SIMPLY TAUGHT: CHEMISTRY 1

BY
AMANDA ENE ADOYI

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PREFACE

This is the first in a series of fundamental Chemistry books that focus on a playful yet factual introduction to basic concepts in Chemistry.

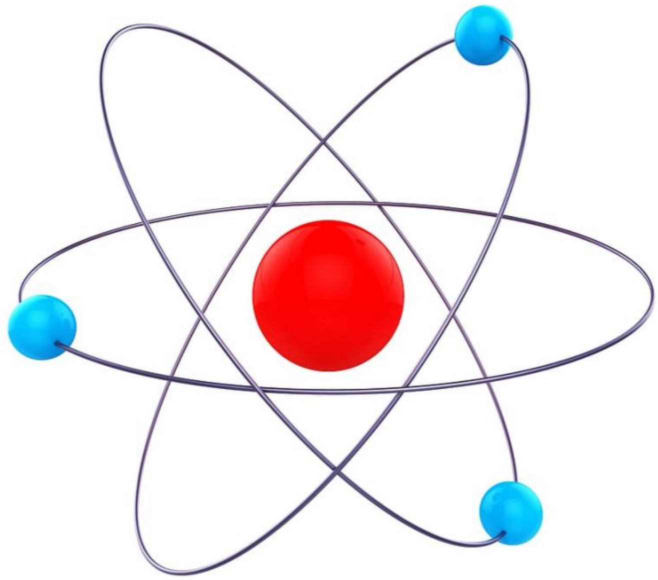
Chemistry plays a major role in society especially in view of the many problems facing the world today such as global warming and the energy crisis. There has never been a better time for Chemists to take center stage in scientific innovation.

This textbook aims to try to inculcate in young (and older) minds a love for the subject that exceeds the desire to simply pass exams and ingrain in them a passion for Chemistry and science at large. It seeks to accomplish this by presenting well known topics in very simple terms that students of all grades (with emphasis on secondary school students) can follow with ease and even teach others in the same simple terms, following a philosophy shared by Richard Feynman in his quote; **"If you can't explain something in simple terms, you don't understand it."** We therefore would be propagating understanding in very simple language in hopes of improving comprehension and properly explaining the concepts presented.

The effort put into this book I ascribe to the idle time spent during the lockdown of 2019, as well as to my wonderful family; Engr. Dr. Mathias Adoyi, Mrs. Helen Adoyi, Dr. Kevin Adoyi and Evans Adoyi. I also dedicate it to my best friend Nnedi Nnamdi-Nwaeze and her family. Lastly, I appreciate all my previous tutors in all the institutions of education I ever attended, especially my lecturers and professors of Chemistry in the University of Abuja.

Amanda Ene Adoyi, B.Sc
Industrial Chemistry
University of Abuja, Nigeria
Alumni

CHAPTER 1: ATOMS



In all the scientific endeavors of mankind none has been quite as revolutionary as the discovery the atom. Indeed it can be argued that the most incredible ideas have stemmed from this field. We are about to dive into a miniature world of particles so small that on the very tip of a needle can be found millions and millions of them. They make up all that we see and despite this appear virtually invisible and can only be observed using very controlled type of experiments. The crazy thing about atoms is that this isn't even the most spectacular feature they possess. We will now delve into their colorful history and note some of these exciting features we talked about. Exams may be tedious but you will be swept away by the world you are about to enter so much that you will be sure to emerge an ecstatic scientist yourself.

A BRIEF HISTORY OF THE ATOM (OR THE MADNESS OF THE ATOM)

One could say the macro world is easily observable and so it is no difficult challenge to observe the things that take place around us except in reality…that would be erroneous. Despite the fact that we can clearly see the things around us we have made several errors when coming to an understanding of these things because they can be difficult to explain. For instance in order to explain lightening the ancient Greeks had adopted the belief that a superhuman in the heavens threw bolts at the earth, their god they knew as Zeus. The ancient Mesopotamians believed that the sky was held up by pillars as in a temple. Let's fast forward to relatively recent times. It was once believed in the 1800's that lead was a wonder substance and so people used it to make hats, coat plates and even swallow it whole to attain beauty! In relation to the lead craze there is a story about people in England who kept dying from consuming tomatoes. Witches were said to use tomatoes to cause those deaths. It was only realized later that the poor tomatoes were not the culprits, the plates were as they were generously coated with lead. So one can see that even the visible world that we can see and touch can be difficult to examine in its entirety. How then could we possibly study micro particles invisible to the eye? And what's more how did we even come to know about them?

Figure 1-1 "Zeus must be really angry guys!" A Greek man probably once said.

The Greeks who could see the invisible

In many texts on the atom the Greeks are seldom mentioned and it was they who began to observe that something was not quite so obvious in the nature of things. In fact the very word 'atom' finds its origin in Greek text and Greek language as 'atomos' meaning indivisible. So we see that the ancients were certainly keen on an idea here. Up until a few hundred years later the atom was indeed considered indivisible and composing all matter and we must give them credit because figuring that out in as early as 460 BC is extraordinary.

Two of these wise ancients are specifically credited with the discovery of the atom. However, that is only based on the data we have. These two are Leucippus and Democritus, the latter a student of the former. They also added that atoms were of different kinds depending on what properties the matter they made had. For instance the atom of water was considered wet and slippery and iron atoms were metallic with hooks. So we can imagine that the atoms of fire could burn. While this may sound ridiculous to modern day scientists as ourselves we must realize how ancient this was. It was way before Jesus had been born! Nonetheless these theories set more modern scientists on a trail and I emphasize the word ‘modern’ because from the time the Greeks noted this to more recent times there was little improvement by way of study on the subject but in 1803 that was to change.

John Dalton, the new Leucippus but not exactly

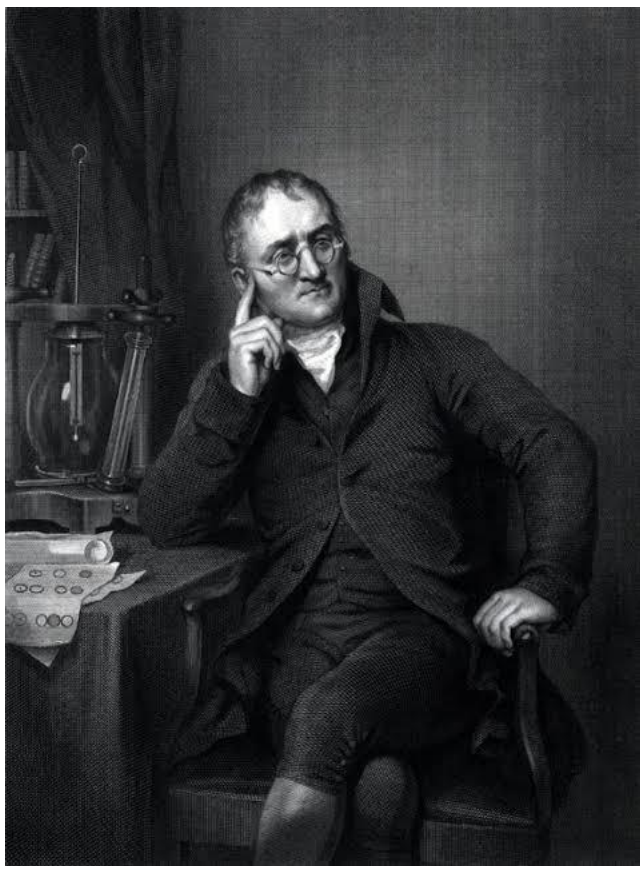


Figure 1-2 John Dalton in a stylish pose

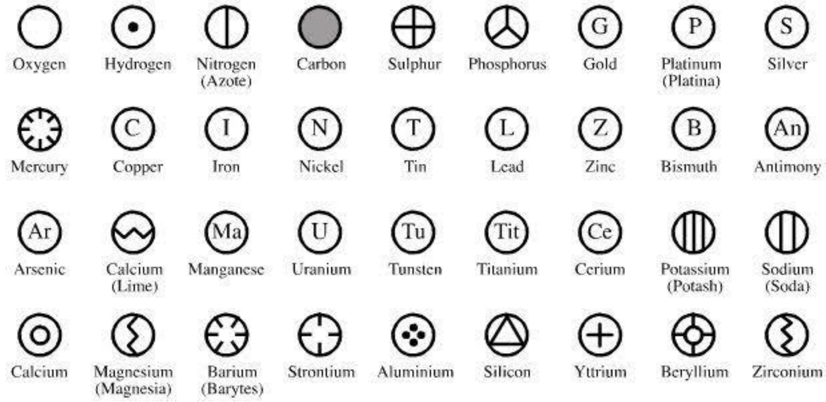


Figure 1-3 John Dalton's symbols for the known elements at the time

A chemist and school teacher who had read the works of the ancient Greeks (most likely) had improved on the works of Leucippus and Democritus stating that atoms were *indivisible, small hard spheres and the atoms of particular elements were identical to each other.* You should hold on to that definition as several points would be ironed out later. He also documented a list of the first chemical symbols of the few discovered elements. He even stated the very first **postulates of the atomic theory:**

1. Matter consists of indivisible particles known as **atoms.**
2. Atoms of the same element show similarities in all ways but differ from atoms of other elements.
3. Atoms can neither be created nor destroyed.
4. When atoms combine, they do so in simple whole number ratios to form compounds.
5. The atom is the smallest unit of matter that can participate in a chemical reaction.

So there we have it. The above postulates are the very basis on which modern chemistry is built and we are only just getting started. Before we move on it would help if you stick to this definition for the time being:

"The atom is the smallest unit of matter that can participate in a chemical reaction."

You'd thank me later.

The boom of the 1900's

Okay technically it began in the late 1800's. We are not entirely certain what John Dalton did in addition to the discoveries he made but he seemed to do something extra like maybe set off an investigation bomb because almost right after his study everyone wanted to gain in on the atom action. It was discovery after discovery and I am sure that if social media existed our phones would have been 'blown' from the overwhelming wealth of new discoveries. Walk with me.

Beginning at the end of the 1800's in the year 1897, we see a studiously engaged Joseph John (J.J) Thompson bent over a cathode ray tube and inspecting it. He has just made a tremendous discovery. He has discovered that unlike what our ancient Greeks and John Dalton believed the atom isn't indivisible. It can be divided and on this 'division' we notice a negatively charged particle of significant mass which he called a 'corpuscle' and we are glad that name did not catch on. However it was a most significant breakthrough. Below is an image showing how this experiment was conducted and don't worry we will walk through the process carefully and I'll have to explain because I am sure Thompson won't have the time (He's second guessing the name).

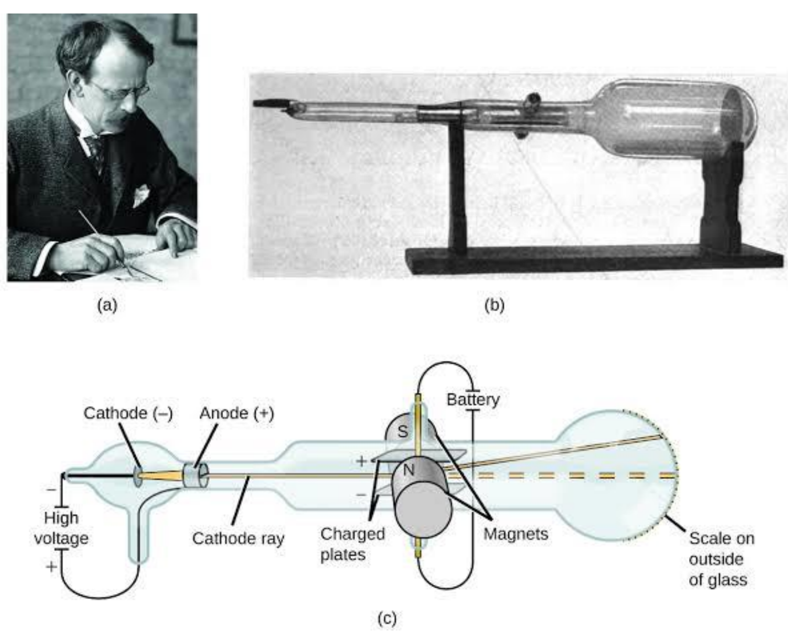


Figure 1-4(a) J.J Thomson, (b) the actual cathode ray tube used, (c) A schematic showing how it works.

Before diving into the discovery of the electron, let's come to understand and appreciate the cathode ray tube. As seen in the image above a cathode ray tube is well, a tube. It is a tube made of glass and with wires connected at its ends. Within the glass compartment is a vacuum (meaning all the air is pumped out) and an electric charge passes through the tube forming a glow.

Before Thompson's experiment many people had known about the cathode ray tube and the glow (rays) produced. Thompson however wondered if this ray was all there was to notice. He then decided to customize a cathode ray tube, adding charged plates on either end. The plates were then given two slits that connected to a scale outside the glass which could be used to measure charge as shown above. On applying a magnetic field across his fine tube he noticed something incredible. The rays had deviated from the straight path. What this showed was that the charge had been affected by the magnetic field.

"So the ray and the charge are as intertwined as pizza and cheese." He said probably, stroking his chin. (He didn't.)

What he had just discovered was that the 'rays' were actually particles as they could be affected by a magnetic field. Further experiments showed that these 'corpuscles' which we would rather call 'electrons' were relatively light(lighter than hydrogen, the lightest element) as well as negatively charged.He later put forward a model of what he conceived the atom to be, and no it had no metal hooks as the ancient Greeks thought instead it was a positively charged sphere with electrons embedded.

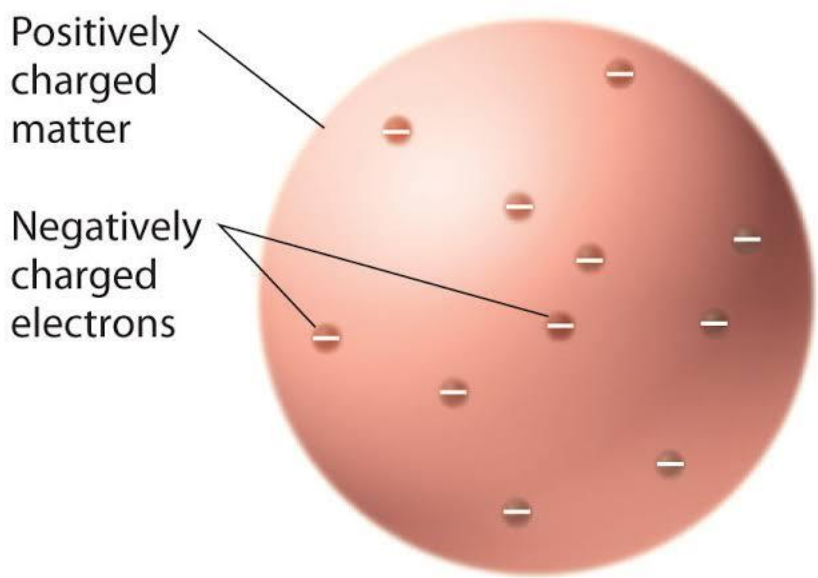


Figure 1-5 The J.J Thomson model of the atom.

This won him the 1906 Nobel Prize which he rightly deserved. So we have met the electron and we should hold on to an important property of it.

“Electrons are negatively charged particles.”

Rutherford Shoots Gold

I still believe this was quite an expensive experiment and you may just agree. Just like Leucippus and Democritus, Ernest Rutherford worked and studied under J.J Thomson. His mentor and teacher had probed into just the surface of the atom and he caught some of that atom fever. In the 1911 experiment which he performed with two of his colleagues Geiger and Marsden, he fired alpha particles at thin sheets of gold foil. Now, alpha particles would be discussed later under radioactivity but what you should know now is that these particles are positive and positive charges are repelled by other positive charges but attracted to negative charges. In addition, alpha particles are quite heavy so it’ll take a lot to deflect them off their course. So walk with me.

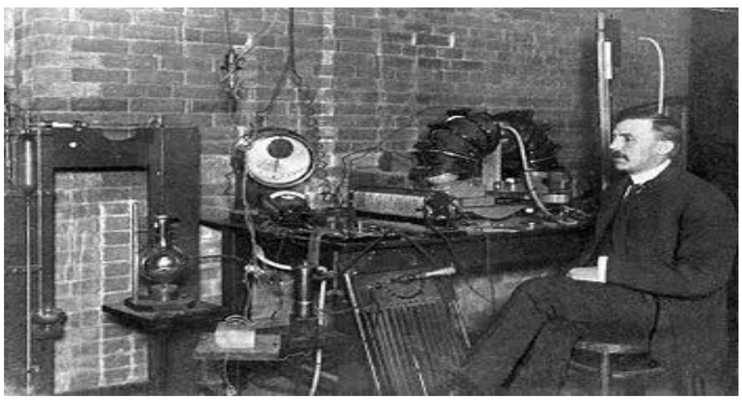


Figure 1-6 Ernest Rutherford

Now, if the atom is a sphere of positive charge as Thomson observed, we should expect that the fired alpha particles would pass through the gold foil sheet (alpha particles are so tiny, they could) and show little to no deflection but this well, was not the case and we can see the surprise on Rutherford’s face. Can you see it? I see it every time I mentally walk by him.

Turns out that most of the alpha particles fired passed through the gold foil. This was not something to make him widen his gaze at the screen, but then the unexpected happened. A few of those particles became deflected but not just deflected, deflected at alarming angles as though the footballer Messi had kicked them hard. We can now walk over to the desk of the great man and bend over his shoulders. In his notes we can see that he is describing the experiment; “It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.” Extraordinary. It is certainly not something anyone should try but I can't imagine shooting a tissue paper with a gun and expecting the bullet to come back and hit me but then I suppose it is probably more economical than firing gold. Rutherford's interpretation of this experiment was that unlike what his mentor had postulated, the atom was not all positively dispersed charged but the charge was concentrated in the middle, a small very dense centre known as the nucleus and the atom itself is mostly composed of empty space. This was such an astounding discovery especially as it happened in only a few years since Thomson's incredible studies. Rutherford naturally had to make some changes to the existing idea of what the atom looked like based on Thomson's work.

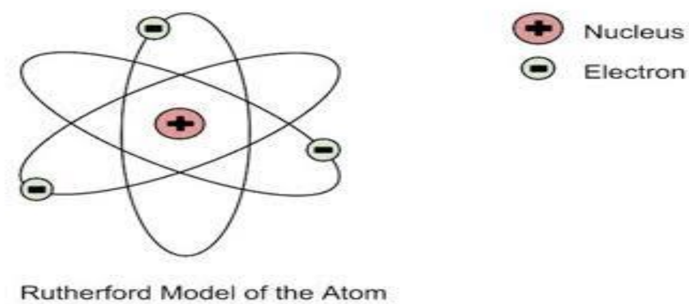


Figure 1-7 Rutherford's atom.

He proposed that the electrons orbited the positively charged nucleus that was situated at the center of the atom.

"The nucleus is the positively charged center of the atom, composed of protons."

Niels Bohr on another level

Thomson and Rutherford were great scientists and everyone knew that but despite how significant their studies were something was just not quite right. According to fundamental scientific laws, spiraling electrons should not remain spiraling around the nucleus and should crash pretty soon like a jet engine in the air out of fuel but Rutherford's atomic model could not explain this. It wasn't magic that kept electrons moving about and someone had to find out what. Then in came Niels Bohr and now it's time to walk with me.

We enter a room and find the man facing a board. We see strange drawings just like the ones below.

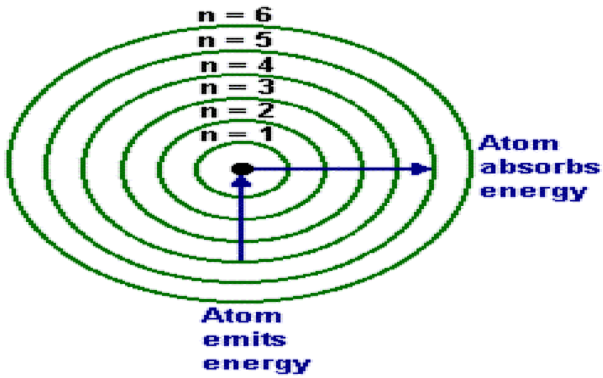


Figure 1-8 Atomic energy levels.

He seems to be frantically writing so I'll explain what is going on. You have probably heard about quantum theory. No? Well it is another of those insane little concepts that have been conceived because the atom is just so strange. It was brought about by a man named Max Plank, who observed in an experiment that radiation was carried in 'packets' called *quanta.* Don't leave just yet, stay with me. We would explain quanta in a while but for now just picture indomie packets. Each packet can only hold so much indomie and not more. Energy according to Max plank was not an indefinite stream as was believed by most but 'indomie packets' of energy instead.

The work of Niels Bohr was based on this concept. He noted that the reason the electrons did not 'crash and burn' into the nucleus was that the electrons could only be located on particular energy levels. So the energy of electrons was quantized or could be said to fit into particular 'electron indomie packets' -which sounds like a good name for a new indomie package. Electrons couldn't just assume any random value but had to remain at these levels and could only move between them. If an electron had acquired energy (maybe due to heating) it could 'jump' to a higher energy level but on releasing that energy it would fall back to its energy state. The ground state or ground level was defined as the lowest energy level an electron could go as you can see in the image above.

At this point in this amazing history we could go on to a happily ever after moment and say that everything was fine and that Bohr was the hero of the day, the last avenger who stood up to Thanos and defeated him (Get the reference?) but unfortunately that is seldom the case in the story of the atom. When scientists thought they cracked a code, they only opened it to find more puzzling problems. The atom has well become a miniature Pandora 's Box.

Niels Bohr's model worked amazingly when applied to the hydrogen atom, but when scientists began involving heavier elements they found more and more complications. We would explain these complications a little later. For now, we should remember that we cannot underestimate the work of Niels Bohr because it helps us understand chemistry at least at the fundamental level. A thorough grasp of Niels Bohr's atomic model is a grasp of chemical bonding and reactivity rates of elements in the periodic table. Since the aim of this text is to narrate the history leading to our present knowledge of the atom, walk with me as we strive to get to the Standard Model of the Atom.

Schrodinger traps a cat

Of course the atomic Pandora's Box had only just begun.After Niels Bohr had taken a crack at this atom wonder, another scientist by the name of Erwin Schrodinger became infected with the fever and set to work trying to straighten out the rumples of Bohr's atom. In 1926 he proposed that electrons instead of being imagined as particles should be pictured as waves instead. He used a plethora of equations to explain this and ended up with a picture of the electrons not as distinct particles but as *electron clouds.* As much as we would love to go into his study and watch him work on coming up with these equations, I'd rather not and am sure you won't want to either, at least not just yet. Chemistry unfolds in layers and soon even Schrodinger's equations would be nothing to fret over.

Figure 1-9 Erwin Schrodinger

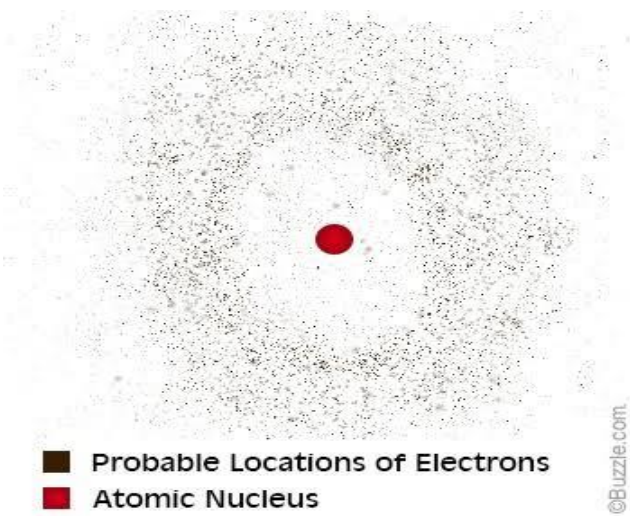


Figure 1-10 The electron cloud

Nonetheless Schrodinger showed that the clouds were only just estimates of the electron's position because we can't really tell where the electrons are. We can only guess likely areas where we may find them. I think this makes sense because you can imagine losing a small marble in a large cotton candy cloud of identical small marbles. Good luck finding it. These areas where electrons may likely be found have been called electron orbitals. You certainly would not want to forget this.