Review Article

The evolution of atomic theory

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ABSTRACT

Imagine that the world around us is made of an uncountable number of small units. Up until 200 years ago, this was pure, perhaps ridiculous speculation. Now it is a widely accepted theory and we call these units atoms. In fact, it is believed that these units are made up of further, smaller units. How have we come to such a conclusion from just two centuries of experimentation?

The Beginning of Atomic Theory

The composition of matter is a question fundamental to our understanding of the world. Many once thought that matter could be split up into infinitesimal pieces; in fact, until the 19th century, the answer to the question remained largely speculative. However, in the years 1803–1807, John Dalton, an English schoolteacher, carried out several experiments based on the laws of conservation of matter and of definite proportions.[1] The flaws in Dalton's conception of the atom were gradually corrected by other scientists, and the atomic model still undergoes modification as new discoveries are made.

Thomson's Model and Rutherford's Correction

The first formal model of an atom was put forth by British scientist J. J. Thomson in 1897, who proposed that an atom consisted of a sphere of positive charge, with negatively charged electrons dotted within it [Figure 1]. It was nicknamed the 'plum-pudding' model, as it represented an atom as a positively charged mass with electrons randomly laid about inside it, much like raisins in a cake[2] (Thomson is also credited with the discovery of the existence of electrons through an experiment involving the deflection of cathode rays with a magnetic field[3]). However, this model was disproved by Ernest Rutherford in an experiment in which α-particles (positively charged products of nuclear radiation) were passed through extremely thin gold foil (only several thousand atoms thick) [Figure 2]. According to Thomson's model, all of the particles should have been deflected very slightly or not at all by the gold atoms. However, a tiny number of particles were deflected sharply. Rutherford remarked that it was 'almost as incredible as if you had fired a 15-inch shell at a piece of tissue paper and it had bounced back and hit you!' Rutherford's revised model therefore consists of an extremely small, dense region in the atom with a positive charge called the nucleus that contains nearly all of its mass, while the rest of the volume is empty space in which electrons move around the nucleus. This explains the sharply deflected particles, as the nucleus had both the mass and the concentration of positive charge to deflect α-particles.

Bohr's Model

Rutherford's model was accurate in that atoms do have nuclei, but the nature of electron movement about the nucleus was still undetermined; most scientists at the time believed electrons orbit the nucleus the way planets orbit the sun. This idea was confronted by Niels Bohr using the idea that energy is quantized. That is, there is a minimum amount of energy called a 'quantum' that can be transferred. This is equal to the amount of energy contained in a single photon. He further proposed that classical laws of physics were inadequate to explain the nature of electron movement, reasoning that if the laws were true, electrons would spiral into and collide with the nucleus. Using the hydrogen atom for simplicity's sake, Bohr's model assigns energy levels where electrons exist, and states that unless they are in those energy levels, electrons radiate energy until they enter an 'allowable' energy level [Figure 3]. This was the beginning of the modern model of atoms involving discrete energy levels held by the electrons. However, the Bohr model still had severe shortcomings in its inability to predict the behavior of more complex atoms.

Schrödinger's Model and the Heisenberg Uncertainty Principle

Based on Louis de Broglie's theory of the wave–particle duality of matter, Erwin Schrödinger expanded upon the Bohr model of the atom. Specifically, Schrödinger formed an equation describing the movement of electrons by treating electrons as waves instead of particles.[4] As electrons are evaluated as wave functions, the model assigns probabilities to

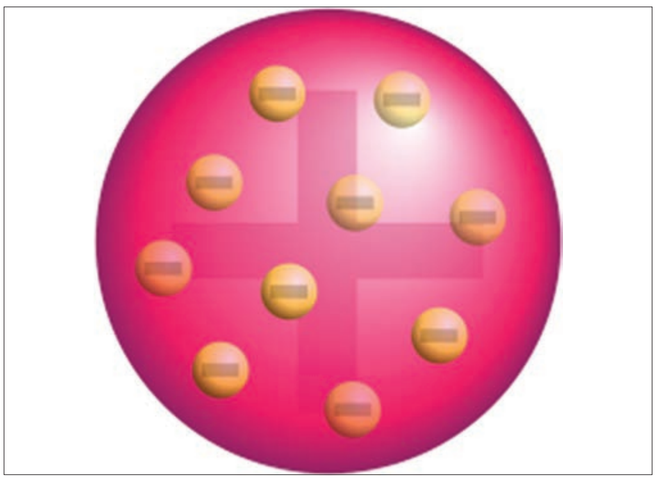

Figure 1: J.J. Thompson's model of an atom [Available from http://upload.wikimedia.org/wikipedia/commons/thumb/f/ff/Plum_pudding_atom.svg/220px-Plum_pudding_atom.svg.png]

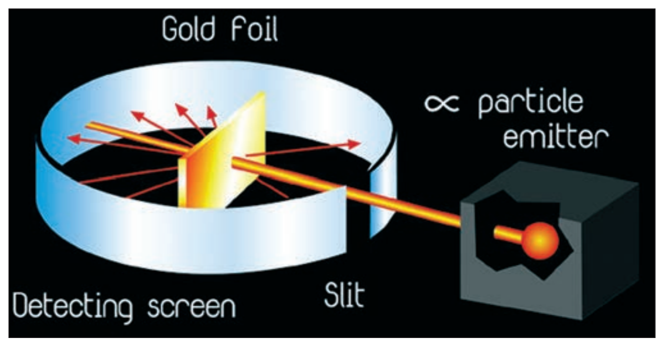

Figure 2: An image depicting Rutherford's experiment [Available from http://www.rsc.org/chemsoc/timeline/graphic/1911_gfoil_02.jpg]

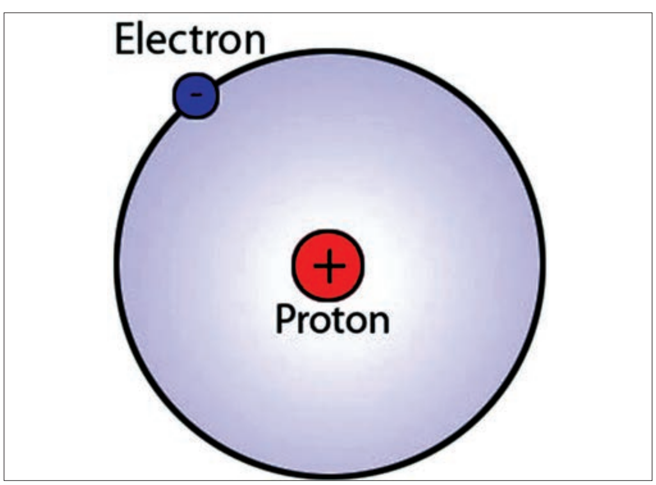

Figure 3: A diagram illustrating Bohr's model [Available from http://www.sciencekids.co.nz/images/pictures/chemistry/hydrogenatom. jpg]

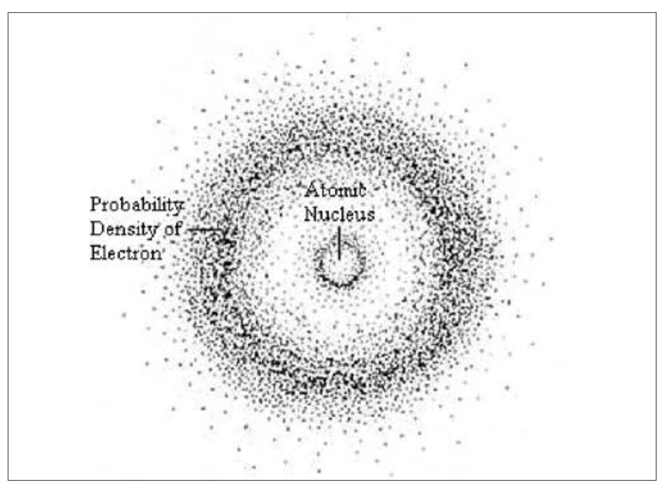

Figure 4: A diagram illustrating the 'electron probability density function' [Available from http://lionsgensci.wikispaces.com/file/view/l15-53-quantum.jpg/137474757/l15-53-quantum.jpg]

where an electron could be at any given time, forming an 'electron probability density function' around the nucleus rather than defining the specific location of an electron [Figure 4]. This uncertainty was looked into by Werner Heisenberg, who proposed that due to the dual nature of matter, there exists a fundamental restriction on the ability to know both the momentum and location of an electron at the same time. Only one could be found at any point in time for any given electron. Therefore, rather than making precise claims about the location and movement of each electron, the modern model assigns probabilities to these results.

Modern Applications of Atomic Theory

Atomic theory plays an important role in both physics and chemistry. By examining the behavior of electrons, scientists have formed cogent explanations for relatively new insights such as the configurations of complex molecules, bonding behavior, and molecule polarity, as well as explanations for more common phenomena such as water tension. Chemists and physicists after Rutherford have also performed similar experiments to Rutherford and his colleagues on a different scale, bombarding radioactive elements with neutrons to form elements that, as far as we can tell, do not exist naturally. By examining some of the smallest particles in the universe, scientists have even managed to create some of the most powerful sources of energy, as well as the single most destructive weapon known to man.

References

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About the Author

Allen Zheng is 17 years old and currently attends Palo Alto High School. He participates in contest mathematics, debates at the national level, and plays tennis recreationally. He especially enjoys math, chemistry, and physics classes in school.