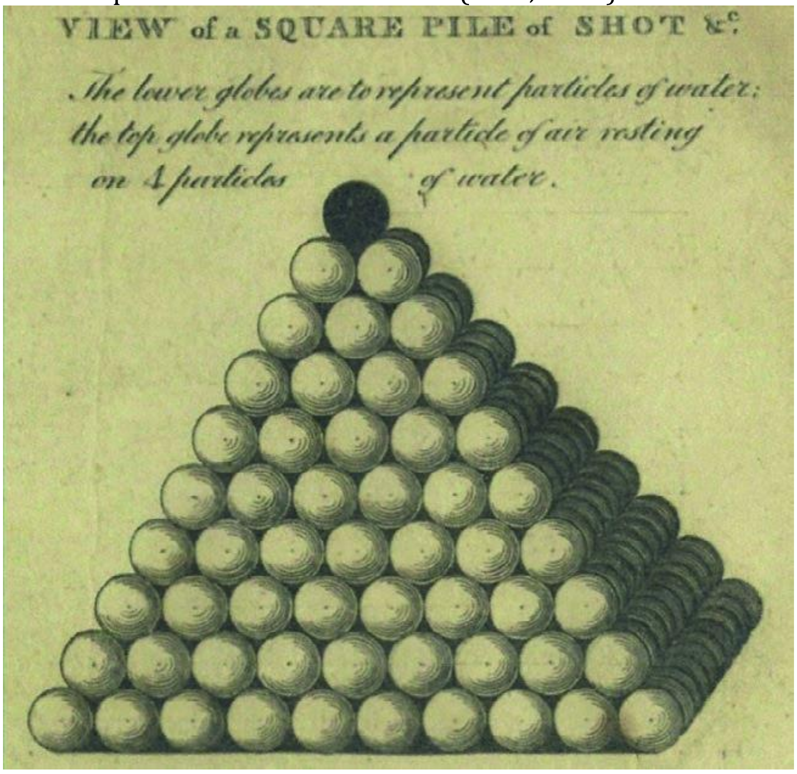
Dalton's second hypothesis supports the law of multiple proportions, which states that if two elements can combine to form more than one compound, then the masses of the first element and a fixed mass of the second element will be proportional to a whole number. and simple. Carbon can form two stable compounds with oxygen, say the first compound is carbon monoxide and the second compound is carbon dioxide. The results of modern measurements show that 1 carbon atom combines with one oxygen atom in the carbon monoxide compound while 1 carbon atom combines with two oxygen atoms in the second compound, namely carbon dioxide. in fact, the ratio of the two compounds is 1 to 2 (Chang, 2005).

John Dalton made significant contributions to the development of atomic theory in chemistry through his experiments and theories. He is credited with introducing the first atomic theory of chemistry, which became the basis for the modern understanding of chemistry and physics.

Dalton conducted early studies in meteorology and considered water vapor to be an "elastic fluid" that did not react chemically with other atmospheric components. He also developed mixed gas theory and the law of partial pressures, which explains how different gases can mix without chemical reactions. Dalton conducted experiments on gas diffusion and the solubility of gases in water under pressure.

Dalton considered oxygen dissolved in water. Dalton described the black sphere as a gas particle that presses on water particles (white spheres) as depicted in Figure 1. Dalton stated that the pressure of dissolved oxygen is 1/27 of the pressure above it, and this pressure is exerted on the walls of the container and the gas on the water, not on the water itself. At equilibrium conditions, atmospheric oxygen presses the dissolved part with the same pressure, namely 1/27, and the remainder, namely 26/27, is the gas pressure at the water surface. There is a repulsive force between the two oxygen layers adjacent to this surface, although it is much smaller, namely 1/27 of the total pressure. This shows Dalton's understanding of how gases dissolve in water and the interactions between dissolved gases and gases in the atmosphere.

Figure 1.
Dalton's profile view of air in water (Salvi, 2023)



The results of these experiments helped him in developing his atomic theory. Dalton noted the importance of the law of multiple proportions in his chemical experiments, which showed that atoms combine in simple whole number ratios to form compounds.

Dalton developed chemical symbols to represent the elementary particles of elements and formulated a table of relative atomic weights. He also tried to relate the solubility of gases to the diameter of their particles. Dalton interacted with other scientists and his work was influenced by the theories of his time, including Boscovich's theory of oscillatory forces and the 18th century concept of potential energy.

Dalton's atomic theory was an extension of a law popularized in 1799 by a chemist named Joseph Proust. Proust stated that your thoughts are different from the same compound containing constituent elements with fixed mass ratios. This stomach statement became known as the law of definite proportion. So, for example, if we have to analyze carbon dioxide samples obtained from different sources, we will find that the mass ratio of carbon and oxygen is always the same in each sample tested. From this it is clear that the mass ratio of different elements in a compound is always fixed, so the ratio of atoms and elements in the compound must also remain constant. (Chang, 2005).

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Dalton's theory made an important contribution to the history of the development of atomic theory, but his theory was not fully established when falsifications emerged from other scientists. Experiments in the 20th century related to the discovery of sub-atomic particles became a falsification of Dalton's statement which stated that atoms were particles that could not be divided further.

The falsification of this theory involves experiments that do not correspond to existing predictions or can be said to have an anomaly that can be explained. Science continues to develop, and these theories are continually tested as technology advances. It is important to remember that in science, a good theory is one that can be replicated and tested, when there is significant evidence that does not match the theory, it may be that the theory needs to be replaced with a new one (Riski, 2021).

Dalton stated that atoms could neither be created nor destroyed. In chemical reactions, the atoms are only rearranged, but there is no change in the atoms themselves. Dalton also conducted experiments to determine relative atomic weights and compiled the first table of atomic weights, which was an important step in the development of atomic theory (Salvi, 2023). Although Dalton made valuable contributions, his theory underwent several modifications and revisions over time. Dalton's atomic theory was falsified through experiments that succeeded in discovering subatomic particles, one of which was Thomson's discovery.

Thomson, who was awarded the Nobel Prize in Physics in 1906 for his discovery of the electron and his work on electrical conduction in gases, proposed an atomic model in which atoms consisted of many negative cells (electrons) in a sphere filled with uniform atoms. positive electrification (Hon & Goldstein, 2013). The first appearance of the expression "plum pudding" in connection with Thomson's theory appears to come from an anonymous representative who attended Thomson's series of lectures at the Royal Institution in March and April 1906.

Thomson, through a series of experiments with a cathode ray tube, discovered that there were particles smaller than atoms, which he called "corpuscles" (later known as electrons), which carried a negative charge. This discovery shows that atoms have an internal structure and are not "indivisible" as proposed by Dalton (Hon & Goldstein, 2013). His discoveries and atomic model provided evidence indicating that Dalton's atomic theory was incomplete and required revision to include the concept of subatomic particles.

In the subsequent development of Atomic Theory, the development of atomic theory continues to develop as a result of discoveries that continue to emerge from other scientists. Experiments carried out by Ernest Rutherford in 1911, which showed that atoms have a nucleus consisting of protons and neutrons, and electrons move around the nucleus, raised a fundamental question, why these negatively charged electrons were not attracted to the nucleus (which contains positive charge). Thomson could not explain the structure of the atom completely and accurately, and needed to be revised with a newer and more accurate atomic theory (Kragh, 2012).

Ernest Rutherford conducted his breakthrough experiments on atomic structure by using alpha particles as probes to probe the internal structure of atoms. His interest in the internal structure of atoms was sparked while he was a professor at the University of Manchester, beginning in 1908, largely inspired by his work on alpha particles (Yerokhin et al., 2021b).

Rutherford's scattering experiment involved shooting a beam of alpha particles, which he believed were dot-shaped helium atoms that had lost two of their electrons, at a thin sheet of metal. By observing how these alpha particles scattered after hitting the foil, Rutherford was able to deduce the presence of a dense, positively charged atomic nucleus at the center of the atom. This was a radical departure from the plum pudding model proposed by J.J. Thomson, who argued that atoms consist of diffuse clouds of positive charge and electrons embedded in them. However, the data from these scattering experiments do not determine the sign of the central charge.

Initially, Rutherford even considered the possibility that the central nucleus might be negatively charged, as he mentioned in his letter to William Bragg in March 1911. However, by the time he published his full paper two months later, he had assumed a nuclear charge (Kragh, 2021).

Rutherford's model of the atom, with a central nucleus surrounded by orbiting electrons, was first presented in a brief paper at the Manchester Literary and Philosophical Society on 7 March 1913, and a detailed paper followed in the Philosophical Magazine. This model laid the foundation for modern atomic physics (Kragh, 2021). It can be concluded that Rutherford's experiments show that most of the alpha particles pass through the foil without deviation, but some alpha particles are reflected back at large angles, this is of course in contrast to Thomson's model which assumes positive charges and electrons are evenly distributed in the atom. Rutherford's experiments with alpha particles led to the revolutionary discovery of the atomic nucleus and the proposal of a new atomic model, marking a significant advance in understanding of the structure of atoms. This experiment was a form of falsification of the previous atomic model that had been developed by Thomson, and paved the way for the development of a more accurate atomic model.

Niels Bohr speculated that electrons were moving around the nucleus similar to planets orbiting the Sun. However, there was a problem with this planetary model: electrons, when moving in orbits, should emit radiation and quickly spiral into the nucleus, causing the atom to annihilate. Bohr addressed this issue by proposing that electrons could exist only in certain quantized energy levels.

Electrons could jump between these energy levels by absorbing or emitting discrete packets of energy called photons. When scientists observed the spectra of atoms, they found that light wasn't smooth but had discrete units within it. Bohr's model explained these spectral lines by associating them with transitions of electrons between energy levels.

The atomic model evolved to include a cloud with electrons and a nucleus containing protons and neutrons. The number of protons and electrons in a neutral atom determines its properties. The properties of atoms, as reflected in the periodic table, are essentially built on the number of electrons.

The planetary model had limitations as electrons were not orbiting like planets but were jumping between orbits. Bohr's model introduced the idea that electrons could only exist in specific energy levels. Transitions between these levels explained the discrete lines observed in atomic spectra. The limitations of the planetary model led to Bohr's advancements, and the quantization of energy levels provided a more accurate description of atomic behavior.

The application of Planck's quantum theory to solve the problem of atomic structure was first carried out by Niels Bohr (1885-1962) in 1913, a scientist from Copenhagen who at that time worked at Rutherford's Laboratory in Manchester. It works based on the theory of electron planets which has been rejected by many physicists.

The aim of Bohr's work was to find new information about the position of electrons around atoms. Niels Bohr started by intensively studying atomic spectra (especially the hydrogen atom spectrum) and applying Max Planck's quantum theory to explain them. The concepts that support Bohr's atomic theory are the atomic spectrum, Planck and Einstein's quantum theory of radiation, and electromagnetic wave radiation.

Waves on the surface of the water will cause an object that is floating to rise and fall, faster or slower, depending on the strength of the wave itself. The ripples caused by a duck are certainly much weaker than those caused by a motorboat. Similarly, electron oscillations will be directly proportional to the intensity of the light wave. Maxwell's equations, which had been supported by Hertz and others, provided strong evidence to support the theory that light is a wave, which has electromagnetic properties. However, until the turn of the century, the evidence was still inadequate. In 1900 Max Planck showed that classical wave theory made several predictions that could not be proven in practice. One of them is radiation produced by black bodies (Hayashi, 2017). He proposed that light comes in discrete particles or in "packets" (quanta) (Sujito et al., 2019).

The situation is made even more complicated by the fact that other experiments prove the opposite. In the double slit experiment, it can be said that electrons have both particle and wave properties. Electrons are viewed as particles, shot one by one through a double slit and then striking a photographic plate screen.

The result is a pattern formed on the plate. The pattern is light dark, which is a typical property of interfering waves. The next question is, does the electron's trajectory before it hits the plate have wave-like symptoms? then, which gap is bypassed? Does the electron pass through both slits at the same time without splitting? This is of course contrary to the laws of common sense, but the truth of this experiment cannot be denied. An electron behaves both as a particle and as a wave. He is in two (or more) places at once, and in several states of motion at once.

The development of quantum physics was a major step in science. The deterministic concept of classical physics began to falter, replaced by a more flexible and dynamic view of nature. It all started with Max Planck's discovery of the quantum, which at first seemed strange and trivial, but went on to change the entire field of physics. This new physics explained radioactive decay and analyzed in detail complex elements. The immense power in the atomic nucleus is revealed. This impacts the uses of nuclear energy, from the potential for destruction to the possibility of a future full of progress through peaceful nuclear fusion. Einstein's theory of relativity states that mass and energy are equivalent. Einstein showed that light could behave like particles. Light and matter are apparently the same. The question of whether subatomic particles are particles or waves is finally answered by quantum mechanics they can behave both at once.

Kozlov (2021) revealed the latest atomic theory including several important advances in atomic physics. One such advance was the development of cooling and trapping techniques that have significantly improved the accuracy of atomic experiments. These techniques are now starting to be applied to highly charged molecules and ions, which will hopefully increase the accuracy of experiments with these species in the near future. In addition, atomic systems, including atoms, ions, and molecules, continue to be used as precision instruments to study fundamental physics and test new theoretical models. Atomic experiments are used to search for fundamental symmetry violations, variations in fundamental constants, and exotic interactions predicted by several models of dark matter and dark energy.

In terms of computational methods, there has been progress in the development of software packages for complex atomic calculations. One such package implements configurational interaction calculations coupled with many-body perturbation theory, which is important for treating atoms with more than four valence electrons. This package shows almost perfect linear scalability and efficiency with the number of processors used for calculations, giving hope that soon most open-shell systems will be able to be treated with fairly good accuracy. Progress has also been made in the calculation of quantum electrodynamic effects for bound many-electron systems, which is important for accounting for quantum electrodynamic effects not only for one- or two-electron atoms, but also for many-electron atoms and molecules. Finally, the level of accuracy of molecular experiments is increasing rapidly and has reached levels that were only recently possible for atoms.

From the long journey related to the development of the theory of atoms, we can both learn that falsification aims to strengthen a truth where the value of truth is very relative. What we think is true now may not be true in the future. There is a value that must be held by a scientist that the truth that we believe is right now, it could be wrong someday, so that a scientific attitude that is open to falsification is something that is important for the development of science.

Conclusion

The analysis revealed that the evolution of theories, including atomic theory, underwent numerous enhancements. Falsification, a pivotal element in science, especially in atomic theory, entailed rigorous experimentation and observation for accuracy assessment. In the development of atomic theory, falsification played a crucial role, exemplified by Dalton's atomic theory. Despite its revolutionary nature, subsequent experiments unveiled subatomic particles, challenging Dalton's ideas and giving rise to a more intricate understanding of atomic structure. The continuous evolution of atomic theory underscored the dynamic nature of scientific knowledge, perpetually refining theories to ensure an accurate representation of the natural world. The scientific method advocated openness to falsification, emphasizing that theories had to be testable and subject to replacement when compelling evidence contradicted them. This openness served as the cornerstone for scientific progress and a more profound comprehension of the universe.

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