Structure of the Atom

Questions about the examination of, “what constitutes matter”, come to us from the ancient Greeks. It was the Greeks, who first attempted to explain the nature of matter.
The ancient Greeks searched for knowledge.
The Greek word for knowledge is “soph” and the Greek word for “admirer or seeker” is “Philo”.
Those that search out understanding are called “Philosophers”.
Those that specialize in the understanding of nature and those things surrounding them are therefore “natural philosophers”.

Models of Matter

A model is a tentative description of a system or theory that accounts for all of its known properties.
Models are invented, for the most part, to interpret the invisible and relate to experimental results.
In ancient Greece, philosophers argued on two concepts of matter. There were two models:

1. The Democritus Model (discontinuous) (400 BC)
- matter is made up of particles that are indivisible- (atomos” — Greek means indivisible)
- these particles are small, hard, incompressible and indestructible.
- two atoms cannot occupy the same space at the same time.
- atoms of different materials differ from each other by their shape, their mass and their size.
- atoms of different materials differ from each other by their shape, their mass and their size.
- atoms are made up of only two things, atoms and emptiness (void).

Those that continued to believe in the indivisibility of matter were called **“atomists”**

2. The Aristotle Model
Aristotle and his followers believed that matter can be divided into an *infinite number of parts.* Matter was as continuous as the number system. An ocean can be divided until the parts are as small as rain drops, and rain drops can be divided into parts as many times as the ocean and these resulting parts could continue to be divisible. Therefore they believed:
- all things were divisible into infinity
- matter was continuous
- matter was made up of four elements: fire, earth, wind, and water.
- the difference in substances was in the proportion of these for elements making up every material.

Since Aristotle was the tutor for Alexander the Great, his explanation of matter was the prevailing one for over a thousand years.

3. John Dalton's Model (1806, a school teacher)
By the beginning of the 19th century the precision of analytical chemistry had improved to such an extent that chemists were able to show that the simple compounds with which they worked contained fixed and unvarying amounts of their constituent elements.
In certain cases, however, more than one compound could be formed between the same elements.
At the same time the French chemist and physicist Joseph Gay-Lussac showed that the volume ratios of reacting gases were small whole numbers (which implies the interaction of discrete particles, later shown to be atoms).
A major step in explaining these facts was the chemical atomic theory, or The Particle Theory purposed by the English scientist John Dalton in 1806.

<u>The seven postulates of Dalton's theory are</u>:
1. All matter is composed of extremely small particles called atoms.
2. Atoms can neither be subdivided nor changed into one another.
3. Atoms cannot be created or destroyed.
4. All atoms of one element are the same in shape, size, mass and all other properties.
5. All atoms of one element differ in these properties from atoms of all other elements.
6. Chemical change is the union or separation of atoms.
7. Atoms combine in small whole number ratios such as 1:1, 1:2, 2:3 etc.

(A postulate is something assumed to be true.)

New definitions:
An **atom** is the smallest particle of an element that has all the chemical properties of that element.
A **molecule** is the smallest particle of a compound which shows all the chemical properties of that compound.

Problems with Dalton's Atomic Theory
The major weaknesses in Dalton's atomic theory were that he did not account for the Law of Multiple Proportions and made no distinction between atoms and molecules.
Thus, he could not distinguish between the possible formulas for water HO and H_2O_2, nor could he explain why the density of water vapour, with its assumed formula HO, was less than that of oxygen, assumed to have the formula O.

(FYI: the solution to these problems was found in 1811 by the Italian physicist Amedeo Avogadro. He suggested that the numbers of particles in equal volumes of gases at the same temperature and pressure were equal and that a distinction existed between molecules and atoms. When oxygen combined with hydrogen, a double atom of oxygen (- a molecule in our terms, i.e. diatomic: O_2), was split, each oxygen atom then combining with two hydrogen atoms, giving the molecular formula of H_2O for water and O_2 and $H_2$for molecules of oxygen and hydrogen). Unfortunately, Avogadro's ideas were overlooked for nearly 50 years, and during this time confusion prevailed among chemists in their calculation. It was not until 1860 that the Italian chemist Stanislao Cannizzaro reintroduced Avogadro's hypothesis. Dalton related the atomic weight of all elements to that for hydrogen, however previously they were taken relative to oxygen, 16)

4. William Crookes' Cathode Ray Tube

Because of the study of static charging of objects (static electricity) it became clear that Dalton's model of the atom was incomplete.
It was shown that the charging of an object was the result of the collection or accumulation of charged particles.
It was discovered that there were two types of charged particles and that objects attracted or repelled depended on the nature of the particles on the charged object.

Science continued to search and try to explain phenomena that occur in nature.
Gases became a subject of curiosity. Once the discovery was made that there were different types of gases, it became important to investigate all the properties of these newly discovered materials.

As you know, the electrical battery was invented in 1800 by Alessandro Volta and experiments were carried out with materials.
A characteristic property that materials were tested for was electrical conductivity.

A person that carried on some research into the conduction of gases was named **William Crookes** who invented what came to be the **Crookes Tube**. Today it is called the **"cathode ray tube"**.

<u>Draw and label a Cathode Ray Tube</u>

Useful definitions:
cathode ray tube: vacuum glass tubes with a metal piece (an electrode) at each end.
Cathode: the negative side of the cathode ray tube.
Anode: the positive side of the cathode ray tube.
Cathode ray: the ray made of negatively charged particles called electrons.

William Crookes was using his tube to test out conductivity of different gases. It never occurred to him that his invention would be used as the source of explanation that would improve Dalton's model.
Dalton's model was unable to explain the phenomena of static electricity. Why do charged objects repel or attract? Why are there only two types of charged materials? Why aren't there only two types of charged materials? Why aren't there three or four types?

All these questions bothered scientists at the time and every effort was made to try to explain these natural phenomena. Then came **Joseph J. Thomson**.

5. Joseph J. Thompson's Model

He built the Pinwheel cathode ray tube. He had seen the Crookes' tube and realized that Dalton was wrong.

As air or gas is removed from the tube a glow in the glass could be noted.

Rays appeared to begin at the cathode (—), and travel toward the anode (+).

Those "things" flying by in the Crookes tube were particles of matter. They were capable of spinning the pinwheel in the Crookes' tube. This meant that they had **mass**. But were they atoms? No, they were smaller than atoms.

Also they were *repelled by charged ebony* which by then had been categorized as negative type material. So, since there was repulsion, these rays that were produced in the Crookes' tube must be of the same negative material. Maybe it was because these were the particles that made the material "negative".

At the time, a battery had two connections. One of the connections was referred to as the *cathode* and the other was the *anode*. In the experiment it became obvious that the rays being produced in the tube came from the cathode side of the battery and therefore were named *Cathode Rays.* Now, we also know that the ray produced was repelled by ebony and was therefore negative material. This means that the cathode (–) is the negative electrode and the anode *(+)* is the positive electrode.

So, what did all this mean to J.J. Thomson?

First, he realized that Dalton had made an error. The indivisible particle of matter, the "Atom" had parts, at least two. One part, that could be formed into rays was negatively charged material. The other part was positively charged material.

Thomson is credited with the discovery of the "**electron**" as the negative particle of matter. Electrons are identical no matter what material the cathode is made of and no matter what gas is present in the tube.

Although Thomson was able to determine that the electron contained mass, all that he was able to measure was the ratio of the charge divided by its mass (e/m) ratio.

J.J. Thomson's model of the atom was very similar to Dalton's. He said that the atom is a positive body that contains embedded electrons, "**Like Raisins in Raisin Bread**". The bread is positive, the raisins negative.

Materials are naturally neutral. They contain the right number of raisins that give the bread balance. That is the positive contains just the right number of negative electric material. However, when rubbed, the friction causes some of the negative to attach itself to the other objects. This causes one object to contain more negative material than it would normally have. The object that lost negative material now is short of negative and is viewed as positive. It is only positive, not because it gained positive matter, but because it is lacking in negative matter. This condition causes the objects to want to come together thereby becoming neutral. It seems that nature wants matter to be neutral.

J.J. Thomson had created a new model that explained static electrification of objects.

Millikan performed an experiment that made it possible to measure the charge on the electron and so calculate the mass of the electron.

Roentgen's X-Rays (1895)
Roentgen experimented with a CRT using an electric current at very high voltage. He noticed that some rays emanated from the apparatus, and that these rays penetrated and passed through different substances.
X-rays have short-waves, a high frequency and very high energy that lets them go through soft tissue. The medical applications very soon became apparent and X-rays are used extensively in medical diagnostics.

Henri Becquerel (1896)
The story is that Becquerel left an unexposed photographic film in a metal cartridge in his desk, on top of the film was a chunk of uranium ore (a mineral called pitchblende).
He found that the film had been exposed even though it had not come into contact with any light.
He decided that uranium spontaneously emitted powerful invisible rays without the application of energy, which unlike light were able to pass through opaque objects.
A substance that gives off these invisible rays is **radioactive**.
The main impact of the discovery of radioactivity was that it *proved that atoms contained parts and that it was definitely divisible.*

Pierre and Marie Curie
They took up the work of Becquerel. They succeeded in isolating two new radioactive elements: Radium and Polonium (after her native Poland).
These are even more radioactive than uranium.
(FYI: Marie Curie was the first woman to hold a professorship at the Sorbonne, the first person to win the Nobel Prize twice, her daughter also won the Nobel Prize.)

6. RUTHERFORD'S MODEL (1909)
Ernest Rutherford placed a few grains of radium salts in the bottom of a hole in a block of lead. The radiation escaped from the hole and was allowed to strike a screen painted with zinc sulphide (individual atoms are far too small to be seen, however, when the phosphorescent screen is struck by an atom or an atomic particle it produces a tiny scintillation of light).
The radiation hitting the screen caused the zinc sulphide to glow in one spot.
By bringing a magnet near the rays 3 spots of light could be seen.
The *rays consisted of 3 types of radiation*.

Rutherford found that *three different rays are emitted by radioactive substances.*
<u>3 Types of Radiation</u>

1. The lightest were the *b* , *Beta Rays,* that were attracted to the positive plate. Beta rays are made of particles having a negative charge, they are in fact *high energy electrons.* They can pass through several mm of aluminum.
2. *Alpha rays, a* , were attracted to the negative pole of the electric field, and hence are themselves *positively charged particles.* They are *helium nuclei* having a mass of 4 amu, and are stopped by a sheet of paper.
3. *Gamma rays, g* , are not deflected by a magnet and therefore are not charged. They are not particles, i.e. they have no mass. They are waves like light or X-rays or microwaves. The gamma rays, *g* , are powerful shortwave rays with a high frequency and high energy. Gamma rays are the most penetrating, they can pass through 5 cm of lead or 30 cm of steel.

Rutherford's Gold Foil Experiment
This was undertaken in the labs at McGill University (Montreal). Rutherford bombarded a very thin gold foil with alpha particles, (positively charged helium nucleus).
He noticed:
1. The majority of the alpha, α -particles penetrated the metal foil undeflected.
2. A few, (about 1 in every 2000), suffered serious deflections as they penetrated the foil.
3. A similar number did not pass through the foil at all but "bounced back" in the direction from which they had come.

Thomson's model did not explain these deflections. This type of behaviour would be expected only if the positive charge and mass of an atom were highly concentrated in a small region. Rutherford called this "**nucleus**". The approach of an alpha, α -particle to a nucleus of high positive charge and mass would lead to repulsive forces strong enough to reverse the direction of the particles.

Rutherford's Planetary Model
1. Most of the mass and all of the positive charge of an atom are centred in a very small region called the *nucleus*. The atom is mostly empty space (i.e. between nucleus and electrons there is nothing).
2. The magnitude of the charge on the nucleus is different for different atoms and is approximately one half of the numerical value of the atomic mass of the element.
3. There must be a number of electrons outside the nucleus of an atom that is equal to the number of units of nuclear charge.

<u>Weaknesses of the Rutherford Model</u>
Classical physicists observed that a moving electric charge, such as an electron, which changes its direction in space, must release (radiate) energy.
Thus, an electron moving around a nucleus in an orbit would be expected to lose energy. If it gives off energy, it will slow down and .: not be able to resist the attraction of the positive nucleus and hence should rapidly spiral into the nucleus and eventually a small mushroom cloud will be seen!!! The collapse of the atom should be observed, however, atoms do not collapse. Therefore, there must be a flaw in Rutherford's model.

SPECTROSCOPY

The spectroscope is an instrument used to see the spectrum of light emitted by different elements.

Each element has its own characteristic light spectrum.

Visible light spectrum

The white light is formed by different colours: ROYGBIV

Each coloured ray has its characteristic wavelength and frequency. There are other rays that can be detectable but not visible.

All the rays form the **ELECTROMAGNETIC SPECTRUM**

Radio, Waves, TV Waves	Micro-waves, Radar, Sonar	infra-Red	Visible light	Ultra-Violet	X-Rays	g -rays

Long waves ---> **Short Waves**

Low Frequency ---> **High Frequency**

Low Energy ---> **High Energy**

7. Niels Bohr's Model (1913)

A Danish scientist, Niels Bohr started looking at the scientific evidence in a different way.

He saw the atom in a different way and came up with a series of postulates.

Bohr's postulates are:

1. In every hydrogen atom there are only certain paths in which an electron is allowed to move. These are called energy levels.
2. Each energy level corresponds to an orbit, a circular path in which the electron can move around the nucleus.
3. Electrons can travel in allowed energy levels without loss of energy.
4. Electrons may jump from one energy level to another.

When the electron is in a stationary state, the atom is stable and does not radiate energy.

An electron in the lowest possible energy level is said to be in the ***ground state*.**

If the electron is heated or given energy, the electron occupies a higher energy level and is said to be in an *excited state***.**

Atoms have only certain allowed orbits, i.e. electrons orbit the nucleus on different energy levels, the energy of an electron is "*quantized*" (i.e. limited to a certain set of values).
Thus, the energy differences are specific values.

An atom radiates energy only when the electron "*jumps*" from one allowed state to a lower one. As an excited electron spontaneously drops from a higher level to a lower energy level, it emeits radiations with a certain frequency.
This frequency depends on:
1. The size of the "jump", and
2. On the final level the electron reaches.

The frequencies of the coloured lines in the visible spectrum of hydrogen matched perfectly with the theory.
Bohr's atom also gained credibility when Bohr was able to predict lines outside the visible region (the ultraviolet) that were later discovered by other scientists.
The fact that atoms could give off distinct spectra has many applications such as neon signs, sodium lamps, flares, identification of elements, composition of stars, etc.

<u>Drawbacks of Bohr's Model</u>
The theory only worked for hydrogen, not for any other element. When applied to multi-electron atoms several series of lines were seen that should not have been there.

Bohr was also wrong in assuring that an electron is a particle whose position and motion can be specified exactly at a given time.

Bohr was also wrong in thinking that the electron moves in an orbit at a fixed radius which changes only when the electron jumps to another orbit having a different fixed radius.